RESEARCH REPORT

Evaluating the Feasibility and Developing Design Requirements and Tools for Large-scale Rainwater Harvesting in Ontario

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Final Report on Research Activities:

Project Title:	Evaluating the Feasibility and Developing Design Requirements and Tools for Large-scale Rainwater Harvesting in Ontario
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Date:	August 1, 2008
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Executive Summary

Introduction

Rainwater harvesting (RWH) is the collection of run-off from roof surfaces and storage of the water in a cistern for later use. Rainwater has been used for domestic applications for centuries in many countries around the world. RWH was common in North America prior to the advent of centralized water supply infrastructure and remains an important practice today in localized rural areas where groundwater sources are poor and centralized infrastructure is not feasible.

Apart from its historical role in the rural context, RWH is quickly gaining relevancy in the urban environment as a component of sustainable urban water management, due to its contribution to both water conservation and on-site stormwater management. It is becoming a standard component of many green building projects.

In anticipation of these trends, a two and a half year research and development project was undertaken and completed at the University of Guelph School of Engineering. The project initially sought to investigate the feasibility of the widespread implementation of rainwater harvesting (RWH) in the residential sector in Ontario. It quickly became evident that RWH is both technically and socially feasible and that what is preventing further uptake is neither the lack of interest nor the appropriateness of the technology; rather, it is simply a lack of capacity: technical, commercial and institutional capacity. The project therefore shifted its focus to capacity development.

Four areas were identified where local, documented experience is lacking and where further investigation would help to build capacity and accelerate the uptake of RWH: 1) water quality data; 2) system performance and design best practices; 3) economic analysis; and 4) policy analysis. This report summarizes these areas of research, discussing method, results and implications for each.

Rainwater quality assessment program

A one-year assessment program was conducted to investigate the quality of stored rainwater and the impact of site conditions and design on water quality. The study comprised of seven sites with RWH systems located within a 30km radius around the City of Guelph, Ontario. At the sites, samples were collected directly from the rainwater cistern and at the point of use (following any post-cistern treatment). Physicochemical and microbiological parameters of the rainwater samples were analyzed to assess the impact of factors such as catchment material, storage material, site environment, weather, season and treatment.

Key findings:

- The physicochemical properties of rainwater were found to be most influenced by the catchment and storage materials, and site environment; whereas,
- Season, temperature, and treatment had the greatest impact upon the microbiological quality of rainwater;
- Post-cistern treatment, by means of a 20 micron particle filter and UV disinfection, was shown to be effective at reducing the number of total and fecal coliforms and turbidity prior to use;
- The general good quality of cistern-stored rainwater indicates that there is minimal risk associated with non-potable applications such as toilet flushing and outdoor use, and following treatment, the quality may be suitable for additional applications such as laundry.

Performance aspects of rainwater harvesting systems

Three demonstration sites were designed and installed at residential locations in Guelph, Ontario. The systems were then monitored to quantify water savings, system losses, and performance in cold weather. At one of these sites, extensive data collection was conducted to evaluate the trends in daily rainfall and rainwater demand; losses from the catchment surface; overflow volumes and frequency; cold weather performance and snowmelt contributions; and municipal water savings.

Key findings:

- The RWH system at Experimental Site 1 yielded 65 m^3 of water for toilet flushing, laundry and outdoor use during the one-year monitoring program. This volume of rainwater was sufficient to meet about 30% of the annual water needs of the water-conserving five person household studied in the City of Guelph;
- Of the rainfall contacting a typical residential asphalt shingle roof, very small rainfall events (<0.5 mm) produced no appreciable increase in cistern volume. For larger events, only a portion of the volume (80%) was collected from the asphalt shingle roof;
- During periods of cold weather, collection efficiency drops to 60%, recovered in the cistern by means of snowmelt;
- Collection of snowmelt demonstrates that RWH systems can continue to perform during winter conditions in Southern Ontario. Results would vary significantly across the country.
- Special consideration must be given to the design of outdoor components to ensure their performance under cold weather conditions.

Cistern sizing model

An excel-based model was created to optimize the sizing of RWH cisterns, given supply, catchment and demand details. The model utilizes historical daily rainfall data for numerous cities throughout Ontario to evaluate the potential volume of rainwater that can be collected and utilized to augment municipal water supplies. To verify the accuracy of the model, its simulations were compared to the performance data collected at Experimental Site 1. To demonstrate the effect of catchment area on the performance of RWH systems, two case studies were evaluated using the cistern sizing model – single-detached households and townhouse units.

Key findings:

- For both townhouse units and single-detached households:
    - At low volumes of rainwater storage (250-3,500 L) substantial increases in performance (municipal water savings) were observed from minor increases in storage volume;
    - At high volumes (above 10,000 L) increases in storage volume were found to have a negligible impact upon the performance of RWH systems, as other factors such as rainwater supply and catchment area limited the amount of rainwater that could be collected and stored for later use;
- A significant difference in water savings potential was observed between single-detached homes and townhouse units. When used for toilet flushing and laundry, RWH systems utilizing the catchment area of a single-detached house provided 67 m^3 annually, whereas only 42 m^3 was available from townhouse units. Catchment area is therefore a significant limiting factor in system design and water savings.

Economic Analysis and Case Study

The implementation of RWH in the City of Guelph was used as a hypothetical case study to provide the context to conduct an economic analysis. The cost of individual RWH systems was estimated for various design configurations and the cistern sizing model was used to determine water savings for each. Both the cost and the water savings were then scaled up, assuming that RWH is implemented in all new residential development from 2006 to 2055. This allowed for the calculation of operational savings to the water utility, as well as lost revenue and deferred infrastructure investment. Finally, comparison was made between the widespread implementation of RWH and water supply options put forth in the City of Guelph 2006 Water Supply Master Plan (WSMP).

Key Findings:

- The cost of an individual RWH system was found to range between \$6,000 and \$14,000[1], depending on the size and configuration of the system and the treatment requirements.
- The most cost-effective system was a 6500 L buried concrete cistern collecting run-off from the roof surface of a single detached home and used to service irrigation, toilets and laundry. This system was approximately \$10,000[1] and yielded 66m^3/yr of rainwater (34% of total demand).
- Implementation of this system in all new developments from 2006 to 2055 produced an 18% reduction in residential demand. This corresponds to operational savings of \$3 million[1] for the municipal utility (assuming a local surface water supply comes on-line in 2025) and lost revenue of \$31 million[1], both over the 50 year time horizon of the WSMP.
- Meeting the water conservation targets defined in the WSMP allowed for a 7-year delay in the move from groundwater to surface water, while RWH provided an additional 3-year delay. This 3-year delay allowed for a reduction of \$6 million[1] in the net present value of the local surface water supply project and a \$25 million[1] dollar reduction in the net present value of the regional surface water supply project.
- Cost benefit analysis of RWH from the homeowner's perspective produced a unit cost[1] of \$4.57/ m^3, while from the societal perspective the cost[1] was \$1.47/ m^3. This difference is due primarily to an extended time horizon to match that used in municipal water supply planning. The lower value is comparable to the cost of conventional surface water supply options for the City of Guelph.

Policy Review

A review of existing policies and regulations was conducted to delineate the regulatory framework for RWH in Ontario. A regulatory framework can be considered to be comprised of policy, regulation and support mechanisms, each of which are equally important and mutually reinforcing. Policies are overarching statements of intent that provide direction and set expectations; regulations are practical and legally binding means of enforcing policies; and support mechanisms include any device that interprets policy and regulation for the layman and encourages implementation, such as educational material, how-to manuals or volunteer incentive programs.

[1] All dollar values in 2006 Canadian dollars.

Key findings:

- No policies specific to RWH could be found in Ontario at the provincial or municipal level. Several policies relate to water conservation and efficiency or sustainable stormwater management, but only one explicitly refers to source substitution. Further, water conservation or stormwater policies that were identified are couched in broader planning legislation with little visibility or enforcement on their own.

- The Ontario Building Code is the primary regulatory device governing RWH. It is more advanced than the National Plumbing Code in that it allows non-potable water to be used for indoor uses, but is limited in that it only allows its use for toilet/urinal flushing. Further, additional clauses related to RWH are scattered and unclear.

- No user-oriented support mechanisms or incentives were identified for RWH. While several municipalities promote rain barrels, there is essentially no mention of bigger systems for indoor use. Further, current municipal pricing structures and building approval processes are generally weak in their ability to encourage water conservation and sustainable stormwater management and thus do not serve to promote RWH.

Policy Analysis

A qualitative study was completed to assess the ability of the existing regulatory framework to facilitate the uptake of RWH and to identify the barriers and opportunities for widespread implementation. A series of semi-structured interviews was conducted with various stakeholders in the Guelph area, including municipal conservation officers, building inspectors, architects, engineers, builders, and RWH suppliers, all involved in some capacity in the implementation of RWH.

Key findings:

- Interest in RWH exists and is growing among all stakeholders.

- The most significant barriers identified were: cost; liability; limited end uses permitted for rainwater in the building code; poor distinction between rainwater, greywater and non-potable water in the building code; and a lack of public awareness.

- The most prevalent solutions proposed by the respondents were: an expanded the list of permissible end uses in building code; stronger provincial endorsement of RWH; technical education for the building sector; and public education regarding water issues, conservation and RWH.

- The development of a regulatory framework for RWH, and sustainable urban water management in general, must strategically encourage both innovation and implementation. New and varied means of managing risk and minimizing liability must be established in a parallel process.

- The development of the regulatory framework for RWH should include: explicit support for source substitution in provincial and municipal policy; restructuring of building code to better accommodate RWH and allow for expanded uses of rainwater; and the development of a best-practices type manual and incentive mechanisms for water conservation and on-site stormwater management.

RESEARCH HIGHLIGHT

July 2009 Technical Series 09-110

Evaluating the Feasibility and Developing Design Requirements and Tools for Large-scale Rainwater Harvesting in Ontario

INTRODUCTION

Rainwater harvesting (RWH) is the process of collecting run-off rainwater from roof surfaces and storing it for later domestic use. Fuelled by a growing interest among homeowners and municipalities to conserve water and improve stormwater management, RWH is rapidly becoming a major part of sustainable building practices across Canada.

This *Research Highlight* describes a project carried out in anticipation of this growing trend by the University of Guelph School of Engineering in partnership with Canada Mortgage and Housing Corporation (CMHC), the Canadian Water Network and several other private and public partners. The goal of the two-and-a-half year project was to investigate the feasibility of widespread residential rainwater harvesting in Ontario.

RESEARCH PROGRAM

At the start of the research program it quickly became evident that rainwater harvesting is both technically feasible and of interest to consumers and the housing industry. The researchers therefore shifted the focus of the project to capacity development.

Specifically, the project partners looked at four key areas where improving capacity could help accelerate the adoption of RWH in Ontario: the quality of rainwater; the design and performance of RWH systems; the economic feasibility of widespread rainwater harvesting; and the role and impact of public policy and regulation.

FOCUS 1: RAINWATER QUALITY

The Study

The question of whether or not rainwater is safe for household use is an essential step in the acceptance of RWH by homeowners and all levels of government.

Several factors can affect rainwater quality. These include the proximity of the collection site to heavy industry or major freeways, the presence of birds or rodents, the prevailing weather conditions, and the materials used in the roof where the water is collected and the cistern where it is stored.

To assess the quality of rainwater in the Guelph area, the researchers conducted a one-year assessment from October 2006 to October 2007 at seven different households with RWH systems, all located within a 30-km radius around the City of Guelph. At each site, approximately 30 samples were collected throughout the year from both the rainwater cistern as well as at the point of use (following any post-cistern treatment).

The samples were analyzed to assess their pH, turbidity, colour, total and fecal coliforms, total organic carbon (TOC), total nitrogen (TN) and UV absorption (254 nm). This data was then used to identify the impact on water quality of each of the following factors:

- Contact with the catchment (collection) surface;
- Storage in a rainwater cistern;
- Temperature and rainfall patterns;
- Seasonal climate variations;

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- Post-cistern treatments; and
- The collection site environment.

Key Findings

The key findings of this yearlong assessment included the following conclusions:

- The physicochemical properties of rainwater were impacted primarily by the roof and cistern material and site environment. Microbiological quality, on the other hand, was affected primarily by the season, temperature and water treatment.
- In general, water quality was found to be better at sites with steel roofs than at those with asphalt shingle roofs. Concrete cisterns also tended to raise the pH of stored rainwater, whereas the pH remained constant when stored in plastic cisterns.
- The colour, turbidity and TN concentration of stored rainwater increased during dry periods, while rainwater quality tended to improve during the winter months.
- Pre-treatment devices (such as gutter screens, leaf-catchers, first-flush devices or coarse filters) and post-cistern treatment devices (such as 20-micron particle filters, carbon filters and UV lamps) reduced turbidity, colour and odour issues, as well as the number of coliforms in the water.
- In general, cistern-stored rainwater was found to be safe for such non-potable applications as toilet flushing and outdoor use. Following treatment, harvested rainwater may also be suitable for additional indoor applications such as laundry.

Table 1 Physicochemical properties of rainwater observed for cistern-stored (CS) and point of use (POU) samples (values: mean ± standard deviation).

Sample Location	pH	Turbidity (NTU)	TOC (mg/L)	TN (mg/L)	Colour (CU)	UV-ABS (254 nm)
Site 1 CS	7.1 ± 0.6	1.1 ± 1.6	3.1 ± 1.9	1.8 ± 0.7	11.1 ± 7.8	0.023 ± 0.026
Site 1 POU	7.2 ± 0.4	0.3 ± 0.1	2.3 ± 2.1	1.6 ± 0.6	7.1 ± 6.4	0.027 ± 0.092
Site 2 CS	5.8 ± 0.9	1.0 ± 0.5	1.8 ± 1.0	1.5 ± 0.4	11.6 ± 10.6	0.031 ± 0.064
Site 2 POU	5.9 ± 1.1	0.8 ± 0.3	2.7 ± 2.1	1.3 ± 0.6	15.2 ± 17.3	0.027 ± 0.040
Site 3 CS	7.2 ± 0.4	1.5 ± 0.7	6.3 ± 4.5	2.0 ± 0.6	25.5 ± 17.0	0.169 ± 0.114
Site 3 POU	7.3 ± 0.3	1.5 ± 0.8	6.9 ± 4.9	2.3 ± 1.5	27.4 ± 19.8	0.191 ± 0.139
Site 4 CS	7.5 ± 0.7	2.6 ± 3.1	8.5 ± 8.3	1.5 ± 0.5	32.8 ± 28.7	0.193 ± 0.177
Site 4 POU	7.0 ± 1.2	1.2 ± 0.5	6.4 ± 5.2	1.5 ± 0.6	24.9 ± 19.4	0.142 ± 0.113
Site 5 POU	8.1 ± 0.7	1.4 ± 0.6	7.4 ± 5.5	1.5 ± 0.5	23.4 ± 10.1	0.188 ± 0.170
Site 6 CS	8.2 ± 0.9	0.9 ± 0.5	2.9 ± 1.7	1.8 ± 0.9	13.1 ± 8.0	0.032 ± 0.056
Site 6 POU	8.2 ± 0.8	0.9 ± 0.3	3.2 ± 1.6	1.7 ± 0.7	13.8 ± 8.1	0.029 ± 0.034
Site 7 POU	7.5 ± 0.4	1.3 ± 0.7	2.4 ± 1.1	1.5 ± 0.3	14.9 ± 8.2	0.041 ± 0.061

TOC – Total Organic Carbon
TN – Total Nitrogen
UV-ABS – Ultraviolet Absorption

Table 2 Microbiological properties of rainwater observed for cistern-stored (CS) and point of use (POU) samples.

Sample Location	Total Coliform (CFU/100mL)			Fecal Coliform (CFU/100mL)		
	Geometric Mean	Range	Portion of Samples >1 CFU/100 mL	Geometric Mean	Range	Portion of Samples >1 CFU/100 mL
Site 1 CS	<1	<1 – 128	76%	<1	<1 – 14	31%
Site 1 POU	<1	<1 – <1	4%	<1	<1 – <1	0%
Site 2 CS	<1	<1 – 86	60%	<1	<1 – 4	11%
Site 2 POU	<1	<1 – <1	0%	<1	<1 – <1	0%
Site 3 CS	<1	<1 – 255	46%	<1	<1 –234	36%
Site 3 POU	<1	<1 – <1	0%	<1	<1 – <1	0%
Site 4 CS	1	<1 – 398	89%	<1	<1 – 400	54%
Site 4 POU	<1	<1 – 12	14%	<1	<1 – <1	0%
Site 5 POU	<1	<1 – 112	42%	<1	<1 – 54	25%
Site 6 CS	<1	<1 – 51	17%	<1	<1 – 10	7%
Site 6 POU	<1	<1 – 40	10%	<1	<1 – 6	7%
Site 7 POU	<1	<1 – 24	28%	<1	<1 – 5	3%
CFU – Colony Forming Units						

FOCUS 2: RWH SYSTEM DESIGN AND PERFORMANCE

The Study

Rainwater harvesting is intended to supplement municipal water supplies by providing homeowners with an alternative supply of safe, reliable water. RWH systems must therefore be designed to both ensure rainwater quality and maximize the volume of water that is collected.

The performance of RWH systems can be affected by factors ranging from the amount of rainfall and size of the collection surface and cistern, to losses from the roof or pre-cistern treatment devices. In Ontario, cold weather can also have an impact on performance, whether through the addition of melting snow or the risk of the system freezing.

To test the performance of RWH systems, demonstration sites were set up in three residential locations in Guelph. At the first site (Experimental Site 1), a rain gauge was installed, water level and temperature sensors were placed inside the cistern, and a water meter was installed on the rainwater plumbing line. All three sites were monitored for a year, and the resulting data was used to assess:

- Trends in daily rainfall and rainwater demand;
- Losses from the catchment surface (roof) and cistern overflows;
- Performance of the RWH systems during cold weather;
- Impact of pre-cistern treatment devices on the quality of the rainwater; and
- Total municipal water savings.

In addition, the researchers also created a "cistern sizing model" to determine the optimum size for rainwater storage cisterns. The model was based on historic daily rainfall data for cities throughout the province, and compared to the actual data collected at Experimental Site 1. The model was then used to evaluate the water storage requirements for two case studies: single-detached homes and townhouses.

Key Findings

The key findings from the performance analysis included:

- The RWH system at Experimental Site 1 collected 65 m^3 of water during the one-year program. This was sufficient to meet about 30 per cent of the annual water needs of a five-person household, demonstrating that the widespread use of rainwater for flushing toilets and washing clothing could reduce residential water demand in Ontario by 22-47 per cent.
- During dry periods (less than 0.5 mm of rainfall), there was no appreciable increase in water volume in the cistern. During heavier rainfalls, only 80 per cent of the additional volume of water was collected. The loss was likely a combination of loss from the catchment roof as well as overflow from the cistern.

- During cold weather, collection efficiency dropped to 60 per cent. However, this loss was largely replaced by water from melting snow. Heating or burying the cistern below the frost penetration depth could also help reduce the risk of freezing, allowing RWH systems to continue to perform adequately during winter conditions.
- For smaller cisterns (250-3,500 L), a relatively minor increase in storage capacity resulted in a substantial increase in water savings. For larger cisterns (above 10,000 L), increases in storage capacity had little impact on system performance.
- A significant difference in the potential for water savings was observed between single-detached homes and townhouses. When used for toilet flushing and laundry, RWH systems provided single-detached homes with 67 m^3 of water annually, but townhouses gained only 42 m^3. It is therefore likely that the catchment surface area is a significant limiting factor in RWH design and potential water savings.

FOCUS 3: ECONOMIC FEASIBILITY

The Study

Cost is generally considered to be one of the most compelling obstacles to the widespread adoption of rainwater harvesting. The researchers developed cost estimates for conceptual RWH systems, based on the demonstration sites installed for this project and other local RWH systems. The RWH model provided estimated water savings for different design configurations and end use patterns. Both the cost and water savings were then scaled up to reflect a scenario where RWH systems were implemented in all new residential development in Guelph from 2006 to 2051. This scenario was compared to the City of Guelph's current 2006 Water Supply Master Plan. Net present value calculations were performed from three different perspectives: the homeowner, the municipal utility, and society.

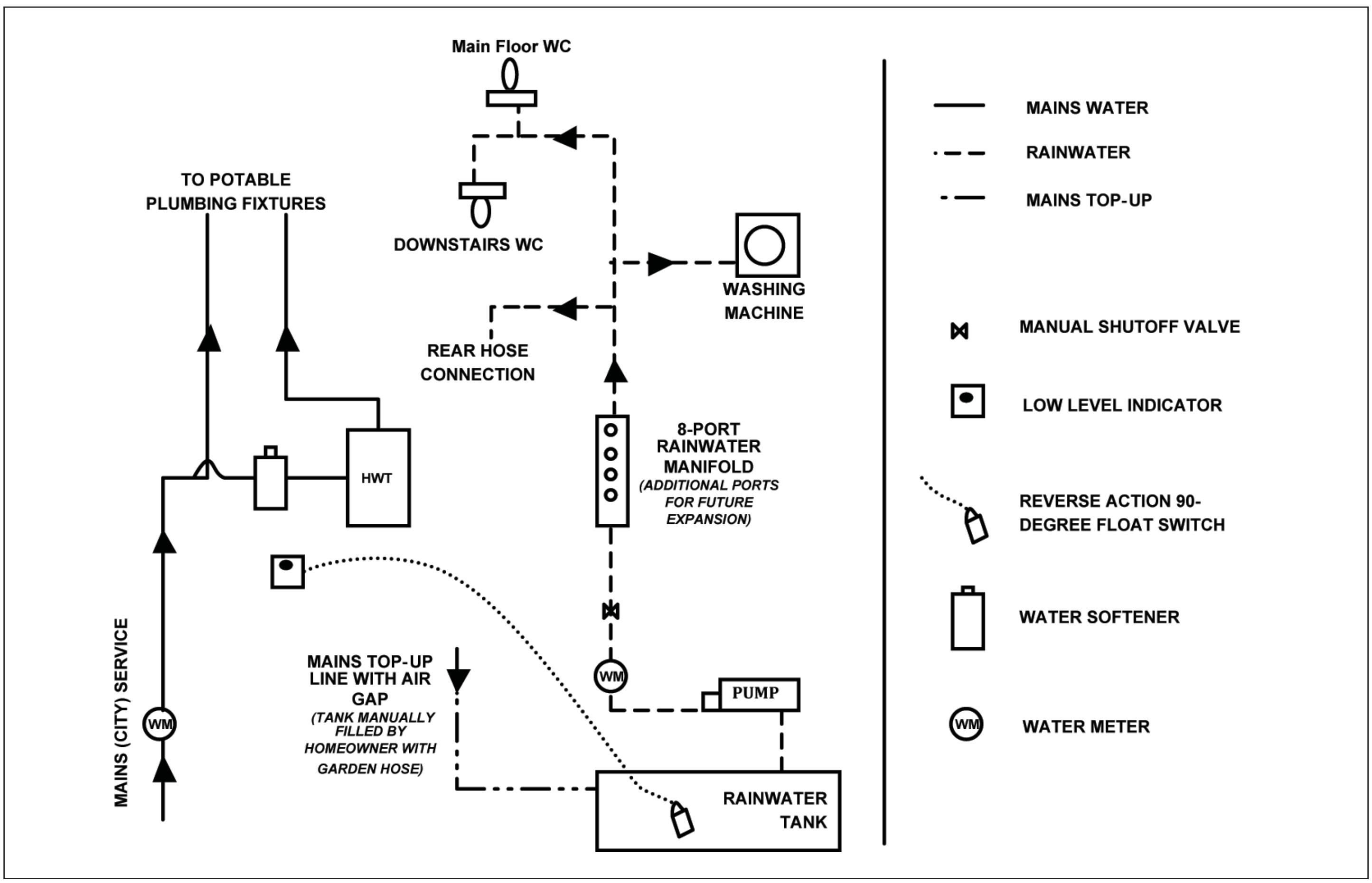

Figure 1 Schematic of the internal plumbing at Experimental Site 1.

[1] All dollar values are in 2006 Canadian dollars.

Key Findings

The economic feasibility analysis revealed that:

- The capital cost to homeowners of an individual RWH system ranged between $6,000[1] and $14,000, depending on its size and configuration.
- Regardless of the size of the tank, the maximum water savings achieved from RWH was 41 per cent for single detached homes and 23 per cent for multi-attached homes. This amounted to about 82 m^3 in water savings per household per year for single detached homes and 42 m^3 per household per year for multi-attached.
- Smaller systems are more cost effective than larger systems because the incremental cost of a larger tank is more than the financial savings realized from the additional water savings.
- Installing 5 m^3 and 3 m^3 of storage capacity in all new single detached and multi-attached dwellings, respectively, from 2006 to 2051, and using rainwater for outdoor use and toilet flushing, would reduce residential water demand in Guelph by 10 per cent.
- The widespread implementation of RWH can offer further savings by delaying the infrastructure investment needed to develop new sources of water. Rainwater harvesting (for toilet flushing and outdoor use) would allow the City of Guelph, for example, to delay the move from groundwater to surface water by two years.

FOCUS 4: THE ROLE OF PUBLIC POLICY

The Study

All the technological advances in rainwater harvesting will be of little value if the appropriate regulatory frameworks and public policies do not permit or promote their use.

The researchers therefore conducted a thorough review of the policies, support mechanisms and regulatory frameworks that are already in place in Ontario. They also carried out a series of interviews with municipal officers, building inspectors, architects, engineers, builders, RWH suppliers and other stakeholders in the Guelph area to identify any barriers or opportunities for the widespread implementation of RWH.

Key Findings

The findings of the policy and regulatory framework review noted that:

- No policies specific to RWH could be found in Ontario at either the provincial or municipal level. Those water conservation and stormwater policies that do exist are couched in broader planning legislation, with little or no visibility or enforcement.
- While the regulatory framework is currently wanting, authorities seem to be aware of the growing interest in RWH and the need to accelerate its progress. At both the provincial and municipal level, there is broad policy support for water conservation and efficiency as well as for sustainable stormwater management practices.
- The Ontario Building Code is the primary regulatory device governing RWH. It is more advanced than the National Plumbing Code in that it allows non-potable water to be used indoors, but it remains limited in that it only allows it to be used for toilet or urinal flushing. Clauses related to RWH in the Code are scattered and unclear.
- No user-oriented support mechanisms or incentives were identified for RWH. Several municipalities promote rain barrels, but there is no mention of larger systems for indoor use. In addition, current municipal pricing structures and building approval processes are generally weak in their ability to promote RWH.
- The most significant barriers to the implementation of RWH identified by the interviewees were: cost; liability; limited end uses permitted for rainwater in the Building Code; poor distinction between rainwater, greywater and non-potable water in the Building Code; and a lack of public awareness.
- The most common solutions proposed by the interview participants included expanding the list of permissible end uses for rainwater in the Building Code, encouraging stronger provincial endorsement of RWH, and educating the building sector and the public about water issues, conservation and RWH.
- According to the interviewees, the regulatory framework for RWH should include: explicit support for source substitution in provincial and municipal policy; restructuring of the Building Code to allow for expanded uses of rainwater; and the development of a best-practices manual and incentive

mechanisms to encourage innovation in water conservation and stormwater management, while establishing new and varied ways of managing risk and minimizing liability.

IMPLICATIONS FOR HOMEOWNERS, MUNICIPALITIES AND OTHER STAKEHOLDERS

Rainwater harvesting is both technically and socially feasible. However, the investment involved in implementing RWH throughout Ontario is not insignificant.

For individual homeowners, the cost of purchasing and installing an RWH system is several times higher than the current price of water. As a result, significant reductions in the cost of RWH systems and/or increases in the price of water will be required if RWH is to become economically competitive at the household level.

The participation of developers and municipalities will also be essential in achieving the economies of scale needed to make RWH more cost-effective. For developers, the benefits may include good will in their communities as supporters of “green” building practices. For municipalities, the benefits of rainwater harvesting include operational savings and a delay in the need for additional water supplies.

When viewed from the perspective of society as a whole, the benefits become much clearer. For Ontario and for Canada, RWH can be seen as an important part of building more sustainable homes and communities.

FURTHER INFORMATION

For more information, a copy of the full report – *Evaluating the Feasibility and Developing Design Requirements and Tools for Large-scale Rainwater Harvesting in Ontario* – is available from the Canadian Housing Information Centre (CHIC) at Canada Mortgage and Housing Corporation.

REFERENCES

Evaluating the Feasibility and Developing Design Requirements and Tools for Large-scale Rainwater Harvesting in Ontario Final Report, prepared by Christopher Despins and Chantelle Leidl for CMHC, August 2008.

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Évaluation de la faisabilité et mise au point des exigences de conception et des outils de collecte à grande échelle des eaux pluviales en Ontario

INTRODUCTION

La collecte des eaux pluviales est le processus par lequel l'eau de pluie s'écoulant des toits est recueillie et stockée en vue d'un usage domestique. Stimulée par l'intérêt croissant des propriétaires et des municipalités envers la conservation de l'eau et l'amélioration de la gestion des eaux de ruissellement, la collecte des eaux pluviales occupe une place de plus en plus marquée dans les pratiques de construction durable à travers le Canada.

La présente édition du *Point en recherche* décrit un projet mené à bien par l'École de génie de l'Université de Guelph, dans l'optique de cette tendance de plus en plus affirmée, en partenariat avec la Société canadienne d'hypothèques et de logement (SCHL), le Réseau canadien de l'eau ainsi que plusieurs autres partenaires publics et privés. Ce projet étalé sur deux ans et demi avait pour objectif d'explorer la faisabilité d'une collecte résidentielle générale des eaux pluviales en Ontario.

PROGRAMME DE RECHERCHE

Au début du programme de recherche, il est vite devenu évident que la collecte des eaux pluviales est réalisable sur le plan technique et intéressante pour les consommateurs et le secteur de l'habitation. Les chercheurs ont par conséquent réaligné le projet sur le développement des capacités.

Plus précisément, les partenaires du projet ont examiné quatre points sur lesquels l'amélioration de la capacité pourrait aider à accélérer l'adoption de la collecte des eaux pluviales en Ontario : la qualité de l'eau de pluie, la conception et le rendement des systèmes collecteurs, la faisabilité économique d'une collecte généralisée des eaux pluviales de même que le rôle et l'impact des politiques publiques et de la réglementation.

PREMIER POINT CENTRAL : LA QUALITÉ DES EAUX PLUVIALES

L'étude

Pour que la collecte des eaux de pluie soit acceptée par les propriétaires et tous les ordres de gouvernement, il est d'abord essentiel de vérifier que les ménages peuvent utiliser l'eau de pluie sans risque.

Plusieurs facteurs peuvent affecter la qualité de l'eau de pluie. Ils comprennent la proximité d'industries lourdes ou d'autoroutes, la présence d'oiseaux ou de rongeurs, les conditions climatiques, les matériaux composant le toit où l'eau est recueillie et les citernes de stockage.

Afin d'évaluer la qualité de l'eau de pluie dans la région de Guelph, les chercheurs ont mené une étude d'un an, d'octobre 2006 à octobre 2007, auprès de sept ménages utilisant des systèmes de collecte des eaux pluviales, tous situés dans un rayon de 30 km de la ville de Guelph. Au cours de l'année, sur chaque site, environ 30 échantillons ont été prélevés directement des citernes et aux points d'utilisation (après traitement post-citerne).

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Les échantillons ont été analysés pour en évaluer le pH, la turbidité, la couleur, la teneur en coliformes totaux et fécaux, en carbone organique total et en azote total ainsi que le niveau d'absorption des UV (254 nm). Ces données ont ensuite été utilisées pour préciser l'impact de chacun des facteurs suivants sur la qualité de l'eau :

- le contact avec la surface collectrice;
- la conservation des eaux de pluie en citerne;
- les régimes climatiques et de précipitations;
- les variations climatiques saisonnières;
- les traitements post-citerne;
- l'environnement du site de collecte.

Résultats clés

Voici les principales conclusions tirées de cette étude d'une année :

- Les propriétés physicochimiques de l'eau de pluie sont affectées par les matériaux qui composent le toit et la citerne ainsi que par le milieu environnant. La qualité microbiologique, par contre, est touchée principalement par la saison, la température et le traitement de l'eau.
- En général, la qualité de l'eau est meilleure sur les sites dont la toiture est en acier plutôt qu'en bardeaux d'asphalte. Les citernes en béton ont tendance à faire augmenter le pH de l'eau stockée alors que le pH demeure stable si l'eau est stockée dans une citerne en plastique.
- La couleur, la turbidité et la concentration en azote total de l'eau de pluie stockée tendent à augmenter pendant les périodes sèches alors que la qualité de l'eau de pluie tend à s'améliorer pendant les mois d'hiver.
- Les dispositifs de pré-traitement (comme les protège-gouttières, pare-feuilles, dispositifs de première vidange et filtres dégrossisseurs) et les dispositifs de traitement post-citerne (comme les filtres à particules de 20 microns, les filtres au charbon et les lampes à UV) réduisent les problèmes de turbidité, de coloration et d'odeur ainsi que la quantité de coliformes dans l'eau.
- En général, les eaux de pluie stockées en citerne peuvent être utilisées sans danger comme eaux non potables, notamment pour la chasse d'eau des toilettes et l'usage extérieur. Après traitement, les eaux pluviales collectées pourraient aussi servir à d'autres usages domestiques intérieurs comme la lessive.

Tableau 1 Propriétés physicochimiques de l'eau de pluie observées pour des échantillons prélevés dans les citernes de stockage (RS) et aux points d'utilisation (PU) (valeur : moyenne ± écart type).

Site de prise d'échantillon	pH	Turbidité (uTN)	COT (mg/l)	AT (mg/l)	Couleur (CU)	ABS UV (254 nm)
Site 1 RS	7,1 ± 0,6	1,1 ± 1,6	3,1 ± 1,9	1,8 ± 0,7	11,1 ± 7,8	0,023 ± 0,026
Site 1 PU	7,2 ± 0,4	0,3 ± 0,1	2,3 ± 2,1	1,6 ± 0,6	7,1 ± 6,4	0,027 ± 0,092
Site 2 RS	5,8 ± 0,9	1,0 ± 0,5	1,8 ± 1,0	1,5 ± 0,4	11,6 ± 10,6	0,031 ± 0,064
Site 2 PU	5,9 ± 1,1	0,8 ± 0,3	2,7 ± 2,1	1,3 ± 0,6	15,2 ± 17,3	0,027 ± 0,040
Site 3 RS	7,2 ± 0,4	1,5 ± 0,7	6,3 ± 4,5	2,0 ± 0,6	25,5 ± 17,0	0,169 ± 0,114
Site 3 PU	7,3 ± 0,3	1,5 ± 0,8	6,9 ± 4,9	2,3 ± 1,5	27,4 ± 19,8	0,191 ± 0,139
Site 4 RS	7,5 ± 0,7	2,6 ± 3,1	8,5 ± 8,3	1,5 ± 0,5	32,8 ± 28,7	0,193 ± 0,177
Site 4 PU	7,0 ± 1,2	1,2 ± 0,5	6,4 ± 5,2	1,5 ± 0,6	24,9 ± 19,4	0,142 ± 0,113
Site 5 PU	8,1 ± 0,7	1,4 ± 0,6	7,4 ± 5,5	1,5 ± 0,5	23,4 ± 10,1	0,188 ± 0,170
Site 6 RS	8,2 ± 0,9	0,9 ± 0,5	2,9 ± 1,7	1,8 ± 0,9	13,1 ± 8,0	0,032 ± 0,056
Site 6 PU	8,2 ± 0,8	0,9 ± 0,3	3,2 ± 1,6	1,7 ± 0,7	13,8 ± 8,1	0,029 ± 0,034
Site 7 PU	7,5 ± 0,4	1,3 ± 0,7	2,4 ± 1,1	1,5 ± 0,3	14,9 ± 8,2	0,041 ± 0,061

COT – Carbone organique total
AT – Azote total
ABS UV – Absorption des ultra-violets

Tableau 2 Propriétés microbiologiques de l'eau de pluie observées pour des échantillons prélevés dans les citernes de stockage (RS) et aux points d'utilisation (PU).

Site de prise d'échantillon	Coliformes totaux (CFU/100 ml)			Coliformes fécaux (CFU/100 ml)		
	Moyenne géométrique	Écart	Portion des échantillons >1 CFU/100 ml	Moyenne géométrique	Écart	Portion des échantillons >1 CFU/100 ml
Site 1 RS	<1	<1 – 128	76 %	<1	<1 – 14	31 %
Site 1 PU	<1	<1 – <1	4 %	<1	<1 – <1	0 %
Site 2 RS	<1	<1 – 86	60 %	<1	<1 – 4	11 %
Site 2 PU	<1	<1 – <1	0 %	<1	<1 – <1	0 %
Site 3 RS	<1	<1 – 255	46 %	<1	<1 –234	36 %
Site 3 PU	<1	<1 – <1	0 %	<1	<1 – <1	0 %
Site 4 RS	1	<1 – 398	89 %	<1	<1 – 400	54 %
Site 4 PU	<1	<1 – 12	14 %	<1	<1 – <1	0 %
Site 5 PU	<1	<1 – 112	42 %	<1	<1 – 54	25 %
Site 6 RS	<1	<1 – 51	17 %	<1	<1 – 10	7 %
Site 6 PU	<1	<1 – 40	10 %	<1	<1 – 6	7 %
Site 7 PU	<1	<1 – 24	28 %	<1	<1 – 5	3 %
CFU – Unité formatrice de colonies						

DEUXIÈME POINT CENTRAL : CONCEPTION ET RENDEMENT DES SYSTÈMES DE COLLECTE DES EAUX PLUVIALES

L'étude

La collecte des eaux pluviales est destinée à compléter l'approvisionnement en eau municipale en procurant aux propriétaires un autre moyen sûr et fiable d'approvisionnement en eau. Les systèmes de collecte doivent par conséquent être conçus à la fois pour assurer la qualité de l'eau de pluie et maximiser les volumes d'eau recueillis.

Le rendement des systèmes de collecte des eaux pluviales peut être touché par des facteurs comme le volume des précipitations, la surface collectrice, le volume de la citerne et les pertes au niveau du toit ou des dispositifs de traitement pré-citerne. En Ontario, le climat froid peut aussi avoir un impact sur le rendement à cause de la neige fondante ou des risques de gel de l'installation.

Pour évaluer le rendement des systèmes de collecte des eaux de pluie, des sites de démonstration ont été installés à trois résidences de Guelph. À la première (Site expérimental 1), ont été installés un pluviomètre, des thermosondes, des sondes de mesure de la profondeur de l'eau dans la citerne et un compteur d'eau sur la conduite d'eau de pluie. Les trois sites ont été surveillés pendant un an et les données obtenues ont été utilisées pour évaluer :

- les tendances des précipitations quotidiennes et de la demande en eau de pluie;
- les pertes de la surface collectrice (toit) et les débordements des citernes;
- le rendement des systèmes de collecte des eaux pluviales par temps froid;
- l'impact des dispositifs de traitement pré-citerne sur la qualité de l'eau de pluie;
- les économies en eaux municipales dans leur ensemble.

De plus, les chercheurs ont créé un « modèle d'évaluation de la taille de la citerne » pour déterminer le format idéal pour les citernes de stockage de l'eau de pluie. Le modèle est fondé sur les données historiques sur les précipitations quotidiennes de villes de l'ensemble de la province et a été comparé aux données recueillies sur le Site expérimental 1. Le modèle a ensuite été utilisé pour évaluer les besoins en stockage de l'eau pour deux études de cas : les maisons individuelles et les maisons en rangée.

Résultats clés

Voici les principales constatations résultant de l'analyse de rendement :

- Durant le programme d'un an, 65 m^3 d'eau ont été recueillis par l'entremise du système de collecte des eaux pluviales du Site expérimental 1. Cette quantité a été suffisante pour répondre à environ 30 % des besoins annuels d'un ménage de cinq personnes, démontrant ainsi qu'une utilisation généralisée des eaux de pluie pour la chasse d'eau des toilettes et la lessive pourrait réduire la demande d'eau résidentielle en Ontario de 22 % à 47 %.
- Au cours des périodes sèches (avec moins de 0,5 mm de précipitations), aucune augmentation appréciable du volume d'eau dans la citerne n'a été observée. Durant les précipitations importantes, seulement 80 % du volume d'eau additionnel a pu être collecté. La perte résulte probablement d'une combinaison des pertes de la surface collectrice et des débordements de la citerne.
- Par temps froid, l'efficacité de la collecte diminue de 60 %. Toutefois, cette perte est largement compensée par l'eau provenant de la fonte de la neige. Le chauffage de la citerne ou son enfouissement en deçà du niveau de pénétration du gel pourrait aussi réduire le risque de gel, permettant ainsi aux systèmes de collecte des eaux pluviales d'avoir un rendement adéquat sous des conditions hivernales.
- Quant aux citernes à petit volume (250 à 3 500 L), lorsqu'on augmente faiblement la capacité de stockage, on obtient une augmentation substantielle des économies d'eau. Pour les citernes plus volumineuses (10 000 L et plus), l'augmentation de la capacité de stockage a peu d'impact sur le rendement du système.

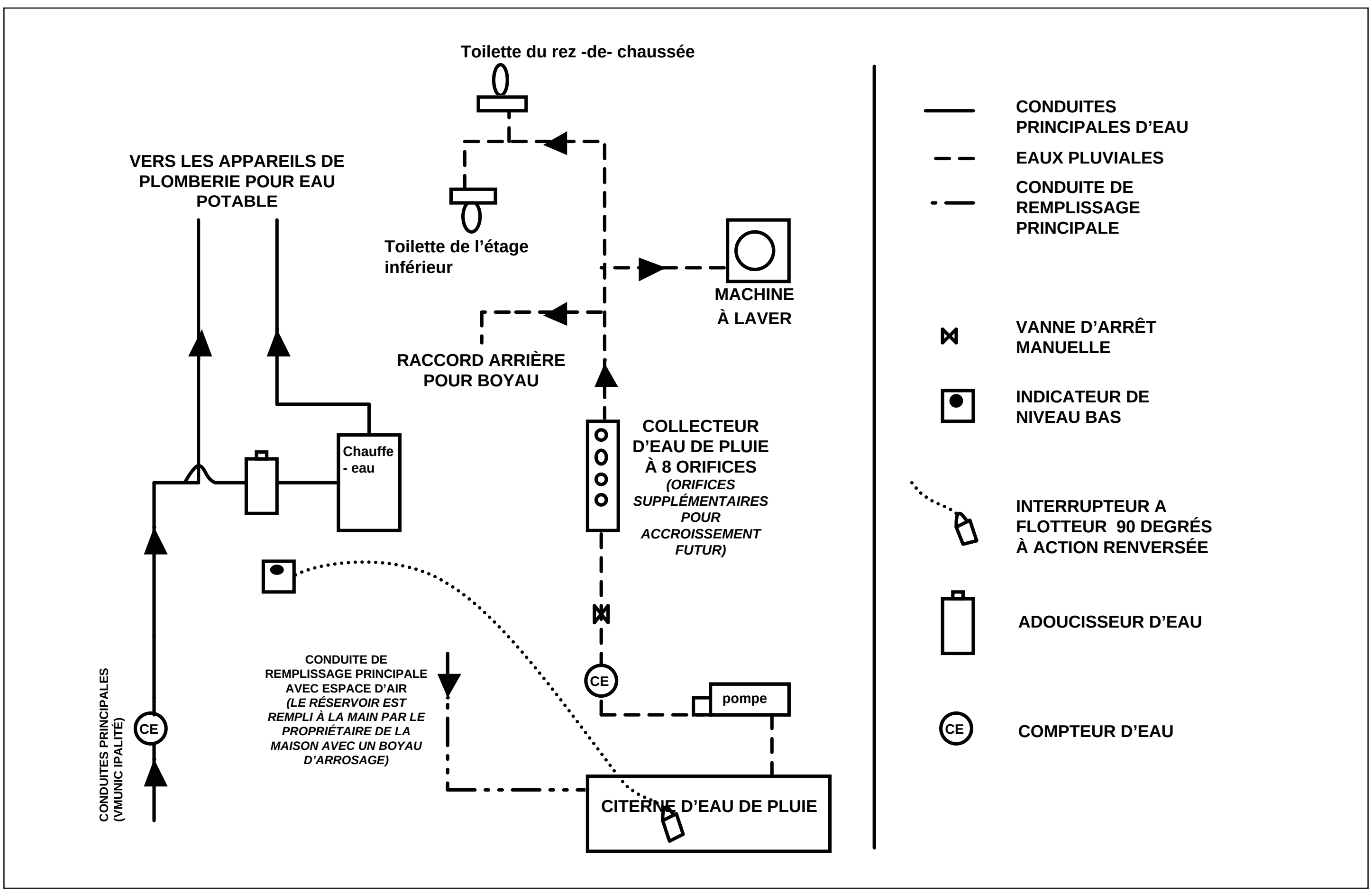

Figure 1 Schéma du réseau de plomberie intérieur du Site expérimental 1.

- Une différence marquée dans le potentiel d'économies d'eau a été observée entre les maisons individuelles et les maisons en rangée. Lorsqu'utilisés pour la chasse d'eau des toilettes et la lessive, les systèmes de collecte des eaux de pluie fournissent 67 m^3 d'eau par année aux maisons individuelles, mais seulement 42 m^3 aux maisons en rangée. Il est par conséquent fort probable que la surface collectrice soit un facteur limitatif dans la conception des systèmes de collecte des eaux de pluie et les économies potentielles en eau.

TROISIÈME POINT CENTRAL : FAISABILITÉ ÉCONOMIQUE

L'étude

Les coûts sont généralement considérés comme l'un des obstacles majeurs à l'adoption généralisée de la collecte des eaux pluviales. Les chercheurs ont préparé des estimations de coûts pour les systèmes conceptuels de collecte des eaux pluviales fondées sur les sites de démonstration installés pour ce projet et sur d'autres systèmes de collecte de la région. Le modèle de collecte des eaux pluviales ainsi préparé évalue l'économie en eau pour différentes configurations et types d'utilisations. Les coûts et les économies d'eau ont ensuite été pondérés pour refléter un scénario dans lequel les systèmes de collecte des eaux de pluie seraient installés dans tous les nouveaux aménagements résidentiels de Guelph de 2006 à 2051. Ce scénario a été comparé au plan directeur d'approvisionnement en eau actuel de la Ville de Guelph. Les calculs de la valeur actuelle nette ont été effectués selon trois perspectives : celle du propriétaire, celle des services publics et celle de la société.

Résultats clés

L'analyse de la faisabilité économique a révélé que :

- Pour le propriétaire d'une maison, le coût d'investissement pour un système autonome de collecte des eaux pluviales va de 6 000 $[1] à 14 000 $ selon ses dimensions et sa configuration.
- Sans égard à la taille de la citerne, les économies maximales réalisées grâce à la collecte des eaux de pluie sont de 41 % pour une maison individuelle et de 23 % pour une maison en rangée. Cela correspond à des économies d'eau d'environ 82 m^3 par ménage par année pour une maison individuelle et de 42 m^3 par ménage par année pour une maison en rangée.
- Les petits systèmes sont plus économiques que les systèmes de grande taille parce que le coût marginal d'une citerne volumineuse est plus important que les économies d'eau additionnelles réalisées.
- L'installation de capacités de stockage de 5 m^3 et de 3 m^3 sur toutes les nouvelles maisons individuelles et en rangée, respectivement, de 2006 à 2051, et l'utilisation de l'eau de pluie à l'extérieur et pour la chasse d'eau des toilettes réduirait la demande en eau résidentielle de 10 % à Guelph.
- La mise en application de la collecte des eaux pluviales peut offrir des économies supplémentaires en reportant les investissements en infrastructures nécessaires pour l'approvisionnement à partir de nouvelles sources d'eau. La collecte des eaux pluviales (pour la chasse d'eau des toilettes et l'usage extérieur) permettrait à la ville de Guelph, par exemple, de reporter de deux ans le besoin d'alimenter la ville en eau à partir de plans d'eau en surface au lieu d'eau souterraine.

[1] Tous les montants sont en dollars canadiens de 2006.

QUATRIÈME POINT CENTRAL : LE RÔLE DES POLITIQUES PUBLIQUES

L'étude

Toutes les avancées technologiques dans la collecte d'eau de pluie n'auront que peu de valeur si les cadres de réglementation et les politiques publiques ne permettent pas leur utilisation, ni n'en font la promotion.

Les chercheurs ont par conséquent procédé à un examen approfondi des politiques, mécanismes de soutien et cadres de réglementation déjà en place en Ontario. Ils ont aussi mené une série d'enquêtes auprès des fonctionnaires municipaux, inspecteurs en bâtiment, architectes, ingénieurs, constructeurs, fournisseurs d'appareils de collecte des eaux pluviales et autres parties prenantes de la région de Guelph afin de relever tout obstacle et toute occasion liés à la mise en application de la collecte des eaux pluviales.

Résultats clés

L'examen du cadre réglementaire et des politiques a révélé ce qui suit :

- Il n'existe actuellement aucune politique particulière visant la collecte des eaux pluviales en Ontario, que ce soit à l'échelon provincial ou municipal. Les politiques actuelles sur la conservation de l'eau et l'eau de ruissellement s'insèrent dans des lois d'aménagement plus vastes et reçoivent une visibilité et une application limitées, voire nulles.
- Alors qu'il demeure nécessaire d'établir un cadre réglementaire, les autorités semblent avoir connaissance de l'intérêt grandissant envers la collecte des eaux pluviales et la nécessité d'en accélérer la progression. Aux échelons provincial et municipal, des politiques appuient la conservation et l'utilisation efficace de l'eau ainsi que les pratiques de gestion durable des eaux de ruissellement.
- Le Code du bâtiment de l'Ontario est le principal outil réglementaire de la collecte des eaux pluviales. Il est plus avancé que le Code national de la plomberie en ce qu'il permet l'utilisation d'eau non potable à l'intérieur. Il demeure toutefois limité puisqu'il ne permet cette utilisation que pour la chasse d'eau (toilettes et urinoirs). Les dispositions du Code relatives à la collecte des eaux pluviales sont éparses et obscures.
- Aucun mécanisme de soutien ou d'incitation à la collecte des eaux pluviales n'a été relevé. Plusieurs municipalités ne font pas la promotion de l'utilisation de barils pour la collecte des eaux de pluie, mais on ne fait pas mention de systèmes plus élaborés pour l'utilisation de l'eau de pluie à l'intérieur. De plus, les structures de prix actuelles des municipalités et les processus d'approbation relatifs à la construction sont généralement déficients dans leur capacité à promouvoir la collecte des eaux pluviales.
- Les obstacles à la mise en œuvre de la collecte des eaux pluviales les plus importants relevés par les participants à l'enquête sont : les coûts, la responsabilité, les usages limités de l'eau de pluie permis par le Code du bâtiment, la faible distinction entre l'eau de pluie, les eaux ménagères et l'eau non potable dans le Code du bâtiment et le manque de sensibilisation du public.
- Les solutions les plus couramment proposées par les participants à l'enquête sont l'expansion de la liste d'utilisations permises des eaux de pluie dans le Code du bâtiment, l'encouragement d'une plus grande participation provinciale à la collecte des eaux pluviales, la sensibilisation du secteur de la construction et du public sur les enjeux liés à l'eau, à sa conservation et à la collecte des eaux pluviales.
- Selon les participants à l'enquête, le cadre réglementaire de la collecte des eaux pluviales devrait comprendre : un soutien explicite au remplacement de la source d'approvisionnement en eau dans les politiques provinciales et municipales, la restructuration du Code du bâtiment pour permettre une plus vaste utilisation de l'eau de pluie et la création d'un manuel sur les pratiques exemplaires et les mécanismes incitatifs pour encourager l'innovation en conservation de l'eau et en gestion des eaux de ruissellement tout en établissant diverses nouvelles manières de gérer les risques et de limiter la responsabilité.

INCIDENCES POUR LES PROPRIÉTAIRES, LES MUNICIPALITÉS ET LES AUTRES PARTIES PRENANTES

La collecte des eaux de pluie est réalisable d'un point de vue technique et social. Toutefois, l'investissement nécessaire à la mise en œuvre de la collecte des eaux pluviales partout en Ontario n'est pas négligeable.

Pour les propriétaires, le coût d'achat et d'installation d'un système de collecte des eaux pluviales est de plusieurs fois supérieur au prix actuel de l'eau. En conséquence, des réductions importantes du coût des systèmes de collecte des eaux pluviales et/ou des augmentations du coût de l'eau seront nécessaires pour que la collecte des eaux pluviales devienne concurrentielle d'un point de vue économique pour les ménages.

La participation des promoteurs et des municipalités sera aussi essentielle à l'atteinte des économies d'échelle nécessaires pour rendre la collecte des eaux pluviales plus rentable. Les promoteurs tireront avantage de l'occasion qui leur est donnée de démontrer leur bonne volonté en tant que défenseurs des pratiques de construction durables dans leur communauté. Pour les municipalités, les avantages de la collecte des eaux de pluie consistent en des économies opérationnelles et le report à plus tard de trouver de nouvelles sources d'approvisionnement en eau.

Du point de vue de la société dans son ensemble, les avantages sont d'autant plus clairs. Pour l'Ontario et le Canada, la collecte des eaux pluviales peut être vue comme une contribution importante à l'édification de maisons et de communautés écologiques.

RENSEIGNEMENTS SUPPLÉMENTAIRES

Pour plus d'informations, vous trouverez la version complète du rapport au Centre canadien de documentation sur l'habitation (CCDH) à la Société canadienne d'hypothèques et de logement.

RÉFÉRENCE

Évaluation de la faisabilité et mise au point des exigences de conception et des outils de collecte à grande échelle des eaux pluviales en Ontario, rapport final, rédigé par Christopher Despins et Chantelle Leidl pour la SCHL, août 2008.

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Aux termes de la partie IX de la ***Loi nationale sur l'habitation,*** le gouvernement du Canada verse des fonds à la SCHL afin de lui permettre de faire de la recherche sur les aspects socio-économiques et techniques du logement et des domaines connexes, et d'en publier et d'en diffuser les résultats.

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Chapter 1 Introduction

In Canada, collecting rainwater for household use was common in the 19th century, but the practice fell out of use with the rise in municipally supplied water and the establishment of local building codes. The use of rainwater as a primary or supplementary source has largely remained only in rural areas where ground water is limited and centralized systems impractical or too costly, for example, the Gulf Islands in British Columbia and areas of Nova Scotia (Islands Trust Fund 2006a; Waller and Scott 1988). At present, rainwater harvesting (RWH) is much less common in urban settings; rather, rainwater collected from rooftops is discharged to natural or artificial water reservoirs through stormwater infrastructure, or is infiltrated on-site. A number of urban residential RWH projects have been initiated in Canada, including the Vento mixed use development in Calgary, Alberta, and the Toronto Healthy House in downtown Toronto, Ontario (Windmill Development Group 2005; Waller et al. 1999). These RWH systems, however, are often incorporated as part of 'green building' demonstration projects, and are not representative of the underdeveloped state of RWH in Ontario and throughout most of Canada.

Internationally, RWH systems are more common. One example is Australia, where in the state of South Australia, RWH is practiced in 51% of the households, 36% of those whom use it as their primary source of potable water (enHealth 2004). Harvesting rainwater is also prevalent in Germany, where comprehensive regulations, standardized designs and industry support have helped to promote the growth of the practice (König 2001). Using rainwater to meet non-potable demands is also a growing practice in the dryer regions of the United States, particularly in the state of Texas. The Texas Water Development Board (TWDB) has promoted the use of rainwater as an important conservation measure, one that will help the state to supplement its water supply in the face of population growth and increasing water demands (TWDB 2005).

These examples show that, in many jurisdictions, RWH is considered an appropriate means for supplying household water demands in rural areas, and for augmenting municipal water supplies in urban environments. However, for RWH to be widely adopted in Canada, the practical aspects of RWH must be understood in the Canadian context, and the issues associated with its widespread implementation must be identified and addressed in a comprehensive and integrated manner.

Issues arising from the widespread implementation of RWH

Advancing the widespread implementation of RWH requires the investigation of technical concerns regarding the performance of RWH systems to ensure the technology is effective, robust and safe. The performance of a RWH system can be defined by both the quality and the quantity of rainwater it produces, as well as by the integrity and durability of the technology and its components. Such issues must be accounted for in the design of each system. Further to these technical concerns, issues such as public awareness and acceptance, economic feasibility and market capacity must also be addressed. The development of a strategic regulatory framework is necessary to simultaneously advance both the technical and non-technical aspects of RWH to allow for widespread implementation.

Quality of rainwater

Studying the quality of rainwater is very important because of its implications for public health and consequently, public acceptance and policy development. In Ontario, the perceived poor quality of rainwater and lack of scientific data limit the allowable end uses of rainwater to toilet flushing and landscape irrigation. In Germany, Australia and parts of the United States, however, the quality of rainwater is considered suitable for additional applications, including clothes washing (DIN 2002; enHealth 2004; TWDB 2005). Treatment can be applied to improve the overall quality of the rainwater and allow for a larger scope of application; however, these advances require a thorough understanding of rainwater quality and the impacts of both system design and treatment.

The quality of water collected in a RWH system is affected by many factors. Site environment such as proximity to heavy industry or major freeways, the presence of birds or rodents, and meteorological conditions have all been identified as potential sources of rainwater contamination (Förster 1998; Taylor et al. 2000; Evans et al. 2006). Several aspects of the rainwater harvesting system itself can also significantly affect the quality of rainwater. The roof surface, for example, can degrade the quality of rain, while the cistern can offer several natural treatment processes to improve the quality of stored water (Simmons et al. 2001; Spinks et al. 2003a). Other proven means of reducing levels of rainwater contamination include the use of a filter or first-flush device to treat roof runoff prior to storage, as well the use of ultra-violet (UV) disinfection, slow sand filtration and hot water systems (Yaziz et al. 1989; Coombes et al. 2000; Kim et al. 2005; Ahammed and Meera 2006).

Quantity of rain from rainwater harvesting systems

Maximizing the quantity of rain supplied from a RWH system is important because the volume of rainwater utilized corresponds directly with municipal water savings. However, this must be balanced with the cost and practicality of increasingly large systems. Several factors affect the quantity of rainwater supplied by a RWH system, including local rainfall patterns, roof size, cistern capacity, and the amount of demand. Theoretically, for every millimetre of rainfall, 1L of water can be collected per square meter of surface area. The size of the roof or ‘catchment’ area therefore limits the amount of rainfall that can be collected. Similarly, the size of the cistern constrains the amount of rainfall that can be stored: the larger the cistern, the greater quantities of runoff can be collected before the storage capacity is exceeded, and the cistern overflows. Further, the actual demand on the system influences the total volume of rainwater captured and supplied. Generally, the higher the demand, the greater the capacity for storage as the water level in the cistern will be continually drawn down and consequently, the higher the volume of rainwater that can be captured and supplied. If demands are too high, however, the tank may frequently be near empty and will have to rely heavily on a make-up system to supply mains water to the end uses. Finally, losses from the system reduce the total volume of water captured. The magnitude of loss depends upon the type of roofing material, the integrity of gutter system, and the pre-cistern treatment devices that are utilized.

Design of rainwater harvesting systems

Careful design can serve to address both the quality and quantity concerns described above. Sizing the cistern according to roof catchment area, precipitation data and end use patterns can maximize the volume of rainwater supplied, while minimizing the size and thus cost of the system. System design must also carefully account for the volume of overflow anticipated and must include a back-up supply of water for dry periods when the tank may be near empty.

Pre-treatment devices such as gutter screens, leaf-catchers, first-flush devices or coarse filters can minimize the ingression of large particles into the system, while post-treatment devices such as particle filters, carbon filters and UV lamps can address issues of turbidity, colour/odour and bacteria, respectively. Apart from specialized treatment technology, simple design considerations such as the placement of the rainwater inlet line, allow for the highest quality possible. Further, independent plumbing lines and proper backflow prevention address the possibility of contaminating the mains water supply with rainwater.

A further design issue prevalent in the Canadian context is cold weather and its impact on system performance. This has implications specifically in terms of the location of the cistern and outdoor collection, treatment and distribution components, as well as in the collection of precipitation during cold months. While many RWH systems and technologies exist around the world, their application and success in the Canadian context depend largely on their performance in cold weather conditions.

Economic analysis for RWH

Conventional approaches to urban water management have largely been governed by conventional methods of economic analysis. As more sustainable approaches to water management are being promoted, it is critical that we evaluate how they perform under traditional economic analysis and that we reconsider the appropriateness of these methods in the context of sustainability. There is the possibility that conventional analyses may be inherently biased toward the status quo and provide a disservice to emerging innovations. As economics is a key factor in public decision making, it is essential that these analyses allow for the equitable comparison of all water management options so that the most sustainable solutions can emerge.

Once appropriate methods of economic analysis are established, it is important that they be used to evaluate actual case studies, considering various perspectives such as homeowners, developers, municipal utilities and society as a whole. There is currently much speculation with respect to the potential impact RWH could have when implemented on a wide scale and the resulting financial implications; however, there has been little actual investigation to date.

Regulatory framework for RWH

While the technical challenges of RWH merit significant attention, advances in these areas are of little value when the practice is confined by a weak regulatory framework that does not permit or encourage RWH.

A regulatory framework includes all binding and voluntary instruments created by different government and non-government authorities, which jointly serve to guide or control targeted activities. It is comprised of three equally important and mutually reinforcing components: policy, regulation, and support mechanisms. This framework is important because it ultimately defines what can and cannot be done, and how. Further, depending on how it is developed, the regulatory framework can serve to actively encourage a practice or it can serve as an impediment to implementation.

RWH crosses into both the building sector and the water sector and both have traditionally been highly regulated jurisdictions with a very strong focus on risk management. Currently, however, there are very few policies, regulations or non-regulatory devices pertaining to RWH in Ontario. It is therefore essential that issues surrounding their role and the process of their formation be explored and debated such that the development of a regulatory framework for RWH can be progressive and enabling. Once policy, regulation and even unregulated best practices are established, it is very difficult to go back and undo them.

Description of study and objectives

To address the above issues and promote the adoption of RWH in Ontario, a multi-stakeholder project was led by the School of Engineering, at the University of Guelph. Of the stakeholders participating in the project, a select group comprised the project partners, who provided funding and in-kind support (listed in Figure 1).

Figure 1: Partners collaborating in the rainwater harvesting project

These partners included members working at the federal (Canada Mortgage and Housing Corporation), provincial (Ontario Centres of Excellence) and municipal (City of Guelph) levels of government; as well as both 'alternative' (Evolve Builders Group) and 'mainstream' (Reid's Heritage Homes) housing developers. In addition, an informal network of local stakeholders, including homeowners, non-profit groups, contractors, industries, suppliers, and conservation agencies were naturally drawn to the project. These partners and local stakeholders all participated in various capacities, providing support for the project in their core areas of expertise. In return, the partners and stakeholders were able to develop their own capacity in regards to RWH through their interactions with the other project participants.

Throughout this participatory process, different aspects of RWH were investigated with the objectives listed below.

Rainwater quality assessment program

A one-year rainwater quality assessment program was initiated to:

1. Assess the quality of rainwater from RWH systems located in Southern Ontario, and
2. Investigate the impact of factors such as:
    a. Site environment,
    b. Seasonal variation,
    c. Contact with a catchment surface,
    d. Storage in a rainwater cistern,
    e. Post-cistern treatment, and
    f. Climate (temperature and rainfall patterns) on the quality of harvested rainwater.

The knowledge gained from this quality assessment program was used to comment upon the appropriate end-uses of rainwater in Ontario, and propose recommendations regarding rainwater treatment.

Performance monitoring program & development of cistern sizing model

A one-year performance monitoring program of a residential RWH demonstration site designed and constructed for this project was initiated to:

1. Monitor the inputs (from rainfall and snowmelt) into the cistern, losses (from overflow) and outputs from the cistern (from household demand) under a variety of conditions, and
2. Analyze the collected data to determine:
    a. The yield from a RWH system, given the unpredictability of weather patterns,
    b. Losses from cistern overflows,

c. Losses from the catchment surface,
d. Cold weather performance,
e. Snowmelt contribution,
f. The performance of pre- and post-cistern treatment devices, and
g. Municipal water savings.

The knowledge gained from the performance monitoring program was used to develop a model for simulating the water balance of RWH systems. This ‘cistern sizing model’ can be used to assist designers with the selection of a rainwater cistern, given local rainfall patterns, catchment area, and the level of rainwater demand. Further, the process of designing and installing three demonstration sites has informed the development of a RWH design, installation and management manual. Both the cistern sizing tool and the design manual are under further development and will be released by CMHC in spring 2009.

Economic Analysis and Case Study

The economic analysis consisted of the following two parts, which maintained the respective objectives:

1. Identifying from literature best practices for conducting an economic analysis such that bulk augmentation, demand management and source substitution can be equitably compared.
2. Using the City of Guelph and the 2006 Water Supply Master Plan as a case study to evaluate the economic performance of RWH systems from the perspective of:
    a. Homeowners,
    b. Developers,
    c. Municipal water utilities, and
    d. Society as a whole.

The results of this case study suggest a potential role for RWH in water supply planning and warrant further investigation.

Policy Review and Analysis

The policy research comprised the following two components:

1. An overview of policies, regulations and support mechanisms relating to water use and conservation and sustainable stormwater management was carried out to identify the existing regulatory framework for RHW in Ontario.
2. A series of stakeholder interviews was then conducted to identify barriers and opportunities for the widespread implementation of RWH, from the perspective of individuals and organizations active in the promotion, implementation and permitting of RWH systems.

Insight from this work was used to inform suggestions regarding appropriate and progressive regulatory measures, as applicable to both provincial and municipal authorities, which will contribute to advancing the practice of RWH in Ontario.

Organization of report

The remainder of this report elaborates on the research methods used to investigate both the technical and non-technical aspects of rainwater harvestings and the results of this work. It is arranged as follows:

Chapter 1: Introduction
Chapter 2: Assessment of Rainwater Quality from RWH Systems in Ontario
Chapter 3: Performance Aspects of RWH Systems
Chapter 4: Cistern Sizing Model
Chapter 5: Economic Analysis for the Widespread Implementation of RWH
Chapter 6: Review of Regulatory Devices Pertinent to RWH in Ontario
Chapter 7: Evaluation of Regulatory Framework for RWH in Ontario

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Chapter 2 Assessment of Rainwater Quality from Rainwater Harvesting Systems in Ontario, Canada

Introduction

Rainwater harvesting (RWH) is the ancient practice of capturing storm runoff from roofs and storing it for a later purpose. The quality of water collected in a RWH system is affected by many factors, including:

1. Environmental conditions such as proximity to heavy industry or major freeways, the presence of birds or rodents (Förster 1998; Taylor et al. 2000);
2. Meteorological conditions such as temperature, antecedent dry periods, and rainfall patterns (Evans et al. 2006);
3. Contact with a catchment material and the dirt and debris that are deposited upon it between rainfall events (Simmons et al. 2000; Van Metre and Mahler 2003);
4. Treatment by pre-cistern treatment devices like filtration or first-flush diversion (Yaziz et al. 1989; Martinson and Thomas 2005);
5. Natural treatment processes taking place within the rainwater cistern (Scott and Waller 1987; Spinks et al. 2003a;); and
6. Treatment by post-cistern treatment devises like particle filtration, ultraviolet disinfection, chlorination, slow sand filtration or hot water systems (Coombes et al. 2000; Kim et al. 2005; Ahammed and Meera 2006; Sazakli et al. 2007).

As part of a research and development project aimed at encouraging rainwater harvesting in Ontario, a one-year rainwater quality assessment program was initiated with the objectives to: (i) assess the quality of rainwater from RWH systems located in the Southern Ontario region of Canada, and (ii) investigate the impact of factors such as: contact with a catchment surface, storage in a rainwater cistern, weather (temperature and rainfall patterns), seasonal variation, post-cistern treatment, and site environment on the quality of harvested rainwater.

Background

Environmental conditions such as the presence of atmospheric pollutants, overhanging foliage, and bird debris can contribute to the contamination of rainwater; however, these factors are site specific and independent of the design of the RWH system itself. While such factors are difficult to control, several features of the RWH system also impact water quality. Catchment material, storage material and treatment are three design considerations that can be optimized to maximize water quality.

Catchment material

Contamination from roof surfaces can come from two main sources. Particles can accumulate on the roof surface either from direct atmospheric deposition, or from overhanging foliage or bird and rodent debris. Alternatively, the roof material itself continuously degrades and can contribute both particulate matter and dissolved chemicals to runoff water. While the former is largely site specific, the impact of different roof materials is fairly consistent regardless of location.

Metal roofs are often associated with the leaching of trace elements, detected in the dissolved form in the runoff itself and adhered to the particulate matter washed from the roof. Förster (1996) reports a three-fold increase in the concentration of dissolved and particulate copper from copper flashings, compared to both pure rainwater and runoff collected from clay or concrete tiles. A similar trend is shown for zinc concentration in runoff from a zinc sheet roof, and to a lesser degree, from zinc gutters. Van Metre and Mahler (2003) compared galvanized metal roofs to asphalt roofs and also found metal roofs to be a greater source of both zinc and cadmium contamination, while asphalt was associated with higher levels of lead and possibly mercury. In contrast, Hart and White (2006) found no significant difference between concentrations of lead, zinc or copper in runoff from asphalt roofs and metal roofs, indicating a wide variation in results among similar roof-based studies.

Apart from metals, the leaching of Polycyclic Aromatic Hydrocarbons (PAHs) from bitumen is another concern associated with asphalt shingles. While this has been observed under artificial and highly exaggerated laboratory conditions (Brant and de Groot 2001), one study of runoff from existing buildings has shown no evidence that asphalt roofs are a source of PAHs (Van Metre and Mahler 2003). Other studies suggest that flat tar felt roofs, however, may be a more significant source due to the more prolonged contact with the tar (Förster 1999). In cases where the concentration of PAHs was higher in the roof runoff than in the precipitation itself, it has been suggested that rather than leaching from the roofing material, the presence of adsorption sites on the roof surface sorbs PAHs from the air during dry periods (Förster 1999; Polkowska et al. 2002).

Of the above studies, the ones based on asphalt shingles and flat tar roofs are most relevant to the Ontario context as these materials are the most common in the residential and industrial sectors, respectively.

Storage material

While roof surfaces are often viewed as a potential source of contamination for rainwater, cisterns can be seen as a means of treatment, offering a series of beneficial processes. For example, as rainwater is often slightly acidic, the increase in pH caused by contact with a concrete tank is beneficial for the protection of the distribution system and the chemical quality of the water by minimizing the potential for leaching metals. In a study evaluating the quality of stored water in a concrete cistern, Scott and Waller (1987) report a rise in pH from 5.0 on the roof surface, to 9.4 in the tank and 10.3 from the tap. A similar trend was observed for alkalinity, calcium and potassium concentrations. Their study also suggests that a higher pH can inhibit coliform growth. During sampling over a two year period, coliform bacteria were only detected during periods of low pH.

Sedimentation also plays a primary role in reducing the contaminant load of stored rainwater. Spinks et al. (2005) observed that the concentrations of aerobic HPC bacteria were 50-100 times higher in the sediment than in the water column. For lead, Spinks et al. (2005) found that this magnification of the concentration in the sediment was as high as 340,000 in some tanks. Scott and Waller (1987) expressed concerns regarding this sediment layer because of the potential for re-suspension by means of low cistern levels, thermal mixing, or the turbulent influx of rainwater during a rainfall event. Others have found that the re-suspension of sludge was minimal, and easily mitigated with proper RWH system design (Spinks et al. 2005).

While storage in cisterns is generally considered to enhance the quality of the rainwater, there is some concern over the potential for chemical leaching. Leaching of zinc from metal tanks was found to be significant in one study, but concrete or plastic tanks did not have any notable impact on the concentration of zinc, lead or copper (Hart and White 2006). The leaching of organic compounds is a concern with plastic tanks, however many American and Canadian regulations now require that any materials used for potable water applications must comply with the NSF/ANSI 61 Standard (NSF 2007). While this certification doesn't guarantee the absence of leached compounds, it ensures the material adheres to minimum established health effects requirements for any chemical contaminants or impurities that are imparted to the water (EPA 2002).

Treatment

To improve the quality of rainwater, a variety of treatment technologies have been developed to mitigate the contamination which takes place following contact with a catchment surface. One treatment technique popularized in Australia is the first-flush device, which is used to divert the first 0.8-3.5mm of rainfall from storage in the rainwater cistern (Martinson and Thomas 2005; TWDB 2005). The rationale for these devices is the first-flush phenomenon reported in the literature, whereby the concentration of contaminants decreases exponentially during the first few millimetres of rainfall. This trend has been observed for a range of contaminants including suspended solids, PAHs, organic compounds and trace metals (Yaziz et al. 1989; Förster 1996; Shu and Hirner 1998; Förster 1999; Li et al. 2007).

Following storage in a rainwater cistern, particle filtration and UV disinfection are other means by which rainwater can be treated. A study by Kim et al. (2005) examined the performance of 5 µm and 1 µm metal membrane filters (comparable to polymeric membrane filters) and UV disinfection on roof-harvested rainwater. The Korean study observed a 50% reduction in the number of total coliforms for rainwater samples treated using a UV lamp, even at the low intensity of $I_{UVA} = 5.4\ W/m^2$ (Kim et al. 2005). Filtration was also found to reduce the number of total coliforms by rejecting them at the membrane surface. A removal efficiency of 78% and >98% was achieved with 5 µm and 1 µm metal membrane filters, respectively. In addition to the rejection of biological organisms, 80% and 95% of the particles present in the rainwater were removed by the 5 µm and 1 µm metal membrane filters, respectively (Kim et al. 2005).

Slow sand filtration is another method shown to be effective at improving the quality of rainwater. Ahammed and Meera (2006) compared two slow sand filters, one with iron hydroxide-coated sand to one with an uncoated sand medium. The uncoated sand filter was shown to achieve a bacterial removal of <21%, whereas the iron hydroxide-coated sand reduced total and fecal coliforms by 97%-99%. Both turbidity and the concentration of the heavy metals zinc and lead showed improvement following slow sand filtration. The turbidity of rainwater collected from a concrete catchment surface was reduced from 8.2 to 0.5-2.4 NTU following slow sand filtration. Zinc levels dropped from 3.6 to 0.1mg/L and lead was reduced by 90% to 0.01mg/L on samples collected from a galvanized iron roofing material (Ahammed and Meera 2006).

Storing rainwater at temperatures typical inside a residential hot water tank (50-70°C) has also been shown to reduce biological contamination. A study of 27 rainwater systems at Figtree Place in Australia found that all coliform bacteria were removed after storage in the hot water tank in the 23 samples collected. This removal efficiency was achieved with rainwater of fairly poor quality. The average number of total coliforms throughout the study was 166 CFU/100mL, with 20 CFU/100mL fecal coliforms (Coombes et al. 2000). Another study showed a similar inactivation for *Escherichia coli* at sub-boiling temperatures. Spinks et al. (2003) observed an almost 5 log reduction in *E. coli* concentrations when the water was maintained at 60°C for a period of 5 minutes in a laboratory setting.

Method

Description of study area and rainfall patterns

The rainwater quality assessment program was comprised of seven households with RWH systems (sites) located in a 30km radius around the City of Guelph. Guelph is located in the southern region of Ontario, Canada, and is approximately 100km west of Toronto (shown in Figure 2-1). The one-year program took place from October 2006 to October 2007, during which time cistern-stored (CS) rainwater samples and point of use (POU) samples were collected at each site concurrently on thirty occasions (with the exception of Site 5 and Site 7, where only POU samples could be collected). In total, 360 individual samples were collected and analyzed.

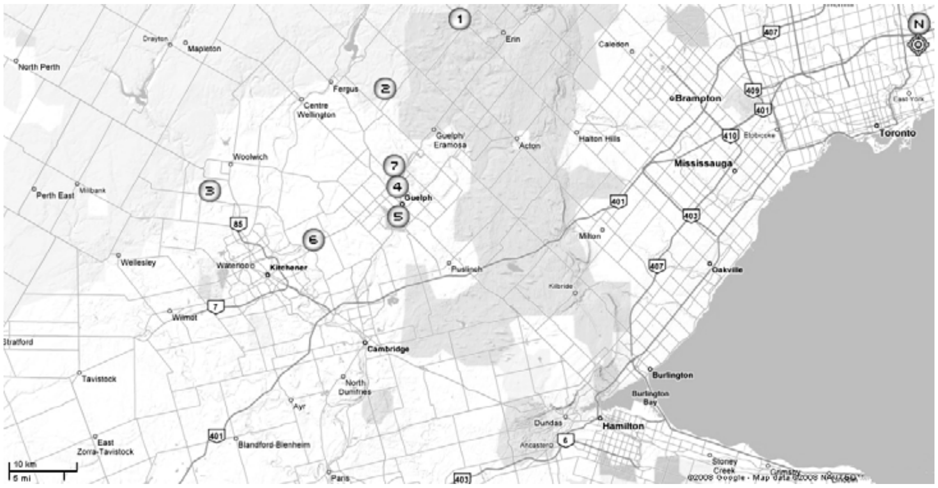

Figure 2-1: Location of the seven sites participating in the quality assessment program

The mean annual precipitation for the City of Guelph is 930mm, with 650mm of this in the form of rainfall from April to November, and the remainder from snowfall which takes place in December to March. The temperature ranges from a daily mean of 17°C in the summer months to -5°C in the winter (Environment Canada 2004).

Rainfall data for the City of Guelph was recorded on a daily basis by a rain gauge maintained as part of this quality assessment program, and daily temperature records were obtained from Environment Canada's (2007) *Canadian Climate Database*. As shown in Figure 2-2, the average monthly temperatures recorded throughout the program were roughly the same as the 1971-2000 climate normals for the City of Guelph, however rainfall differed in some months (Environment Canada 2007).

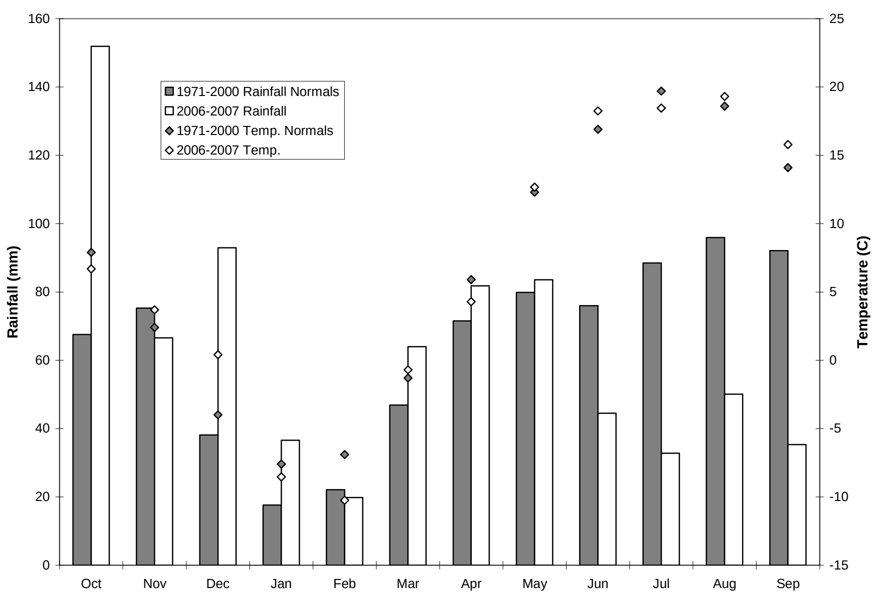

Figure 2-2: Climate normals, monthly rainfall accumulations and mean monthly temperatures for the City of Guelph during the quality assessment program

Monthly rainfall accumulations for the City of Guelph were roughly 40% higher than average between the months of October – December 2006, and were slightly below average from January-May 2007. The months of June and July had the greatest deviation from average rainfall figures, where a 60% decline in monthly rainfall was observed as drought-like conditions were present throughout much of Southern Ontario.

Site characteristics

While each of the sites that participated in the quality assessment program was unique in some respects, surveys conducted at each site revealed that several characteristics were shared among sites (summarized in Table 2-1). Only two types of storage material were utilized, concrete and plastic, whereas steel and asphalt shingle comprise the two predominant catchment materials. There is also an even distribution between urban and rural sites. The RWH systems at these sites were between one to three years old, with the exception of Site 3, which had been in use for approximately eight years.

Table 2-1: Site characteristics

Site	*Location*	*Site Environment*	*Catchment Material*	*Storage Material*	*Treatment*	*Rainwater Applications*
1	Town of Erin	• Rural • Mature trees on property	Steel	Plastic	• Slow sand filter • Granulated activated carbon • UV lamp • On-demand hot water heater	• Drinking & cooking • Hot water service • Bathing
2	Guelph-Eramosa	• Rural • Mature trees on property	Steel	Concrete cinder block with NSF polymer coating	• 20 Micron particle filter • UV lamp	• Dishwasher • Laundry • Toilet flushing • Outdoor use
3	St. Jacobs	• Rural • Mature Trees on property	Asphalt shingle	Concrete cinder block	Hot water tank	• Hot water service • Bathing • Toilet flushing • Outdoor use
4	Guelph	• Urban • Mature trees overhanging the catchment surface	Asphalt shingle	Precast concrete	• 20 Micron particle filter • UV lamp	• Laundry • Toilet flushing • Outdoor use
5	Guelph	• Urban • Mature trees on property	Asphalt shingle	Precast concrete	First-flush device	• Laundry • Toilet flushing • Outdoor use
6	Breslau	• Industrial • Immature trees on property	Flat membrane	Precast concrete	• Inline vortex pre-filter • Fine mesh pump inlet filter	• Toilet flushing • Outdoor use
7	Guelph	• Urban • Immature trees on property	Steel	Precast concrete	No treatment	• Toilet flushing • Outdoor use

Table 2-1 also lists the applications for which rainwater was used at each site. The majority of the sites used rainwater to service, at minimum, toilet flushing and outdoor use, with two sites (Site 1 and Site 3) meeting nearly all household water demand with rainwater. In general, the degree of treatment increased in proportion to the number of rainwater applications, with the combination of particle filtration and UV disinfection the most prevalent method of post-cistern treatment.

Sample collection and laboratory analysis

Two sampling mediums were used to collect the rainwater samples. A 1L polypropylene Nalgene® bottle was used to collect rainwater for analyzing pH, turbidity, colour, total and fecal coliforms; and a 250mL amber glass bottle was used for total organic carbon (TOC), total nitrogen (TN) and UV-absorbance measurements. Prior to sampling, the Nalgene® bottles were rinsed with Milli-Q water and sterilized in an autoclave at 121°C at 15psig for 30 minutes. All glassware was acid washed with a 1:1 solution of sulphuric acid and Milli-Q water and baked in a 100°C oven for a minimum of 12 hours.

The cistern-stored rainwater samples were collected by lowering each bottle to the approximate centre of the cistern to produce a composite of the top half of the cistern's water column. Point of use samples were collected from a kitchen tap, hose bib or other suitable location downstream of the post-cistern treatment units employed at each site. To minimize time variability between samples, samples from all locations were collected on the same day and transported to the laboratory by car during a 6-8 hour sampling period.

The following parameters were analyzed throughout the quality assessment program: pH, turbidity, colour, total coliforms, fecal coliforms, total organic carbon (TOC), total nitrogen (TN) and UV absorption (254 nm). The analytical procedures outlined in Standard Methods for the Examination of Water and Wastewater were used for measuring pH, turbidity, total and fecal coliforms (APHA 1995). TN was determined using a Shimadzu TOC-V_{CSH} with a TNM-1 total nitrogen measuring unit, and colour was measured with a LaMotte SMARTSpecctro Spectrophotometer utilizing a Platinum Cobalt method wavelength calibration curve. Total organic carbon and UV absorption were analyzed following EPA Method 415.3 (EPA 2005).

The pH, turbidity, colour, TOC, TN, and UV-absorption were measured in duplicate from individual sub-samples of the collected rainwater, and total coliform and fecal coliform were plated in triplicate to minimize experimental error. TOC samples were acidified with sulphuric acid to pH $\leq$2, and analyzed within one week of sample collection. Analysis of all the remaining water quality parameters was completed within a maximum of 24-hours following sample collection.

In addition to the in-house testing program detailed above, polycyclic aromatic hydrocarbons (PAHs), total metals, *Campylobacter* and *Legionella* were examined by an external testing facility for selected sites sampled on November 6, 2006 and May 31, 2007. For these water quality parameters, sample collection and analysis was performed in accordance with SW486 8270, EPA 200.8 and SW846 7470A, Health Canada MFLP-46, and ISO 11731, respectively.

Statistical analysis

Statistical analysis of the rainwater quality data was performed using SAS® Ver. 9.1. Since none of the water quality parameters met the assumption of normality, a logarithmic transformation and the removal of a maximum of eight outliers from each parameter was sufficient to achieve normality in all but three cases. Total and fecal coliforms, which were highly skewed towards <1 CFU/100mL, as well as UV absorbance, failed to meet the assumption of normality.

For the parameters that were normally distributed, a mixed statistical model was used to determine if the independent variables of site environment and post-cistern treatment had a statistically significant impact upon rainwater quality. The effect of site environment was assessed by comparing the quality of cistern-stored rainwater between sites, whereas the treatment effect was detected by comparing the quality of the point of use samples to the quality of the cistern-stored samples. To determine whether cistern-stored rainwater quality varied over time (seasonal variation), the SAS® repeated function was utilized.

The influence of weather on cistern-stored rainwater quality was assessed utilizing site-specific temperature and rainfall data collected as part of this study and from the Environment Canada (2007). Three weather-based parameters were placed into the SAS® mixed model statement as covariates: average temperature in the week prior to sample collection, total rainfall in the week prior to sample collection, and the total number of dry days between rainfall events (the antecedent dry period).

To determine the effect of catchment material and storage material, sites were grouped by material in SAS® using contrast statements. Contrasts were used to compare the quality of rainwater stored in concrete cisterns to that of plastic cisterns, and the quality of cistern-stored rainwater collected from asphalt shingle roofs to steel roofs. To further investigate the effect of site environment contrasts were also performed comparing the quality of rainwater in urban locations to that of rural locations.

A bivariate linear logistic regression model was used for total and fecal coliforms to analyze these parameters based upon the presence or absence of coliforms. Similar to the mixed model, site, treatment, weather and the contrasts were included in the analysis. The level of statistical significance for all tests was set at $\alpha = 0.05$.

Results and Discussion

The physicochemical and microbiological rainwater quality data are reported in Table 2-2 and Table 2-3, respectively.

Table 2-2: Physicochemical properties of rainwater observed for cistern-stored (CS) and point of use (POU) samples (values: mean ± standard deviation)

Sample Location	pH	Turbidity (NTU)	TOC (mg/L)	TN (mg/L)	Colour (CU)	UV-ABS (254nm)
Site 1 CS	7.1 ± 0.6	1.1 ± 1.6	3.1 ± 1.9	1.8 ± 0.7	11.1 ± 7.8	0.023 ± 0.026
Site 1 POU	7.2 ± 0.4	0.3 ± 0.1	2.3 ± 2.1	1.6 ± 0.6	7.1 ± 6.4	0.027 ± 0.092
Site 2 CS	5.8 ± 0.9	1.0 ± 0.5	1.8 ± 1.0	1.5 ± 0.4	11.6 ± 10.6	0.031 ± 0.064
Site 2 POU	5.9 ± 1.1	0.8 ± 0.3	2.7 ± 2.1	1.3 ± 0.6	15.2 ± 17.3	0.027 ± 0.040
Site 3 CS	7.2 ± 0.4	1.5 ± 0.7	6.3 ± 4.5	2.0 ± 0.6	25.5 ± 17.0	0.169 ± 0.114
Site 3 POU	7.3 ± 0.3	1.5 ± 0.8	6.9 ± 4.9	2.3 ± 1.5	27.4 ± 19.8	0.191 ± 0.139
Site 4 CS	7.5 ± 0.7	2.6 ± 3.1	8.5 ± 8.3	1.5 ± 0.5	32.8 ± 28.7	0.193 ± 0.177
Site 4 POU	7.0 ± 1.2	1.2 ± 0.5	6.4 ± 5.2	1.5 ± 0.6	24.9 ± 19.4	0.142 ± 0.113
Site 5 POU	8.1 ± 0.7	1.4 ± 0.6	7.4 ± 5.5	1.5 ± 0.5	23.4 ± 10.1	0.188 ± 0.170
Site 6 CS	8.2 ± 0.9	0.9 ± 0.5	2.9 ± 1.7	1.8 ± 0.9	13.1 ± 8.0	0.032 ± 0.056
Site 6 POU	8.2 ± 0.8	0.9 ± 0.3	3.2 ± 1.6	1.7 ± 0.7	13.8 ± 8.1	0.029 ± 0.034
Site 7 POU	7.5 ± 0.4	1.3 ± 0.7	2.4 ± 1.1	1.5 ± 0.3	14.9 ± 8.2	0.041 ± 0.061

Table 2-3: Microbiological properties of rainwater observed for cistern-stored (CS) and point of use (POU) samples

Sample Location	Total Coliform (CFU/100mL)			Fecal Coliform (CFU/100mL)		
	Geometric Mean	Range	Portion of Samples >1 CFU/100mL	Geometric Mean	Range	Portion of Samples >1 CFU/100mL
Site 1 CS	<1	<1 – 128	76%	<1	<1 – 14	31%
Site 1 POU	<1	<1 – <1	4%	<1	<1 – <1	0%
Site 2 CS	<1	<1 – 86	60%	<1	<1 – 4	11%
Site 2 POU	<1	<1 – <1	0%	<1	<1 – <1	0%
Site 3 CS	<1	<1 – 255	46%	<1	<1 –234	36%
Site 3 POU	<1	<1 – <1	0%	<1	<1 – <1	0%
Site 4 CS	1	<1 – 398	89%	<1	<1 – 400	54%
Site 4 POU	<1	<1 – 12	14%	<1	<1 – <1	0%
Site 5 POU	<1	<1 – 112	42%	<1	<1 – 54	25%
Site 6 CS	<1	<1 – 51	17%	<1	<1 – 10	7%
Site 6 POU	<1	<1 – 40	10%	<1	<1 – 6	7%
Site 7 POU	<1	<1 – 24	28%	<1	<1 – 5	3%

From the data presented in Table 2-2 and Table 2-3, a number of trends are evident. The mean turbidity of rainwater samples collected from the cisterns ranged from a low of 0.9±0.5 NTU at Site 6 to a high of 2.6±3.1 NTU at Site 4. The mean pH of the cistern-stored rainwater across all sites was neutral at 7.3, with a standard deviation of 1.0. Total nitrogen was detected in relatively small concentrations in the cisterns at the seven sites, ranging from 1.5±0.4 mg/L at Sites 2 and 4 to 2.0±0.6 mg/L at Site 3.

High variability in the quality data was observed with TOC, colour, and UV absorption. With TOC, this variability can be observed at Sites 3 and 4, which had TOC concentrations of 6.3±4.5 mg/L and 8.5±8.3 mg/L, respectively. At the point of use, Site

4 had a mean colour of 24.9 CU, but during the assessment program, rainwater colour at this site ranged from a minimum of 4 to a maximum 64.5 CU. At Site 3, a slight difference in mean UV absorption is observed from the cistern (0.169±0.114) to the point of use (0.191±0.139), however, the implications of this difference are difficult to assess due to the large standard deviations of the data.

Total coliforms were detected above 1 CFU/100mL in 114 of the 360 cistern-stored and point of use rainwater samples collected throughout the quality assessment program. The incidence rate for the detection of fecal coliforms was lower at 14%, with 52 out of 360 samples having greater than 1 CFU/100mL. The portion of samples with coliforms present (above 1 CFU/100mL) on a site-by-site basis is presented in Table 2-3. As seen in the table, total and fecal coliforms ranged from <1 (below detection limits) to 400 CFU/100mL. Despite this range, the geometric mean of the total and fecal coliforms was <1 CFU/100mL at each site, with the exception of Site 4, which had a geometric mean of 1 CFU/100mL total coliforms.

To determine the factors that influenced rainwater quality, statistical analysis was performed. A summary of this analysis is presented in Table 2-4. Since UV absorption did not meet the criteria for normality, it is not included in Table 2-4, however, a statistically significant correlation was found between UV absorption and TOC (Spearman's r=0.51), which indicates that trends observed for TOC are generally applicable to UV absorption as well.

Table 2-4: Statistical analysis p-values (p<0.05 statistically significant)

Statistical Tests	pH	Turbidity	TOC	TN	Colour	Total Coliforms	Fecal Coliforms
Catchment material contrast	***0.0015***	***0.0008***	***<.0001***	***0.0320***	***0.0003***	0.8948	**0.0295**
Storage material contrast	***0.0002***	***0.0006***	***0.0004***	0.1385	***0.0004***	0.2753	0.2765
Rainfall	0.0683	0.7840	0.3301	0.7659	***0.0010***	0.7545	0.9436
Antecedent dry period	0.4212	***0.0318***	0.6550	***0.0340***	***0.0377***	0.6438	0.7506
Seasonal variation	***0.0221***	***<.0001***	***<.0001***	***<.0001***	***<.0001***	N/A	N/A
Temperature	0.9194	0.8711	0.7739	0.9522	0.0988	***<.0001***	***<.0001***
Post-cistern treatment	0.8482	***0.0105***	0.8202	0.1095	0.1156	***<.0001***	***<.0001***
Site environment	***0.0009***	***0.0026***	***0.0011***	***0.0185***	***0.0020***	***<.0001***	***<.0001***
Urban vs. rural sites contrast	***0.0010***	***0.0062***	***0.0040***	***0.0237***	***0.0044***	0.3102	0.3867

The statistical analysis revealed several important trends, the first of which is the overall sensitivity of the water quality parameters to both the design aspects of RWH systems and environmental conditions. The influence of each factor on rainwater quality is discussed below.

Catchment material

Nearly all water quality parameters (pH, turbidity, total organic carbon, total nitrogen and colour) were found to vary significantly based upon the type of catchment material, either asphalt shingle or steel. In general, poorer quality was observed at sites utilizing asphalt shingle roofs for rainwater collection. This trend is shown for turbidity in Figure 2-3.

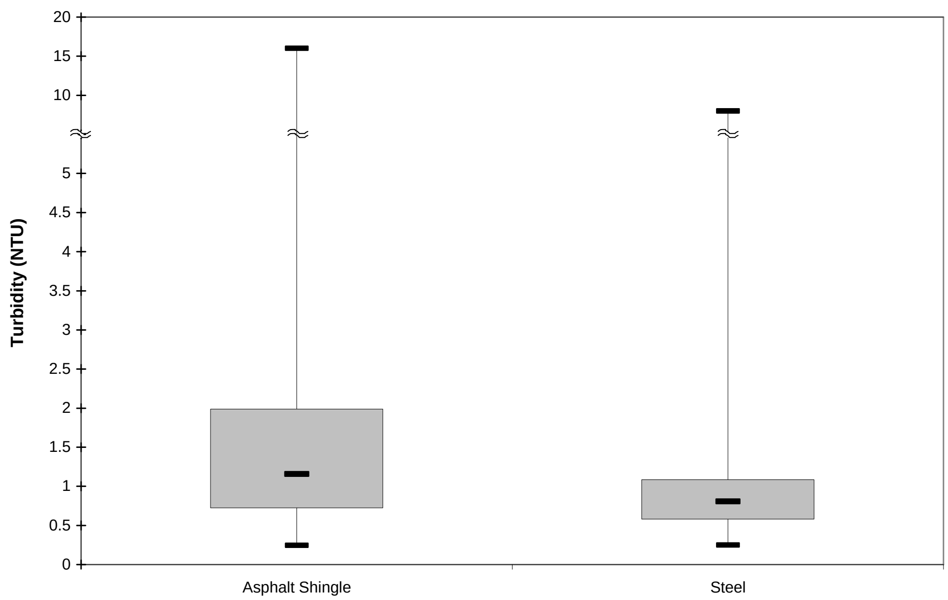

Figure 2-3: Box-and-whisker plots of the cistern-stored (CS) turbidity among sites with asphalt shingle and steel catchment materials. Each box represents the bounds of the first and third quartile, the median is marked by the horizontal line inside the box, and the ends of the 'whiskers' represent the minimum and maximum.

The three sites that utilized asphalt shingles as a catchment surface (Sites 3, 4, and 5) had cistern-stored rainwater with a mean turbidity of 1.6 NTU, whereas at the sites with steel roofs (Sites 1, 2, and 7) the mean turbidity was about 40% lower, at 1.0 NTU. Similar trends were observed with TOC and colour: sites with asphalt shingles had means of 5.8 mg/L TOC and 23 CU, and the sites with steel roofs had lower values of 2.5 mg/L TOC and 23 CU in the samples collected from the rainwater cisterns.

The influence of catchment material on rainwater quality, particularly turbidity, has been reported in other studies. In a study examining different catchment materials in northern China, Zhu et al. (2004) found that cistern-stored rainwater turbidity ranged from 2.0-3.5 NTU when collected from mortar roofs, whereas the turbidity of rainwater collected from cement-paved courtyards was higher at 3.0-6.5 NTU. Another study, by Yaziz et al. (1989) examined the direct roof runoff from galvanized iron and concrete tile roofs. Although comparisons between this study and Yaziz et al. (1989) are difficult due to the different sampling locations, a similar trend was observed – the runoff turbidity ranged from 10-22 NTU from the galvanized iron roof, while concrete tile roofs had substantially higher values of 24-56 NTU.

These findings indicate that the design characteristics of RWH systems, such as the selection of a catchment material, can have a significant impact upon rainwater quality. Yaziz et al. (1989) and Shu and Hirner (1997) have proposed that this trend may be attributed to the material properties of different catchment surfaces, as some may provide a greater surface area for the adsorption of atmospheric debris between rainfall events. This hypothesis was supported by this study, as poorer quality was observed at sites with textured surface of the asphalt shingles, as opposed to the relatively flat surface of the steel roofs.

Storage material

Storage material had a statistically significant ($p<0.05$) effect on a fewer number of quality parameters (pH, turbidity, total organic carbon and colour) as catchment material. Of these parameters, pH was the most sensitive to the type of storage material. The variation in pH between sites with concrete cisterns and those with plastic cisterns is presented in Figure 2-4.

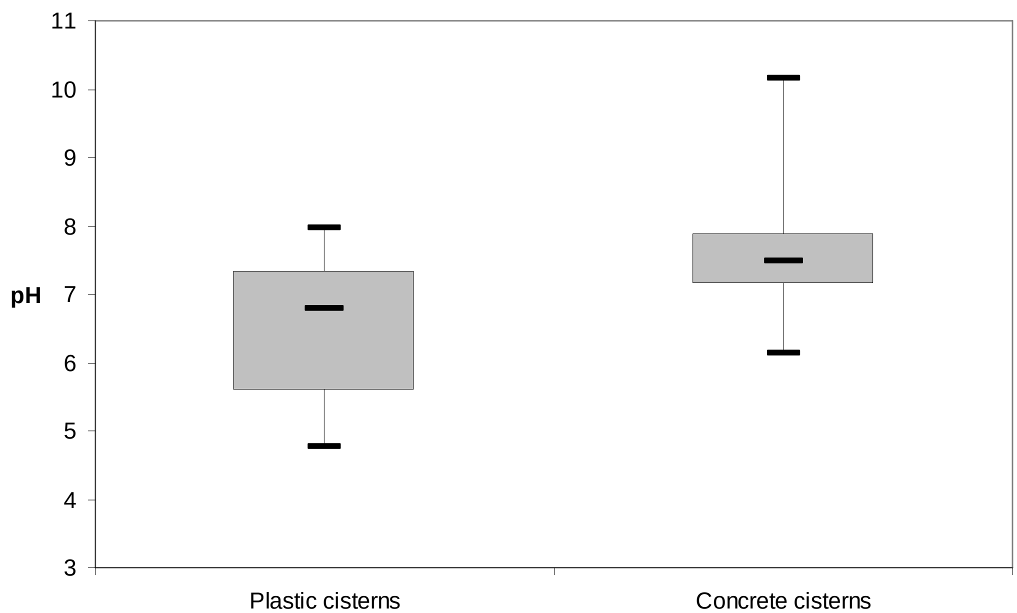

Figure 2-4: Comparison of the cistern-stored (CS) pH among sites with plastic and concrete cisterns.

The pH of rainwater stored in plastic cisterns tended to be slightly acidic. The minimum pH was 4.8 at Site 2, although the mean of all sites was higher at 6.5. Conversely, the rainwater at sites with concrete cisterns was more basic, with a mean of 7.7 and a maximum of 10.2 at Site 6. Similar patterns were observed with the other water quality parameters. For instance, the mean colour of rainwater stored in concrete cisterns was 21.8 CU, whereas for plastic cisterns colour was only 11.1 CU. Turbidity and TOC of rainwater stored in plastic cisterns had means of 0.8 NTU and 2.5 mg/L TOC, while 5.4 mg/L TOC and 1.4 NTU were detected in rainwater sampled from the concrete cisterns.

Comparison of these results to those presented in the literature, Sazakli et al. (2007) reported a similar range of pH values, 7.6-8.8, for rainwater stored in concrete cisterns in Greece. In a study of 125 household RWH systems in New Zealand, Simmons et al. (2000) also found a statistically significant difference between concrete and non-concrete cisterns (plastic, wood, fibreglass or galvanized iron) which had median pH values of 7.5 and 5.9, respectively. Scott and Waller (1987) and Zhu et al. (2004) attribute the increased pH in concrete cisterns to the leaching of calcium carbonate from the cistern walls; however, it is unclear what factors led to the heightened levels of TOC and turbidity at the sites with concrete cisterns.

Weather

The three weather based criteria (temperature, rainfall, and the antecedent dry period) were found to have little effect upon the majority of the water quality parameters. Colour was effected by the amount of rainfall ($p<0.05$) and the antecedent dry period ($p<0.05$), while turbidity and TN also varied with the length of the dry period.

In general, the colour, turbidity and TN concentration of the cistern-stored rainwater tended to increase during dry periods, indicating that some aspects of rainwater quality, especially the colour, are more sensitive to rainfall or drought conditions than other water quality parameters, and will thus naturally vary to a great extent depending upon climatic conditions.

A significant relationship between temperature and the number of total and fecal coliforms was also discovered. Since changes in temperature followed a seasonal trend, the effect of temperature on coliform counts shall be discussed within this context.

Seasonal variation

Differences of a statistically significant level were observed with all water quality parameters with respect to time (seasonal variation effect). Rainwater quality tended to improve following the summer months, with the highest quality rainwater detected during the winter. This trend was most evident with total and fecal coliforms, shown in Figure 2-5.

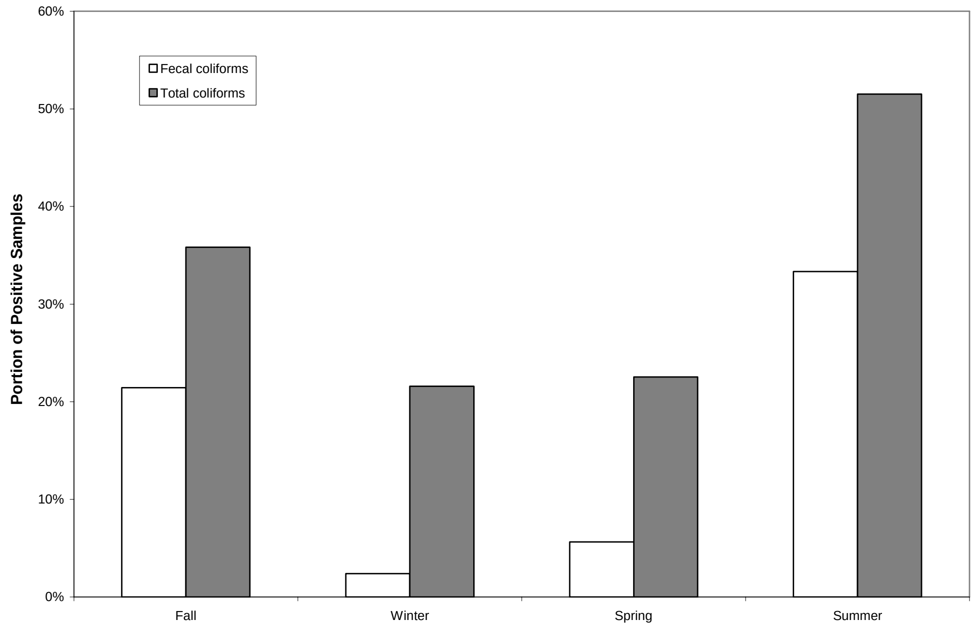

Figure 2-5: Seasonal variation in the portion of samples positive for the presence of total and fecal coliforms (CS & POU combined)

During the summer months, 50% of the total coliform samples and 30% of the fecal coliform samples tested positive for the presence of coliforms (≥1 CFU/100 mL). In contrast, during the winter total and fecal coliforms were present in only 22% and 2% of samples, respectively. This decline in microbiological activity throughout the winter months could be attributed to a number of factors. One possibility is that the colder air temperatures between December 2006 and April 2007 (ranging from -19.2 to 14.4°C) inhibited the growth of bacteria within the cistern itself, thereby reducing the number of samples with coliforms present. Another potential contributor to the fewer number of samples with coliforms in the winter and spring months is the decreased activity of animals and birds. The decreased fecal contamination of the catchment surface by birds and animals during these months would likely reduce the influx of fecally-contaminated rainwater into the cistern.

Statistical analysis of the rainwater data provides some indication that the former of the above scenarios is most likely. As shown in Table 2-4, temperature had a highly significant effect upon both total and fecal coliforms. While this finding on its own is inconclusive, (i.e., was it from temperature, or from decreased animal activity in response to temperature?) when combined with the results from two additional statistical tests, temperature, rather than animal activity, seems to be the most important contributor to decreased coliform counts in the winter.

The first of these test results is the weak positive correlation between temperature and both total and fecal coliforms, estimated at 0.101±0.020, and 0.120±0.023. This correlation suggests that as the temperature increased, the presence of total and fecal coliforms at the sites tended to increase as well. The second set of supporting data is the failure to find a significant impact from the number of consecutive dry days, or the volume of rainfall in the week prior to sample collection, on the biological parameters. If bird or animal activity was the primary contributor to the presence of total and fecal coliforms, one would expect to see a significant correlation for either the antecedent dry period (during which time fecal deposits would accumulate) or the rainfall in the week prior to sample collection (an indicator of whether fecal material had been transferred to the cistern following a rainfall event). Since neither of these tests was statistically significant, it suggests that temperature inside the cistern has a greater impact on the presence of total and fecal coliforms than did an external source such as bird or rodent debris.

This premise has some support from the research findings of Sazakli et al. (2007) and Simmons et al. (2000). Simmons et al. (2001) found statistically significant seasonal variations in total coliforms (p=0.086) and fecal coliforms (p=0.031), while the Sazakli et al. (2007) reported a nearly identical seasonal trend in the presence of total coliforms. The Sazakli et al. (2007) study detected the lowest ratio of positive samples in the winter months, which gradually increased in the spring and summer, with autumn having the highest number of positives detected. Although it was the summer, and not autumn, that had the highest number of positive samples in the quality assessment program, the similarities between these studies shows that seasonal variation (specifically the difference in temperature between seasons) may influence the level of microbiological activity inside rainwater cisterns.

A statistically significant seasonal effect was also detected with the physicochemical parameters, however unlike total and fecal coliforms, temperature was not the source of this variation, as this factor lacked significance. The physicochemical parameters tended to follow the same trend as the total and fecal coliforms, with poorer quality rainwater observed during the summer and fall. This trend is presented in Figure 2-6 for the TOC concentration in cistern-stored rainwater.

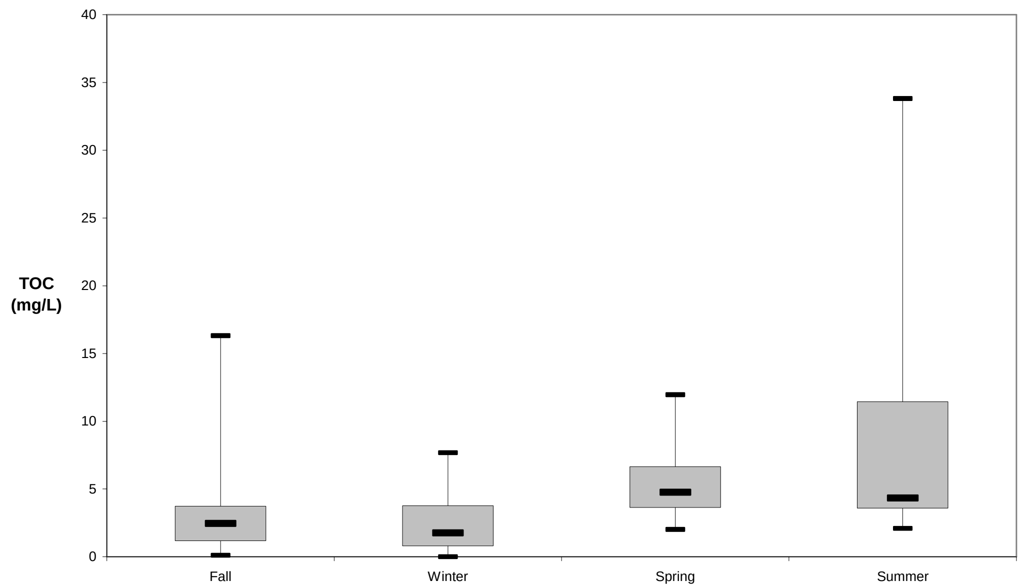

Figure 2-6: Seasonal variation in TOC concentration in cistern-stored (CS) rainwater samples

As seen in Figure 2-6, the TOC concentration was especially poor during the summer, during which time the TOC varied from a low of 2.1 mg/L at Site 6 to a high of 33.9 mg/L at Site 4. Reports of a seasonal trend in rainwater quality have come from Germany with the PAH benzo[b]fluoranthene, and Greece with conductivity (Förster 1999; Sazakli et al. 2007) however, in both cases an opposite trend was observed as quality tended to improve in the summer months. A possible explanation for this discrepancy is that in this study lower levels of atmospheric pollutants may have been present during the winter months. Cold climate conditions, including the presence of snow on the ground and decreased animal and plant activity, may have reduced the transfer of particulate matter and organics onto the catchment surface.

Treatment effect

The use of post-cistern treatment devices was found to have a significant impact upon three water quality parameters – turbidity, total and fecal coliforms. This treatment effect is demonstrated by observing the decrease in both the mean and the range of rainwater turbidity and coliform counts in the point of use samples compared to the pre-treated rainwater from the cistern. The effect of treatment on turbidity is provided in Figure 2-7.

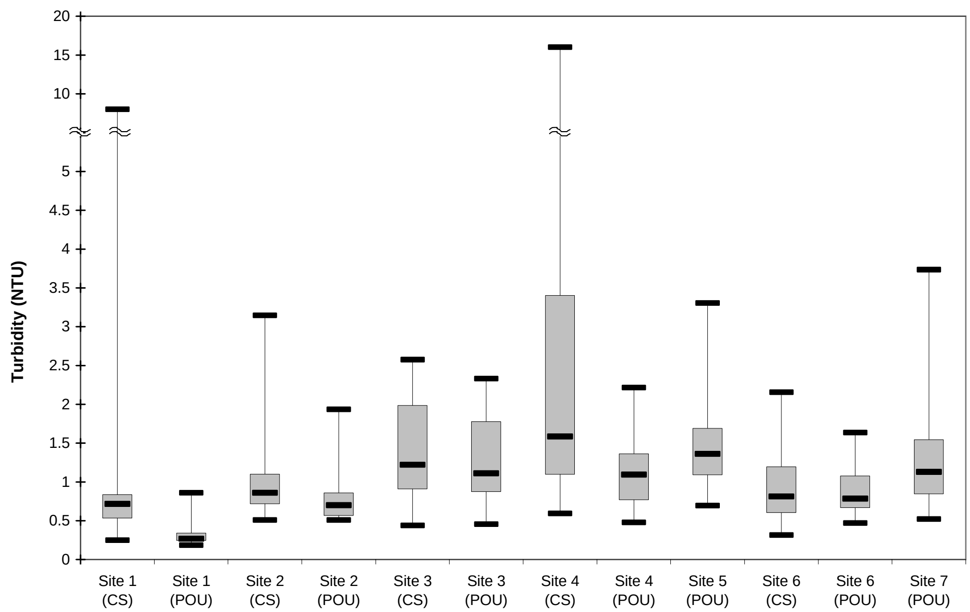

Figure 2-7: Comparison of turbidity in cistern-stored (CS) and point of use (POU) rainwater samples

As seen in Figure 2-7, turbidity decreased by roughly 20% at Site 2, 60% at Site 4, and 75% at Site 1 from the rainwater cistern to the point of use. These observations can be attributed to the use of particle filtration at each of these three sites. Site 2 and Site 4 both employed a 20 micron particle filter, whereas the higher removal efficiency at Site 1 was from the use of a slow sand filter. Site 3 and Site 6 also showed a decrease in turbidity, even though they did not employ the same degree of filtration as the other sites. In the case of Site 3, the reduction in turbidity is most likely due to particle settling within the cistern itself. Particle settling likely improved turbidity at Site 6 as well, as did the use of German-designed fine mesh filter installed on the pump inlet.

The reduction in the number of total and fecal coliforms following post-cistern treatment is shown in Figure 2-8 and Figure 2-9.

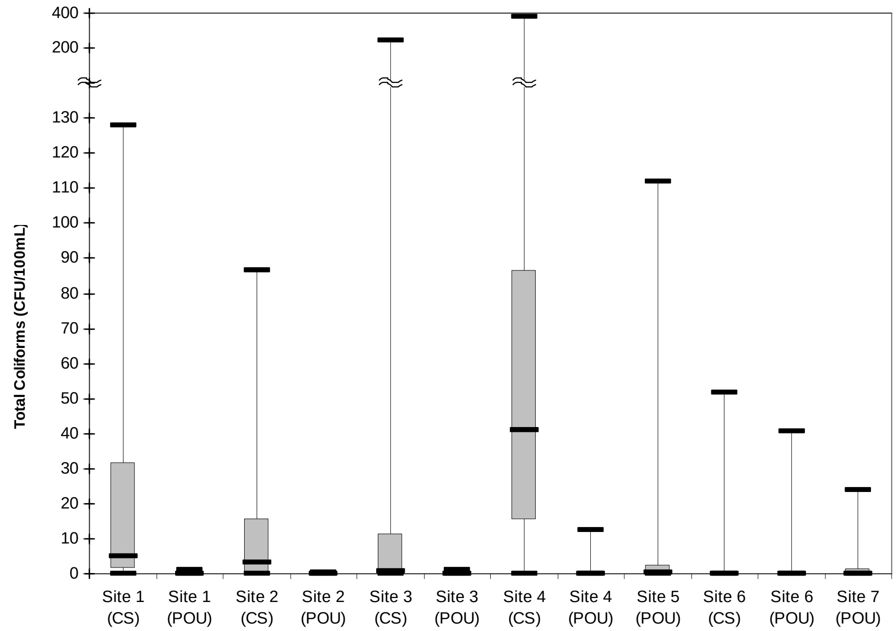

Figure 2-8: Comparison of the total coliforms in cistern-stored (CS) and point of use (POU) rainwater samples

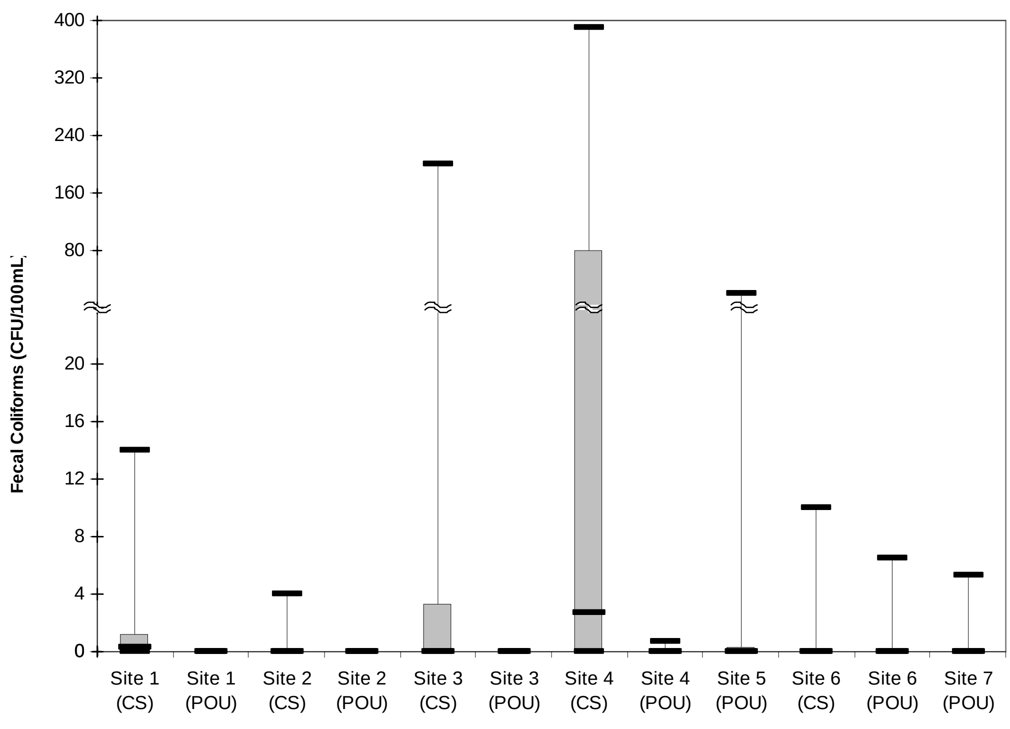

Figure 2-9: Comparison of the fecal coliforms in cistern-stored (CS) and point of use (POU) rainwater samples

Of the samples that tested positive for the presence of total coliforms in the rainwater cistern, 96% had <1 CFU/100mL following treatment. Similarly, 97% of the cistern-stored rainwater samples positive for fecal coliforms had <1 CFU/100mL at the point of use. Of note is that the reduction in the number of total and fecal coliforms took place regardless of the post-cistern treatment technique applied: UV lamp, slow sand filter, or hot water tank.

The treatment effect of the hot water tank, in particular, is of interest, and was observed at the only site employing rainwater hot water service (Site 3). Total coliforms and fecal coliforms decreased to <1 CFU/100mL following storage in a typical residential hot water tank, at approximately 60°C. This level of treatment was achieved with 100% effectiveness (n=30), even when as many as 60 CFU/100mL total coliforms were present in the cistern-stored rainwater. This treatment effect is consistent the work by Coombes et al. (2000) and Spinks et al. (2003b) demonstrating the bacteriological inactivation properties of temperatures present in hot water tanks.

Site environment

A statistically significant difference was detected in all of the water quality parameters between sites. This difference in cistern-stored rainwater quality is most evident with Site 4, which consistently had the poorest quality of all the sites throughout the course of study. The characteristics of Site 4 were quite similar to several of the other sites, particularly Sites 3 and 5, however, these sites did not exhibit the poor quality of Site 4. Thus, it is likely that at Site 4, environmental conditions (a site environment effect) had an effect on rainwater quality far more detrimental than at the other sites.

Evidence of a site environment effect is provided by comparing the total and fecal coliforms at Sites 3, 4, and 5. Site 4 had the same catchment and storage materials as Sites 3 and 5, and was located a distance of only 7km from Site 5, yet it had a much higher number of coliforms than these sites. One could argue that the higher microbiological loading at Site 4 was the lack of a first-flush device or other type of pre-cistern treatment. Although Site 5 had many of the same characteristics of Site 4, it employed a first-flush device to divert the first millimetre of roof runoff from entering the cistern. Excluding this first millimetre of rainfall, and with it, the easily mobilized dirt and debris deposited on the roof surface between rainfall events, may have contributed to the lower number of total and fecal coliforms detected at this location. The data from Site 3, which did not use a pre-cistern treatment device, indicates that pre-cistern treatment alone is not the only factor influencing the number of total and fecal coliforms. The number of total and fecal coliforms in the cistern at Site 3 was consistently lower than that at Site 4, despite the lack of pre-treatment.

Site conditions have been identified as a source of potential contamination by Förster (1998) and Van Metre and Mahler (2003), however, due to the proximity of Sites 4 and 5, it is thought that rather than different rates of atmospheric deposition on the catchment surface, conditions specific to Site 4 contributed to its poor overall quality. For instance, the quality of the cistern-stored rainwater may have been affected by the presence of several mature trees overhanging the roof. This site had the greatest number of trees of all of the sites monitored, and was the only site with trees directly overhanging the roof surface. The deposition of plant matter onto the catchment surface from the overhanging trees may have adversely affected the quality of runoff stored in the rainwater cistern.

A statistically significant site environment effect was also observed when sites from urban settings (Sites 4, 5, and 7) were compared to rural sites (Sites 1, 2, and 3). The trend was detected with all water quality parameters, except total and fecal coliforms. In general, the quality of rainwater in rural locations was better than that harvested in urban settings, with the exception of TN. The mean concentration of TN in the cistern-stored rainwater from rural sites 1.7 mg/L, whereas in the urban cisterns, the concentration was 1.5 mg/L. This exception may be due to the increased use of nitrogen-containing agricultural inputs in rural settings. Some of the aerosolized agricultural inputs may have collected on the catchment surface during dry periods, and was subsequently transferred into the cistern following a rainfall event.

PAHs

The PAHs benzo[a]pyrene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, and indeno[1,2,3-cd]pyrene, classified as “probably carcinogenic to humans” by the Government of Canada (1994), and fifteen other PAHs recognized by the Canadian Council of Ministers for the Environment (CCME), were analyzed on samples collected from the rainwater cisterns at Sites 1, 2, 4, 5 and 6 on November 2006 and May 2007. Detection limits of the PAHs ranged from 0.005 µg/L for Benzo[a]pyrene to 4 µg/L for Acridine, while the remaining PAHs were detected at a concentration above 0.02 µg/L in the rainwater samples. Despite the sensitivity of the detection limits, none of the twenty CCME PAHs were found above the detection limits from the rainwater samples collected at the five sites in November 2006 and May 2007.

Förster (1996, 1998) has reported that PAH concentrations in roof runoff can vary between different roof surfaces during the same rainfall event, and also vary from the location of roofs to sources of PAHs (such as highways). Another study, by Van Metre and Mahler (2003), reported spatial variations in the PAHs pyrene, fluoranthene and phenanthrene in rainwater samples, but found no difference between roofing materials. In this study, the identical findings between sites and across different sampling periods prevent conclusions such as those presented by Förster or Van Metre and Mahler. The presence of these organic substances in rainwater cisterns, at present, cannot be attributed to Ontario-specific catchment or storage materials, or from higher rates of atmospheric deposition of PAHs in urban environments. Additional study is recommended to assess the degree of rainwater contamination posed by PAHs across a greater variety of rainwater cisterns, including older RWH systems, to see if design characteristics, or bioaccumulation, influence the presence of these substances.

Metals

Analysis of the metals present in the cistern-stored rainwater, provided in Table 2-5, revealed that only calcium (0.8-12.2 mg/L) and strontium (0.001-0.12 mg/L) were present above detection limits at all of the sites tested.

Table 2-5: List of selected metals from metals analysis performed in the fall and spring seasons

Metal	Fall Samples (collected Nov. 6/06)				Spring Samples (collected May 31/07)				Detection Limit	Units
	SITE 1	SITE 2	SITE 4	SITE 5	SITE 1	SITE 2	SITE 4	SITE 6		
Aluminum	<0.01	<0.01	***0.01***	***0.03***	<0.01	***0.13***	***0.07***	***0.08***	0.01	mg/L
Arsenic	***0.001***	***0.001***	<0.001	***0.002***	<0.001	<0.001	<0.001	***0.001***	0.001	mg/L
Cadmium	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	mg/L
Calcium	***1.2***	***0.8***	***4.9***	***7.1***	***12.2***	***7.0***	***13.0***	***10.4***	0.5	mg/L
Copper	<0.001	***0.347***	<0.001	***0.002***	<0.001	***0.524***	***0.004***	***0.01***	0.001	mg/L
Lead	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	mg/L
Magnesium	<0.5	<0.5	<0.5	***1.2***	***2.1***	***0.8***	***0.6***	***0.7***	0.5	mg/L
Manganese	***0.01***	***0.004***	<0.001	***0.004***	***0.004***	***0.017***	***0.021***	***0.005***	0.001	mg/L
Mercury	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	mg/L
Sodium	***0.6***	***0.5***	***0.7***	***3.7***	<0.5	<0.5	***3.9***	***2.6***	0.5	mg/L
Strontium	***0.002***	***0.001***	***0.014***	***0.12***	***0.018***	***0.011***	***0.038***	***0.032***	0.001	mg/L
Tin	<0.001	<0.001	***0.005***	***0.003***	<0.001	<0.001	<0.001	<0.001	0.001	mg/L
Zinc	***0.243***	***0.169***	<0.003	***0.012***	***0.316***	***0.501***	***0.05***	***0.022***	0.003	mg/L

Aluminum, arsenic, copper, magnesium, manganese, silicon, sodium, tin and zinc were also detected in low concentrations at some of the sites. Although arsenic was detected at two of the sites, Site 1 and Site 2, the average concentration of 0.001 mg/L at these sites was well below the MAC in drinking water (0.01 mg/L) set by Health Canada (Health Canada 2007). Other metals of concern, such as cadmium (MAC ≤0.005 mg/L), lead (MAC ≤0.01 mg/L), and mercury (MAC ≤0.001 mg/L) were also below these levels in the cistern-stored rainwater (Health Canada 2007).

The results of the metals analysis shows that there are some similarities between the sites in this study and trends discussed in the literature. Van Metre and Mahler (2003) have reported elevated concentrations of zinc and cadmium from metal rooftops. Higher levels of zinc and lead in have also been detected in rainwater collected from galvanized iron roofs and zinc sheet roofs (Yaziz et al. 1989; Förster 1996; Simmons et al. 2001). Although this trend was not detected for cadmium or lead in this study, as both heavy metals were below detection limits, it was observed for zinc. The median zinc concentration from steel roofs in this study was 0.28 mg/L, roughly 23 times higher than the zinc concentration from the asphalt shingle roofs.

The increased levels of zinc in the rainwater collected from the steel roofs can be attributed to its use in the galvanizing process, to protect steel from corrosion. The absence of the other two metals, lead and cadmium, may be due to the design characteristics of the steel roofing products supplied in Ontario. The two sites that utilized a steel catchment surface used a product from the same manufacturer, which coats the metal surface with a ceramic-based paint. This method of sealing the catchment surface may have minimized weathering and corrosion, reducing the leaching of metals during rainfall events.

Similar concerns regarding the leaching of metals from asphalt shingle roofs have been raised by Van Metre and Mahler (2003), who observed a potential correlation between asphalt shingles and the leaching of mercury. This relationship, however; was not found in this study. No mercury leachate was detected above the 0.0001 mg/L detection limit in any of the sites employing asphalt shingles, or from the sites with steel roof surfaces.

Thus, although zinc levels from steel roofs were elevated compared to asphalt shingle roofs, the rainwater collected from both catchment surfaces had zinc concentrations well below the 5.0 mg/L aesthetic objectives (AO) set by the *Guidelines for Canadian Drinking Water Quality* (Health Canada 2007). The absence of any other significant degree of metal contamination, from either roof material, suggests that both asphalt shingle and steel roofing (with respect to metals) are suitable for the collection of rainwater.

Legionella and Campylobacter

The results of the *Legionella* and *Campylobacter* analysis showed that neither pathogen was detected in the rainwater. Additional samples from Site 4 and Site 5 were sent for further *Campylobacter* analysis in July 2007. These two sites were selected because of the large number of fecal coliforms detected in the pre-treated rainwater at the sites in the previous sampling period (79 CFU/100mL at Site 4, and 54 CFU/100mL at Site 5). Despite the heightened microbiological loading in the rainwater systems at these sites, *Campylobacter* was not detected.

Studies reviewed by Lye (2002) have reported the presence of *Campylobacter* in rainwater harvesting systems in New Zealand, and have documented an outbreak of Legionnaire's disease in the U.S. Virgin Islands from rainwater contaminated by *Legionella pneumophila*. Albrechtsen (2002) detected *Campylobacter* twice out of seventeen samples, but failed to find *Legionella pneumophila* in fourteen samples from rainwater cisterns in Denmark.

The absence of *Legionella* and *Campylobacter* in the rainwater cisterns in this study (even with large numbers of fecal coliforms present) and the infrequent detection of these pathogens in the literature suggests that *Legionella* and *Campylobacter* are not predominant within all RWH systems. Additional sample collection and analysis is recommended to determine if the factors considered in this study, including RWH system design, season, and site environment impact the presence and number of these pathogens.

Conclusions

The physicochemical properties of rainwater were most influenced by the catchment and storage materials and site environment. Catchment surfaces employing steel roofs provided rainwater of higher quality than did asphalt shingle roofs. The material properties of asphalt shingles may have contributed to poorer quality runoff, due to the adsorption of atmospheric particulates deposited on the catchment surface between rainfall events. Concrete cisterns tended to raise the pH of stored rainwater over time, whereas the pH remained constant when stored in plastic cisterns. The quality of harvested rainwater appears to depend, in part, upon the location in which RWH systems are operated. In some cases, site environment may have a detrimental impact on rainwater quality, as was observed at Site 4.

Season, temperature, and extent of treatment had the greatest impact upon the microbiological quality of the rainwater. During the summer and fall seasons total and fecal coliforms were detected in a greater proportion of samples, and were also detected in greater numbers. Post-cistern treatment, by means of a 20 micron particle filter and UV disinfection, was shown to be effective at reducing the number of total and fecal coliforms and turbidity prior to use. Following post-cistern treatment, the number of samples with detectable levels of total and fecal coliforms was reduced, on average, by 96% and 97%, respectively. The average reduction in turbidity was 42%.

These findings show that while quality can be expected to vary due to environmental conditions, the rainwater from a RWH system can consistently achieve high quality through the selection of appropriate catchment and storage materials and the application of post-cistern treatment.

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Chapter 3 Performance Aspects of Rainwater Harvesting Systems

Introduction

The suitable end uses of rainwater depend, in part, upon the ability of RWH systems to adequately meet the needs placed upon them. One method of assessing this ability is through the performance of RWH systems – the ability of RWH systems to reduce dependence on municipal water supplies – measured as the ratio of rainwater supply (or yield) to rainwater demand. The performance of a RWH system can be evaluated over a short duration, such as during a rainfall event, or over longer periods of time, like days, months or years. This flexibility with respect to time provides the ability to examine all aspects of a RWH system, and determine how each contributes towards (or detracts from) the overall performance of the RWH system.

The factors affecting the performance of a RWH system include obvious items like the volume of rainfall, the size of the catchment area, cistern capacity and the amount of rainwater demand, but other factors, such as losses from the roof and pre-cistern treatment device may also have a significant impact upon system performance. Another important aspect, particularly in cold climates like Ontario, is the performance of RWH systems during periods of cold weather. Cold weather performance issues include the contributions to cistern volume that take place from snowmelt, and the risk of freezing of various components of a RWH system.

To collect data regarding the performance of a typical RWH system, three RWH systems were installed in experimental sites (households) located in the City of Guelph. At the first experimental site, an extensive one year performance monitoring program was carried out. A rain gauge was installed at the site, a water level sensor and temperature sensor were placed inside the rainwater cistern, and a water meter was installed on the rainwater plumbing line. The collected data was used to assess: (i) trends in daily rainfall and rainwater demand, (ii) losses due to cistern overflows, (iii) losses from the catchment surface, (iv) cold weather performance, (v) snowmelt contributions, and (vi) municipal water savings. Observations from all three experimental sites were used to comment upon the quality of cistern-stored and point of use rainwater, the impact of cold climate, and the issues associated with the operation and maintenance of pre-cistern treatment devices.

Method

Design approach for the RWH experimental sites

The review of RWH practices in developed nations indicates that each nation has developed its own unique approach to the design of RWH systems, as well as its own accepted end uses for rainwater. These differences have emerged as adaptations in response to local factors such as the extent and availability of freshwater sources, climactic conditions, tolerance to risk, costs, and public acceptance. Consequently, it can be claimed that these approaches are the most appropriate where they were first developed (i.e., the German model works best in Germany). Thus, rather than select one of these models and evaluate its suitability for RWH in Ontario, the aim of this project was to develop a new model, one that was specifically suited for Ontario. To facilitate this process, the central aspects of the 'appropriate technology' framework – knowledge transfer, technology transfer and capacity development – were utilized.

Although the term 'appropriate technology' is typically used within an international development context, its concepts can be equally applied for use within developed nations. Schumacher (1973) is credited with coining the expression "intermediate [appropriate] technology" to describe a "technology of production by the masses, making use of the best of modern knowledge and experience, conducive to decentralization, compatible with laws of ecology, gentle in its use of scarce resources, and designed to serve the human person instead of making him the servant of machines." Thus, for technology to be considered appropriate, it must share some, or all, of the following characteristics: have a low capital cost, meet the basic needs of users, use local materials whenever possible, employ local skilled labour, be culturally/socially appropriate, and be sustainable (McCullagh 1977).

Appropriate technology's emphasis on working in the community, utilizing local materials, and hiring local labour promotes a participatory approach to technology development. This participatory approach not only facilitates the transfer of technology from the designer to the user, but also the transfer of knowledge between parties. For this appropriate technology to be successfully integrated within a community, the process of technology transfer and knowledge transfer should take place with as many stakeholders as possible (Dickinson 1977). Often, relevant stakeholders include users, local contractors, as well as members from municipal, provincial and federal levels of government. By involving local stakeholders in this two-way exchange of information, it is possible to build capacity to independently plan, design, and implement this knowledge and technology in the future. The act of building this capacity in stakeholders, referred to as capacity development, often has a greater impact than the technology itself as it empowers them to embrace the technology and continuously adapt it to meet their local needs. Knowledge and technology transfer can build capacity at a variety of different levels, including: technological capacity, regulatory capacity, institutional capacity, economic (market) capacity and public capacity.

The concepts within the appropriate technology framework were applied to this project by involving as many stakeholders as possible in the design, installation and operation of three RWH systems in the City of Guelph. Of these stakeholders, a select group comprised the project partners, who provided funding and in-kind support. These partners included members working at the federal, provincial and municipal levels of government; as well as both ‘green’ and ‘mainstream’ housing developers. In addition, an informal network of local stakeholders, including non-profit groups, contractors, industries, suppliers, and conservation agencies were naturally drawn to the project. These partners and local stakeholders all participated in various capacities, providing support for the project in their core areas of expertise. In return, the partners and stakeholders were able to develop their own capacity in regards to RWH through the interactions they had when working with the other project participants.

The RWH system at the second experimental site is an excellent example of the application of this appropriate technology approach. The RWH system was incorporated as one of a number of energy and water efficient ‘green’ technologies in a LEED Platinum model home built by Reid’s Heritage Homes, one of the project partners. The design of the RWH system at the LEED Platinum home was a collaborative process, one that involved numerous design sessions and meetings between staff from Reid’s Heritage Homes, the City of Guelph, the research group, homeowners, and members from the informal group of stakeholders. These stakeholders included RH_2O North America Inc., which provided technical and material support for the project, as well as Patton Plumbing which installed the plumbing components for the rainwater system. The RWH system at the LEED Platinum home received a wide level of support from all of the project partners, so much so that a ground-breaking ceremony was held specifically for the RWH system. This ground-breaking ceremony was attended by key members from the project partners, as well as Guelph Mayor Karen Farbridge, and interested members of the community.

In addition to collaboratively producing this technology, the stakeholders have gained capacity in specific areas. RH_2O North America was able to develop technical capacity through the design and installation of their first RWH system for a mainstream housing developer. For the City of Guelph, the approvals process for the RWH system improved the regulatory capacity of the inspectors and officials working at the City of Guelph Planning & Building Services. Development of institutional capacity also took place for the City of Guelph, as numerous city staff were, for the first time, introduced to the concept of domestic RWH while participating on this project. The project was also beneficial for Reid’s Heritage Homes since the LEED Platinum home, and the RWH system specifically, provided a vehicle for the developer to advertise their ‘green’ credentials through print and television media attention. The LEED Platinum home currently serves as a model home for Reid’s Heritage Homes, and is open to the public. It also serves to provide additional design and water quality data for the RWH project. Showcasing RWH in a mainstream suburban home builds public capacity and acceptance of the practice.

Experimental sites

The following paragraphs outline the unique characteristics of each experimental site and RWH system. Further technical details regarding the experimental sites are provided in the Appendix at the end of this chapter.

Experimental Site 1

The first experimental site was a rainwater harvesting system designed and installed in an existing suburban home in Guelph. A suitable site was selected at the front of the property, where an 8,000 L pre-cast concrete cistern was installed, as shown in Figure 3-1.

Figure 3-1: Installation of the pre-cast concrete rainwater cistern

To prevent rainwater from freezing inside the cistern, it was placed in an excavated area with a depth of 2.1 m, which provided approximately 0.7 m of cover from the top of the cistern to grade. If the thickness of the concrete and the head space in the cistern due to the overflow height are also considered, the minimum separation between grade and the cistern-stored rainwater is 1.0 m when the cistern is full, and 2.2 m when the cistern is at its low level. This burial depth ensures that the majority of the time, rainwater is stored below the 1.2 m frost penetration depth in Guelph (Ontario Provincial Standard 2005). Rainwater collected from the asphalt shingle roof of the home is treated by means of a first-flush device, which operates utilizing the principles shown in Figure 3-2.

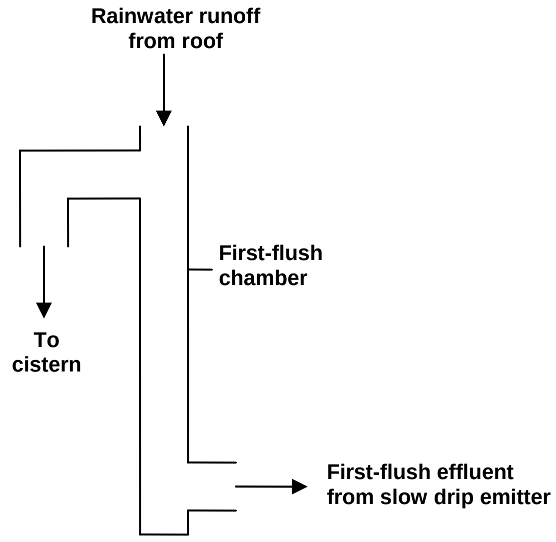

Figure 3-2: Schematic of a first-flush device

The first-flush device custom designed for the Experimental Site 1 site is shown in Figure 3-3.

Figure 3-3: First-flush Device with close-up of slow drip mechanism and bottom cleanout

The first-flush device installed at the retrofit experimental site consisted of off-the-shelf plumbing components, specifically a 150 mm (6 in.) diameter SDR 35 PVC first-flush chamber, which overflowed into a parallel 75 mm (3 in.) SDR35 PVC line connected to the rainwater cistern. A globe valve performed the role of the slow release mechanism.

The bottom of the PVC pipe was connected to a cleanout (shown in the blown-up section of Figure 3-3) which was a threaded cap that could be removed to dispose of the dirt and debris that collect in the first-flush device. The Texas Rainwater Harvesting Manual (TWDB 2005) recommends first flush volumes ranging from 41 to 82 L for a 100 m^2 roof surface. However, it was decided that 100 L (equivalent to the first 1 mm of rainfall on the site's 100 m^2 roof) would be diverted using the first-flush device. This greater volume was selected due to the extended age of the asphalt roofing material and the desire for high quality rainwater given the homeowner's preference for no other treatment beyond the first-flush device.

To provide rainwater to the fixtures inside the home, a Grundfos Constant Pressure System, comprised of a submersible pump, small pressure tank and controller unit was selected for the RWH system (see the Appendix at the end of this chapter for technical details). Rainwater distribution inside the home was centralized in an eight port copper manifold with cross-linked polyethylene (PEX) connections (shown in Figure 3-4). The manifold provided the homeowner with the opportunity to easily connect additional appliances and/or fixtures to the rainwater supply in the future.

Figure 3-4: Rainwater supply manifold

Four ports of the manifold are currently being serviced by rainwater: two toilets, the washing machine, and an exterior hose bib. A schematic of the rainwater plumbing is provided in Figure 3-5.

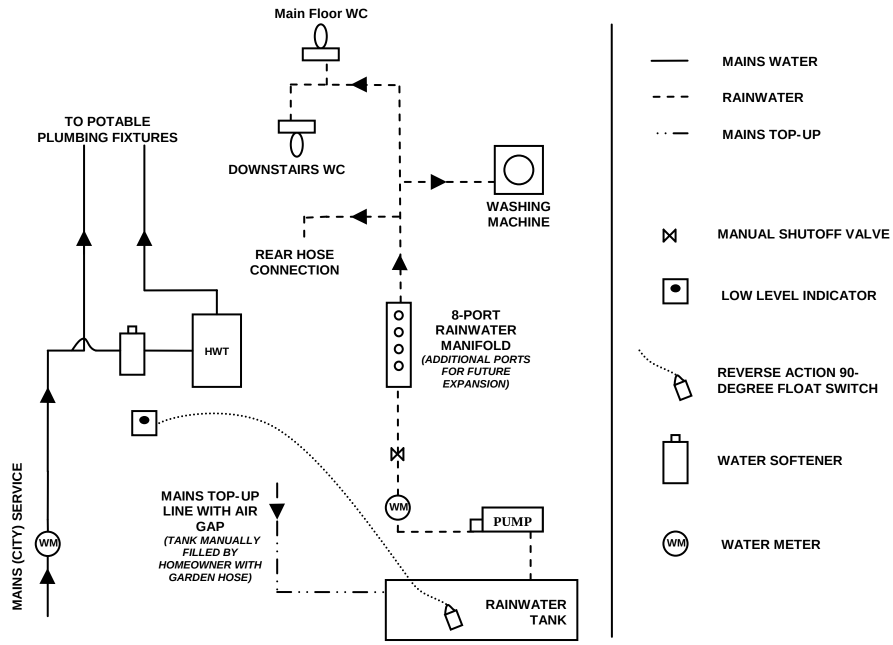

Figure 3-5: Schematic of the internal plumbing at Experimental Site 1

When the cistern runs dry a float switch inside the cistern prevents the pump from operating until the cistern is refilled either by subsequent rainfall, or by manually filling it with municipal (mains) water via a hose at the front of the property. In times of excessive rainfall, the overflow is directed to the municipal stormwater infrastructure.

Experimental Site 2

The second experimental site was the design and installation of a RWH system in a new single detached home. The rainwater harvesting system was designed in collaboration with the City of Guelph, Reid's Heritage Homes, and RH_2O North America Inc. To evaluate the performance of a German-style RWH system in Ontario's cold climate, the RWH system installed at the second experimental site incorporated several RWH components supplied from Germany. The home and cistern installed at the rear of the property are shown in Figure 3-6.

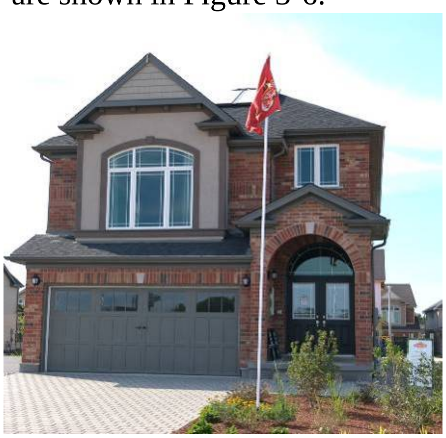


Figure 3-6: [Left] LEED Platinum home, [Right] installation of rainwater cistern

The RWH system at the Reid's Heritage Homes LEED Platinum Home consists of a fibreglass shingle roof used to collect the rainwater. Prior to storage in the underground 6,500 L pre-cast concrete cistern, the rainwater is passed through a 3P Technik cascade filter to improve its quality. An illustration of the filter and a detailed description of the treatment process is provided in Figure 3-7.

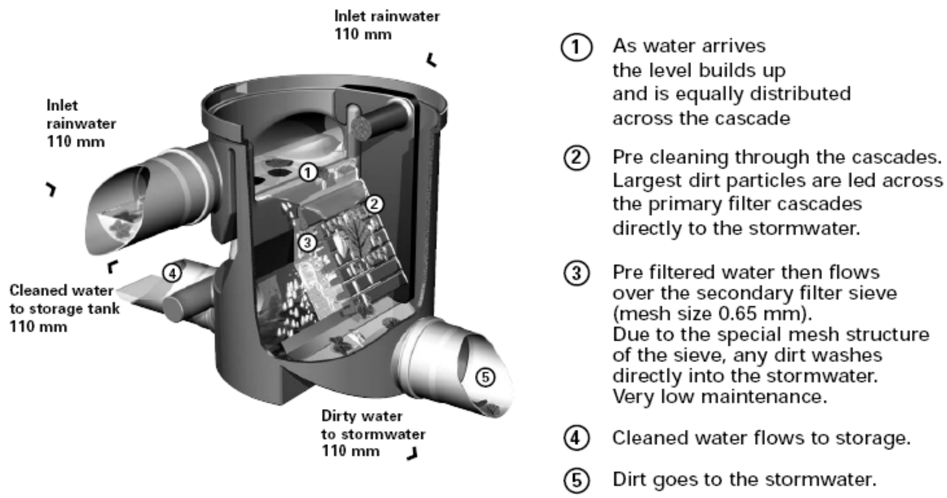

Figure 3-7: VF1 filtration process [© 3P Technik 2006]

In addition to the particulate filter, an experimental below-ground first-flush device developed at the School of Engineering was installed at the site to evaluate the suitability of this method of pre-cistern treatment.

The rainwater stored in the cistern is pressurized via an Idrogo 40/86 submersible pump with a fine mesh floating suction filter, and piped into the building through an independent piping system. In situations where the rainwater cistern is temporarily dry, a controller unit with a built-in backflow prevention device (an air gap) partially fills the cistern with mains water to ensure that domestic rainwater demands are continually met. Overflow from the cistern is directed to an infiltration trench located on the property.

The number of fixtures serviced by rainwater in the LEED Platinum Home is more extensive than what was achieved at the first experimental site. In addition to toilet flushing, landscape irrigation and laundry, an on-demand hot water heater was installed to provide non-potable hot water service to the washing machine and dishwasher (shown in Figure 3-8).

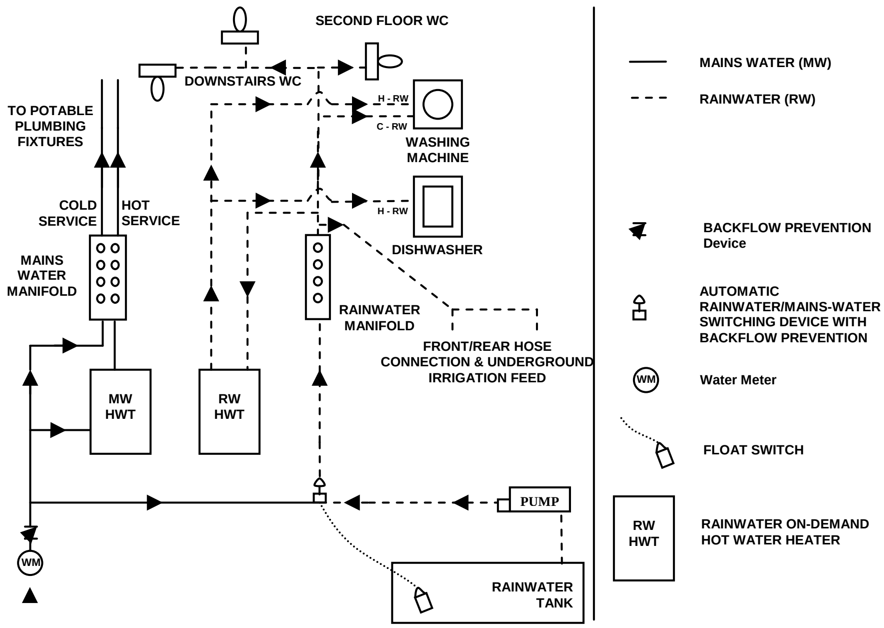

Figure 3-8: Schematic of the internal plumbing at Experimental Site 2

These additional applications push the boundaries of acceptable indoor uses of non-potable water in Ontario, which, as discussed, is currently limited by the 2006 Ontario Building Code to toilets and urinals. The City of Guelph temporarily approved these uses to provide a means for evaluating the suitability of RWH for hot water demands in a typical home setting.

Experimental Site 3

A lower cost above ground RWH system utilizing a 1,000 L plastic tank was designed and installed as part of the third experimental site. This system was located at an older smaller footprint home near downtown Guelph. The small size of this property and the limited space inside the home for the storage of rainwater necessitated placing the plastic tank outside and above ground. This design was similar to that of a typical Australian RWH system, thus providing an opportunity to observe how an Australian RWH system would perform in the cold weather climate of Southern Ontario.

Like the first experimental site, an asphalt shingle roof was used to collect the rainwater, and a simple first-flush device was used to pre-treat the rainwater prior to storage. In addition to this first-flush device, a Leaf Eater® downspout filter was utilized to remove leaves and other coarse debris (located above the first-flush device in Figure 3-9). Both the Leaf Eater® and the first-flush device were products supplied by the Australian company Rain Harvesting Pty Ltd., so as to emulate as much as possible the performance of an Australian RWH system. Another treatment step, although not shown in Figure 3-9, was the placement of a 250 micron ‘sock filter’ on the conveyance network, just prior to its discharge into the above-ground tank.

Figure 3-9: Exterior components of RWH system at Experimental Site 3

To minimize the cost of the RWH system, a ½-HP shallow well jet pump was purchased from a local hardware retailer and was utilized to supply rainwater throughout the home. Rainwater was used to service toilet flushing and the washing machine (shown in Figure 3-10).

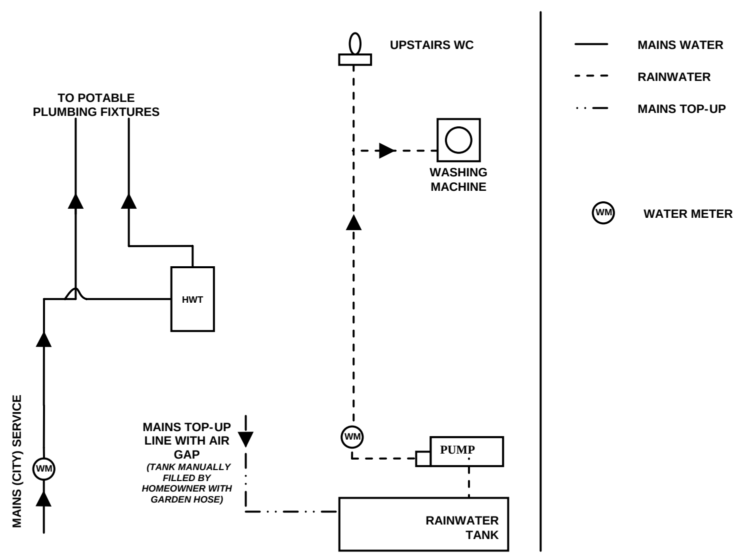

Figure 3-10: Schematic of the internal plumbing at Experimental Site 3

Overflow from the cistern was directed to the front of the property and discharged to grade. Like the first experimental site, the cistern must be filled manually with mains water when there is insufficient rainfall to meet demand. To protect the pump from dry running during these periods, a pressure switch with a low pressure cut-off was installed between the pump and pressure tank. A float switch could not be used because of the geometry of the plastic tank.

Performance Monitoring

The water level and temperature within the cistern at Experimental Site 1 were monitored with an accuracy of ±0.008 m and ±0.2°C using a WL400 Water Level Sensor and a WQ101 Temperature Sensor from Global Water Instrumentation Inc. In addition to cistern level and temperature monitoring, a Hoskin Scientific Ltd. 4000 Series Rain Gauge was installed on the property to record rainfall quantity and timing at the site. The volume of rainwater and mains water used on a daily basis were also recorded (with ± 0.4 L accuracy), using Multi-Jet 5/8" Water Meters installed on the independent rainwater and mains water plumbing lines in the home. Data was logged using a Dickson ES120 Pro Series Universal Input Data Logger, which captured the 4-20 mA signals from the temperature and water level sensors with a one hour resolution; and a HOBO Event Logger for the rain gauge. The water meters were manually inspected on a daily basis for a three month period at the beginning of the study, and collected on a bi-monthly basis thereafter. Data logger records were downloaded on a regular basis using a laptop computer. Details regarding the calibration of the performance monitoring equipment are provided in the Appendix at the end of this chapter.

Results

Daily rainfall and rainwater demand

The cistern volume and daily rainfall at the first experimental site, from Oct. 2006-Oct. 2007, are given in Figure 3-11 below.

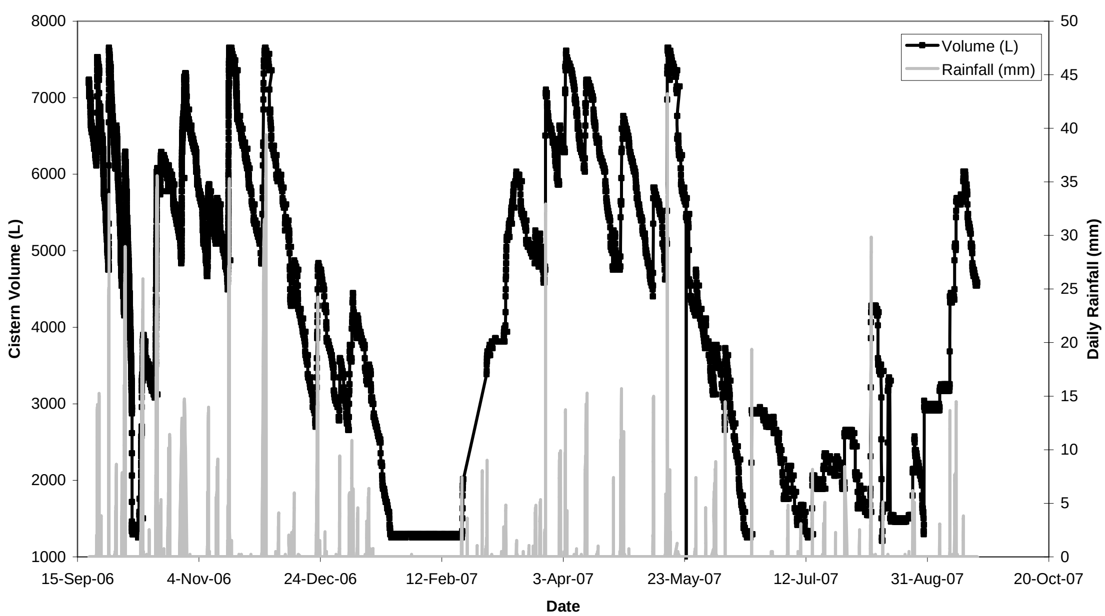

Figure 3-11: Cistern volume and rainfall at Experimental Site 1

One of the trends immediately evident from Figure 3-11 is the variable nature of the cistern volume. This repeating cycle is characterized by sharp inclines in the volume following rainfall, followed by a slower decline in volume as a result of normal demand. Throughout the monitoring period, the cistern volume varied from a minimum volume of 1,250 L to a maximum of 7,650 L. Below the minimum volume, the float switch inside the cistern prevented the pump from operating to prevent dry running. To simplify monitoring of the RWH system, topping up the cistern with mains water was not performed. The rainwater cistern was at the minimum volume, or "empty," a total of 55 days between Oct. 2006 and Oct. 2007; many of those days taking place during the winter months of January and February 2007. Above the 7,650 L threshold, the cistern overflowed into an existing stormwater infrastructure connected to the property. Overflows from the cistern were observed on eight days throughout the year.

The similarities in the rate of cistern volume decline between rainfall events show that the demand for rainwater was relatively consistent over the monitoring period. This is the case for this site because rainwater was used primarily for toilet flushing and for laundry, demands that vary little throughout the year. If rainwater was used for outdoor applications such as plant and lawn watering, an increase in demand would likely have been observed throughout the summer months.

The frequency and volume of daily rainfall at the site are also presented in Figure 3-11. The average annual precipitation for the City of Guelph is 930 mm, with 650 mm of this in the form of rainfall from April to November, and the remainder from snowfall which takes place in December to March (Environment Canada 2004). The high frequency and large volumes of rainfall between the months of October-December 2006 (seen in Figure 3-11) were roughly 40% higher than the monthly climate normals. Between January and May 20007 the observed rainfall was slightly below average; however the greatest deviation took place during summer months of June and July. Monthly rainfall during these months was 40% below the norms as drought-like conditions were present throughout much of Southern Ontario. Despite these variations from historical rainfall patterns, the amount of rainfall recorded during the monitoring program, 791 mm, was slightly higher than the 765 mm rainfall normal (although within the annual standard deviation of rainfall of ±115 mm). Thus, while the monitoring program observed a year with some seasonal variations, the annual volume of rainfall was within the typical range recorded in the climate normals for the City of Guelph. This provided the monitoring program the opportunity to characterize the performance of the RWH system during a typical year under a number of conditions: large volume rainfall events, frequent smaller events, infrequent rainfall, snowfall, and snowmelt.

The effect of frequent, but smaller, daily accumulations of rainfall can be observed throughout April and May of 2007. During this two month period, daily rainfall accumulations of less than 15 mm took place on 21 occasions and were greater than 15 mm on only four days. Daily rainfall <15 mm contributed an estimated 6,500 L of rainwater to the cistern, whereas rainfall larger than >15 mm contributed 5,600 L in total. Over the entire one-year study period, this trend changes somewhat, as rainfall <15 mm and >15 mm contributed equal quantities of runoff to the cistern at Experimental Site 1. These observations suggest that smaller more frequent daily rainfall accumulations tend to play an equally important role in meeting the demands of RWH systems as the less frequent larger volume daily rainfalls.

Cistern overflows

As previously discussed, the cistern overflowed eight times throughout the one-year monitoring period. From Figure 3-11, it is evident that the majority of these overflows took place during days with large amounts of rainfall, when the rainfall exceeded 35mm. The largest loss of rainwater due to overflow occurred over a two day period from November 30 to December 2, 2007. If the cistern had a greater storage capacity, an additional 2,000 L would have been captured and available to meet future rainwater demands. In total, approximately 8,000 L of rainwater was lost due to overflow during the one year period, which corresponds to 96 mm of rainfall (given the catchment area and the losses discussed in the subsequent section). If the cistern had the capacity to store this additional volume, the number of dry days could have theoretically been reduced by 29 days, given the 270 L average daily rainwater demand of the household for the fixtures serviced by the RWH system.

Losses from the catchment surface

A rainfall loss factor was observed while monitoring the performance of the RWH system at the first experimental site. The 791 mm of rainfall recorded at the site corresponds to a potential capture volume of 79.1 m^3 from the 100 m^2 catchment surface. Of this volume, the water meter installed on the rainwater line indicated that only 65.2 m^3 had been used to serve the non-potable demands inside the home. Thus a rainwater loss of almost 20% took place in the RWH system. This figure, however, provides little information as to the mechanism(s) behind this loss. For instance, was this loss primarily associated with overflows from the cistern, or were losses taking place on the catchment surface?

To better characterize the loss factor from the roof, the first flush device (which has its own intrinsic loss factor) was disconnected from the RWH system so that only losses from the catchment surface were observed. Over a three month period, daily recordings of the rainwater water meter were made, and compared to the data automatically collected from the rain gauge and cistern water level sensor. To facilitate this comparison, daily rainfall was calculated by summing the number of ‘rainfall events’ (rain bucket tips) recorded by the rain gauge at Experimental Site 1 on a daily interval. Using this method, rainfall losses were calculated using a model adapted from Fewkes (1999):

$$\sum_{t=1}^{T} V_t = \left[\left(\sum_{t=1}^{T} R_t \cdot C_t \right) - F_t \right] \cdot A \qquad \textbf{[1]}$$

Where V_t is the volume of water captured (in L) over a daily interval t, which is dependent upon the sum of the rainfall events in one day, R_t (mm), runoff losses throughout the day, C_t (%), a fixed once-daily runoff loss, F_t (mm), and the catchment surface area, A (m^2).

The three months of collected data were inspected for dates with rainfall, and a total of 18 days (without overflow) were compiled (see Table 15 in this chapter's Appendix). The volume of rainwater captured during each day ($V_{t.}$) was estimated using the following:

$$V_t = V_f - V_d - V_b \qquad \textbf{[2]}$$

Where V_f is the cistern volume at the end of each day (L), V_d is the volume of rainwater withdrawn from the cistern to meet non-potable demands (L), and V_b is the cistern volume at the beginning of the day (L).

The 18-day data set was sorted by rainfall volume, and the volume of rainwater captured ($V_{t.}$) from these individual rain events was analyzed. Figure 3-12 illustrates the relationship between the rainfall events and the corresponding contribution to cistern volume.

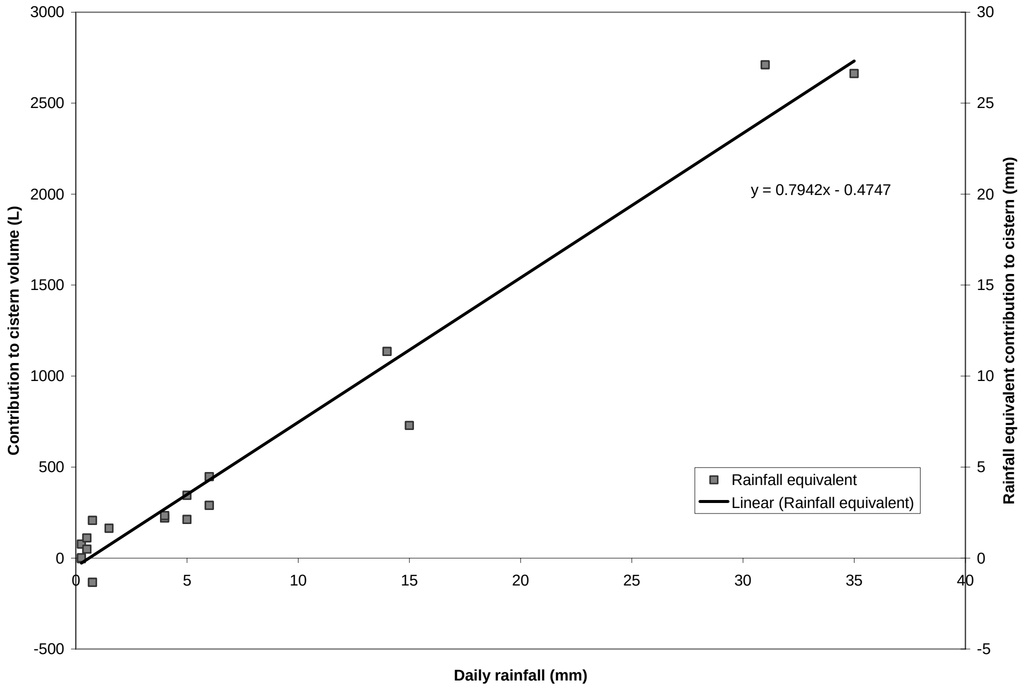

Figure 3-12: Rainfall and corresponding volume addition to cistern at Experimental Site1

One of the first trends evident from the data in Figure 3-12 is the inconsistency in the volume of rainwater captured on days with little rainfall. For daily accumulations below 1.5 mm, both additions and subtractions to the cistern volume are observed, indicating that the contribution of these small amounts of daily rainfall may depend upon environmental factors. One such factor could be ambient temperatures and its influence upon the rate at which rainwater evaporates from the roof surface before collection. Another factor may be the antecedent dry period, which impacts the amount of water that is required to wet the roof material before runoff takes place. A third factor, which may explain the subtractions to the cistern volume is that these volume contributions lie within the range of error of the monitoring equipment (±41 L), and thus it is difficult to assess the impact of these small amounts of rainfall with a great degree of accuracy.

Days with rainfall greater than 1.5 mm showed more consistent additions to the cistern volume, however, the efficiency with which rainwater was collected (measured by the ratio of the actual volume contribution to the expected volume contribution) varied widely between rainfall amounts. The collection efficiency ranged from a minimum of 44% to a maximum 86%, with higher efficiencies observed during days with larger amounts of rainfall. This trend is important because it supports the premise of a once-daily fixed rainfall loss. The collection efficiency of smaller rainfalls was lower than that of larger rainfalls because the fixed loss would constitute a larger proportion of small rainfalls compared with larger ones.

To estimate this fixed loss, the contribution to the cistern volume was converted into equivalent millimetres of rainfall by dividing the volume contribution by the 100 m^2 surface area of the catchment surface. These rainfall equivalents were placed on a second y-axis on Figure 3-12, and a linear trend line was fitted to the rainfall equivalent data. From Figure 3-12, the linear trend line indicates that, on days with rainfall, approximately 80% of rainfall was collected as runoff in the cistern, and a 0.5 mm rainfall loss took place. Thus, these findings indicate that for a typical suburban home with an asphalt shingle roof, a 0.5 mm fixed rainfall loss and a 20% continuous loss characterize the volume of water captured from runoff on a daily basis. This continuous loss is likely due to meteorological conditions such as the angle of rainfall, or due to wind blowing rainwater off of the roof prior to collection in the gutters. Design factors like leaks in the guttering, and leaks at the transition from the downspouts to the pipe conveyance network may have also contributed to this continuous loss of runoff. Fixed losses are likely due to the need to wet the catchment surface prior to runoff taking place.

Cold weather performance

Because of the need for RWH systems to operate under cold weather conditions in Ontario, the monitoring program focused upon cold weather performance. The most obvious concern regarding cold weather is the potential for freezing in the pre-cistern treatment device (by first-flush diversion or filtration), conveyance system or the rainwater cistern when temperatures drop below 0°C. The cold weather performance of these components at the experimental sites is described below.

Pre-cistern treatment devices

Most first-flush devices divert rainwater from the cistern by collecting large volumes of rainwater in a chamber that has a slow drip emitter to discharge the water slowly over time and 'reset' the device for the next period of rainfall. This accumulated water is a risk factor for cold weather use, particularly if the slow drip emitter becomes clogged and the chamber does not drain at a sufficient rate.

A total of four first-flush devices were evaluated during the performance monitoring program. Three of these devices were constructed from locally sourced off-the-shelf plumbing components based upon the design presented in *The Texas Guide to Rainwater Harvesting* (TWDB 2005), whereas another was assembled utilizing a pre-packaged first-flush kit from an Australian supplier of RWH products. All three were installed outdoors, and were integrated into RWH systems at the experimental sites (Experimental Sites 1 and 2) under actual use conditions. In all three cases, the rainwater contained within the first flush chamber froze and irreparably damaged the pre-cistern treatment device.

The second first-flush device installed at Experimental Site 1, was designed to be easily disconnected from the conveyance network during cold periods, however, this too froze due to the onset of cold weather before the homeowner could disconnect the unit. Because of the issues associated with the standard first-flush devices, a fourth device, designed for burial to protect against the formation of ice in the first-flush chamber, was attempted. The device was found to protect against frost, but encountered other problems, which are discussed further in the pre-cistern treatment performance section.

Unlike first-flush devices, filters do not require the temporary storage of water to treat the runoff from the catchment surface. As such, there is less of an obvious risk surrounding the use of these devices in cold climates.

The performance of three different filtration mechanisms was observed as part of the study. The first filter, a buried unit imported from Germany for the second experimental site, continued to remove particulate matter during the winter months. The below-ground filter treated the roof runoff during periods of snowmelt without accumulating any ice throughout the winter. The second and third filtration options – a leaf screen combined with a 250 micron polyethylene "sock filter" (installed above-ground on the downspout at Experimental Site 3) – had some problems, as ice tended to accumulate in both the leaf screen filter and the sock filter during freeze and thaw periods.

These findings indicate that outdoor treatment devices located above-ground (first-flush or filtration) are at risk for the accumulation of ice during periods of cold weather. To ensure that RWH systems continue to perform during winter months, treatment devices may need to be disconnected, or located in a temperature controlled environment such as indoors or buried below the frost penetration depth.

Conveyance system

The only occasion where rainwater froze in the conveyance network was attributed to the failure of the first-flush device installed at Experimental Site 1. Once the water in the first-flush chamber had frozen, runoff from the roof was blocked from entering the cistern, and thus froze in the downspout above the pre-cistern treatment device. No other cold weather related issues were detected during the performance monitoring program. These findings indicate that as long as the conveyance system is installed with a sufficient slope towards the cistern, and that the conveyance pipe network is buried below the frost penetration depth, then freezing in the conveyance system should not be an issue.

Cistern location

Prior to the planned winter decommissioning of the RWH system at Experimental Site 3, the rainwater stored in the above-ground tank froze due to an early onset of cold weather. No obvious signs of damage to the plastic tank were observed, however, the tank was not completely full at the time the rainwater froze, which likely mitigated the damage that would have occurred had it been full.

At Experimental Site 1, the temperature of cistern-stored rainwater is provided in Figure 3-13.

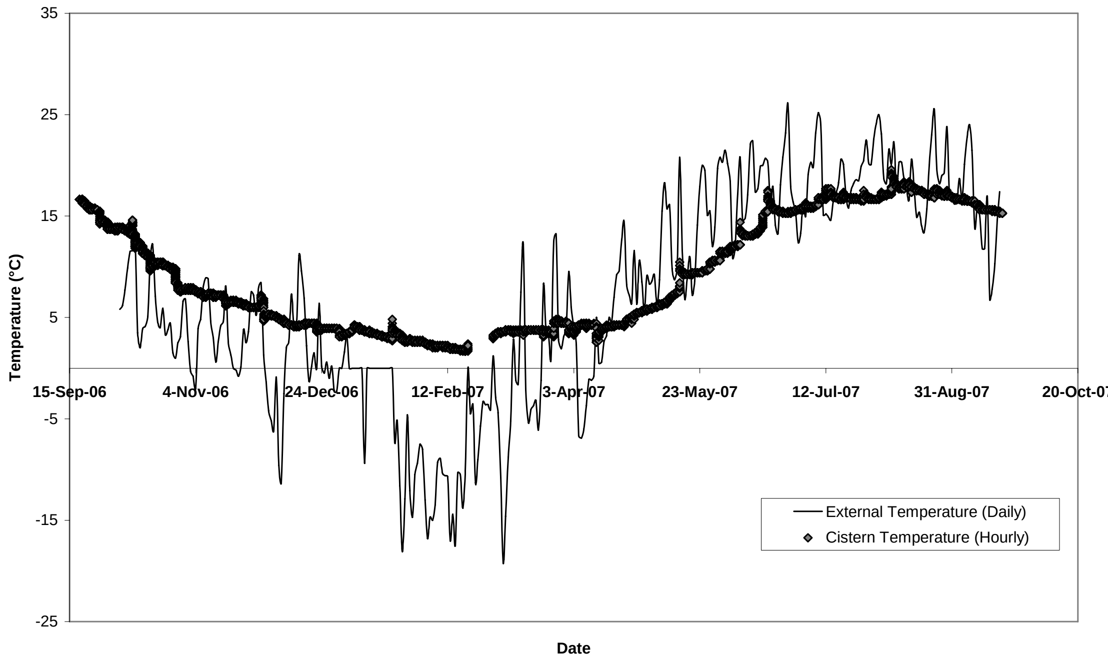

Figure 3-13: Cistern-stored rainwater temperature and ambient air temperature at Experimental Site1

The extreme cold conditions observed from January 14th to February 18th showed that even with ambient air temperatures as low as -20°C, the rainwater stored below the frost penetration depth did not freeze. As seen in Figure 3-13, the water temperature in the cistern followed the downward trend of the outside air temperature, but bottomed out during the period of extreme cold temperatures, dropping no lower than 1.7°C. A two-week gap in cistern temperature (starting February 20, 2007) can also be observed in Figure 3-13, this gap took place due to the accidental disconnection of the temperature sensor from the electricity supply.

These findings indicate that one means of ensuring that rainwater does not freeze is to bury the cistern below the frost penetration depth. In addition to providing sufficient thermal cover for times when the cistern was full, the risk of freezing would be further reduced during periods of extreme cold weather, as the water level would tend to be far below the frost level due to the lack of inputs from rainfall or snowmelt. Alternatively, the water inside the cistern could be heated to prevent freezing, or the cistern could be located in a temperature controlled environment. Otherwise, unexpected cold weather may cause rainwater to freeze in an above-ground tank located outdoors.

Snowmelt contribution

Another issue for cold climates is the contribution of snowfall to the volume of water in the rainwater cistern. This was assessed for Experimental Site 1 by examining the performance of the RWH system following the transition from rainfall to snowfall once temperatures consistently fell below freezing in January 2007. From January 14th to

February 18th the maximum daily ambient air temperature ranged from a low of -15.4°C to a high of -0.8°C. Throughout this period, 39 cm of snow fell and remained on the ground because of the low temperatures. The water equivalent of this snowfall, estimated by melting the snow while it fell, was 43.2 mm (Environment Canada 2007). Snowfall appears to have had a negligible impact on increasing the volume of water stored in the cistern, as seen in Figure 3-11. However, with warmer temperatures in late February a portion of this snowfall contributed to the stored water volume.

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

During this cold period, the daily non-potable water demand eventually exceeded the volume of stored rainwater, and the cistern ran dry. The limited contribution of snowmelt to the cistern volume has implications for RWH systems installed where snowfall comprises a greater proportion of the annual precipitation. These systems will have poorer capture efficiencies and thus, would meet a lower water demand than systems located in areas with more frequent freeze-thaw periods.

Performance of pre-cistern treatment devices

As discussed in the cold weather performance section, some of the pre-cistern treatment devices (primarily the first-flush devices) encountered problems during periods of cold weather.

In warm weather, the above-ground first-flush diverters operated without any problems, but homeowner maintenance of these devices may be quite significant due to the accumulation of sediment at the bottom of the first-flush chamber. The maintenance schedule of a first-flush device will vary depending upon environmental conditions such as the amount of atmospheric deposition onto the catchment surface or whether tree branches overhang the roof surface, however if not inspected and cleaned once every two-three months, sediment tends to block the slow drip emitter that drains the chamber between periods of rainfall. This problem was experienced with the experimental buried first-flush system (shown in Figure 3-14).

Figure 3-14: Experimental buried first-flush device [LEFT] exterior, [RIGHT] interior, showing slow drip emitter attached to the first-flush device via a pitless adapter

The slow drip emitter at the bottom of the first-flush chamber was attached to the first-flush device using a sliding coupling device (a pitless adapter) so that it could be easily removed for cleaning. However, once installed at Experimental Site 2, it was difficult to see the slow drip emitter to remove it since, once clogged, the first-flush chamber remained filled with highly turbid first-flush runoff. Furthermore, due to its underground location, the slow drip emitter was about 1.1m below grade, which meant that it was difficult to retrieve the emitter, even with a tool custom-designed to perform this function.

Conversely, although the German-designed RWH filter was also buried, it was easier to access the filtration unit for cleaning since it was located near the top of the device (see the schematic in Figure 3-7 for details). Cleaning the filter was also an easier process than the first-flush device, since instead of disassembling the slow drip emitter to remove the fine debris clogging the emitter; the filter was cleaned simply by means of scrubbing it with a coarse bristle brush while rinsing it with water from a garden hose. Thus, while a below-ground first-flush device was shown to be feasible in terms of preventing ice accumulation, further design work must be performed to improve their operation and maintenance accessibility to the levels of that provided by the custom-designed German RWH technology.

Another issue was the treatment effect of the pre-cistern treatment devices. The extensive pre-cistern treatment at Experimental Site 3 (leaf screen, first-flush device, and 250 micron sock filter) was ineffective at addressing the high levels of turbidity and colour in the cistern-stored rainwater. Although this poor quality may be due to factors independent of treatment, such as environmental factors or the above-ground placement of the tank, it is evident that pre-cistern treatment alone is not sufficient to ensure that stored rainwater is of high quality. Further research is required to examine the degree to which these devices improve rainwater quality.

Municipal water savings

In addition to helping to estimate runoff losses, water meter data was also used to provide insight into the potential household municipal water savings from the installation of a RWH system. The annual mean daily mains water and rainwater demand at the first experimental site are given in Figure 3-15.

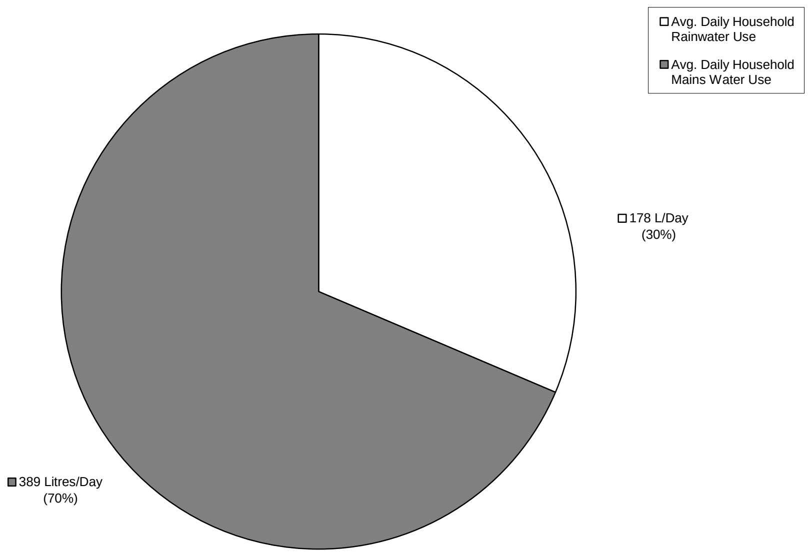

Figure 3-15: Average daily mains water and rainwater use at Experimental Site 1

As seen in Figure 3-15, on average, the daily rainwater demand was 570 L/day at the Experimental Site 1 household, 30% of which was met by rainwater (178 L/day or 36lpcd) with the remainder met by mains water (389 L/day or 78lpcd). Of note is that this average rainwater demand includes the days for which rainwater was unavailable. Examination of rainwater use exclusively on days where rainwater was available reveals that the daily mean rainwater demand was higher at 272 L/day (54lpcd). This finding indicates that if rainwater was always available, rainwater use could have offset mains water use by as much as 47% at Experimental Site 1. It is important, however, to qualify these reductions in mains water use as those to be expected at water conserving homes. The mean daily water use in the five person household at Experimental Site 1 was 62% lower than the 1320 L/day (264lpcd) which is the average water use of a five person household residing in the City of Guelph (City of Guelph 2006). If the rainwater use at Experimental Site 1 (178 L/day) were applied to a five person household with average water use, the reduction in mains water use by 22% when including dry periods.

These statistics demonstrate that the use of rainwater for flushing toilets and washing clothing could reduce residential average day demand from a low of 22% to as much as 47% if RWH systems were widely adopted in new and existing homes. These findings also demonstrate that RWH is most efficient when used in conjunction with water conservation and fixtures, such as low-flow toilets and front-loading washing machines.

Conclusions

The performance monitoring program revealed a number of significant trends with respect to RWH systems. Most important of these trends was the significant reduction in municipal water use following the installation of a RWH system. The RWH system at Experimental Site 1 yielded 65 m^3 of water during the one-year performance monitoring program, which corresponded to approximately 178 L per day for toilet flushing and laundry. This volume of rainwater was sufficient to meet 30% of the annual water needs of the water conserving five person household located in the City of Guelph that was studied.

From the observations at Experimental Site 1, it is evident that rainwater demand plays an important role in determining the performance of a RWH system, as daily demands must be met regardless of the size of the catchment area, cistern volume, rainfall patterns or rainfall quantity. If demands regularly exceed the volume of stored rainwater, the cistern will often run dry, and the overall performance of the RWH system will decline. This trend also applies if rainwater demands are too low. The performance of the RWH system will decline due to the increased losses from overflows.

Smaller, more frequent, daily rainfall accumulations (<15 mm) tended to play an equally important role in meeting the demands of the RWH system as the less frequent larger (>15 mm) rainfall accumulations. Despite contributing similar quantities of rainwater overall, days with large amounts of rainfall were also subject to losses from the cistern overflowing. This finding demonstrates that larger cisterns tend to improve the performance of RWH systems by collecting greater quantities of runoff before an overflow occurs. It also suggests that performance improvements from increasing cistern capacity are finite – as the cistern size is increased, eventually other factors, such as rainfall depths, catchment area, or rainwater demand will constrain the performance of a RWH system.

Losses taking place at the catchment surface was another issue identified by the performance monitoring program. The monitoring at the first experimental site revealed that for very small amounts of rainfall, no appreciable increase in cistern volume took place and that for larger volumes of rainfall, only a percentage of the total volume was recovered. Analysis of the data from Experimental Site 1 indicates that for an asphalt shingle roof, 80% of rainwater is collected as runoff from the catchment surface, and a fixed loss of 0.5 mm takes place on a daily basis. Similar analysis during periods of cold weather (below 0°C) showed that about 60% of snowfall was recovered in the cistern by means of snowmelt.

Freezing issues were observed during the performance monitoring program, but were limited to three applications where the potential for freezing had been identified prior to installation in the field. The first was in the diversion chamber of three first-flush devices. The runoff that had accumulated in the chambers froze before being drained by the slow drip emitter, which caused irreparable damage to the pre-cistern treatment device. The second location where freezing occurred was inside the above-ground plastic tank at the third experimental site. The rainwater stored in the above-ground tank froze prior to the RWH system's planned winter decommissioning due to the sudden onset of cold weather. The final area where freezing took place was in the filtration devices installed on the downspout of Experimental Site 3. No problems were detected with the above- or below-ground components of the conveyance system. Furthermore, while the temperature of rainwater stored in the below-ground cistern at Experimental Site 1 did decrease during the winter, it never froze, despite air temperatures as low as -20°C. These observations clearly show that first-flush devices and rainwater cisterns should not be located outdoors or above ground due to the risk of freezing. Instead, these should be placed below the frost penetration depth, or located in a temperature controlled environment to ensure that freezing does not take place.

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Appendix

Experimental sites

Table 3-1: Technical details of experimental sites

	Experimental Site 1	Experimental Site 2	Experimental Site 3
House Details	20-year-old suburban bungalow	New single detached suburban home	50-year-old small footprint home
Roof Surface Area	100 m^2	120 m^2	80 m^2
Cistern	8,000L pre-cast concrete	6,500L pre-cast concrete	1,000L plastic
Pump	Grundfos 10GPM submersible	Idrogo 40/86 submersible	Mastercraft ½-HP jet pump
Pump Accessories	Grundfos Constant Pressure System: • 2 Gallon pressure tank • Pressure sensor • CU301 control unit	Floating suction filter on pump inlet Pump controller unit	Combined jet pump and pressure tank package: • 5 Gallon pressure tank • Low pressure cut-off switch
Treatment/Filtration	First-flush device	3P Technik cascade filter	Leaf Eater downspout filter First-flush device
Mains Make-up (when RW cistern runs dry)	Manual cistern top-up with mains water via a garden hose	Automatic mains top-up with built in backflow prevention device (air gap)	Manual cistern top-up with mains water via a garden hose
External Plumbing	• 3" SDR35 PVC Pipe (rainwater conveyance line) • 1 ¼" Black Poly Pipe (pump line)	• 4" SDR35 PVC Pipe (rainwater conveyance line) • 1" Rubber hose (pump line)	• 3" SDR35 PVC Pipe (rainwater conveyance line) - 1" Black Poly Pipe (pump line)
Internal Plumbing	IPEX 8-Port PEX Manifold ½" PEX service lines	½" PEX service lines On-demand hot water system	½" PEX service lines
Rainwater Services	• Toilets • Washing machine • Hose bib	• Toilets • Washing machine (both cold and hot service) • Dishwasher (hot service) • Irrigation system	• Toilets

Calibration of monitoring equipment

WQ101 Temperature Sensor

The WQ101 Temperature Sensor was calibrated in the School of Engineering laboratory using the experimental setup shown in Figure 3-16.

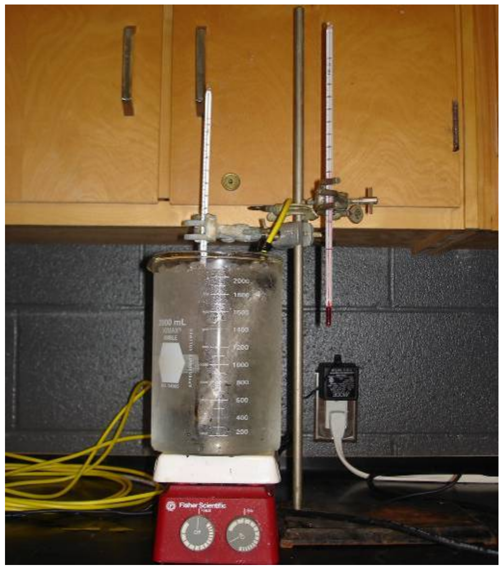

Figure 3-16: Experimental setup for the calibration of the WQ101 Temperature Sensor

As seen in Figure 3-16, the experimental setup consisted of the temperature sensor submerged within a 2,000 mL KIMAX beaker filled with water (a water bath). Two thermometers were used, one to monitor the ambient air temperature in the laboratory, and the other to measure the temperature of the water bath. A magnetic stir bar was used to circulate the water within the water bath, ensuring consistent temperatures throughout.

Ice was added to the water bath to establish the sensor output (measured in mA) at 0°C, and a Fisher Scientific hot plate was used to increase the temperature of the water to a maximum of 32°C. As the temperature was slowly increased, a Dickson ES120 data logger recorded the sensor output, and the temperature on the thermometer was manually recorded. Following the collection of this data, the time, temperature and sensor output values were correlated, and plotted in Figure 3-17.

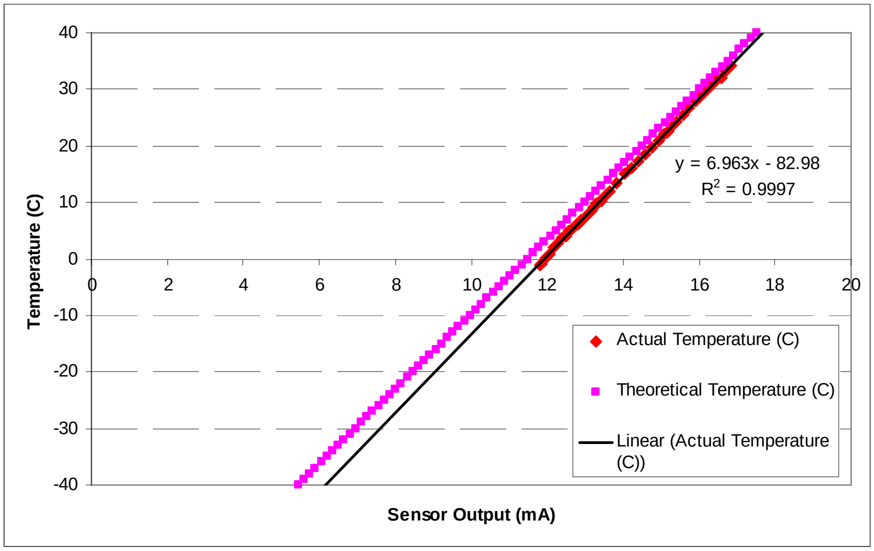

Figure 3-17: WQ101 Temperature Sensor calibration curve

Figure 3-17 presents the resulting experimental calibration curve, as well as the manufacturer's recommended calibration curve. As seen in the figure, both curves are quite similar; however the experimental values are shifted further down the x-axis. Thus, the experimentally derived curve reports a slightly lower temperature value at the same sensor output than the manufacturer's curve. Since the monitoring program was more concerned regarding lower temperatures in the rainwater cistern because of freezing issues, the experimental calibration curve was selected as the most appropriate, and most conservative, measurement of the rainwater temperature within the cistern.

WL400 Water Level Sensor

The calibration curve for the WL400 Water Level Sensor was derived in the field using the actual rainwater cistern it would be placed in throughout the monitoring program. The cord on the water level sensor was marked off at 5.0 in. increments using zip ties. This process was repeated ten times, marking out 50 in. in total. The sensor was lowered into the cistern following each of the 5inch increments until the sensor reached the bottom of the cistern. The time, water height and sensor input were correlated and plotted in Figure 3-18.

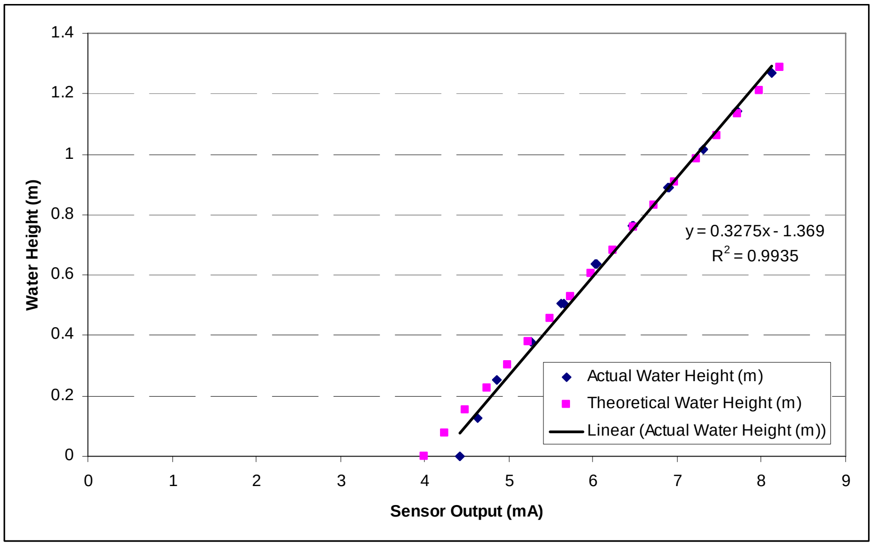

Figure 3-18: WL400 Water Level Sensor calibration curve

As seen in Figure 3-18 the experimental and manufacturer's calibration curves deviate slightly with very little water cover, but are quite similar when measuring water heights of 0.2-1.2 m. Although both curves were quite similar, the experimentally derived curve was selected to provide additional accuracy in measuring the water height during dry periods. These water height values were then converted into volume equivalents by multiplying them by the width and depth dimensions of the cistern.

Multi-Jet 5/8" water meter

Water meter accuracy was assessed by comparing water meter readings to the actual volume of water flowing past the meter. Rainwater was collected from a discharge port downstream of the water meter, and the volume of water was measured with a 1000mL KIMAX Class A graduated cylinder. This process was repeated over a range of volumes to determine variations in accuracy over time. The following volumes were analyzed: 1, 2, 5, 10 and 15 Gallons. The results are summarized in Table 3-2.

Table 3-2: Meter readings (gallons) and litres measured

Meter Reading (Gallons)	Equivalent Litres (L)	Litres Measured (L)	Difference (L)	Error (%)
1	3.79	3.55	0.235	6.22
1	3.79	3.55	0.235	6.22
2	7.57	7.32	0.250	3.31
2	7.57	7.48	0.090	1.20
5	18.93	19.35	0.422	2.23
5	18.93	19.2	0.272	1.44
10	37.85	37.5	0.354	0.94
10	37.85	37.65	0.204	0.54
15	56.78	56.2	0.581	1.02
15	56.78	56.55	0.231	0.41

From Table 3-2, it is evident that as the volume of water increased, the difference between the meter reading and the actual volume of water passing through the meter decreased. Thus, it was concluded that meter accuracy was sufficient for daily readings, as these would often be in excess of 15Gallons, and that a correction factor to adjust for error was unnecessary.

4000 Series Rain Gauge

The accuracy of the rain gauge was assessed by dispensing known quantities of water into the rain gauge collection funnel, and comparing these volumes to the number of rain bucket tips (RBTs) recorded by the HOBO Event data logger connected to the rain gauge. To simulate a range of rainfall intensities, a number of known quantities of water were dispensed into the rain gauge collection funnel. These volumes ranged from 1 mL to 100 mL, and utilized 1, 5, 10 and 15 mL pipettes, as well as a 100 mL graduated cylinder. All laboratory glassware was Class A. These trials were repeated such that the total volume of water passing through the rain gauge was 355 mL. Table 3-3 below summarizes the times when water was dispensed into the rain gauge and the corresponding times when the HOBO event logger recorded a RBT.

Table 3-3: Time and volume of water dispensed into 4000 Series Rain Gauge

Time	Volume of Water Dispensed (mL)	Rain Bucket Tip (RBT)
4:47:00 PM	1	-
4:48:00 PM	1	-
4:49:00 PM	1	-
4:50:00 PM	1	-
4:51:00 PM	1	-
4:55:00 PM	5	-
4:55:07 PM	-	1
4:56:00 PM	5	-
4:56:54 PM	-	2
4:57:00 PM	5	-
4:58:00 PM	5	-
4:58:20 PM	-	3
4:58:00 PM	5	-
4:59:00 PM	5	
4:59:38 PM	-	4
5:02:00 PM	10	-
5:02:07 PM	-	5
5:03:00 PM	10	-
5:03:04 PM	-	6
5:03:16 PM	-	7
5:04:00 PM	10	-
5:04:08 PM	-	8
5:05:00 PM	10	-
5:05:20 PM	-	9
5:06:00 PM	10	-

5:06:28 PM	-	10
5:06:42 PM	-	11
5:09:00 PM	15	-
5:09:16 PM	-	12
5:09:35 PM	-	13
5:10:00 PM	15	-
5:10:23 PM	-	14
5:10:58 PM	-	15
5:12:00 PM	15	-
5:12:41 PM	-	16
5:12:56 PM	-	17
5:14:00 PM	15	-
5:14:41 PM	-	18
5:14:57 PM	-	19
5:15:00 PM	15	-
5:15:55 PM	-	20
5:16:08 PM	-	21
5:16:23 PM	-	22
5:20:00 PM	100	-
5:20:15 PM	-	23
5:20:17 PM	-	24
5:20:19 PM	-	25
5:20:21 PM	-	26
5:20:23 PM	-	27
5:20:24 PM	-	28
5:20:26 PM	-	29
5:20:29 PM	-	30
5:20:31 PM	-	31
5:20:33 PM	-	32
5:20:35 PM	-	33
5:20:39 PM	-	34
5:22:00 PM	100	-
5:22:11 PM	-	35
5:22:14 PM	-	36
5:22:16 PM	-	37
5:22:19 PM	-	38
5:22:22 PM	-	39
5:22:23 PM	-	40
5:22:26 PM	-	41
5:22:28 PM	-	42
5:22:30 PM	-	43
5:22:32 PM	-	44
5:22:34 PM	-	45
5:22:37 PM	-	46
5:22:41 PM	-	47
TOTAL	**355mL**	**47 RBT**

By dividing the total volume of water by the sum of the rain bucket tips (from Table 3-3) the volume of water per RBT was found to be 7.6mL/RBT. Knowing that 1mm of rainfall on a 1 m^2 area provides 1 L of water, 1 mm of rainfall on the 8 in. diameter (0.03243 m^2) rain gauge would correspond to 32.43 mL. Thus, with these two pieces of information, the amount of rainfall in millimetres per RBT was calculated as 0.2329 mm/RBT (0.0092 in./RBT). Comparing this observed value to the 0.01 in./RBT reported by the manufacturer, the error is quite high at approximately 10%. However, this high degree of error was likely the cause of simulating such large intensity rainfall events. Thus, it was concluded that the manufacturer's reported value of 0.254 mm/RBT (0.01 in./RBT) would be used throughout the monitoring program, with the knowledge that this value may have less accuracy during more intense rainfall events.

Additional performance monitoring data

Rainfall loss factors

Table 3-4: Rainfall and corresponding increase in cistern volume at Experimental Site 1

Rainfall (mm)	Volume of Rainwater Added to Cistern (L)	Ratio of Vol. Added to Rainfall (%)	Ratio with loss factor included
0.25	-3.30	-0.13	-
0.25	75.92	2.99	-
0.25	0.93	0.04	-
0.51	109.91	2.16	-
0.51	48.77	0.96	-
0.76	-133.21	-1.75	-
0.76	206.61	2.71	-
1.52	163.13	1.07	-
4.06	219.15	0.54	0.86
4.32	233.45	0.54	0.83
4.57	344.36	0.75	1.13
4.83	211.08	0.44	0.64
6.35	447.35	0.70	0.93
6.35	289.33	0.46	0.60
13.97	1,134.33	0.81	0.91
14.73	728.94	0.49	0.55
31.50	2,710.62	0.86	0.90
35.31	2,662.32	0.75	0.79

Chapter 4 Cistern Sizing Model

Introduction

One of the most important tasks in the design of RWH systems is the selection of an appropriately-sized rainwater cistern. Cistern sizing must optimize the performance of a RWH system while also making trade-offs between other issues such as space limitations. The consequence of selecting an inappropriately sized cistern is a RWH system that performs inefficiently. If the cistern is too small, water demands will regularly exceed the volume of stored rainwater, and the cistern will require constant refilling from an alternative supply, or run dry if no such supply is available. Conversely, while larger cisterns can collect a greater volume of rainwater, this extra storage capacity may often be underutilized.

To determine the appropriate cistern size for a particular RWH system, three sets of information are required: supply, catchment and demand details. With these details, a model can be generated that simulates the performance of various cistern sizes under historical rainfall patterns. In these calculations, the inputs and demands on the cistern are modelled on a volume basis with a daily time interval. Following this modelling, an optimum cistern size can be selected by balancing the trade-offs associated with either too little, or too much, rainwater storage capacity.

Some RWH models have already been developed, and include those by Fewkes (1999) for households in the United Kingdom, and Scott and Mooers (1994) for the regional sizing of rainwater cisterns in Nova Scotia. Guidelines for sizing rainwater cisterns have also been provided in the DIN 1989-1 standard, *Guidance on use of Rainwater Tanks*, and the *Texas Guide to Rainwater Harvesting* (DIN 2002; enHealth 2004; TWDB 2005). However, what all of these models and guidelines lack are catchment details and demand details that specifically address the rainfall patterns, local materials, and permitted end uses of rainwater in Ontario. As it is these very details that distinguish the performance of a RWH system, these guidelines and models are ill suited for selecting an appropriate cistern size for use in Ontario. Therefore, to address this lack of regionally-specific guidance on sizing cisterns for RWH systems in Ontario, a cistern sizing model was developed.

Method

Model overview

The model was developed based on the concept that it must be accessible and easy to use for the widest audience possible, without compromising the quality of the outcome. To that end, the model was developed in Microsoft Excel, a commonly available data analysis program. For users who may be unfamiliar with Excel, a graphical interface was created using Visual Basic that offered more recognizable features like drop-down lists and clearly defined fields for data entry. This interface made it easier for users of all skill levels to enter data into the model, while also ensuring the quality of the modelling because only valid responses (i.e., the correct type of data, and/or data within the correct range) were permitted in each field.

In addition to assisting users with the means of data entry, the data that is collected can be readily provided by the user without the need for intimate details of the rainwater catchment or rainwater demand. For instance, rather than ask the user for the litres of water used per toilet flush, the model asks the user to specify the type of toilet utilized. A database of catchment details and demand details works in the background to relate these responses into rainwater inputs and withdrawals from the cistern. The database also contains typical water use figures for a number of applications, like the average number of toilet flushes per day. If the user selects toilet flushing as one of the rainwater demands, the model automatically recommends this value to the user. This simplifies the process of sizing a general use RWH cistern by users like designers or municipalities, since it frees them from assuming these figures, or searching for these figures themselves. Users with easier access to these types of details, such as homeowners and/or contractors, have the option of adjusting the values recommended by the model.

Following the entry of the catchment and demand details, the user specifies whether to perform either a manual or automatic analysis of cistern performance. If the user selects manual analysis, they may enter up to a maximum of eight cistern volumes, otherwise the model automatically selects eight cistern sizes based upon the amount of rainwater demand. Both the manual and automatic analyses also offer the option to compare up to three different scenarios side-by-side. This provides users with the ability to model the impact from any number of changes to either rainwater catchment or rainwater demand. Examples of these changes include comparing the performance of identical systems located in different parts of the province, increasing or decreasing the catchment area or switching to more water efficient fixtures.

Once the modelling is complete, the simulated performance of each cistern size is reported to users through a variety of tables and figures. These provide the user with the following information for each cistern: the annual volume of rainwater that can be captured, the annual volume of rainwater demand that can be met (also referred to as the rainwater yield), and the corresponding performance (the ratio of yield and demand).

Model database

Historical precipitation records for the province of Ontario were obtained from the Ontario Ministry of the Environment (MOE). These records were comprised of daily precipitation (both rainfall and snowfall) values collected from 350 climate stations located throughout province. For each of these climate stations, the daily data record extended for a period of 55 years, from 1950-2005. Of note is that these data sets contained no missing values. The precipitation data had been processed to ‘fill in’ missing values, thereby providing a comprehensive record throughout Ontario, even in remote regions of the province (Schroeter et al. 2006).

To improve the performance of the cistern sizing model, only a subset of this precipitation data was included in the model database. For each climate station, instead of inputting all of the daily precipitation records for each of the 55 years on record, only five years of daily rainfall data was included along with the annual precipitation (both rainfall and snowfall) for all 55 years. These five years of data were specially selected to represent the range (minimum, first quartile, median, third quartile, and maximum) in the annual volume of rainfall for each climate station. These years represented the rainfall patterns observed during the driest year on record as well as the daily rainfall events recorded on the wettest year on record. This process was also repeated to select a five year data set based upon the frequency of rainfall events. Each of these years was representative of the progression from the year with the least number of rainfall events through to the year with the highest number of rainfall events.

To differentiate the performance of the different types of roofing materials common in Ontario, each was assigned a fixed loss (in mm), and a continuous loss factor. For instance, when applied to asphalt shingles these classifications were assigned values of 0.5 mm, and 20%, respectively, based upon the findings of this project at Experimental Site 1. Thus, of the rainfall that takes place over a daily time interval, 20% is lost because of climactic conditions (wind, temperature, etc.) and leaks in the guttering and conveyance system, and a fixed loss of 0.5 mm occurs as the catchment surface must be wetted prior to runoff taking place. Since the monitoring program only took place on an asphalt shingle roof, the fixed loss and continuous loss factors for other catchment materials were sourced from values reported in the literature, or extrapolated based upon the project findings if no data was available. The same approach was taken in modelling the impact of rainwater pre-cistern treatment by first-flush device or by filtration technology. Based upon their operating principles, first-flush devices were assigned a high fixed loss but a negligible continuous loss factor, whereas the opposite was assigned for filtration. For further information, please refer to Table 16 in this chapter's Appendix for the fixed losses and continuous loss factors for the various catchment materials and pre-cistern treatment devices included in the model.

To assist in the calculation of daily rainwater demands, a database of water consumption figures for residential fixtures and appliances was developed (see Table 17 in the Appendix at the end of this chapter). Since non-potable water use (including rainwater) is currently restricted to toilet flushing and outdoor use in Ontario, the database focused upon these end uses. To model the impact of toilet flushing, the database includes the following: older 'conventional' toilets - 13.2 L per flush (lpf), newer 'low flow' toilets – 6 lpf, dual flush toilets - 4.8 lpf, and pint flush toilets - 0.5 lpf. To estimate the amount of rainwater used for irrigation, figures from Vickers (2001) were utilized. The model assumes that 12.7 L of water is required per square meter of turf to provide the equivalent of 12 mm of rainfall, half of that amount (6.4 L/m^2) is needed to provide 6.2 mm of cover, and a 30 minute watering with a hose consumes approximately 567 L. The model also includes water consumption values for conventional and high-efficiency appliances, such as washing machines and dishwashers; as well as some values for hot water services like showering. Although some of these end use applications are beyond the current scope of the OBC, the inclusion of these items in the model ensures that it retains its usefulness, even as more progressive end uses are permitted in the province.

Method for modelling the performance of RWH systems

The cistern sizing model simulates the performance of rainwater cisterns using the iterative approach presented in Figure 4-1.

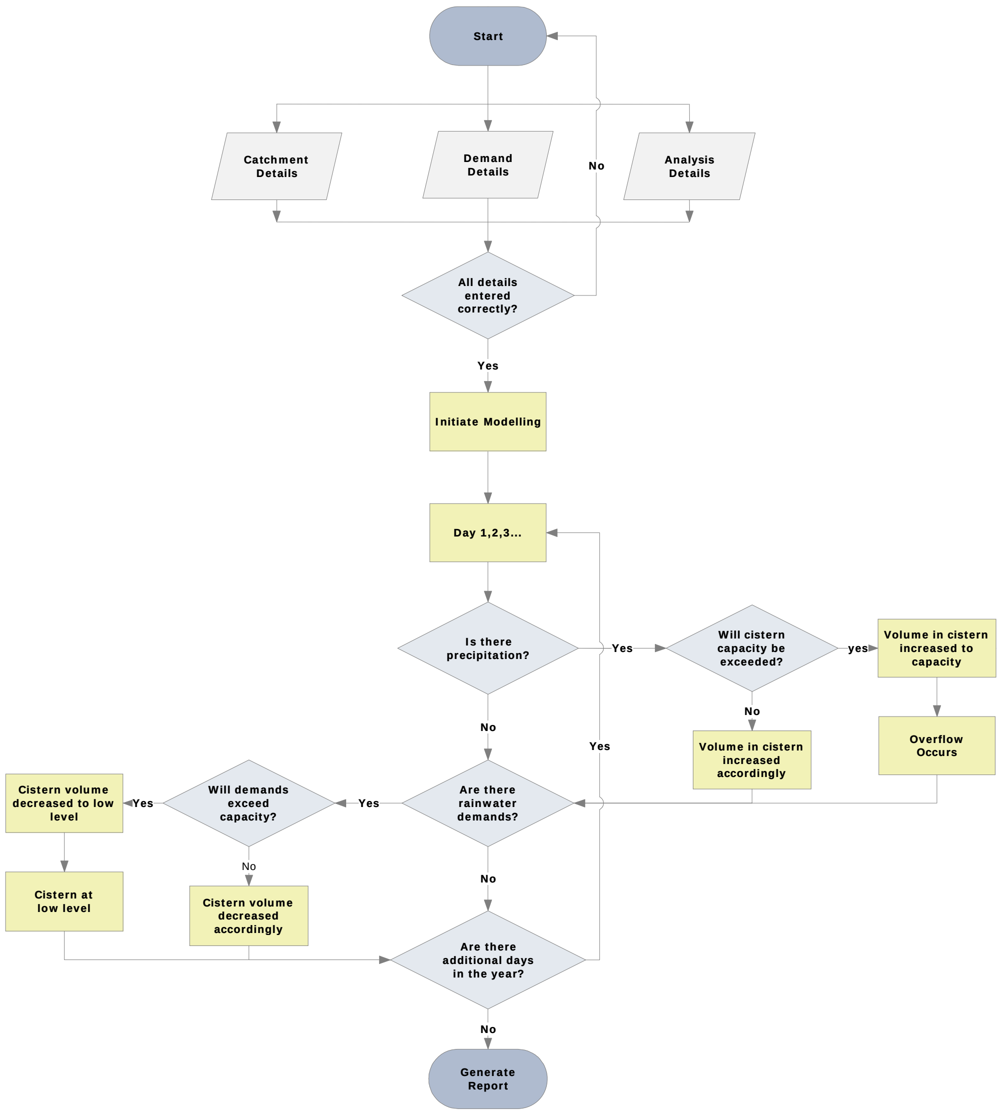

Figure 4-1: Iterative approach utilized in the cistern sizing model

As seen in the flowchart in Figure 4-1, for each day in the five year record of precipitation, the model tracks the changes that take place in the volume of stored rainwater. These daily changes include inputs from precipitation (if it rains and/or snows on a particular day), and outputs from the cistern to meet rainwater demands. While simulating these inputs and outputs, the model employs the 'yield after storage' rules:

1. *If the amount of precipitation exceeds the storage capacity of the rainwater cistern, it overflows, and this excess volume of rainwater is lost.*
2. *If the amount of demand exceeds the maximum possible yield from the cistern, it goes dry, and cannot meet further demands until replenished from subsequent rainfall events.*

To perform these high level operations, the values of several variables are calculated daily and tracked within the model. A sketch of a typical RWH system illustrating the relationships between these variables is provided in Figure 4-2.

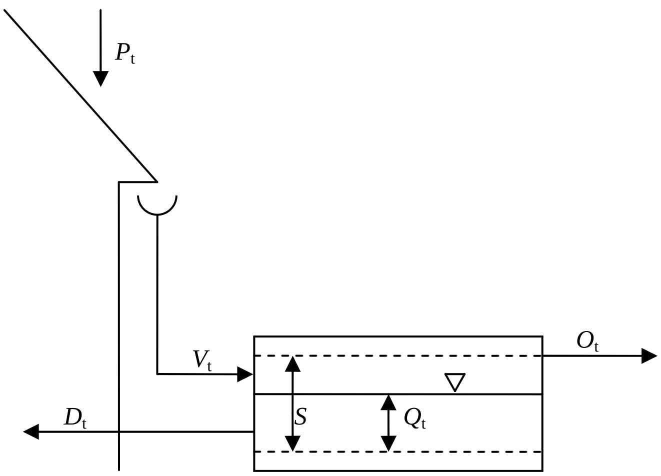

Figure 4-2: Variables comprising the cistern sizing model [Adapted from: Fewkes 1999]

Where:

P_t	= Precipitation (rainfall and snowmelt) during one day (mm)
V_t	= Rainwater runoff for that day (L)
D_t	= Rainwater demand for that day (L)
Q_t	= Quantity of rainwater in the cistern for that day (L)
O_t	= Overflow for that day (L)
S	= Storage capacity (L)
t	= time (day)

The inputs into the cistern are characterized by the amount of precipitation, the catchment area, and the losses that take place prior to storage in the cistern. The model simulates runoff using equation [3].

$$\sum_{t=1}^{T} V_t = \left[\left(\sum_{t=1}^{T} P_t \cdot CR_t \cdot CT_t \right) - FR_t - FT_t \right] \cdot A \qquad \textbf{[3]}$$

Where P_t is the sum of the precipitation events (in mm) taking place on a daily time interval t, CR_t and CT_t are the continuous losses from the roof and pre-cistern treatment devices, FR_t and FT_t are the roof and pre-cistern treatment fixed losses (mm) and A is the catchment surface area (m^2).

Of note from Equation [3] is that it contains the term precipitation, which includes both rainfall and snowfall. Many of the guides and models developed elsewhere do not consider the contribution of snowmelt to the volume of water stored in the cistern (enHealth 2004; TWDB 2005; Fewkes 1999; DIN 2002). This trend though, is less likely an omission on the part of the authors of these guides and models; instead it is more likely due to the temperate climates where these guides and models were produced. For such regions, snowfall would make negligible contributions to the cistern volume. However, even in regions where snowfall regularly takes place, like Nova Scotia, Scott and Mooers (1994) exclude snowmelt. For regions with cold climates, like Ontario, snowfall represents a significant proportion of the total precipitation throughout the year and should not be ignored. Thus, snowmelt was included in the cistern sizing model. The contribution of snowmelt was quantified using the data collected from the performance monitoring program. The observations from the monitoring program define the amount of daily precipitation (in mm) as:

$$P_t = R_t + \left(S_t \cdot CS_t\right) \quad \textbf{[4]}$$

Where R_t is the daily rainfall (mm), S_t is the water equivalent of the snowmelt contribution (mm), and CS_t is the continuous snowmelt loss factor (%). For the snowmelt loss factor, the cistern sizing model uses a 40% loss factor based on observations from the performance monitoring program.

Another assumption that is made by the model is that snowmelt occurs on a regular monthly basis during the winter months. In practice, this contribution should only take place when ambient air temperatures rise above 0°C, and the accumulated snowfall turns into snowmelt. While the model could account for this, to do so would have required the inclusion of daily temperature data, which would almost double the size of the database.

The demands placed upon the rainwater cistern are dependent upon the number applications for which rainwater is used, the volume used by each application, and frequency of use. The model simulates demand using the following equation:

$$D = \sum_{t=1}^{T} D_t = \left(T + U + I + W_c + L_c + O_c\right) + \left(DW + W_h + L_h + O_h\right) \quad \textbf{[5]}$$

Where each term represents the daily volume (in L) of rainwater used for: toilet flushing (T), urinal flushing (U), irrigation (I), as well as cold ($_c$) and/or hot ($_h$) water service for washing machines (W), lavatory faucets (L), dishwashers (DW) and other unspecified applications (O).

Prior to summing these demands, each component requires additional calculations that vary depending upon the data collection method. For instance, the volume of rainwater required for toilet flushing is a factor of the number of people utilizing the toilet, the flush volume of the toilet (L), and the number of flushes per person per day. Another example is outdoor irrigation, which is only included during months with warm weather – April to October. The calculations used to determine each of the terms in Equation [5] are given in Table 18 in the Appendix at the end of this chapter.

The equations that describe the iterative rule-based approach of the cistern sizing model were adapted from Fewkes (1999). Like Fewkes (1999), the model operates under the ‘yield after spillage’ rule. This rule assumes that rainwater demands are drawn from the cistern after additions from precipitation.

The daily yield (Y_t) from the rainwater cistern (in L) is defined by the following expression (Fewkes 1999):

$$Y_t = \min\left[D_t, Q_t\right] \quad \textbf{[6]}$$

Where the rainwater yield is a function of either the rainwater demand (D_t) or the quantity of stored rainwater (Q_t), whichever is lowest. In other words, if the quantity of stored rainwater is insufficient to meet all of the rainwater demand, then the yield from the cistern will be the remaining quantity of water in the cistern. Otherwise, if there is sufficient rainwater ($D_t \leq Q_t$), then the yield from the cistern is the total rainwater demand.

A similar approach is used for determining the quantity of rainwater in the cistern (Q_t):

$$Q_t = \min\left[\left(Q_{t-1} + V_t\right), S\right] - Y_t \quad \textbf{[7]}$$

Where the volume of water in the cistern is a function of the rainwater yield subtracted from the volume of stored rainwater (Q_{t-1}) plus the inputs from roof runoff (V_t), *unless* these inputs are greater than the storage capacity of the cistern (S), in which case the yield is subtracted from the value. Another conservative measure implemented within the model is that it assumes that at the start of each of the five years of daily rainfall data, the volume of stored rainwater is equal to zero. In other words, the cistern sizing model assumes that the cistern is initially dry and must be filled prior to yielding rainwater. This assumption ensures that comparisons between different cisterns are not biased due to the increase in performance from the initial volume of stored water.

For each of the cistern sizes considered by the cistern sizing model, Equations [3]-[8] are repeated daily throughout the 5-year precipitation record. Following this analysis, the annual performance of the RWH system (P_T) is expressed, in percent, as (Fewkes and Butler 1999):

$$P_T = \left(\frac{\sum_{t=1}^{T} Y_t}{\sum_{t=1}^{T} D_t} \right) \cdot 100 \qquad \textbf{[8]}$$

Where ΣY_t is the actual yield from the cistern (L) over the one year period *T*, and ΣD_t is the sum of the daily demand (L) for fixtures utilizing rainwater from the cistern.

Model performance

The performance of the cistern sizing model was assessed by simulating the performance of a RWH system with characteristics identical to those of Experimental Site 1. Since actual performance data was collected at the first experimental site over a period of one year, this provided the opportunity to compare the model's predictions to the performance of a real RWH system. To ensure the validity of the comparison, the rainfall data collected at the site was imported into the model. The predicted and the actual volume are compared in Figure 4-3.

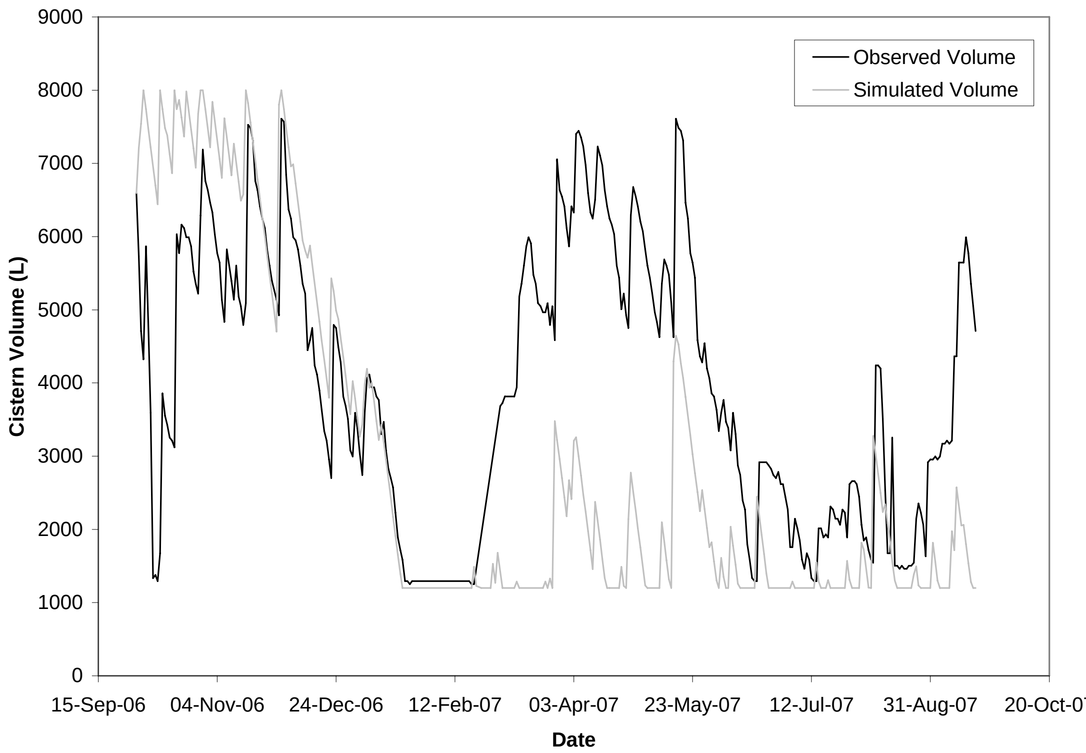

Figure 4-3: Observed and simulated cistern volume for Experimental Site 1

An initial inspection of Figure 4-3 reveals a combination of both consistencies and inconsistencies between the model's predicted volume and the observed volume. Specifically, a high degree of correlation is observed from November 1, 2006 to February

19, 2007, whereas the correlation is less apparent before this period, or afterwards. These inconsistencies, however, can primarily be attributed to the performance of the actual RWH system, and not flaws within the model.

The first of these discrepancies is observed on October 7, 2006. On this date a significant decline in cistern volume is observed, whereas no such decline is predicted by the model. The difference between the two can be attributed to a leak that developed on the rainwater pump line, which led to the emptying of the cistern. Once this issue was addressed, and subsequent rainfall events had refilled the tank, a high degree of correlation between the predicted and observed volumes is achieved until February 19, 2007. The divergence that takes place following this date can be attributed to the rainwater usage patterns of the homeowner. During the extended period through which the cistern was consistently dry, the homeowner switched all of the fixtures back to the municipal water supply. Thus, when subsequent rainfall events took place, the volume of water in the cistern substantially increased as a result of the lag between the homeowner switching back to the rainwater supply. During this lag, the cistern was allowed to fill nearly to capacity before use resumed. Meanwhile, during this same period the model assumed that whenever rainwater was available, regardless of how little, it was used to meet daily rainwater demands. Thus, the model predicted demands that did not take place until a later point in time.

To more accurately quantify the degree of correlation between the simulated values and the observed values, the two sets of data were statistically analyzed. Because of the issues associated with the performance of the actual RWH system, only the dates from of November 1, 2006 to February 19, 2007 were considered, and the model was restarted on October 10, 2006 to match the low level volume (1,200 L) of the actual cistern following the leak. Given this criteria, a strong degree of correlation (Spearman's r=0.947) was detected between the simulated and observed volumes. This finding indicates that under normal operating conditions the model accurately predicts the performance of a real RWH system.

Additional support for the validity of the model is found when comparing the overall model performance to that of the observed performance. These details are summarized in Table 4-1.

Table 4-1: Comparison of observed cistern volume to model's simulated volume at Experimental Site 1

Source	Rainwater demand (m^3)	Days the Cistern was Dry	Number of Overflows	Rainwater Yield (m^3)	RWH System Performance
Model	100	148	7	61.1	61.1%
Observed	100	55	7	65.1	65.1%

The data from Table 4-1 further highlights the impact of the homeowner's rainwater usage patterns on the performance of the actual RWH system. The model predicted that the cistern would be dry for 148 days, whereas only 55 dry days were observed. This discrepancy can be attributed to the increase in cistern volume that took place in

February. The lack of demand during this period decreased the number of days when the cistern went dry. One other issue that may have contributed to this decreased dry period is that the homeowner reported that demands were occasionally reduced during drier periods by flushing the toilets less frequently.

Of the remaining performance aspects in Table 4-1, a much higher degree of association between the observed and model values is evident. Of note are the overall performances of both the modelled cistern and the observed cistern, which are only 6% different. The similar performance values, despite the disparity between the model and observed dry days, can be explained by returning to the issue of the increase in cistern volume in February, as previously discussed. Similar yields from both the modelled and actual cistern (to meet rainwater demands) can be seen in Figure 4-3 in the months following this period. The difference between the two is that the model did not have the buffer provided by the increase in cistern volume in February. Thus, rainwater demands would tend to draw down the simulated cistern volume to a low level (run dry), whereas with the actual cistern, this did not take place due to the additional stored quantity of rainwater.

These findings indicate that the cistern sizing model was able to simulate the day-to-day variation in the volume of cistern-stored rainwater at Experimental Site 1. Subsequently, the model is considered to be best suited for estimating the performance of RWH systems similar in design to Experimental Site 1.

For RWH systems that differ from these criteria, the accuracy of the simulation may not be as great as that observed for Experimental Site 1. For instance, for industrial applications, losses upon the catchment surface (which are often a flat roof) may differ from those of the sloped asphalt-shingle roof from which the loss factors were derived. However, this is not a significant barrier for modelling the performance of domestic RWH systems in Ontario, since many homes in the province share similar characteristics to those of the first experimental site, and the model has the ability to adapt to different characteristics that may exist at other sites. The collection of additional performance data from sites with different supply, catchment and demand characteristics is recommended to verify the proficiency of the model under these conditions.

Results and discussion

Following the verification of the cistern sizing model's performance, the model was used to investigate how the three factors – supply, catchment, and demand – influenced the performance of RWH systems in general. The cistern sizing model was subsequently used to investigate the performance of RWH systems under two practical scenarios: a single-detached home and a townhouse unit. For each of these scenarios, varying levels of rainwater demand were simulated with cistern volumes ranging from 250 to 20,000 L of storage.

To provide a frame of reference for comparing the performance of RWH systems with different catchment and demand characteristics, a baseline scenario was first developed. This baseline scenario is comprised of locally sourced figures that are typical for households in the City of Guelph and throughout much of Ontario. The baseline scenario assumes that for both single-detached households and townhouse units runoff is collected from an asphalt shingle roof located in the City of Guelph and that the RWH system supplies 254 L/day to meet the demands of toilet flushing and outdoor water use for a three person household (Vickers 2001). The only difference between the baseline scenarios of the single-detached households and the townhouse units is the catchment area, which are based upon the average roof areas for new single-detached homes (140 m^2) and townhouse units (80 m^2) produced by Reid's Heritage Homes (2007). Further details regarding the baseline scenario are provided in this chapter's Appendix.

General trends in the performance of RWH systems

Supply

The impact of supply upon the performance of RWH systems was modelled using the range (minimum, first quartile, median, third quartile, and maximum) of annual rainfall volumes for the City of Guelph. The model output is provided in Figure 4-4, in which the system performance is compared to cistern volume.

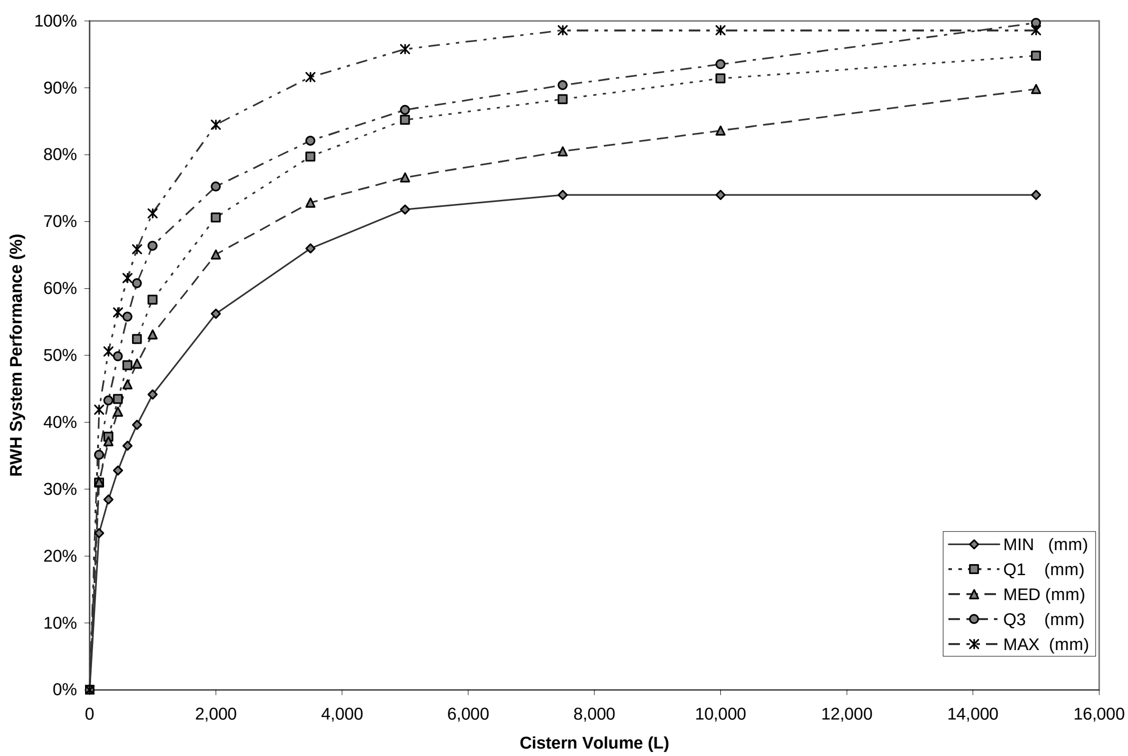

Figure 4-4: Performance of baseline scenario under increasing volumes of annual rainfall

As one would expect, Figure 4-4 demonstrates that the performance of RWH systems tends to improve in years that have a greater amount of annual rainfall. Improvements in performance are also observed from increasing the storage capacity of the rainwater cistern. The rate of improvement in performance, however, tends to decrease as storage volume is increased, until a maximum performance is achieved. For instance, during the year with the lowest rainfall on record (MIN in Figure 4-4) this maximum performance occurs once 5,000 L of rainwater storage is utilized.

Of note from Figure 4-4 is the wide range of values that is observed. During the year with the lowest amount of rainfall on record, a 5,000L cistern only met 72% of the intended demand (93 m^3), a value much lower than the 96% anticipated for the year with the highest recorded rainfall volume. These figures are significant for households that lack access (or have limited access) to a supplementary supply of water, from either a municipality or well. For such homes, to ensure a security of supply during dry periods, the designer may wish size the cistern assuming a worst case scenario – in this case, the minimum amount (or possibly the first quartile) of rainfall for Guelph on record. This would require the selection of a larger cistern size than if the median or maximum rainfall levels were considered, but it would reduce the number of days the cistern ran dry each year. By minimizing the number of dry days, the costs of operating the RWH system are reduced, as it decreases the amount of water that must be brought in by other means (such as water truck) to make up the shortfall in the rainwater yield. Conversely, in urban centres where mains top-up supplies are readily available, the designer could assume that the RWH system operates under the median-maximum scenarios, and select a smaller cistern size to reduce the capital cost.

Another trend that is evident from Figure 4-4 is that the performance of a RWH system can be dramatically improved by expanding the storage capacity beyond an initial minimum range. Subsequent increases to the storage capacity beyond these volumes tend to yield diminishing returns in performance on a per litre of storage basis. Eventually, the size of the cistern no longer limits the performance of the RWH system; it is the other factors – supply, catchment, and demand – that constrain the maximum level of performance that is achievable.

An exception seen in Figure 4-4 is the first quartile performance figures, which were higher than those of the median year despite it having greater amounts of rainfall. This observation demonstrates the impact of snowmelt – the particular year used to represent the median year had less snowfall than the first quartile year, and consequently its overall performance suffered due to low cistern volumes during the winter months.

Catchment area

To examine the role of catchment area on the performance of RWH systems, the baseline scenario was modified to include both smaller and larger catchment areas while holding all other aspects constant. The model output for median Guelph precipitation is given in Figure 4-5.

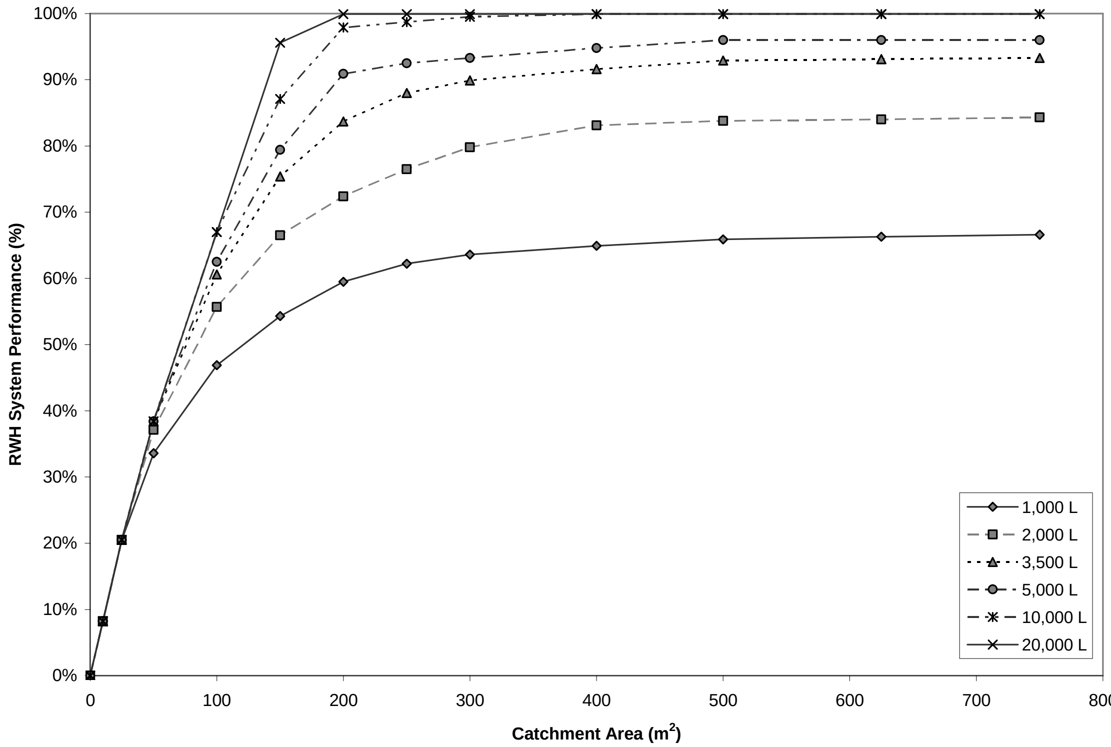

Figure 4-5: Performance of baseline scenario with increases to catchment area

It is evident from the results shown in Figure 4-5 that the smaller storage volumes limit the ability of the RWH system to meet demand. Gains in performance are achieved until the capacity is increased above 10,000 L, at which point almost no difference is apparent with larger storage (the 20,000 L cistern) as it is the catchment and the amount of demand that now constrain performance.

The substantially larger catchment areas considered in Figure 4-5 far exceed that of typical homes in Ontario, and as such, the maximum performances that are observed cannot be achieved in most cases. In Guelph, a roof surface area of 110 to 200 m^2 is typical for new home construction (Reid's Heritage Homes 2007). This range lies directly where the performance of RWH systems is most sensitive to increases in catchment area in the Guelph climate. The implications of this finding are that there are vastly different performances for single-detached homes and multi-unit dwellings such as apartment buildings or townhouses. These multi-unit dwellings have much the same water demands as single-detached homes, but can collect far less rainwater due to their smaller per-household catchment areas.

Rainwater demand

The impact of increasing the amount of daily rainwater demand of the baseline scenario is illustrated in Figure 4-6.

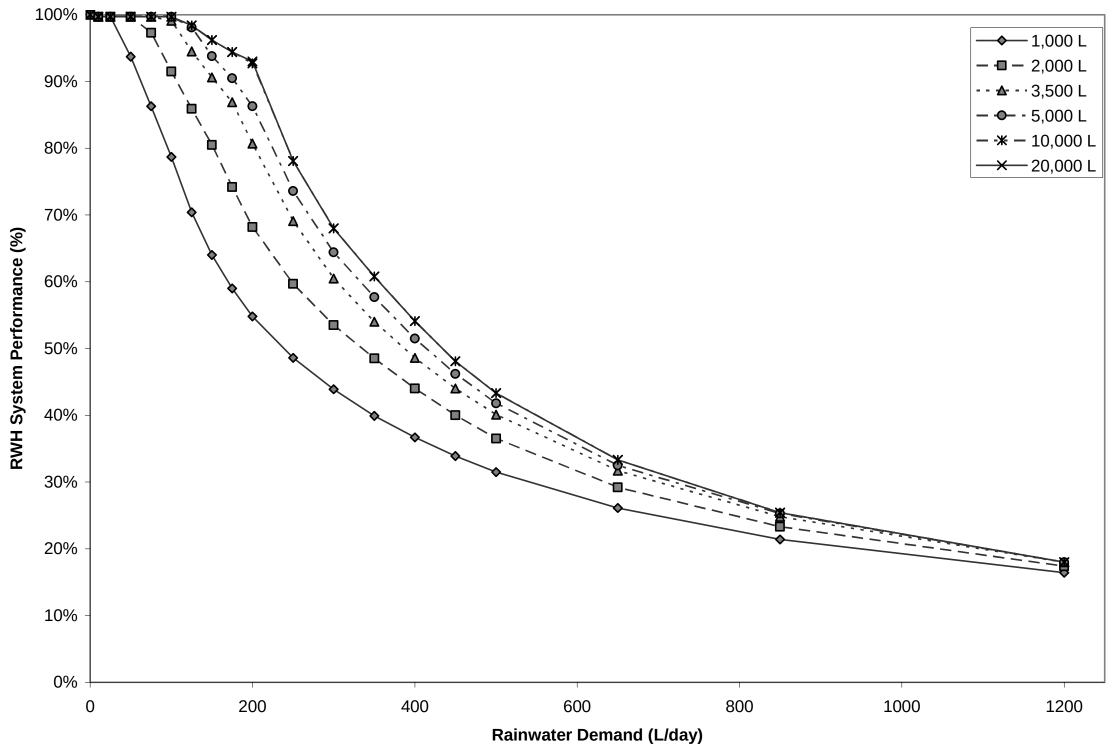

Figure 4-6: Performance of baseline scenario with increases to rainwater demand

As seen in Figure 4-6, when minimal demands are placed upon the baseline RWH system, almost all cisterns, regardless of capacity, are capable of providing sufficient rainwater to meet 100% of the intended demand. This capability, however, diminishes rapidly as the daily demands are increased, and the RWH system becomes increasingly incapable of meeting these demands. Like Figure 4-5, a distinction between cistern performances can be observed initially, but eventually all cisterns, regardless of capacity, have the same level of performance. This trend is observed because the benefits derived from increased storage – the ability to collect more (from overflowing less) rainwater from intense rainfall events – become insignificant in comparison to the amount of rainwater that is demanded on a daily basis.

Performance of RWH Systems for typical single-detached households and townhouse units

Following the assessment of the general performance aspects of RWH systems, the baseline scenario was modified to simulate various 'real world' rainwater demands of single-detached households and townhouse units. To simplify the comparison between the single-detached homes and townhouses, both were assumed to have the same number of people per residence – three persons, the median number per single-detached home in Canada (Statistics Canada 2007). With this assumption, both residences had the same rainwater demands per household.

The following demands were considered: i) only toilet flushing (31 lpcd); ii) toilet flushing and outdoor use (57 lpcd); iii) toilet flushing, outdoor use and laundry (with a top loading washing machine) (140 lpcd); iv) toilet flushing, outdoor use and laundry (with a more water efficient front loading washing machine) (121 lpcd); and v) all indoor and outdoor use except drinking (172 lpcd in a water efficient household) (Vickers 2001).

Single-detached household

The modelling results from the single-detached house scenario are presented in Figure 4-7.

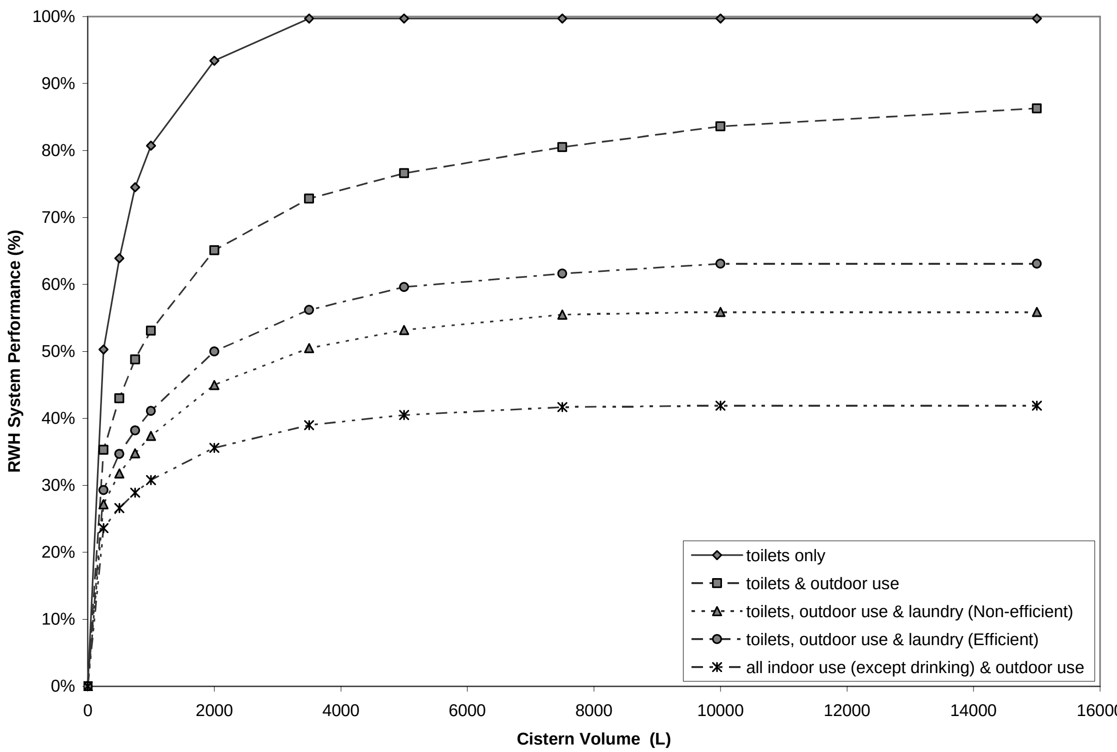

Figure 4-7: Performance of typical single-detached household under varying end use scenarios

From Figure 4-7, it is obvious that small increases in cistern capacity within the lower range of 250-3,500 L have a significant impact on RWH system performance. As such, capacities within this range are not recommended unless space or cost limitations prohibit the installation of a larger cistern. For a size of 5,000 L it can be seen that if rainwater is used for just toilet flushing, it meets nearly all (99.7%) of the intended demand under these conditions. This scenario is inefficient however, as the amount of rainwater that overflowed from the cistern, 41 m^3, exceeds the 34 m^3 of rainwater that was used throughout the year for toilet flushing. The scenario of toilets plus outside use has a lower efficiency of 77%, but it diverts 18 m^3 of the rainwater that was lost to overflow in the toilet only scenario to meet the increased demands from outside use. Even though more water is saved (76 m^3) with the case of using rainwater for all indoor (except drinking) and outdoor use, the performance of the RWH system suffers because of the higher rainwater demands placed upon it. The performance of this scenario falls below 50%, which indicates that the RWH system would need to provide greater quantities of water from supplementary supplies than actual rainwater.

Townhouse Unit

Identical demand scenarios were modelled on the townhouse unit, and are shown in Figure 4-8.

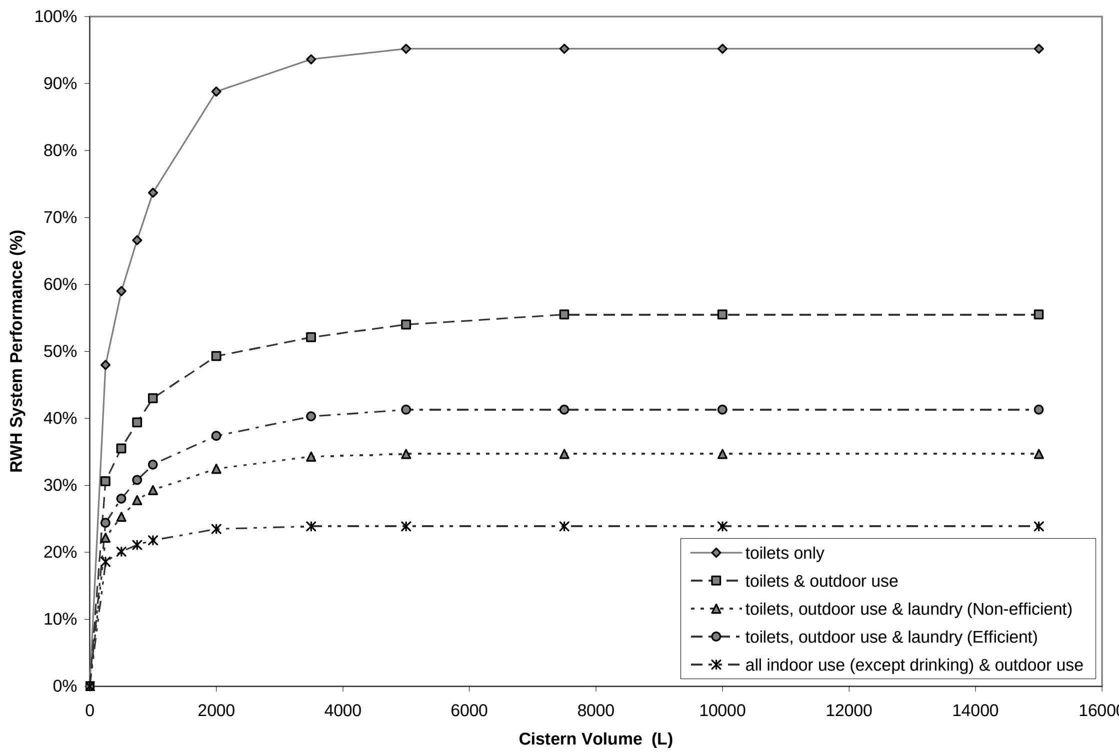

Figure 4-8: Performance of typical townhouse unit under varying end use scenarios

As seen in Figure 4-8, with the exception of toilet flushing, the overall performance figures for the townhouse are decreased for each of the demand scenarios because of the smaller catchment area available to collect the rainfall. With a 5,000 L cistern, the townhouse RWH system is able to meet nearly all of the demand for toilet flushing (supply: 32 m^3, performance: 95%), but the overflow volume is dramatically lower than that of a single-detached home at 9.4 m^3. These findings indicate that only about 42 m^3 of rainwater can be collected annually from a typical townhouse, compared with the 75 m^3 that is available from a single-detached home. Consequently, when demand is increased beyond toilet flushing, a large drop in performance is observed since almost all of the maximum supply is consumed by toilet flushing.

Comparison between single-detached household and townhouse unit

When 'real world' demands are simulated on the single-detached homes and townhouse units, the cistern sizing model demonstrates that a RWH system is largely incapable of supplying sufficient rainwater to meet all indoor and outdoor use (excluding direct consumption demands). The performance of RWH systems under such conditions was about 24% and 40% for townhouses and single-detached homes respectively.

Differences between the two types of residences can also be observed through the use of a 50% performance benchmark as a means of comparison. This benchmark compares the RWH systems based upon their ability to provide equal, or greater, quantities of water sourced from rainfall than from supplementary supplies. Using this benchmark, it is evident from Figure 4-7 and Figure 4-8 that with the townhouse unit, many of the demand scenarios that were considered did not meet this benchmark, whereas with the single-detached home the 50% performance criteria was met by a greater number of scenarios.

With single-detached homes, the 50% performance benchmark is met by the combination of toilet flushing, outdoor use and laundry, which utilizes between 65-69 m^3 of rainwater annually (depending upon the efficiency of the washing machine). The performance of a 5,000 L cistern under these demand scenarios was 60% and 53%, respectively. When these same demands are placed upon a RWH system supplying rainwater to a townhouse unit, the performance decreases to 41% and 35% depending on whether a front- or top-loading washing machine is used in the household. For both these applications, the townhouse RWH system is only able to provide 42 m^3 of rainwater annually.

Conclusions

The cistern sizing model was developed for the purpose of addressing the lack of regionally-specific guidance on sizing cisterns for RWH systems in Ontario. The goal was to design a model that was accessible for all users, regardless of their familiarity with the various aspects of RWH, while also providing an accurate assessment of cistern performance. To accomplish this task, the cistern sizing model includes an easy-to-use interface and an extensive database, and its accuracy was verified by comparing its simulations to an actual RWH system. Once the cistern sizing model's accuracy was confirmed, it was used to examine how rainwater catchment and rainwater demand influenced the performance of RWH systems in Ontario. The findings (presented in Figure 4-4-Figure 4-6) showed that, in general, the appropriate size of cistern is determined by the amount of supply (dependent upon geographical location), the catchment details (the roof surface area, and the losses from the roof material) and the amount of rainwater demand.

Several important trends were observed for typical single-detached homes and townhouse units. From the initial range of cisterns considered (250-3,500 L) substantial increases in performance were achieved for minor increases in storage volume. Consequently, the selection of rainwater cisterns within this lower range is only recommended where space limitations prohibit the installation of larger cisterns. At the opposite extreme, cisterns that had a storage capacity above 10,000 L were found to have a negligible impact upon the performance of RWH systems with catchment areas of typical homes. Thus, for households with similar catchment and demand details as those of the baseline scenario, the installation of a cistern larger than 10,000 L is considered unnecessary.

A 50% performance benchmark was used as a means for comparing single-detached homes and townhouses. Simulations performed with the cistern sizing model showed that, with a minimum of 5,000 L of storage, this benchmark could be met while supplying rainwater for toilet flushing, outdoor use and laundry in single-detached homes, whereas in townhouse units, this criteria could only be met with toilet flushing and outdoor use (excluding laundry).

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Appendix

Model database

Table 4-2: Catchment details in cistern sizing model database

	Typical Residential Figures	Unit	Source
Steel Roof	0.25	Rainfall Loss Factor (mm)	Assumption
Asphalt Roof	0.5	Rainfall Loss Factor (mm)	RWH Project findings
Fiberglass Roof	0.5	Rainfall Loss Factor (mm)	Assumption
Slate/Terra Cotta Roof	1.5	Rainfall Loss Factor (mm)	Assumption
Green Roof	3.0	Rainfall Loss Factor (mm)	Assumption
Tar & Gravel Flat Roof	1.0	Rainfall Loss Factor (mm)	Assumption
Asphalt Built-up Flat Roof	1.0	Rainfall Loss Factor (mm)	Assumption
Hypalon (Rubber) Flat Roof	1.0	Rainfall Loss Factor (mm)	Assumption
Steel Roof	10.0%	Continuous Rainfall Loss Ratio (%)	Assumption
Asphalt Shingle Roof	20.0%	Continuous Rainfall Loss Ratio (%)	DIN 2002; RWH Project findings
Fiberglass Roof	20.0%	Continuous Rainfall Loss Ratio (%)	Assumption
Slate/Terra Cotta Roof	25.0%	Continuous Rainfall Loss Ratio (%)	Assumption
Green Roof	50.0%	Continuous Rainfall Loss Ratio (%)	DIN 2002
Tar & Gravel Flat Roof	40.0%	Continuous Rainfall Loss Ratio (%)	DIN 2002
Asphalt Built-up Flat Roof	20.0%	Continuous Rainfall Loss Ratio (%)	DIN 2002
Hypalon (Rubber) Flat Roof	20.0%	Continuous Rainfall Loss Ratio (%)	DIN 2002
First Flush Pre-cistern treatment	0.5	Rainfall Loss Factor (mm)	TWDB 2006
Filtration Pre-cistern - treatment	0.0	Rainfall Loss Factor (mm)	WISY 2006
N/A - No Treatment	0.0	Rainfall Loss Factor (mm)	-
First Flush Pre-cistern treatment	0.0%	Continuous Rainfall Loss Ratio (%)	TWDB 2006
Filtration Pre-cistern treatment	10.0%	Continuous Rainfall Loss Ratio (%)	WISY 2006
N/A - No Treatment	0.0%	Continuous Rainfall Loss Ratio (%)	-
Snow Melt Contribution	50.0%	Percent of Snowfall transferred to cistern	RWH Project findings
Tank Dead Volume	15.0%	Percent of Total Tank Volume	Assumption

Table 4-3: Demand details in cistern sizing model database

	Typical Residential Figures	Unit	Source
Conventional Toilet	13.2	Liters per flush	Vickers 2001
Low-flow Toilet	6.0	Liters per flush	Vickers 2001
Dual-flush Toilet	4.8	Liters per flush	Vickers 2001
Pint Flush Toilet	0.5	Liters per flush	Vickers 2001
Toilet Flushes per Person per Day	5.1	flushes per person per day	Vickers 2001
Conventional Urinal	6.0	Liters per flush	Vickers 2001
Low-flow Urinal	3.8	Liters per flush	Vickers 2001
High Efficiency Urinal	1.9	Liters per flush	Vickers 2001
Waterless Urinal	0.0	Liters per flush	Vickers 2001
Urinal Flushes per Person per Day	2.3	flushes per person per day	Vickers 2001
Top-loading Washing Machine	150.0	Liters per load	Vickers 2001
Front-loading Washing Machine	100.0	Liters per load	Vickers 2001
Cold Setting - Ratio of Cold Water	100.0%	Water ratio	-
Cold Setting - Ratio of Hot Water	0.0%	Water ratio	-
Warm Setting - Ratio of Cold Water	50.0%	Water ratio	-
Warm Setting - Ratio of Hot Water	50.0%	Water ratio	-
Hot Setting - Ratio of Cold Water	0.0%	Water ratio	-
Hot Setting - Ratio of Hot Water	100.0%	Water ratio	-
Laundry Schedule	2.6	Loads per person per week	Vickers 2001
Conventional Irrigation (equiv.: 0.5" cover)	12.7	L/m^2	Vickers 2001
Efficient Irrigation (equiv.: 0.25" cover)	6.4	L/m^2	Vickers 2001
Hose watering (30 minutes)	567.0	Litres	Vickers 2001
Irrigation Surface Area	100.0	M^2	-
Irrigation Schedule	2.0	Times Irrigated per week	Vickers 2001
Lavatory/Laundry Faucet Use (COLD)	24.5	Liters per person per day	Vickers 2001
Lavatory/Laundry Faucet Use (HOT)	16.4	Liters per person per day	Vickers 2001
Standard Dishwasher (HOT)	45.6	Liters per load	Vickers 2001
High Efficiency Dishwasher (HOT)	26.4	Liters per load	Vickers 2001
Dishwasher Schedule	0.7	Loads per person per week	Vickers 2001
Conventional Shower	9.5	Liters per minute	Vickers 2001
Low-flow Shower	6.4	Liters per minute	Vickers 2001
High Efficiency Shower	3.8	Liters per minute	Vickers 2001

Table 4-4: Demand calculations

Demand Items	Calculation	
Toilet flushing	$T = N \times M_T \times F_T$	N = Number of users M_T = Model of toilet[1] F_T = Frequency of use
Urinal flushing	$U = N \times M_U \times F_U$	N = Number of users M_U = Model of urinal[1] F_U = Frequency of use
Irrigation	$I = A \times E_I \times F_I$	A = Area irrigated (m^2) E_I = Irrigation efficiency[1] F_I = Irrigation frequency
Washing machine	$W = N \times M_W \times F_W$	N = Number of users M_W = Model of washing machine[1] F_W = Frequency of use
Dishwasher	$D = N \times M_D \times F_D$	N = Number of users M_D = Model of dishwasher[1] F_D = Frequency of use
Lavatory faucet	$L = N \times T_L$	N = Number of users T_L = Typical per person faucet water consumption[1]
Other	Volume specified by user	N/A

[1]see Table 4-3 for details.

Baseline scenario

Table 4-5: Supply and catchment details for baseline scenario

City:	Guelph
Setting:	Residential
Total Number of People:	3
Days Occupied per Week:	7
Roof Surface Area (m^2):	140 (single-detached house) OR 80 (townhouse unit)
Roofing Material:	Asphalt Shingle
Fixed loss (mm):	0.5
Continuous Loss Factor (%)	20
Pre-cistern treatment of Rainwater	N/A
Fixed Loss (mm):	0
Continuous Loss Factor (%)	0
Contribution of snow melt (%)	45.0%
Rainwater cistern dead space (%)	15.0%
Cistern Volume 1 (L)	1,000
Cistern Volume 2 (L)	2,000
Cistern Volume 3 (L)	3,500
Cistern Volume 4 (L)	5,000
Cistern Volume 5 (L)	7,500
Cistern Volume 6 (L)	10,000
Cistern Volume 7 (L)	15,000
Cistern Volume 8 (L)	20,000

Table 4-6: Baseline scenario - demand details for toilet flushing and outdoor use

COLD				Liters per capita per day (lpcd)
Toilets	Low-flow (1996+)	*Flushes per day:*	5.1	30.6
Urinals	N/A	*Flushes per day:*	0.0	0.0
Washing Machine	N/A	*Loads per week:*	0.0	0.0
	N/A			
Irrigation & Landscaping	Hose Watering - 30min	*Area irrigated (m^2)*	100.0	54.0
		No. of times irrigated per week:	2.0	
Lavatory/Laundry Faucets (L)	N/A	*Uses per person per day:*	0.0	0.0
Other (L)	N/A	*Uses per person per day:*	0.0	0.0
HOT				
Dishwasher	N/A	*Loads per week:*	0.0	0.0
Washing Machine				0.0
Shower	N/A	*Minutes per shower:*	0.0	0.0
Lavatory/Laundry Faucets (L)	N/A	*Uses per person per day:*	0.0	0.0
Other (L)	N/A	*Uses per person per day:*	0.0	0.0
			Total water use per person per day	84.6
			Daily water demand	254.0

Chapter 5 Economic Analysis for the Widespread Implementation of Rainwater Harvesting in Guelph, Ontario

Introduction

As discussed in Chapter 7, cost is generally perceived to be a very significant barrier for RWH in Ontario. As shown in the interviews, many stakeholders feel that municipalities have much to gain from the widespread implementation of RWH, in terms of relieving pressure on their own water and stormwater systems, and that they should provide incentives for implementation. However, little work has been documented that quantifies the financial impacts of widespread RWH, particularly in the Canadian context. As financial analysis has a dominant role in decision-making, both public and private, it is critical that the cost-savings associated with RWH be evaluated and understood.

This chapter offers a starting point for the further exploration of these issues. Experience gained through the installation of three demonstration sites is used to evaluate capital and operating costs and expected water savings and stormwater reduction for individual systems. These results are then scaled up to model widespread implementation at the municipal level, using the City of Guelph as a case study. Analyses are presented for three different perspectives: household, municipal utility and society.

Literature Review

Few studies could be found that thoroughly assess the economic performance of RWH systems. Several studies offer a simple analysis, including only a narrow scope of costs and benefits calculated for a single moment in time, with no consideration of uncertainty. Thus, important components of a cost-benefit analysis are not accounted for (Government of Canada 2007). Such papers from early conferences of the International Rainwater Catchment Systems Association report varying results. Case studies from Tanzania and rural Hawaii both conclude that the cost of RWH systems can be comparable to that of the alternative centralized water supply (Latham and Schiller 1987; Fok and Leung1982), while examples from Micronesia and Puerto Rico suggest that RWH can be many times more expensive than conventional water supply systems (Geselbracht 1987; Morris et al. 1984). However, these studies all come from rural or island contexts, largely in the developing world, and so both the RWH systems and centralized water supply systems assessed are very different than those used in Canada. In addition, the brevity of the publications prevent thorough evaluation of the findings. The results therefore shed little light on the performance of RWH in Canadian cities

More recent studies consider RWH in the context of both stormwater and drinking water systems. From the perspective of stormwater management, Herrmann and Hasse (1997) demonstrated that RWH systems can be used to replace stormwater retention tanks and that over the long term, they are a more cost effective alternative. With respect to storm sewer pipes, Pickering et al. (2007) argue that RWH alone would not reduce the need for sewer capacity as collection systems are designed based on peak flow of larger events, which must be assumed to occur when tanks are full. Hardy et al. (2004), however, show reductions in the peak flow from a 5-year design storm ranging from 0% to 15%, varying for cities with different climates. Coombes (2002) integrated RWH with other components of Water Sensitive Urban Design (WSUD), including infiltration trenches and a recharge basin, such that traditional stormwater systems could be completely eliminated. He found a total cost saving of $1000 (2008 CAD) per lot, compared to conventional infrastructure. Savings of up to $516 (2008 CAD) per lot were reported where RWH systems were used in conjunction with onsite stormwater detention tanks and a traditional collection system (Coombes 2002).

In the context of municipal water provision, several studies compare the cost of RWH with that of other demand or supply side alternatives. A summary of these findings is shown in Table 7.

.

Table 7. Summary of cost for RWH systems

Study Location	Cost of RWH As given (2007 CAD/m^3)	Study Details	Reference
Seattle, USA	3.80 USD/ccf (1.65 CAD/m^3) [1]	Stormwater collection for commercial landscape irrigation	Seattle Public Utilities, 1998
	14.63 USD/ccf (6.53 CAD/m^3) [1]	RWH systems to service toilets in new non-residential developments	
	41.30 USD/ccf (18.14 CAD/m^3) [1]	RWH systems to service toilets in new residential developments	
Amsterdam, Netherlands	15.6 NLG/m^3 (22.55 CAD/m^3) [2]	Communal RWH system for 4 detached houses, to service toilets	Van der Hoek et al., 1999
Denmark	26–83 DKK/m^3 (6.85–21.37CAD/m^3) [2]	Case study of RWH in apartment buildings	Mikkelsen et al., 1999
	10 DKK/m^3 (2.56 CAD/m^3) [2]	Home made RWH systems	
Sydney, AU	2.11 AUD/m^3 (2.53 CAD/m^3) [1]	RWH systems in 80% of homes	White and Howe, 1998
Canberra, AU	4.45 AUD/m^3 (4.31 CAD/m^3) [1]	New single detached homes with 10,000L RWH system for indoor and outdoor use	Turner et al., 2005
	10.62 AUD/m^3 (10.30 CAD/m^3) [1]	Retrofit of single detached homes with 5000L RWH system for indoor and outdoor use	
Newcastle, AU	0.30 AUD/m^3 (0.35 CAD/m^3) [1]	9000L above-ground plastic cistern serving toilets, laundry and hot water fixtures.	Coombes, 2002

Study Location	Cost of RWH As given (2007 CAD/m^3)	Study Details	Reference
Sydney, Perth, Adelaide, and Newcastle, AU	2.81-5.25 AUD/m^3 (3.00-5.60 CAD/m^3) [1]	Range of values represented in water plans for Australian cities with varying climatic conditions.	Marsden and Pickering, 2006
Sydney, AU	Roof Area 200m^2 50m^2 2.03 5.10 AUD/m^3 (1.86 4.68 CAD/m^3) [1]	10,000L cistern for out-door uses, toilets, laundry and hot water fixtures	Pickering et al., 2007
Adelaide, AU	Roof Area 200m^2 50m^2 3.13 11.59 AUD/m^3 (2.84 10.63 CD/m^3) [1]	10,000L cistern for out-door uses, toilets, laundry and hot water fixtures	Pickering et al., 2007

1.Calculated by inflating cost in given currency to 2007 using on-line calculators (Reserve Bank of Australia, 2008; U.S. Department of Labor, 2008) and then converting to Canadian dollars.
2. Calculated by averaging the daily exchange rate for 1999, multiplying by the value in foreign currency and inflating to 2007 values (Bank of Canada, 2009a, 2009b).

Significant variability is shown in the unit cost of RWH. System design has a large impact on capital cost and can be greatly influenced by climate, for example. The Australian climate allows for the use of above-ground tanks, while in many parts of Europe and North America cold temperatures require that the cistern be buried, thus incurring additional excavation costs. The volume of rainwater utilized is determined by local precipitation patterns, collection areas and the range of end uses serviced by rainwater, which vary among the studies. Further to these technical differences, methods of economic analysis vary significantly in sophistication and affect the final result. Therefore, while the above table gives an indication of expected costs, the collective results cannot be used to predict the cost of RWH systems in Canada without further investigation of local conditions.

One study in Australia compared the cost of different water supply schemes, including RWH (Marsden and Pickering, 2006). Rainwater was found to be more expensive than almost all other options except for certain cases of long distance conveyance. It was on par with or slightly more expensive than greywater alternatives. A summary of this work is shown in Figure 9.

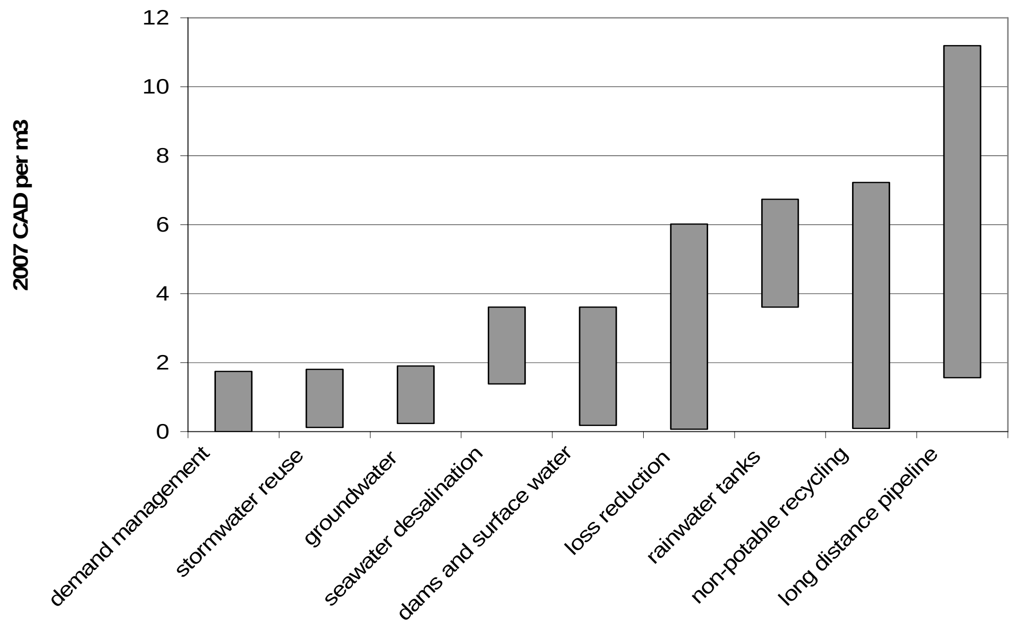

Figure 9. Cost comparison for water supply alternatives. Adapted from Marsden and Pickering, 2006.

Methodology

This analysis was conducted following the basic methods laid out in the Canadian Cost-Benefit Analysis Guide (Government of Canada 2007), applied to the perspective of the homeowner, the utility perspective and society in general.

Data regarding the cost of RWH systems was drawn from parallel work that involved the design and installation of three demonstration sites. The performance of RWH systems and their resulting financial benefit was determined based on a spreadsheet model created for the purpose of sizing and optimizing RWH systems. Details of this work are documented in Chapter 4 and assumptions for the model are given in Appendix A.

The following scenarios were used throughout the analysis.

Housing Scenarios

1. Single detached home (160 m^2 roof area, 2.95 people/unit)
2. Multi-attached home (80 m^2/unit roof area, 2.68 people/unit, 6 units/building)

Tank Capacity Scenarios

1. Ranging from 1000 L to 10,000 L

End use Scenarios

1. Max Use: outdoor use and all indoor use except kitchen (90% of total demand, 169 lpcd)
2. O-T-L: outdoor use, toilet flushing and laundry (44% of total demand, 82 lpcd)
3. O-T: outdoor use and toilets flushing (25% of total demand, 47 lpcd)
4. Outdoor: Outdoor use only (7% of total demand, 14 lpcd)

Total household water use will be lower for multi-attached homes than for single detached homes due to the smaller number of people in each unit, indicated in under "Housing Scenarios".

The end use patterns assumed for this analysis correspond to a typical water efficient home in North America (Vickers 2001) and are shown in Figure 10. All appliances for the simulated home are assumed to be water efficient (6 L/flush for toilets and 100 L/load for washing machines). The total daily consumption is 188 lpcd, approximately equivalent to the City of Guelph's conservation target (City of Guelph 2008b).

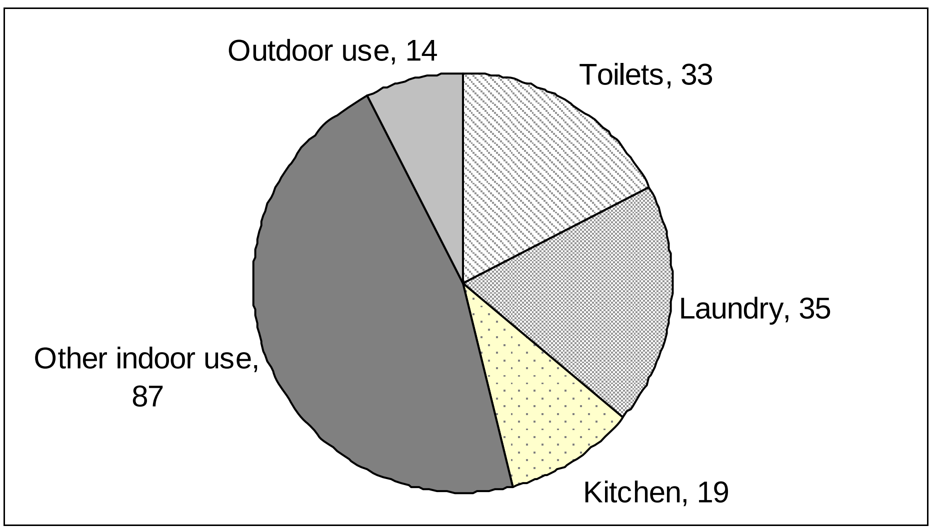

Figure 10. Household water demand patterns for model system (lpcd)

Water savings and cost information for individual systems were scaled up to the municipal level and evaluated in the context of the City of Guelph Water Supply Master Plan (WSMP) (2006) and the Water Conservation and Efficiency Update Strategy (WCESU) (2008b).

The following sections discuss the results of the analysis for each of the three economic perspectives: homeowner, municipal utility and society.

Homeowners' Perspective

Water Savings

The RWH model was used to determine the municipal water savings achieved under different tank sizes and end-use patterns, the results of which are shown in Figure 11.

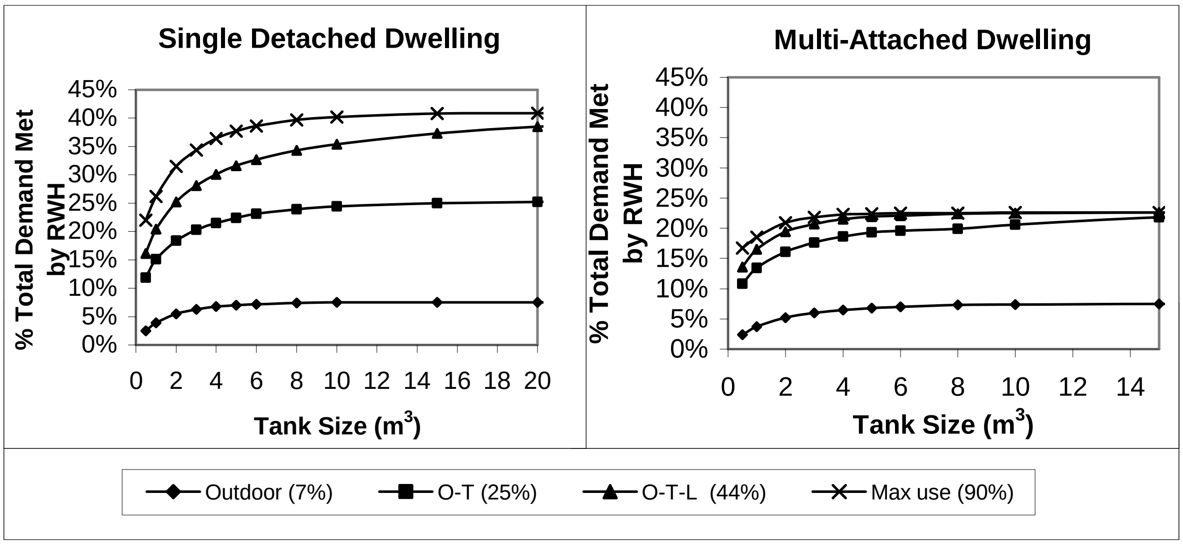

Figure 11. Water supplied by different configurations of RWH tanks

Three key points are illustrated in Figure 11. First, regardless of tank size or total demand (ie. end use), the maximum water savings achieved from RWH is 41% for single detached homes and 23% for multi-attached homes. This corresponds to 82m^3 per household per year (m^3/hh/yr) and 42 m^3/hh/yr, respectively. These volumes represent close to the total volume of rain falling on the catchment area (minus overflow from very large events) and are primarily a function of roof area.

Second, the same tank can provide a wide range of water savings, depending on the end use scenario. For the single detached home, each increment in end use provides a significant increase in water savings, until the maximum potential savings are reached under the Max Use scenario. For the multi-attached home, maximum savings are achieved with fewer end use applications, due to the limited quantity of rainwater available (smaller roof area). In this case there is little benefit to increasing end uses beyond outdoor fixtures and toilet flushing.

Finally, for each end use scenario, larger tank sizes produce diminishing returns in terms of water savings. There is an optimal range of tank sizes (corresponding to the leveling off of the graph) that will provide close to the maximum possible water savings. Tank sizes above this range may prove less economical as they produce only incremental or no improvement in water savings.

Figure 11 can be used to determine the optimal tank size and end use in order to maximize water savings; however these values must be combined with cost data to determine the most economically efficient option, or the greatest water savings per dollar of investment.

Capital Cost of RWH Systems

Single detached and multi-attached dwellings were considered separately in this analysis as the average roof size varies significantly. Two RWH systems were considered for each case. The first system involved rainwater storage in a number of plastic tanks joined in series and located in the basement. The second option was an individual buried concrete tank for single detached homes and a communal buried tank for multi-attached homes, shared by 6 units. In addition, system design was varied based on anticipated end use. Table 8 indicates the use of pumps, pretreatment and post-treatment[2] for the different end use scenarios.

Table 8. Design configuration for different end use scenarios.

Outdoor use and toilet flushing (O-T)	Outdoor use, toilet flushing and laundry (O-T-L)	Outdoor use & all indoor use except kitchen (Max Use)
Small, inexpensive, generic pump	Higher quality RWH pump	Larger, higher quality RWH pump
No pretreatment	Pretreatment	Pretreatment
No post treatment	No post treatment	Post treatment

All cost data came from local suppliers of RWH equipment and installation costs incurred in the demonstration sites built for the purpose of the project. The resulting price of each design configuration is shown in Figure 12. A detailed breakdown of costs is shown in Appendix B at the end of this chapter.

[2] Pretreatment consisted of coarse filtration using a commercially available RWH filter. Post-treatment consisted of a 5 micron particle filter and a UV lamp.

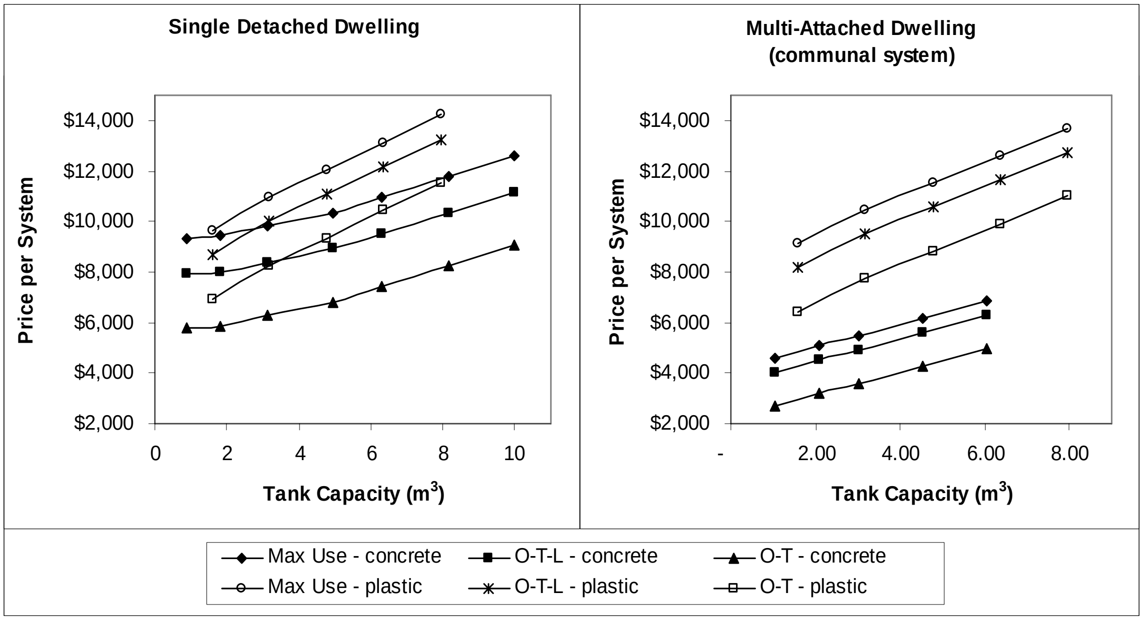

Figure 12. 2007 market price of RWH systems for single detached homes and multi-attached homes

NOTE: Includes provincial and federal sales tax. Does not include developers mark-up, reduction due to anticipated economies of scale or potential rebates and incentives. The cost for the plastic tank systems does not include the value of the space used by the tanks.

Despite the need for excavation, concrete tanks were shown to be less expensive for both dwelling types due largely to the fact that the cost per cubic meter of capacity decreases rapidly for larger tanks. As the plastic tank design involved a series of individual tanks, there was no economy of scale for larger systems. The concrete tank configurations are used for the remainder of the analysis.

Cost Benefit Analysis of RWH Systems

Using the cost data from Figure 12 and the water savings data from Figure 11, a cost-benefit analysis was performed to determine the net present value (NPV) of different concrete RWH systems for single detached homes. The following parameters were used to determine the base case:

- System cost: 30% increase is assumed due to developer mark-up. 20% reduction is assumed due to efficiencies gained in bulk purchase and installation.

- Water and wastewater rates: Taken from City of Guelph projections to 2013 (City of Guelph, 2008a). A constant rate increase of 1.5% per year is assumed thereafter due to increasing operational/energy costs. Real rates are used, which do not include an assumed inflation rate of 2%.

	2006	2007	2008	2009	2010	2011	2012	2013	2014 - 2021
Water	$0.64/m^3	+10%	+6%	+17%	+8%	+8%	+8%	+8%	+1.5% per yr
Sewer	$0.84//m^3	+0%	+6%	+17%	+8%	+8%	+8%	+8%	+1.5% per yr

- Discount rate: 8% real discount rate (Government of Canada, 2007)
- Time horizon: 15 years
- Wastewater rates: Tariffs are assumed not to be collected for the volume of rainwater discharged to the sanitary sewer system due to the current inability to meter this volume of water. Savings are therefore accrued from reduced water and wastewater tariffs.

Figure 13 shows the total cost in NPV terms of meeting household water demand. The base case indicates full reliance on mains water for all household needs, and the remaining cases represent the integration of RWH systems to varying degrees. These calculations are shown in Appendix C.

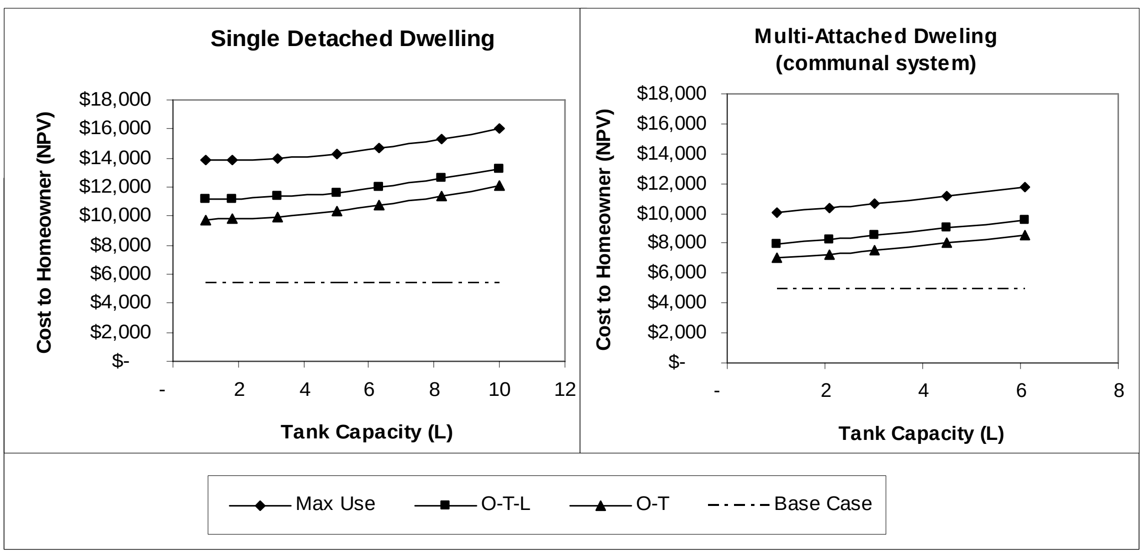

Figure 13. Net present value of RWH for different end-use scenarios. The base case assumes no rainwater use.

As Figure 13 indicates, the NPV of the cost of RWH is greater for single detached dwellings than for multi-attached dwellings, due to the higher capital cost of having a private vs. a shared system. In both cases, the net present cost increases with increasing end uses. Even though water savings increase with additional end use, the corresponding economic savings are less than the cost of the upgraded system components recommended for that application. For example, it is recommendable to install a prefilter device if using rainwater for laundry, but the economic savings due to the added water savings provided by laundry use are less than the cost of the filter. Therefore, it is the simplest system, using rainwater for outdoor use and toilet flushing, which has the lowest net present cost. Similarly, the added water savings achieved by increasing the tank size do not provide sufficient economic payback to cover the incremental cost of the tank. Therefore, the smallest systems have the lowest net present cost.

A sensitivity analysis was done for one of the above scenarios: a 5000L cistern used to provide rainwater for outdoor use and toilet flushing for a single detached home. Three key parameters were assessed:

- Discount rate: 8% ± 4%
- System cost reduction: 20% ± 10%
- Water rates: 50% and 200% of the assumed annual rate increase

Table 9 shows the range of values resulting from altering these three parameters for the selected scenario. In all cases, the use of mains water has a significantly lower NPV than the use of rainwater.

Table 9. Sensitivity analysis for discount rate, system cost and water rate.

	Mains Water Only		RWH: Toilets-Outdoor	
Base Case	$5,411		$10,325	
Discount Rate	$6,998 4%	$4,335 12%	$ 10,529 4%	$10,028 12%
System Cost Decrease	- -	- -	$9,614 30%	$11,035 10%
Water Rate Increase	$4,634 50%	$7,471 200%	$9,710 50%	$11,956 200%

As water rates increase, it becomes more economical to supplement mains water with rainwater. In the analysis, water rates were increased to the point where the NPV of the RWH scenario equaled that of the scenario where only mains water is used. Assuming base case discount rate and system cost, the annual increase in water rates would have to be approximately 6 times higher than projected in order to for RWH to be economically advantageous (for the scenario assessed in Table 7).

Municipal Perspective

The water savings achieved for individual RWH systems were scaled up to determine the impact of widespread implementation on the total water demand of the city. RWH is assumed to be implemented in all new residential development, following the 1.5% growth projection adopted by the City of Guelph in the Local Growth Management Strategy (City of Guelph. 2008a).

The modelled systems are as follows:

- Single and semi-detached dwellings: 5.0 m^3 buried concrete cisterns used for outdoor applications and toilets (45 m^3/hh/yr water savings).
- Multi-attached dwellings: 18.0 m^3 buried concrete cisterns used for outdoor applications and toilets, shared between six dwellings (32.7 m^3/hh/yr water savings per dwelling).

The Outdoor-Toilet end-use scenario was selected because it has the lowest net present cost of the three scenarios, as shown in Figure 13. Even though Figure 13 indicates that systems with a smaller cistern size result in a slightly lower cost, local suppliers of RWH systems suggest that typical installations for single family dwellings are between 4m^3 and 6m^3 (Robinson, S. RH2O North America Inc, Personal Communication, June 4, 2009). A cistern of 5 m^3 was therefore chosen for this case.

Total municipal water savings are determined for this scenario and are used as the basis to calculate the NPV of the base case with no RWH, and the case of widespread RWH implementation. Assumptions and calculations are shown in Appendix D.

Water Savings

By 2051, more than 35,000 RWH systems will be in place, providing over 4,000 m^3/day of rainwater. This represents a reduction in average residential demand of approximately 10%, or 5% of total average municipal demand.

In addition to average demand, municipalities are also interested in reducing peak demand. Peak day demand data from 1997 to 2005 was obtained from the City of Guelph and compared to the results of the RWH model. For 8 of the 9 years, peak demand occurred on a day where the RWH cistern was empty. Therefore, RWH does not have a reliable impact on the reduction of peak demand. Even the installation of much larger cisterns (10,000L) only provided rainwater for one additional peak day demand throughout the nine years. RWH systems may be designed specifically to meet peak demand by having large tanks used only for outdoor use; however, this may reduce the impact of RWH on average municipal demand.

Cost Savings

While the design of water treatment and distribution infrastructure is based on peak demand, the decision to expand a source of water or develop additional sources is a function of average demand. Most surface or ground water sources can tolerate short periods of high demand as long as the average demand does not exceed their sustainable yield. Therefore, while RWH may have little impact on the sizing of new infrastructure, it can impact the timing of new sources through its impact on average demand. Further, the reduction of average demand allows for savings in operation and maintenance costs.

Following the original schedule for new water supplies, as laid out in the Water Supply Master Plan (City of Guelph 2006), new ground water sources would come on-line in 2012 and surface water supply would come on-line in 2020. These dates correspond to average projected demands of 55,000 m^3/day and 61,000 m^3/day, respectively, and assume the 10% conservation goal of the WSMP is met. Under the most recent population and demand projections given in the Water Conservation and Efficiency Update Strategy (WCESU), including the revised water conservation target, these same average demands would occur in 2021 and 2028, respectively. Therefore, the capital investment schedule and subsequent commissioning of the new ground water and surface water supplies can be pushed back by 9 and 8 years, respectively. This scenario is the base case to which the implementation of RWH is compared.

Based on the results of the model, the installation of RWH in all new residential development saves sufficient water such that the 55,000 m^3/day and 61,000 m^3/day average demand criteria for new supplies can each be delayed by an additional 2 years. Thus, when RWH is implemented on a wide scale, new ground water supplies are not required to come on-line until 2023 and surface water supply is not required until 2030. Figure 14 highlights the demand projections in the WSMP, the WCESU and with the implementation of RWH, and illustrates the timing of new ground and surface water supplies under each scenario.

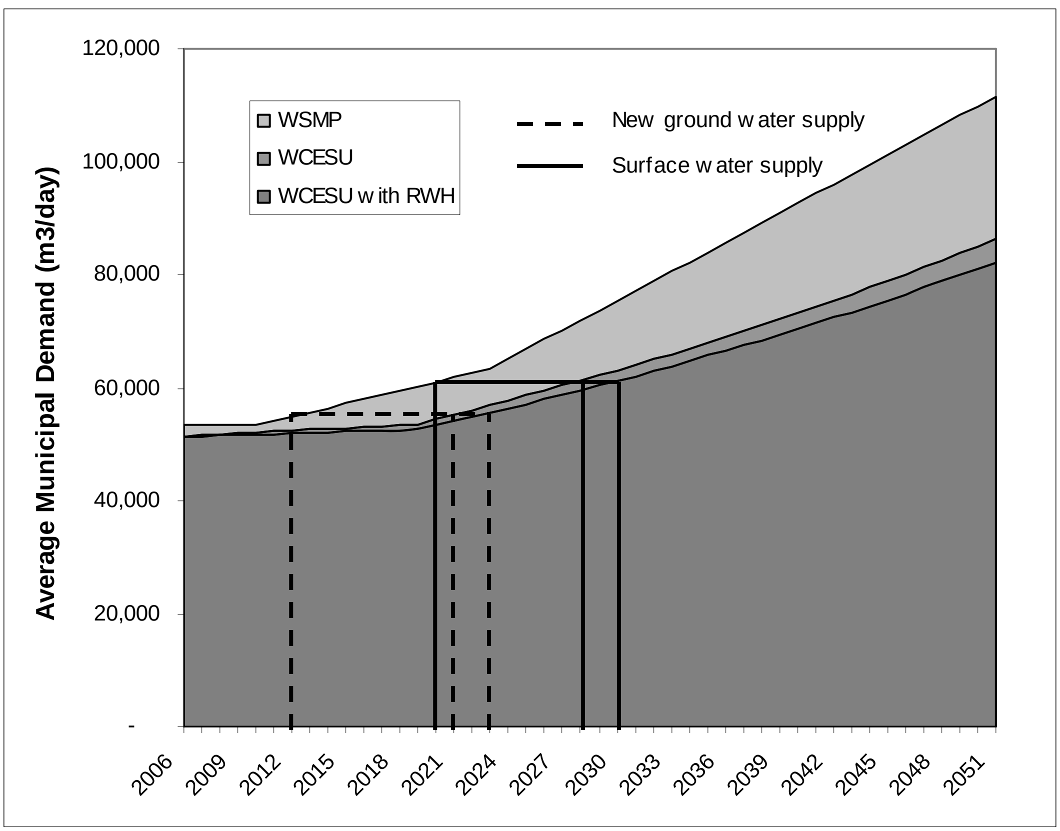

Figure 14. Timing of new water supplies under WSMP, WCESU and with the implementation of RWH.

The NPV of the base case (WCESU scenario) and the RWH case were calculated and compared. Municipal savings result from both the delay in capital investment for new water supplies, as well as from reduced operational costs for the production of potable water (ie. energy or chemical costs). The WSMP considers two possible surface water supplies: a local supply (Guelph Lake) and a regional supply (Lake Erie). Each has its own schedule of financial investments and operating costs. The impact of RWH was evaluated for each of these options.

Table 10 summarizes the NPV of the capital investment and operational costs associated with each case. The RWH case assumes that 100% of the cost of RWH systems is born by the homeowner and is therefore not included in the costs shown here. NPV is calculated over the 45 year time period, from 2006 to 2051, corresponding to the timeframe of the WCESU.

Table 10. Comparison of NPV for surface water supplies, with and without RWH.

Surface Supply Option	Net Present Value	Base Case	With RWH	Difference
Local Surface Water Supply	Capital Investment	$ 64,500,000	$ 61,500,000	-4%
	Operational Costs	$ 19,500,000	$ 19,000,000	-4%
	Total NPV	$ 84,000,000	$ 80,500,000	-4%
Regional Surface Water Supply	Capital Investment	$ 122,000,000	$ 110,000,000	-10%
	Operational Costs	$ 19,000,000	$ 19,000,000	-1%
	Total NPV	$ 141,000,000	$ 129,000,000	-8%

As shown, the total savings due to RWH are $3.5 million for the local surface water supply, and $12 million for the regional surface water supply. In both cases, the majority of savings comes from the delay in infrastructure investment. Even a delay of 2 years can produce significant savings for very large projects. These savings could be used to fund a number of different incentive or subsidy programs for RWH. Greater savings would be expected if rainwater is used for additional applications, such as laundry.

The principle cost to the utility, assuming no municipal subsidies are given for RWH systems, is the loss of revenue due to reduced water sales, and correspondingly, the decrease in fees collected for wastewater. This must be compensated for by increasing the water and wastewater tariffs. Accounting for both the operational savings and the lost revenue, it was determine that at the end of the 45 year period, the City of Guelph rates would have to be approximately 5% higher than the scenario with no RWH, in order to maintain the same revenue stream. As the total costs of the water supply system would be further reduced due to the savings in capital investment, this represents an upper bound for tariff increase.

Societal Perspective

Analysis from the societal perspective combines the costs and benefits for the homeowner and the municipality. The baseline scenario is the same as for the municipal perspective, with the addition of the cost to homeowners of softening municipal water. It includes the capital and operational costs of the existing and expanded groundwater supply and either the local or regional surface water supply, following the investment schedule determined as a result of the WCESU. The monetized value for carbon emissions is also included.

The RWH scenario then adds the following costs and benefits:

- Capital cost of RWH systems, including developer mark up and cost reduction due to economies of scale. (The same systems are used for the societal perspective as for the municipal perspective.)
- Homeowner operational costs, including regular replacement of pumps
- Municipal operational savings
- Municipal savings due to delayed infrastructure investment
- Salvage value of RWH systems, based on straight line depreciation
- Market value of carbon emissions for RWH systems
- 45 year time period (2006 to 2051)

Savings in water tariffs are not included as these represent a transfer payment from the homeowner to the municipality: a benefit to the homeowner and a cost to the municipality which would cancel each other out.

Following these calculations, shown in Appendix E, the NPV of the baseline scenario for the local surface water supply is $84 million and the corresponding RWH scenario is $123 million, representing an increase of 45%. For the regional water supply, the baseline NPV is $142 million and the RWH scenario is 19% higher, at $168 million.

Discussion

While RWH is shown to be more costly than conventional supply alternatives, the economic performance can be expected to improve. Municipal water rates will increase as full cost recovery is implemented and as water treatment processes become more costly, in attempt to remove increasingly complex contaminants. Additional capital cost reduction may result due to both economies of scale and to the integration of RWH with other water sensitive technologies, such as greywater reuse and on-site stormwater management structures. This will allow for synergistic effects that are precluded when viewing RWH in isolation, making the integrated system more economical than any single component. Further, the total life cycle impacts of RWH vs. conventional systems must be considered in order to properly compare the two options, as well as the contributions that RWH makes towards a broader culture of conservation and enhanced water security. In this light, the future for RWH therefore appears somewhat optimistic.

However, if we consider the severity of the issues facing the urban water sector and recognize the inability of existing approaches to fully respond, particularly in light of the uncertainty posed by climate change, this optimism takes on a sense of urgency. Diversity plays a critical role in ensuring the sustainability and security of water supplies. This includes diversity of sources and quality of water utilized, as well as diversity in the scale of technology and its ownership, management and administration. Systems that cover this scope of variability will allow for adaptation to future scenarios, which are uncertain and unpredictable at this time. RWH is not a "silver bullet" solution, but it can serve as an important bridge in the transition to this new approach for sustainable urban water management. It is particularly suited for this role for two reasons. First, rainwater is of high quality and requires little treatment for most purposes, and second, RWH already enjoys a high level of social acceptance, due to its historic use in Canada and its continued use in the rural context. In addition, rainwater harvesting has the dual benefit of water supply and stormwater management.

Conclusion

For homeowners, the net present value of RWH currently does not compare favorably to municipally supplied water; however, if homeowners bear the cost of RWH, then significant savings can be had at the municipal level, in terms of reduced operating costs and delayed infrastructure investment. Under this analysis, RWH also does not appear to be advantageous at the societal level; however, a detailed life cycles assessment is required to properly compare conventional systems and RWH before such a conclusion can be made. Further, broader externalities need to be considered to properly assess the value of RWH, including its contribution to diversity and adaptability of water systems.

Given the history of subsidies in the water sector, which have in part sustained the development of centralized water and wastewater infrastructure; it is obvious that short term economic performance is not always the principle criteria for investment. Rather, goals such as public health and societal progress have governed decision-making and have allowed funds to be made available. These goals have largely been achieved in the North American context and the challenges we now face are with respect to resource conservation, climate change adaptation, environmental sustainability and water security. Like public health, addressing such challenges must be given priority over short term economic criteria. As it took decades of investment to develop the current system of both physical and institutional infrastructure for water management, so too will it require a serious commitment to develop a new, more sustainable approach. RWH is one of many technologies that may make up this new approach.

Acknowledgements

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Appendix A: Assumptions for construction of model

Data used to determine water savings from RWH systems (input for EXCEL model)

Parameter	Value	Reference
Roof area	Single detached - 160 m2 Multi-attached – 80 m2	Reids Heritage Homes, 2007 Sample of 7 local units
Household occupancy	Single detached - 2.95 Multi-attached – 2.68	Statistics Canada, 2007
Rainwater demand patterns	Toilets – 33 lpcd Laundry – 35 lpcd Indoor demand – 172 lpcd Total demand – 188 lpcd	Adapted from Mayer et al., 2003/04 Adapted from Mayer et al., 2003/04 Adapted from Vickers, 2001 Adapted from Vickers, 2001 (Total demand equivalent to WSMP 2025 conservation target)
Outdoor consumption	Average of 14 lpcd, throughout the year, applied only May to September. Distributed according to rainfall patterns.	Adapted from Mayer et al., 1999 Assumes water efficiency further minimizes outdoor demand such that conservation targets are met.
RWH system losses	1.5 mm wetting loss 20% continuous loss	Despins, 2008 Despins, 2008
Snow melt	50% capture if temperature raises above 0^oC within three days following snow event	Based roughly on performance of RWH system built and monitored for this project

Appendix B: Cost data for RWH system

Description of design features for RWH scenarios.

Scenario 1 Outdoor use and toilet flushing (O-T)	**Scenario 2** Outdoor use, toilet flushing and laundry (O-T-L)	**Scenario 3** Outdoor use & all indoor use except kitchen (Max Use)
Small, inexpensive, generic pump	Higher quality RWH pump	Larger, higher quality RWH pump
No pretreatment	Pretreatment	Pretreatment
No post treatment	No post treatment	Post treatment

Cost of buried concrete RWH systems for single detached homes [L] and Multi-Attached homes [R]. Multi-attached homes share a communal system, but the cost shown is per dwelling.

Individual Systems - Single Detached				Communal System: Multi-Attached Homes			
Capacity (m^3)	End Use Scenario 1	2	3	Capacity per dwelling (m^3)	End Use Scenario 1	2	3
0.9	$ 5,798	$ 7,925	$ 9,344				
1.8	$ 5,875	$ 8,003	$ 9,422	1.05	$ 2,718	$ 4,044	$ 4,590
3.15	$ 6,263	$ 8,390	$ 9,810	2.10	$ 3,191	$ 4,518	$ 5,063
4.95	$ 6,789	$ 8,916	$ 10,335	3.03	$ 3,602	$ 4,928	$ 5,474
6.3	$ 7,398	$ 9,525	$ 10,944	4.53	$ 4,279	$ 5,605	$ 6,151
8.15	$ 8,217	$ 10,345	$ 11,764	6.05	$ 4,959	$ 6,285	$ 6,831
10	$ 9,048	$ 11,176	$ 12,595				
4.5	$ 6,586	$ 8,713	$ 10,132				

Cost of indoor plactic RWH systems for single detached homes [L] and Multi-Attached homes [R]

Single Detached				Multi-Attached Homes			
Capacity (m^3)	End Use Scenario 1	2	3	Capacity (m^3)	End Use Scenario 1	2	3
1.59	$ 6,949	$ 8,681	$ 9,655	1.59	$ 6,433	$ 8,165	$ 9,140
3.18	$ 8,270	$ 10,002	$ 10,977	3.18	$ 7,754	$ 9,487	$ 10,461
4.77	$ 9,347	$ 11,079	$ 12,054	4.77	$ 8,831	$ 10,563	$ 11,538

CONCRETE TANK OPTION FOR SINGLE DETACHED HOMES

Scenario 1: Outdoor use and toilet flushing
Scenario 2: Outdoor use, toilet flushing and laundry
Scenario 3: Outdoor use and all indoor use except kitchen

Component	Assumption	Scenario	Unit Cost	No.	Contractor Discount	Tax	Labour**	Total Cost	Source
Tank and tank modifications	Capacity: 900 L	all	940	1	inc.	11%	inc.	1,043	RH2O, 2008
	Capacity: 1800 L	all	1010	1	inc.	11%	inc.	1,121	
	Capacity: 3150 L	all	1225	1	inc.	11%	inc.	1,360	
	Capacity: 4500 L	all	1250	1	inc.	11%	inc.	1,388	
	Capacity: 4950 L	all	1375	1	inc.	11%	inc.	1,526	
	Capacity: 6300 L	all	1750	1	inc.	11%	inc.	1,943	
	Capacity: 8150 L	all	2250	1	inc.	11%	inc.	2,498	
	Capacity: 10000 L	all	2761	1	inc.	11%	inc.	3,064	
Tank excavation	Capacity: 900 L	all	199	1	inc.	inc.	inc.	199	Based on excavation cost for demonstration system (Reid's Heritage Homes, 2008)
	Capacity: 1800 L	all	199	1	inc.	inc.	inc.	199	
	Capacity: 3150 L	all	348	1	inc.	inc.	inc.	348	
	Capacity: 4500 L	all	643	1	inc.	inc.	inc.	643	
	Capacity: 4950 L	all	707	1	inc.	inc.	inc.	707	
	Capacity: 6300 L	all	900	1	inc.	inc.	inc.	900	
	Capacity: 8150 L	all	1164	1	inc.	inc.	inc.	1,164	
	Capacity: 10000 L	all	1429	1	inc.	inc.	inc.	1,429	
Pretreatment	filter	2	600	1	10%	11%	inc.	599	RH2O, 2008
	filter, calming inlet, overflow	3	925	1	10%	11%	inc.	924	
	Installation of all tank related components	all*	1000	1	inc.	11%	inc.	1,110	
Pump	1/2HP Jet Pump + pressure switch + 2 float switches	1	527	1	10%	11%	inc.	526	Canadian Tire, 2007; Accu Pumps, 2007
	Small RH2O submersible pump kit with floating inlet	2	750	1	10%	11%	inc.	749	RH2O, 2008
	Large RH2O submersible pump kit with floating inlet	3	1000	1	10%	11%	inc.	999	
Electrical	rainbank rainwater control system	all	875	1	10%	11%	inc.	874	
	Electrical service and Rough-ins	all	250	1	inc.	inc.	inc.	250	Based on installation cost for demonstration system (Reid's Heritage Homes, 2008)
	Electrical service to Tank (conduit,etc)	all	300	1	inc.	inc.	inc.	300	
Plumbing	4" PVC and first flush device (Gutter to cistern)	all	1100	1	inc.	inc.	inc.	1,100	
	1" water line from tank into house	all	200	1	inc.	inc.	inc.	200	
	Additional plumbing (manifolds,bypass valves)	all*	1500	1	inc.	inc.	inc.	1,500	
Treatment	filtration - BB housing 10" + 20/5 micron cartridges	3	57	2	inc.	11%	1	127	Accupump, 2007
	UV treatment - TROJAN UVMAX "C" UV Sterilizer	3	673	1	20%	11%	1	598	
	labour cost per hour	3	60					120	Evolve Builders, 2008

* Half of the shown cost for Scenario 1

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Stan's Plumbing. 2007. Personal Communication. October to December, 2007.

INDOOR PLASTIC TANK OPTION FOR SINGLE DETACHED AND MULTI-ATTACHED HOME

Scenario 1: Outdoor use and toilet flushing
Scenario 2: Outdoor use, toilet flushing and laundry
Scenario 3: Outdoor use and all indoor use except kitchen

Component	Assumption	Scenario	Unit Cost	No.	Contractor Discount	Tax	Labour**	Total Cost	Source
Tanks	Capacity: 1590 L each (#41215)	all	755	1 to 5	20%	11%	inc.	838	Diverse Plastics, 2008
Connecting tanks in series (3" connections with ball valves)	2 tanks	all	483		inc.	inc.	inc.	483	Design based on Guelph Guelph Campus Co-op RWH system - parts sourced from Stans Plumbing, 2007
	3 tanks	all	722		inc.	inc.	inc.	722	
	4 tanks	all	967		inc.	inc.	inc.	967	
	5 tanks	all	1213		inc.	inc.	inc.	1213	
Pretreatment	filter, calming inlet, overflow	2,3	925		10%	11%	inc.	924	RH2O, 2008
	Installation of all tank related components	all*	1000		inc.	11%	inc.	1110	
Pump	1/2HP Jet Pump + pressure switch + 2 float switches	1	527		10%	11%	inc.	526	Accu Pumps, 2007
	Small RH2O submersible pump kit w floating suction filter	2	750		10%	11%	inc.	749	(RH2O, 2007)
	Large RH2O submersible pump kit w floating suction filter	3	1000		10%	11%	inc.	999	
Electrical	rainbank rainwater control system	all	875		10%	11%	inc.	874	
	Electrical service and Rough-ins	all	250		inc.	inc.	inc.	250	Based on installation cost for demonstration system (Reid's Heritage Homes, 2008)
	Electrical service to Tank (conduit,etc)	all	300		inc.	inc.	inc.	300	
Plumbing	1" water line from tank into house	all	200		inc.	inc.	inc.	200	
	Additional plumbing (manifolds, bypass valves)	all*	1500		inc.	inc.	inc.	1500	
	Inlets - 4" at grade to 2" PVC SDR 40 in basement (single)	all	263	3	20%	11%	8	699	Design developed within project - not tested - parts sourced from Stans Plumbing
	Inlets - 4" at grade to 2" PVC SDR 40 in basement (multi)	all	263	2	20%	11%	6	466	
	Overflow -3 float valves + 3" overflow to drain (single)	all	446		20%	11%	4	396	
	Overflow -2 float valves + 3" overflow to drain (multi)	all	330		20%	11%	3	293	
Treatment	filtration - BB housing 10" + 5 micron cartridge	3	57	2	inc.	11%	1	127	Accu Pumps, 2007
	UV treatment - TROJAN UVMAX "C" UV Sterilizer	3	673		20%	11%	1	598	
Labour	labour per hour	3	60						Evolve Builders, 2008

* Half of the shown cost for Scenario 1
** Labour requirements, where shown, are estimated based on labour used in demonstration sites.

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Stan's Plumbing. 2007. Personal Communication. October to December, 2007.

COMMUNAL CONCRETE TANK OPTION FOR MULTI-ATTACHED HOMES (6 UNITS PER SYSTEM)

Scenario 1: Outdoor use and toilet flushing
Scenario 2: Outdoor use, toilet flushing and laundry
Scenario 3: Outdoor use and all indoor use except kitchen

Component	Assumption	Cost	Contractor Discount	Tax	Labour	Cost	Scaling Factor for Different End Use Scenarios		
							1	2	3
Tank and tank modifications	Capacity: 6300 L	1750	inc.	11%	inc.	1,943	1	1	1
	Capacity: 8150 L	2250	inc.	11%	inc.	2,498	1	1	1
	Capacity: 10900 L	3000	inc.	11%	inc.	3,330	1	1	1
	Capacity: 12600 L	3500	inc.	11%	inc.	3,885	1	1	1
	Capacity: 14850 L	4125	inc.	11%	inc.	4,579	1	1	1
	Capacity: 18200 L	5000	inc.	11%	inc.	5,550	1	1	1
	Capacity: 27200 L	7500	inc.	11%	inc.	8,325	1	1	1
	Capacity: 36320 L	10000	inc.	11%	inc.	11,100	1	1	1
Tank excavation	Capacity: 6300 L	900	inc.	inc.	inc.	900	1	1	1
	Capacity: 8150 L	1164	inc.	inc.	inc.	1,164	1	1	1
	Capacity: 10900 L	1557	inc.	inc.	inc.	1,557	1	1	1
	Capacity: 12600 L	1800	inc.	inc.	inc.	1,800	1	1	1
	Capacity: 14850 L	2121	inc.	inc.	inc.	2,121	1	1	1
	Capacity: 18200 L	2600	inc.	inc.	inc.	2,600	1	1	1
	Capacity: 27200 L	3886	inc.	inc.	inc.	3,886	1	1	1
	Capacity: 36320 L	5189	inc.	inc.	inc.	5,189	1	1	1
Pretreatment	filter, calming inlet, overflow	925	10%	11%	inc.	924	0	2	2
	Installation of all tank related components	1000	inc.	11%	inc.	1,110	1	2	2
Pump	1/2HP Jet Pump + pressure switch + 2 float switches	527	10%	11%	inc.	526	0	0	0
	Small RH2O submersible pump kit with floating inlet	750	10%	11%	inc.	749	2	0	0
	Large RH2O submersible pump kit with floating inlet	1000	10%	11%	inc.	999	0	2	3
Electrical	rainbank rainwater control system	875	10%	11%	inc.	874	2	2	2
	Electrical service and Rough-ins	250	inc.	inc.	inc.	250	2	2	2
Plumbing	Electrical service to Tank (conduit,etc)	300	inc.	inc.	inc.	300	2	2	2
	4" PVC and first flush device (Gutter to cistern)	1100	inc.	inc.	inc.	1,100	2	2	2
	1" water line from tank into house	200	inc.	inc.	inc.	200	10	10	10
	Additional plumbing (manifolds,bypass valves)	1500	inc.	inc.	inc.	1,500	3	6	6
Treatment	filtration - BB duplex housing 20" + cartridges	418	20%	11%	1	371	0	0	1
	UV treatment - TROJAN UVMAX "F" UV Sterilizer	1580	20%	11%	2	1,403	0	0	1
	additional plumbing for treatment	1000	inc.	inc.	inc.	1,000	0	0	1
Labour	labour per hour	60							
Contingencies	20% of total system cost to account for uncertainty								

Note: This system represents a conceptual design that has not been installed. It uses the same components as the single family concrete cistern system, scaled up and reconfigured as a large communal -type design. Treatment and mains make-up are assumed to be cenralized. As the design and associated cost are highly speculative, a 20% contingency cost has been added.

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Stan's Plumbing. 2007. Personal Communication. October to December, 2007.

Appendix C. Calculation of Net Present Value for Homeowners

Assumptions used in NPV calculations for homeowners

Parameter	**Value**	**Reference**
Time horizon	15 years, 2006 – 2021	
Useful life of RWH system	45 years Linear depreciation	Approximation based on anecdotal experience
Developer mark up	20%	Reid's Heritage Homes, 2007
Electricity	0.75 kwh/m^3 x \$0.08 /khw = \$0.06 /m^3	Energy consumption based on average from observed value at demonstration site, Pickering et al. 2007 and Mikkelsen et al. 1999
Pump replacement Filter replacement UV replacement	Max Use: \$900 (every 10 years) O-T-L: \$650 (every 10 years) O-T: \$426 (every 10 years) \$21 (every 4 months) \$117 (every year)	RH2O, 2008 RH2O, 2008 Canadian Tire, 2007 Approximation based on anecdotal experience
Maintenance	\$30/yr	Assumed
Reduced water softening	1.12 kg salt /m^3 water softened \$0.25 /m3 6.5 m^3/yr water savings	Accu Pumps, Technical Services Calculated from market prices Accu Pumps, Technical Services
2006 water and wastewater rates	Water - \$0.69/m3 Wastewater - \$0.84/m3	City of Guelph, 2007a
Reduction in system cost	Baseline: 20% Low: 30% High: 10%	Assumed
Water rates (Not including 2% inflation)	Baseline: Guelph's projection to 2013, 1.5% annual increase thereafter Low: 2 x annual percent increase from baseline scenario High: 0.5 x annual percent increase from baseline scenario	City of Guelph, 2008a; 1.5% increase assumed due to increasing operational costs (ie. energy)
Financial discount rate (real)	Baseline: 8% Low: 12% High: 4%	Government of Canada, 2007

NET PRESENT VALUE CALCULATIONS: SINGLE DETACHED HOME WITH 5000L CONCRETE CISTERN

Capital Costs

Developer mark-up	30%
System price decrease	20%
(due to economies of scale)	

Maintenance Costs

Electricity	$ 0.06 per m^3 of rainwater
Annual maintenance	$ 30.00
Softening salt	$ 0.28 per m^3 of mains water

Financial Parameters

Discount rate	8.0%

Scenario	1	2	3
Filter price	$ 21.30	-	-
Number of filters per year	3	-	-
UV lamp replacement	$ 117	-	-
Pump replacement	$ 799	$ 599	$ 421

Water Rates and Demand

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Guelph water rate increase (real)			8%	6%	17%	8%	8%	8%	8%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Guelph wastewater rate increase (real)			0%	3%	17%	8%	8%	8%	8%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
water rate	$/m3	0.69	0.75	0.79	0.92	1.00	1.08	1.16	1.26	1.28	1.30	1.31	1.33	1.35	1.37	1.40	1.42
wastewater rate	$/$m^3$	0.84	0.84	0.87	1.01	1.09	1.18	1.28	1.38	1.40	1.42	1.44	1.46	1.48	1.51	1.53	1.55
per capita residential demand	lpcd	232	229	225	221	218	214	211	207	204	201	188	188	188	188	188	188
annual hh demand	m^3/yr	250.3	246.3	242.3	238.4	234.5	230.8	227.0	223.4	219.8	216.2	202.6	202.6	202.6	202.6	202.6	202.6

Base Case - No RWH		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
water cost	$	172.7	183.5	191.4	220.3	234.1	248.8	264.3	280.9	280.5	280.1	266.4	270.4	274.4	278.5	282.7	286.9
wastewater cost	$	210.3	206.9	209.6	241.3	256.4	272.5	289.5	307.6	307.2	306.8	291.7	296.1	300.6	305.1	309.7	314.3
salt cost	$	69.3	68.2	67.1	66.0	64.9	63.9	62.8	61.8	60.8	59.8	56.1	56.1	56.1	56.1	56.1	56.1
discounted	$	452.3	424.6	401.3	418.9	408.3	398.2	388.6	379.5	350.4	323.5	284.5	267.0	250.6	235.2	220.8	207.2
NPV	**$ 5,411**																

Scenario 1 (max use)		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Costs - RWH																	
capital costs and installation	$	8,268	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
developer mark-up	$	2,480	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
electricity (pump)	$	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
pump replacement	$											799					
filter replacement	$	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64
UV lamp replacement	$	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117
maintenance	$	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Costs - mains water																	
water bill	$	121	127	132	151	159	168	177	186	184	183	167	170	172	175	178	180
wastewater bill	$	147	144	144	165	174	184	193	204	202	200	183	186	189	192	195	197
water softening - salt savings	$	48	47	46	45	44	43	42	41	40	39	35	35	35	35	35	35
salvage value	$																7,924
Sum of costs and savings	$	11,281	534	538	577	593	610	628	647	642	637	1,401	607	612	618	623	- 7,295
Discounted sum	$	11,281	495	462	458	436	415	396	377	347	319	649	260	243	227	212	- 2,300
NPV	**$ 14,277**																

Scenario 2 (toilets, irrigation and laundry)		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Costs- RWH																	
capital costs and installation	$	7,133	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
developer mark-up	$	2,140	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
electricity (pumping)	$	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
pump replacement	$											599					
maintenance	$	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Costs - mains water																	
water bill	$	129	137	142	162	171	181	191	202	200	198	183	186	189	192	195	198
wastewater bill	$	157	154	155	177	187	198	209	221	219	217	201	204	207	210	213	216
water softening - salt	$	52	51	50	49	47	46	45	44	43	42	39	39	39	39	39	39
salvage value	$																6,791
Sum of costs and savings	$	9,645	375	380	422	440	459	479	500	496	492	1,056	462	468	474	480	- 6,304
Discounted sum	$	9,645	347	326	335	323	312	302	292	268	246	489	198	186	174	164	- 1,987
Net Present Value	**$ 11,620**																

Scenario 3 (outdoor + toilets)		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Costs - RWH																	
capital costs and installation	$	5,431	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
developer mark-up	$	1,629	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
electricity (pump)	$	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
pump replacement	$											421					
maintenance	$	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Costs - mains water																	
water bill	$	142	150	156	179	189	200	212	224	223	222	207	210	214	217	220	223
wastewater bill	$	173	169	171	196	207	219	232	246	244	243	227	230	234	237	241	245
water softening - salt savings	$	57	56	55	54	52	51	50	49	48	47	44	44	44	44	44	44
salvage value	$																5,153
Sum of costs and savings	$	7,464	408	414	461	482	504	527	552	549	545	932	517	524	531	537	- 4,608
Discounted sum	$	7,464	377	355	366	354	343	332	322	296	273	432	222	208	195	183	- 1,453
NPV	**$ 10,270**																

NET PRESENT VALUE CALCULATIONS PER DWELLING: 6 MULTI ATTACHED HOMES WITH 18,000L COMMUNAL CONCRETE CISTERN

Capital Costs

Developer mark-up	30%
System price decrease	20%
(due to economies of scale)	

Maintenance Costs

Electricity	$ 0.06 per m^3 of rainwater
Annual maintenance	$30.00
Softening salt	$ 0.28 per m^3 of mains water

Financial Parameters

Discount rate	8.0%

Scenario	1	2	3
Filter price	$21.30	-	-
Number of filters per year	3	-	-
UV lamp replacement	$ 117	-	-
Pump replacement	$ 799	$ 599	$ 599

Water Rates and Demand

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Guelph water rate increase			8%	6%	17%	8%	8%	8%	8%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Guelph wastewater rate increase			0%	3%	17%	8%	8%	8%	8%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
water rate ($/$m^3$)		$ 0.69	$ 0.75	$ 0.79	$ 0.92	$ 1.00	$ 1.08	$ 1.16	$ 1.26	$ 1.28	$ 1.30	$ 1.31	$ 1.33	$ 1.35	$ 1.37	$ 1.40	$ 1.42
wastewater rate ($/m3)		$ 0.84	$ 0.84	$ 0.87	$ 1.01	$ 1.09	$ 1.18	$ 1.28	$ 1.38	$ 1.40	$ 1.42	$ 1.44	$ 1.46	$ 1.48	$ 1.51	$ 1.53	$ 1.55
per capita residential demand	lpcd	232	229	225	221	218	214	211	207	204	201	188	188	188	188	188	188
annual hh demand	m^3/yr	227.4	223.7	220.1	216.6	213.1	209.6	206.3	202.9	199.7	196.4	184.0	184.0	184.0	184.0	184.0	184.0

Base Case - No RWH		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
water cost	$	156.9	166.7	173.9	200.2	212.7	226.0	240.1	255.2	254.8	254.4	242.0	245.6	249.3	253.0	256.8	260.7
wastewater cost	$	191.0	187.9	190.5	219.2	233.0	247.5	263.0	279.5	279.1	278.7	265.0	269.0	273.1	277.2	281.3	285.5
salt cost	$	62.9	61.9	60.9	59.9	59.0	58.0	57.1	56.2	55.3	54.4	50.9	50.9	50.9	50.9	50.9	50.9
discounted	$	410.9	385.7	364.6	380.5	370.9	361.8	353.0	344.7	318.3	293.9	258.4	242.6	227.7	213.7	200.6	188.2
NPV	**$ 4,916**																

Scenario 1 (max use)		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Costs - RWH																	
capital costs and installation		$ 5,464	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
developer mark-up		$ 1,639	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
electricity (pump)		$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2
pump replacement												$ 799					
filter replacement		$ 64	$ 64	$ 64	$ 64	$ 64	$ 64	$ 64	$ 64	$ 64	$ 64	$ 64	$ 64	$ 64	$ 64	$ 64	$ 64
UV lamp replacement		$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117
maintenance		$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30
Costs - mains water																	
water bill		$ 129	$ 137	$ 142	$ 163	$ 172	$ 182	$ 193	$ 204	$ 203	$ 202	$ 189	$ 192	$ 194	$ 197	$ 200	$ 203
wastewater bill		$ 157	$ 154	$ 155	$ 178	$ 189	$ 200	$ 211	$ 224	$ 222	$ 221	$ 207	$ 210	$ 213	$ 216	$ 219	$ 223
water softening - salt savings		$ 52	$ 51	$ 50	$ 49	$ 48	$ 47	$ 46	$ 45	$ 44	$ 43	$ 40	$ 40	$ 40	$ 40	$ 40	$ 40
salvage value																	$ 5,372
Sum of costs and savings		$ 7,655	$ 555	$ 561	$ 603	$ 622	$ 643	$ 664	$ 687	$ 683	$ 680	$ 1,448	$ 655	$ 661	$ 667	$ 673	-$ 4,693
Discounted sum		$ 7,655	$ 514	$ 481	$ 479	$ 458	$ 437	$ 418	$ 401	$ 369	$ 340	$ 671	$ 281	$ 262	$ 245	$ 229	-$ 1,479
NPV	**$ 11,762**																

Scenario 2 (toilets, irrigation and laundry)		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Costs- RWH																	
capital costs and installation		$ 5,028	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
developer mark-up		$ 1,508	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
electricity (pumping)		$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2
pump replacement												$ 599					
maintenance		$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30
Costs - mains water																	
water bill		$ 129	$ 137	$ 142	$ 163	$ 173	$ 183	$ 194	$ 205	$ 204	$ 203	$ 189	$ 192	$ 195	$ 198	$ 201	$ 204
wastewater bill		$ 157	$ 154	$ 156	$ 179	$ 189	$ 200	$ 212	$ 224	$ 223	$ 222	$ 208	$ 211	$ 214	$ 217	$ 220	$ 224
water softening - salt		$ 52	$ 51	$ 50	$ 49	$ 48	$ 47	$ 46	$ 45	$ 44	$ 43	$ 40	$ 40	$ 40	$ 40	$ 40	$ 40
salvage value																	$ 4,875
Sum of costs and savings		$ 6,907	$ 375	$ 381	$ 423	$ 442	$ 463	$ 484	$ 507	$ 504	$ 500	$ 1,069	$ 475	$ 481	$ 487	$ 494	-$ 4,375
Discounted sum		$ 6,907	$ 347	$ 326	$ 336	$ 325	$ 315	$ 305	$ 296	$ 272	$ 250	$ 495	$ 204	$ 191	$ 179	$ 168	-$ 1,379
Net Present Value	**$ 9,538**																

Scenario 3 (outdoor + toilets)		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Costs - RWH																	
capital costs and installation		$ 3,967	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
developer mark-up		$ 1,190	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
electricity (pump)		$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2
pump replacement												$ 599					
maintenance		$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30
Costs - mains water																	
water bill		$ 132	$ 140	$ 145	$ 167	$ 177	$ 187	$ 198	$ 210	$ 209	$ 208	$ 194	$ 197	$ 200	$ 203	$ 206	$ 209
wastewater bill		$ 161	$ 158	$ 159	$ 183	$ 193	$ 205	$ 217	$ 230	$ 228	$ 227	$ 213	$ 216	$ 219	$ 223	$ 226	$ 229
water softening - salt savings		$ 53	$ 52	$ 51	$ 50	$ 49	$ 48	$ 47	$ 46	$ 45	$ 44	$ 41	$ 41	$ 41	$ 41	$ 41	$ 41
salvage value																	$ 3,910
Sum of costs and savings		$ 5,535	$ 381	$ 387	$ 431	$ 451	$ 472	$ 494	$ 517	$ 514	$ 511	$ 1,080	$ 486	$ 493	$ 499	$ 505	-$ 3,398
Discounted sum		$ 5,535	$ 353	$ 332	$ 342	$ 331	$ 321	$ 311	$ 302	$ 278	$ 256	$ 500	$ 209	$ 196	$ 183	$ 172	-$ 1,071
NPV	**$ 8,550**																

Appendix D. Calculation of Net Present Value for Municipality

Assumptions used in NPV calculations for municipal utility

Parameter	Value	Reference
Modelled systems	Single detached: 5.0 m^3, 45 m^3/hh/y Multi-attached: 18.0 m^3 shared by 6 units, 32 m^3/hh/y savings	
Population	2006 population: 114,943 1.7% annual growth rates	Statistics Canada, 2006 Meridian Planning Consultants, 2007
Housing stock	2006: 28,659 single detached 5097 multi-attached	Calculated from : Statistics Canada, 2006
Housing density	Assume current housing mix remains the same throughout analysis (single detached: multi-attached: high density ~65:20:15)	Garforth International, 2007
Housing occupancy	Assumes current occupancy is maintained throughout analysis. Single detached - 2.95 Multi-attached – 2.68	Statistics Canada, 2007
Water consumption: Total Residential	 2006: 447 lpcd 2006: 232 lpcd Residential portion is 52%	Calculated from 2006 production volumes (City of Guelph, 2007b) and Population data from above City of Guelph, 2006b
Water conservation goals	By 2019: 2861 m^3/day non-residential 5913 m^3/day residential	City of Guelph, 2008b
Capital cost for new supplies	As per Water Supply Master Plan	City of Guelph, 2006
Operating expenses for new and existing supplies	Existing groundwater: \$0.062/m^3 New groundwater: \$0.047/m^3 Regional surface water: \$0.080/m^3 Local surface water: \$0.288/m^3	City of Guelph, 2006

Sample calculations are shown in the following table for the local surface water supply. (Guelph Lake option). Note that WCESU refers to demand estimated in the Water Conservation and Efficiency Strategy Update (City of Guelph, 2008b).

Municipal Perspective: NPV Calculations for RWH Systems and Local Surface Water Supply Option

WSMP DATA		-	1	2	3	4
Year		2,006	2,007	2,008	2,009	2,010
Total peak demand (1.5 PF)	m3/day	80,000	80,000	80,000	80,000	80,000
Total average demand	m3/day	53,333	53,333	53,333	53,333	53,333
Capital Costs						
Existing groundwater supply	$	-	1,907,363	7,143,887	6,464,375	13,346,700
New groundwater supply	$	-	25,000	25,000	25,000	150,000
Local surface water supply	$	-	-	150,000	150,000	150,000
O/M Costs						
Existing groundwater	$ / m3	0.062				
New groundwater	$ / m3	0.047				
Local surface water	$ / m3	0.288				

BASE CASE: WCESU CONSERVATION		-	1	2	3	4
Year		2,006	2,007	2,008	2,009	2,010
Population (1.5% growth)		114,943	116,667	118,417	120,193	121,996
Total average demand (no conservation)	m3/day	51,387	52,158	52,940	53,734	54,540
Total average demand (WCESU goal)	m3/day	51,387	51,556	51,725	51,895	52,064
Capital Costs						
Conservation	$		300,500	325,200	375,600	1,990,959
Existing groundwater supply	$	-	1,907,363	7,143,887	6,464,375	13,346,700
New groundwater supply	$	-	-	-	-	-
Local surface water supply	$	-	-	-	-	-
O/M Costs						
Conservation	$					
Existing groundwater	$	1,162,888	1,166,718	1,170,548	1,174,378	1,178,208
New groundwater	$					
Local surface water	$					
Present Value						
Discounted capital costs	**$ 84,143,858**	-	2,044,318	6,403,538	5,429,793	11,273,637

WCESU CONSERVATION AND RWH		-	1	2	3	4
Year		2,006	2,007	2,008	2,009	2,010
Population (1.5% growth)		114,943	116,667	118,417	120,193	121,996
Total average demand (no conservation)	m3/day	51,387	52,158	52,940	53,734	54,540
Total average demand (WCESU conservation)	m3/day	51,387	51,556	51,725	51,895	52,064
Total RW demand	m3/day	62	125	189	254	320
Total average mains demand	m3/day	51,325	51,431	51,536	51,640	51,744
Capital Costs						
Conservation	$		300,500	325,200	375,600	1,990,959
Existing groundwater supply	$	-	1,907,363	7,143,887	6,464,375	13,346,700
New groundwater supply	$	-	-	-	-	-
Local surface water supply	$	-	-	-	-	-
O/M Costs						
Conservation	$					
Existing groundwater	$	1,161,481	1,163,883	1,166,263	1,168,622	1,170,958
New groundwater	$	-	-	-	-	-
Local surface water	$	-	-	-	-	-
Present Value						
Discounted capital costs	**$ 80,590,348**	-	2,044,318	6,403,538	5,429,793	11,273,637

WSMP DATA	5	6	7	8	9	10
Year	2,011	2,012	2,013	2,014	2,015	2,016
Total peak demand (1.5 PF)	81,154	82,308	83,462	84,615	85,769	86,923
Total average demand	54,103	54,872	55,641	56,410	57,179	57,949
Capital Costs						
Existing groundwater supply	3,565,685	3,565,685	3,565,685	3,565,685	3,565,685	-
New groundwater supply	632,140	632,140	632,140	632,140	632,140	7,215,200
Local surface water supply	100,000	100,000	100,000	100,000	100,000	200,000
O/M Costs						
Existing groundwater						
New groundwater						
Local surface water						

BASE CASE: WCESU CONSERVATION	5	6	7	8	9	10
Year	2,011	2,012	2,013	2,014	2,015	2,016
Population (1.5% growth)	123,826	125,684	127,569	129,482	131,425	133,396
Total average demand (no conservation)	55,358	56,189	57,032	57,887	58,755	59,637
Total average demand (WCESU goal)	52,233	52,402	52,572	52,741	52,910	53,079
Capital Costs						
Conservation	1,990,959	1,990,959	1,911,459	1,911,459	1,911,459	1,911,459
Existing groundwater supply	3,565,685	3,565,685	3,565,685	3,565,685	3,565,685	-
New groundwater supply	-	-	-	-	-	25,000
Local surface water supply	-	-	-	-	-	150,000
O/M Costs						
Conservation	1,046,386	86,771	98,814	147,671	565,858	134,448
Existing groundwater	1,182,038	1,185,868	1,189,698	1,193,528	1,197,358	1,201,189
New groundwater						
Local surface water						
Present Value						
Discounted capital costs	3,781,759	3,501,628	3,195,861	2,959,130	2,739,936	966,434

WCESU CONSERVATION AND RWH	5	6	7	8	9	10
Year	2,011	2,012	2,013	2,014	2,015	2,016
Population (1.5% growth)	123,826	125,684	127,569	129,482	131,425	133,396
Total average demand (no conservation)	55,358	56,189	57,032	57,887	58,755	59,637
Total average demand (WCESU conservation)	52,233	52,402	52,572	52,741	52,910	53,079
Total RW demand	387	455	524	594	665	738
Total average mains demand	51,846	51,947	52,047	52,147	52,245	52,342
Capital Costs						
Conservation	1,990,959	1,990,959	1,911,459	1,911,459	1,911,459	1,911,459
Existing groundwater supply	3,565,685	3,565,685	3,565,685	3,565,685	3,565,685	-
New groundwater supply	-	-	-	-	-	-
Local surface water supply	-	-	-	-	-	-
O/M Costs						
Conservation	1,046,386	86,771	98,814	147,671	565,858	134,448
Existing groundwater	1,173,273	1,175,564	1,177,833	1,180,078	1,182,299	1,184,496
New groundwater	-	-	-	-	-	-
Local surface water	-	-	-	-	-	-
Present Value						
Discounted capital costs	3,781,759	3,501,628	3,195,861	2,959,130	2,739,936	885,375

WSMP DATA	11	12	13	14	15	16
Year	2,017	2,018	2,019	2,020	2,021	2,022
Total peak demand (1.5 PF)	88,077	89,231	90,385	91,538	92,692	93,846
Total average demand	58,718	59,487	60,256	61,026	61,795	62,564
Capital Costs						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	7,215,200	7,215,200	7,215,200	7,215,200	-	-
Local surface water supply	200,000	200,000	200,000	200,000	14,000,000	14,000,000
O/M Costs						
Existing groundwater						
New groundwater						
Local surface water						

BASE CASE: WCESU CONSERVATION	11	12	13	14	15	16
Year	2,017	2,018	2,019	2,020	2,021	2,022
Population (1.5% growth)	135,397	137,428	139,489	141,582	143,705	145,861
Total average demand (no conservation)	60,531	61,439	62,361	63,296	64,246	65,209
Total average demand (WCESU goal)	53,249	53,418	53,587	54,391	55,207	56,035
Capital Costs						
Conservation	1,911,459	1,911,459	1,911,459			
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	25,000	25,000	150,000	632,140	632,140	632,140
Local surface water supply	150,000	150,000	100,000	100,000	100,000	100,000
O/M Costs						
Conservation	135,447	136,447	137,447	616,606		
Existing groundwater	1,205,019	1,208,849	1,212,679	1,230,869	1,249,332	1,249,332
New groundwater					13,996	28,202
Local surface water						
Present Value						
Discounted capital costs	894,847	828,562	794,764	249,265	230,801	213,705

WCESU CONSERVATION AND RWH	11	12	13	14	15	16
Year	2,017	2,018	2,019	2,020	2,021	2,022
Population (1.5% growth)	135,397	137,428	139,489	141,582	143,705	145,861
Total average demand (no conservation)	60,531	61,439	62,361	63,296	64,246	65,209
Total average demand (WCESU conservation)	53,249	53,418	53,587	54,391	55,207	56,035
Total RW demand	811	885	961	1,037	1,115	1,194
Total average mains demand	52,438	52,533	52,627	53,354	54,092	54,841
Capital Costs						
Conservation	1,911,459	1,911,459	1,911,459			
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	-	25,000	25,000	25,000	150,000	632,140
Local surface water supply	-	150,000	150,000	150,000	100,000	100,000
O/M Costs						
Conservation	135,447	136,447	137,447	616,606		
Existing groundwater	1,186,669	1,188,816	1,190,939	1,207,396	1,224,100	1,241,054
New groundwater	-	-	-	-	-	-
Local surface water	-	-	-	-	-	-
Present Value						
Discounted capital costs	819,792	828,562	767,187	59,581	78,810	213,705

WSMP DATA	17	18	19	20	21	22
Year	2,023	2,024	2,025	2,026	2,027	2,028
Total peak demand (1.5 PF)	95,000	97,586	100,172	102,759	105,345	107,931
Total average demand	63,333	65,057	66,782	68,506	70,230	71,954
Capital Costs						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	-	-	-	-	-	-
Local surface water supply	14,000,000	14,000,000	14,000,000	1,055,500	1,055,500	1,055,500
O/M Costs						
Existing groundwater						
New groundwater						
Local surface water						

BASE CASE: WCESU CONSERVATION	17	18	19	20	21	22
Year	2,023	2,024	2,025	2,026	2,027	2,028
Population (1.5% growth)	148,049	150,270	152,524	154,812	157,134	159,491
Total average demand (no conservation)	66,188	67,180	68,188	69,211	70,249	71,303
Total average demand (WCESU goal)	56,876	57,729	58,595	59,474	60,366	61,271
Capital Costs						
Conservation						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	632,140	632,140	7,215,200	7,215,200	7,215,200	7,215,200
Local surface water supply	100,000	200,000	200,000	200,000	200,000	200,000
O/M Costs						
Conservation						
Existing groundwater	1,249,332	1,249,332	1,249,332	1,249,332	1,249,332	1,249,332
New groundwater	42,621	57,257	72,112	87,190	102,494	102,494
Local surface water						95,184
Present Value						
Discounted capital costs	197,875	208,242	1,718,191	1,590,918	1,473,072	1,363,956

WCESU CONSERVATION AND RWH	17	18	19	20	21	22
Year	2,023	2,024	2,025	2,026	2,027	2,028
Population (1.5% growth)	148,049	150,270	152,524	154,812	157,134	159,491
Total average demand (no conservation)	66,188	67,180	68,188	69,211	70,249	71,303
Total average demand (WCESU conservation)	56,876	57,729	58,595	59,474	60,366	61,271
Total RW demand	1,274	1,355	1,438	1,522	1,607	1,693
Total average mains demand	55,602	56,373	57,157	57,952	58,759	59,578
Capital Costs						
Conservation						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	632,140	632,140	632,140	632,140	7,215,200	7,215,200
Local surface water supply	100,000	100,000	100,000	200,000	200,000	200,000
O/M Costs						
Conservation						
Existing groundwater	1,241,054	1,241,054	1,241,054	1,241,054	1,241,054	1,241,054
New groundwater	13,045	26,286	39,726	53,367	67,213	81,267
Local surface water	-	-	-	-	-	-
Present Value						
Discounted capital costs	197,875	183,217	169,646	178,534	1,473,072	1,363,956

Municipal Perspective: NPV Calculations for RWH Systems and Local Surface Water Supply Option

WSMP DATA	23	24	25	26	27	28
Year	2,029	2,030	2,031	2,032	2,033	2,034
Total peak demand (1.5 PF)	110,517	113,103	115,690	118,276	120,862	123,448
Total average demand	73,678	75,402	77,126	78,851	80,575	82,299
Capital Costs						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	-	-	-	-	-	-
Local surface water supply	1,055,500	1,055,500	1,055,500	1,055,500	1,055,500	1,055,500
O/M Costs						
Existing groundwater						
New groundwater						
Local surface water						

BASE CASE: WCESU CONSERVATION	23	24	25	26	27	28
Year	2,029	2,030	2,031	2,032	2,033	2,034
Population (1.5% growth)	161,883	164,311	166,776	169,278	171,817	174,394
Total average demand (no conservation)	72,372	73,458	74,560	75,678	76,813	77,965
Total average demand (WCESU goal)	62,190	63,123	64,070	65,031	66,006	66,996
Capital Costs						
Conservation						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	7,215,200	-	-	-	-	-
Local surface water supply	14,000,000	14,000,000	14,000,000	14,000,000	14,000,000	1,055,500
O/M Costs						
Conservation						
Existing groundwater	1,249,332	1,249,332	1,249,332	1,249,332	1,249,332	1,249,332
New groundwater	102,494	102,494	102,494	102,494	102,494	102,494
Local surface water	191,797	289,858	389,391	490,416	592,957	697,035
Present Value						
Discounted capital costs	3,613,273	2,207,791	2,044,251	1,892,825	1,752,615	122,347

WCESU CONSERVATION AND RWH	23	24	25	26	27	28
Year	2,029	2,030	2,031	2,032	2,033	2,034
Population (1.5% growth)	161,883	164,311	166,776	169,278	171,817	174,394
Total average demand (no conservation)	72,372	73,458	74,560	75,678	76,813	77,965
Total average demand (WCESU conservation)	62,190	63,123	64,070	65,031	66,006	66,996
Total RW demand	1,780	1,869	1,959	2,051	2,144	2,238
Total average mains demand	60,410	61,254	62,110	62,980	63,862	64,758
Capital Costs						
Conservation						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	7,215,200	7,215,200	7,215,200	-	-	-
Local surface water supply	200,000	200,000	14,000,000	14,000,000	14,000,000	14,000,000
O/M Costs						
Conservation						
Existing groundwater	1,241,054	1,241,054	1,241,054	1,241,054	1,241,054	1,241,054
New groundwater	95,531	110,009	110,009	110,009	110,009	110,009
Local surface water	-	88,718	178,767	270,166	362,937	457,099
Present Value						
Discounted capital costs	1,262,922	1,169,372	3,097,799	1,892,825	1,752,615	1,622,792

WSMP DATA	29	30	31	32	33	34
Year	2,035	2,036	2,037	2,038	2,039	2,040
Total peak demand (1.5 PF)	126,034	128,621	131,207	133,793	136,379	138,966
Total average demand	84,023	85,747	87,471	89,195	90,920	92,644
Capital Costs						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	-	-	-	-	-	-
Local surface water supply	1,055,500	-	-	-	-	-
O/M Costs						
Existing groundwater						
New groundwater						
Local surface water						

BASE CASE: WCESU CONSERVATION	29	30	31	32	33	34
Year	2,035	2,036	2,037	2,038	2,039	2,040
Population (1.5% growth)	177,010	179,665	182,360	185,096	187,872	190,690
Total average demand (no conservation)	79,135	80,322	81,527	82,750	83,991	85,251
Total average demand (WCESU goal)	68,001	69,021	70,057	71,108	72,174	73,257
Capital Costs						
Conservation						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	-	-	-	-	-	-
Local surface water supply	1,055,500	1,055,500	1,055,500	1,055,500	1,055,500	1,055,500
O/M Costs						
Conservation						
Existing groundwater	1,249,332	1,249,332	1,249,332	1,249,332	1,249,332	1,249,332
New groundwater	102,494	102,494	102,494	102,494	102,494	102,494
Local surface water	802,675	909,900	1,018,733	1,129,199	1,241,321	1,355,125
Present Value						
Discounted capital costs	113,284	104,893	97,123	89,929	83,267	77,099

WCESU CONSERVATION AND RWH	29	30	31	32	33	34
Year	2,035	2,036	2,037	2,038	2,039	2,040
Population (1.5% growth)	177,010	179,665	182,360	185,096	187,872	190,690
Total average demand (no conservation)	79,135	80,322	81,527	82,750	83,991	85,251
Total average demand (WCESU conservation)	68,001	69,021	70,057	71,108	72,174	73,257
Total RW demand	2,334	2,431	2,530	2,630	2,732	2,835
Total average mains demand	65,667	66,590	67,527	68,478	69,443	70,422
Capital Costs						
Conservation						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	-	-	-	-	-	-
Local surface water supply	14,000,000	1,055,500	1,055,500	1,055,500	1,055,500	1,055,500
O/M Costs						
Conservation						
Existing groundwater	1,241,054	1,241,054	1,241,054	1,241,054	1,241,054	1,241,054
New groundwater	110,009	110,009	110,009	110,009	110,009	110,009
Local surface water	552,674	649,682	748,145	848,085	949,525	1,052,486
Present Value						
Discounted capital costs	1,502,585	104,893	97,123	89,929	83,267	77,099

WSMP DATA	35	36	37	38	39	40
Year	2,041	2,042	2,043	2,044	2,045	2,046
Total peak demand (1.5 PF)	141,552	144,138	146,724	149,310	151,897	154,483
Total average demand	94,368	96,092	97,816	99,540	101,264	102,989
Capital Costs						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	-	-	-	-	-	-
Local surface water supply	-	-	-	-	-	-
O/M Costs						
Existing groundwater						
New groundwater						
Local surface water						

BASE CASE: WCESU CONSERVATION	35	36	37	38	39	40
Year	2,041	2,042	2,043	2,044	2,045	2,046
Population (1.5% growth)	193,550	196,454	199,400	202,391	205,427	208,509
Total average demand (no conservation)	86,530	87,828	89,145	90,482	91,839	93,217
Total average demand (WCESU goal)	74,356	75,471	76,603	77,752	78,918	80,102
Capital Costs						
Conservation						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	-	-	-	-	-	-
Local surface water supply	1,055,500	1,055,500	1,055,500	-	-	-
O/M Costs						
Conservation						
Existing groundwater	1,249,332	1,249,332	1,249,332	1,249,332	1,249,332	1,249,332
New groundwater	102,494	102,494	102,494	102,494	102,494	102,494
Local surface water	1,470,637	1,587,881	1,706,883	1,827,671	1,950,271	2,074,709
Present Value						
Discounted capital costs	71,388	66,100	61,204	-	-	-

WCESU CONSERVATION AND RWH	35	36	37	38	39	40
Year	2,041	2,042	2,043	2,044	2,045	2,046
Population (1.5% growth)	193,550	196,454	199,400	202,391	205,427	208,509
Total average demand (no conservation)	86,530	87,828	89,145	90,482	91,839	93,217
Total average demand (WCESU conservation)	74,356	75,471	76,603	77,752	78,918	80,102
Total RW demand	2,940	3,046	3,154	3,263	3,374	3,487
Total average mains demand	71,416	72,425	73,449	74,489	75,544	76,615
Capital Costs						
Conservation						
Existing groundwater supply	-	-	-	-	-	-
New groundwater supply	-	-	-	-	-	-
Local surface water supply	1,055,500	1,055,500	1,055,500	1,055,500	1,055,500	-
O/M Costs						
Conservation						
Existing groundwater	1,241,054	1,241,054	1,241,054	1,241,054	1,241,054	1,241,054
New groundwater	110,009	110,009	110,009	110,009	110,009	110,009
Local surface water	1,156,991	1,263,064	1,370,728	1,480,007	1,590,925	1,703,507
Present Value						
Discounted capital costs	71,388	66,100	61,204	56,670	52,473	-

WSMP DATA	41	42	43	44	45
Year	2,047	2,048	2,049	2,050	2,051
Total peak demand (1.5 PF)	157,069	159,655	162,241	164,828	167,414
Total average demand	104,713	106,437	108,161	109,885	111,609
Capital Costs					
Existing groundwater supply	-	-	-	-	-
New groundwater supply	-	-	-	-	-
Local surface water supply	-	-	-	-	-
O/M Costs					
Existing groundwater					
New groundwater					
Local surface water					

BASE CASE: WCESU CONSERVATION	41	42	43	44	45
Year	2,047	2,048	2,049	2,050	2,051
Population (1.5% growth)	211,636	214,811	218,033	221,304	224,623
Total average demand (no conservation)	94,615	96,034	97,475	98,937	100,421
Total average demand (WCESU goal)	81,304	82,523	83,761	85,018	86,293
Capital Costs					
Conservation					
Existing groundwater supply	-	-	-	-	-
New groundwater supply	-	-	-	-	-
Local surface water supply	-	-	-	-	-
O/M Costs					
Conservation					
Existing groundwater	1,249,332	1,249,332	1,249,332	1,249,332	1,249,332
New groundwater	102,494	102,494	102,494	102,494	102,494
Local surface water	2,201,014	2,329,214	2,459,337	2,591,411	2,725,467
Present Value					
Discounted capital costs	-	-	-	-	-

WCESU CONSERVATION AND RWH	41	42	43	44	45
Year	2,047	2,048	2,049	2,050	2,051
Population (1.5% growth)	211,636	214,811	218,033	221,304	224,623
Total average demand (no conservation)	94,615	96,034	97,475	98,937	100,421
Total average demand (WCESU conservation)	81,304	82,523	83,761	85,018	86,293
Total RW demand	3,602	3,718	3,836	3,955	4,077
Total average mains demand	77,702	78,806	79,925	81,062	82,216
Capital Costs					
Conservation					
Existing groundwater supply	-	-	-	-	-
New groundwater supply	-	-	-	-	-
Local surface water supply	-	-	-	-	-
O/M Costs					
Conservation					
Existing groundwater	1,241,054	1,241,054	1,241,054	1,241,054	1,241,054
New groundwater	110,009	110,009	110,009	110,009	110,009
Local surface water	1,817,778	1,933,762	2,051,487	2,170,977	2,292,260
Present Value					
Discounted capital costs	-	-	-	-	-

Municipal Perspective: NPV Calculations for RWH Systems and Regional Surface Water Supply Option

WSMP DATA		0	1	2	3	4	5
Year		2006	2007	2008	2009	2010	2011
Total peak demand (1.5 PF)	m3/day	80,000	80,000	80,000	80,000	80,000	81,154
Total average demand		53,333	53,333	53,333	53,333	53,333	54,103
Capital Costs							
Existing groundwater supply		$ -	$ 1,907,363	$ 7,143,887	$ 6,464,375	$ 13,346,700	$ 3,565,685
New groundwater supply		$ -	$ 25,000	$ 25,000	$ 25,000	$ 150,000	$ 632,140
Regional surface water supply		$ -	$ 80,000	$ -	$ -	$ -	$ 50,000
O/M Costs							
Existing groundwater	per m3	$ 0.062					
New groundwater	per m3	$ 0.047					
Regional surface water supply	per m3	$ 0.080					

* Schedule of capital investment and commissioning of water supplies assumes reaching 10% water conservation target by 2010.

BASE CASE: WCESU CONSERVATION		0	1	2	3	4	5
Year		2006	2007	2008	2009	2010	2011
Population (1.5% growth)		114,943	116,667	118,417	120,193	121,996	123,826
Total average demand (no conservation)	m3/day	51,387	52,158	52,940	53,734	54,540	55,358
Total average demand (WCESU goal)	m3/day	51,387	51,556	51,725	51,895	52,064	52,233
Capital Costs							
Conservation			300,500	325,200	375,600	1,990,959	1,990,959
Existing groundwater supply		$ -	$ 1,907,363	$ 7,143,887	$ 6,464,375	$ 13,346,700	$ 3,565,685
New groundwater supply		$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply		$ -	$ -	$ -	$ -	$ -	$ -
O/M Costs							
Conservation							$ 1,046,386
Existing groundwater		$ 1,162,888	$ 1,166,718	$ 1,170,548	$ 1,174,378	$ 1,178,208	$ 1,182,038
New groundwater							
Regional surface water supply							
Present Value							
Discounted capital costs	**$ 122,030,165**	$ -	$ 2,044,318	$ 6,403,538	$ 5,429,793	$ 11,273,637	$ 3,781,759
Discounted operational costs	**$ 19,119,450**	$ 1,162,888	$ 1,080,294	$ 1,003,556	$ 932,259	$ 866,018	$ 1,516,628
Discounted total costs		$ 1,162,888	$ 3,124,612	$ 7,407,094	$ 6,362,052	$ 12,139,655	$ 5,298,387
NPV total costs	**$ 141,149,616**						

WCESU CONSERVATION AND RWH		0	1	2	3	4	5
Year		2006	2007	2008	2009	2010	2011
Population (1.5% growth)		114,943	116,667	118,417	120,193	121,996	123,826
Total average demand (no conservation)	m3/day	51,387	52,158	52,940	53,734	54,540	55,358
Total average demand (WCESU conservation)	m3/day	51,387	51,556	51,725	51,895	52,064	52,233
Total RW demand	m3/day	62	125	189	254	320	387
Total average mains demand	m3/day	51,325	51,431	51,536	51,640	51,744	51,846
Capital Costs							
Conservation			300,500	325,200	375,600	1,990,959	1,990,959
Existing groundwater supply		$ -	$ 1,907,363	$ 7,143,887	$ 6,464,375	$ 13,346,700	$ 3,565,685
New groundwater supply		$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply		$ -	$ -	$ -	$ -	$ -	$ -
O/M Costs							
Conservation							$ 1,046,386
Existing groundwater		$ 1,161,481	$ 1,163,883	$ 1,166,263	$ 1,168,622	$ 1,170,958	$ 1,173,273
New groundwater		$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply		$ -	$ -	$ -	$ -	$ -	$ -
Present Value							
Discounted capital costs	**$ 110,433,980**	$ -	$ 2,044,318	$ 6,403,538	$ 5,429,793	$ 11,273,637	$ 3,781,759
Discounted maintenance costs	**$ 18,871,068**	$ 1,161,481	$ 1,077,669	$ 999,883	$ 927,690	$ 860,689	$ 1,510,662
Discounted total costs		$ 1,161,481	$ 3,121,987	$ 7,403,421	$ 6,357,482	$ 12,134,327	$ 5,292,421
NPV total costs	**$ 129,305,047**						

Municipal Perspective: NPV Calculations for RWH Systems and Regional Surface Water Supply Option

WSMP DATA	6	7	8	9	10	11	12
Year	2012	2013	2014	2015	2016	2017	2018
Total peak demand (1.5 PF)	82,308	83,462	84,615	85,769	86,923	88,077	89,231
Total average demand	54,872	55,641	56,410	57,179	57,949	58,718	59,487
Capital Costs							
Existing groundwater supply	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ -	$ -	$ -
New groundwater supply	$ 632,140	$ 632,140	$ 632,140	$ 632,140	$ 7,215,200	$ 7,215,200	$ 7,215,200
Regional surface water supply	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 10,583,000	$ 10,583,000	$ 10,583,000
O/M Costs							
Existing groundwater							
New groundwater							
Regional surface water supply							

* Schedule of capital investment and commissioni

BASE CASE: WCESU CONSERVATION	6	7	8	9	10	11	12
Year	2012	2013	2014	2015	2016	2017	2018
Population (1.5% growth)	125,684	127,569	129,482	131,425	133,396	135,397	137,428
Total average demand (no conservation)	56,189	57,032	57,887	58,755	59,637	60,531	61,439
Total average demand (WCESU goal)	52,402	52,572	52,741	52,910	53,079	53,249	53,418
Capital Costs							
Conservation	1,990,959	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459
Existing groundwater supply	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ 25,000	$ 25,000	$ 25,000
Regional surface water supply	$ -	$ -	$ -	$ 80,000	$ -	$ -	$ -
O/M Costs							
Conservation	$ 86,771	$ 98,814	$ 147,671	$ 565,858	$ 134,448	$ 135,447	$ 136,447
Existing groundwater	$ 1,185,868	$ 1,189,698	$ 1,193,528	$ 1,197,358	$ 1,201,189	$ 1,205,019	$ 1,208,849
New groundwater							
Regional surface water supply							
Present Value							
Discounted capital costs	$ 3,501,628	$ 3,195,861	$ 2,959,130	$ 2,779,956	$ 896,955	$ 830,514	$ 768,995
Discounted operational costs	$ 801,979	$ 751,835	$ 724,608	$ 882,047	$ 618,658	$ 574,903	$ 534,235
Discounted total costs	$ 4,303,607	$ 3,947,695	$ 3,683,739	$ 3,662,003	$ 1,515,613	$ 1,405,417	$ 1,303,230

NPV total costs

WCESU CONSERVATION AND RWH	6	7	8	9	10	11	12
Year	2012	2013	2014	2015	2016	2017	2018
Population (1.5% growth)	125,684	127,569	129,482	131,425	133,396	135,397	137,428
Total average demand (no conservation)	56,189	57,032	57,887	58,755	59,637	60,531	61,439
Total average demand (WCESU conservation)	52,402	52,572	52,741	52,910	53,079	53,249	53,418
Total RW demand	455	524	594	665	738	811	885
Total average mains demand	51,947	52,047	52,147	52,245	52,342	52,438	52,533
Capital Costs							
Conservation	1,990,959	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459
Existing groundwater supply	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ 25,000
Regional surface water supply	$ -	$ -	$ -	$ -	$ -	$ 80,000	$ -
O/M Costs							
Conservation	$ 86,771	$ 98,814	$ 147,671	$ 565,858	$ 134,448	$ 135,447	$ 136,447
Existing groundwater	$ 1,175,564	$ 1,177,833	$ 1,180,078	$ 1,182,299	$ 1,184,496	$ 1,186,669	$ 1,188,816
New groundwater	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Present Value							
Discounted capital costs	$ 3,501,628	$ 3,195,861	$ 2,959,130	$ 2,739,936	$ 885,375	$ 854,103	$ 768,995
Discounted maintenance costs	$ 795,485	$ 744,911	$ 717,341	$ 874,514	$ 610,926	$ 567,033	$ 526,280
Discounted total costs	$ 4,297,114	$ 3,940,772	$ 3,676,472	$ 3,614,449	$ 1,496,302	$ 1,421,135	$ 1,295,275

NPV total costs

Municipal Perspective: NPV Calculations for RWH Systems and Regional Surface Water Supply Option

WSMP DATA	13	14	15	16	17	18
Year	2019	2020	2021	2022	2023	2024
Total peak demand (1.5 PF)	90,385	91,538	92,692	93,846	95,000	97,586
Total average demand	60,256	61,026	61,795	62,564	63,333	65,057
Capital Costs						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 7,215,200	$ 7,215,200	$ -	$ -	$ -	$ -
Regional surface water supply	$ 10,583,000	$ 10,583,000	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 40,000,000
O/M Costs						
Existing groundwater						
New groundwater						
Regional surface water supply						

* Schedule of capital investment and commissioni

BASE CASE: WCESU CONSERVATION	13	14	15	16	17	18
Year	2019	2020	2021	2022	2023	2024
Population (1.5% growth)	139,489	141,582	143,705	145,861	148,049	150,270
Total average demand (no conservation)	62,361	63,296	64,246	65,209	66,188	67,180
Total average demand (WCESU goal)	53,587	54,391	55,207	56,035	56,876	57,729
Capital Costs						
Conservation	1,911,459					
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 150,000	$ 632,140	$ 632,140	$ 632,140	$ 632,140	$ 632,140
Regional surface water supply	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 10,583,000
O/M Costs						
Conservation	$ 137,447	$ 616,606				
Existing groundwater	$ 1,212,679	$ 1,230,869	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332
New groundwater			$ 13,996	$ 28,202	$ 42,621	$ 57,257
Regional surface water supply						
Present Value						
Discounted capital costs	$ 776,379	$ 232,242	$ 215,039	$ 199,110	$ 184,361	$ 2,806,578
Discounted operational costs	$ 496,438	$ 628,993	$ 398,254	$ 372,900	$ 349,175	$ 326,973
Discounted total costs	$ 1,272,818	$ 861,235	$ 613,293	$ 572,010	$ 533,536	$ 3,133,551

NPV total costs

WCESU CONSERVATION AND RWH	13	14	15	16	17	18
Year	2019	2020	2021	2022	2023	2024
Population (1.5% growth)	139,489	141,582	143,705	145,861	148,049	150,270
Total average demand (no conservation)	62,361	63,296	64,246	65,209	66,188	67,180
Total average demand (WCESU conservation)	53,587	54,391	55,207	56,035	56,876	57,729
Total RW demand	961	1,037	1,115	1,194	1,274	1,355
Total average mains demand	52,627	53,354	54,092	54,841	55,602	56,373
Capital Costs						
Conservation	1,911,459					
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 25,000	$ 25,000	$ 150,000	$ 632,140	$ 632,140	$ 632,140
Regional surface water supply	$ -	$ -	$ 50,000	$ 50,000	$ 50,000	$ 50,000
O/M Costs						
Conservation	$ 137,447	$ 616,606				
Existing groundwater	$ 1,190,939	$ 1,207,396	$ 1,224,100	$ 1,241,054	$ 1,241,054	$ 1,241,054
New groundwater	$ -	$ -	$ -	$ -	$ 13,045	$ 26,286
Regional surface water supply	$ -	$ -	$ -	$ -	$ -	$ -
Present Value						
Discounted capital costs	$ 712,032	$ 8,512	$ 63,048	$ 199,110	$ 184,361	$ 170,705
Discounted maintenance costs	$ 488,445	$ 621,002	$ 385,887	$ 362,252	$ 338,944	$ 317,151
Discounted total costs	$ 1,200,477	$ 629,513	$ 448,936	$ 561,362	$ 523,305	$ 487,856

NPV total costs

Municipal Perspective: NPV Calculations for RWH Systems and Regional Surface Water Supply Option

WSMP DATA	19	20	21	22	23	24
Year	2025	2026	2027	2028	2029	2030
Total peak demand (1.5 PF)	100,172	102,759	105,345	107,931	110,517	113,103
Total average demand	66,782	68,506	70,230	71,954	73,678	75,402
Capital Costs						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 40,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000
O/M Costs						
Existing groundwater						
New groundwater						
Regional surface water supply						

* Schedule of capital investment and commissioni

BASE CASE: WCESU CONSERVATION	19	20	21	22	23	24
Year	2025	2026	2027	2028	2029	2030
Population (1.5% growth)	152,524	154,812	157,134	159,491	161,883	164,311
Total average demand (no conservation)	68,188	69,211	70,249	71,303	72,372	73,458
Total average demand (WCESU goal)	58,595	59,474	60,366	61,271	62,190	63,123
Capital Costs						
Conservation						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ -
Regional surface water supply	$ 10,583,000	$ 10,583,000	$ 10,583,000	$ 10,583,000	$ 40,000,000	$ 40,000,000
O/M Costs						
Conservation						
Existing groundwater	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ -	$ -	$ -
New groundwater	$ 72,112	$ 87,190	$ 102,494	$ -	$ -	$ -
Regional surface water supply				$ 1,789,116	$ 1,815,953	$ 1,843,192
Present Value						
Discounted capital costs	$ 4,124,058	$ 3,818,572	$ 3,535,715	$ 3,273,810	$ 8,041,470	$ 6,307,973
Discounted operational costs	$ 306,195	$ 286,748	$ 268,548	$ 329,091	$ 309,284	$ 290,670
Discounted total costs	$ 4,430,252	$ 4,105,320	$ 3,804,263	$ 3,602,901	$ 8,350,755	$ 6,598,644

NPV total costs

WCESU CONSERVATION AND RWH	19	20	21	22	23	24
Year	2025	2026	2027	2028	2029	2030
Population (1.5% growth)	152,524	154,812	157,134	159,491	161,883	164,311
Total average demand (no conservation)	68,188	69,211	70,249	71,303	72,372	73,458
Total average demand (WCESU conservation)	58,595	59,474	60,366	61,271	62,190	63,123
Total RW demand	1,438	1,522	1,607	1,693	1,780	1,869
Total average mains demand	57,157	57,952	58,759	59,578	60,410	61,254
Capital Costs						
Conservation						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 632,140	$ 632,140	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ 7,215,200
Regional surface water supply	$ 50,000	$ 10,583,000	$ 10,583,000	$ 10,583,000	$ 10,583,000	$ 10,583,000
O/M Costs						
Conservation						
Existing groundwater	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054
New groundwater	$ 39,726	$ 53,367	$ 67,213	$ 81,267	$ 95,531	$ 110,009
Regional surface water supply	$ -	$ -	$ -	$ -	$ -	$ 1,788,610
Present Value						
Discounted capital costs	$ 158,060	$ 2,406,188	$ 3,535,715	$ 3,273,810	$ 3,031,305	$ 2,806,764
Discounted maintenance costs	$ 296,772	$ 277,716	$ 259,895	$ 243,228	$ 227,641	$ 495,124
Discounted total costs	$ 454,832	$ 2,683,904	$ 3,795,610	$ 3,517,038	$ 3,258,946	$ 3,301,889

NPV total costs

Municipal Perspective: NPV Calculations for RWH Systems and Regional Surface Water Supply Option

WSMP DATA	25	26	27	28	29	30
Year	2031	2032	2033	2034	2035	2036
Total peak demand (1.5 PF)	115,690	118,276	120,862	123,448	126,034	128,621
Total average demand	77,126	78,851	80,575	82,299	84,023	85,747
Capital Costs						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 9,579,480
O/M Costs						
Existing groundwater						
New groundwater						
Regional surface water supply						

* Schedule of capital investment and commissioni

BASE CASE: WCESU CONSERVATION	25	26	27	28	29	30
Year	2031	2032	2033	2034	2035	2036
Population (1.5% growth)	166,776	169,278	171,817	174,394	177,010	179,665
Total average demand (no conservation)	74,560	75,678	76,813	77,965	79,135	80,322
Total average demand (WCESU goal)	64,070	65,031	66,006	66,996	68,001	69,021
Capital Costs						
Conservation						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000
O/M Costs						
Conservation						
Existing groundwater	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 1,870,840	$ 1,898,902	$ 1,927,386	$ 1,956,297	$ 1,985,641	$ 2,015,426
Present Value						
Discounted capital costs	$ 5,840,716	$ 5,408,071	$ 5,007,473	$ 3,477,412	$ 3,219,826	$ 2,981,320
Discounted operational costs	$ 273,176	$ 256,735	$ 241,283	$ 226,762	$ 213,114	$ 200,288
Discounted total costs	$ 6,113,892	$ 5,664,805	$ 5,248,756	$ 3,704,173	$ 3,432,940	$ 3,181,608

NPV total costs

WCESU CONSERVATION AND RWH	25	26	27	28	29	30
Year	2031	2032	2033	2034	2035	2036
Population (1.5% growth)	166,776	169,278	171,817	174,394	177,010	179,665
Total average demand (no conservation)	74,560	75,678	76,813	77,965	79,135	80,322
Total average demand (WCESU conservation)	64,070	65,031	66,006	66,996	68,001	69,021
Total RW demand	1,959	2,051	2,144	2,238	2,334	2,431
Total average mains demand	62,110	62,980	63,862	64,758	65,667	66,590
Capital Costs						
Conservation						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 7,215,200	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 30,000,000
O/M Costs						
Conservation						
Existing groundwater	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 1,813,623	$ 1,839,012	$ 1,864,782	$ 1,890,938	$ 1,917,486	$ 1,944,433
Present Value						
Discounted capital costs	$ 6,894,265	$ 5,408,071	$ 5,007,473	$ 4,636,549	$ 4,293,101	$ 2,981,320
Discounted maintenance costs	$ 264,821	$ 248,638	$ 233,446	$ 219,186	$ 205,799	$ 193,233
Discounted total costs	$ 7,159,086	$ 5,656,708	$ 5,240,919	$ 4,855,734	$ 4,498,900	$ 3,174,553

NPV total costs

WSMP DATA	31	32	33	34	35	36
Year	2037	2038	2039	2040	2041	2042
Total peak demand (1.5 PF)	131,207	133,793	136,379	138,966	141,552	144,138
Total average demand	87,471	89,195	90,920	92,644	94,368	96,092
Capital Costs						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480
O/M Costs						
Existing groundwater						
New groundwater						
Regional surface water supply						

* Schedule of capital investment and commissioni

BASE CASE: WCESU CONSERVATION	31	32	33	34	35	36
Year	2037	2038	2039	2040	2041	2042
Population (1.5% growth)	182,360	185,096	187,872	190,690	193,550	196,454
Total average demand (no conservation)	81,527	82,750	83,991	85,251	86,530	87,828
Total average demand (WCESU goal)	70,057	71,108	72,174	73,257	74,356	75,471
Capital Costs						
Conservation						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000
O/M Costs						
Conservation						
Existing groundwater	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 2,045,657	$ 2,076,342	$ 2,107,487	$ 2,139,099	$ 2,171,186	$ 2,203,754
Present Value						
Discounted capital costs	$ 2,760,481	$ 2,556,001	$ 2,366,668	$ 2,191,359	$ 2,029,036	$ 1,878,737
Discounted operational costs	$ 188,233	$ 176,904	$ 166,257	$ 156,251	$ 146,847	$ 138,009
Discounted total costs	$ 2,948,715	$ 2,732,906	$ 2,532,925	$ 2,347,610	$ 2,175,883	$ 2,016,746

NPV total costs

WCESU CONSERVATION AND RWH	31	32	33	34	35	36
Year	2037	2038	2039	2040	2041	2042
Population (1.5% growth)	182,360	185,096	187,872	190,690	193,550	196,454
Total average demand (no conservation)	81,527	82,750	83,991	85,251	86,530	87,828
Total average demand (WCESU conservation)	70,057	71,108	72,174	73,257	74,356	75,471
Total RW demand	2,530	2,630	2,732	2,835	2,940	3,046
Total average mains demand	67,527	68,478	69,443	70,422	71,416	72,425
Capital Costs						
Conservation						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000
O/M Costs						
Conservation						
Existing groundwater	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 1,971,784	$ 1,999,545	$ 2,027,723	$ 2,056,323	$ 2,085,352	$ 2,114,817
Present Value						
Discounted capital costs	$ 2,760,481	$ 2,556,001	$ 2,366,668	$ 2,191,359	$ 2,029,036	$ 1,878,737
Discounted maintenance costs	$ 181,436	$ 170,361	$ 159,965	$ 150,205	$ 141,042	$ 132,440
Discounted total costs	$ 2,941,917	$ 2,726,363	$ 2,526,633	$ 2,341,564	$ 2,170,078	$ 2,011,177

NPV total costs

WSMP DATA	37	38	39	40	41	42
Year	2043	2044	2045	2046	2047	2048
Total peak demand (1.5 PF)	146,724	149,310	151,897	154,483	157,069	159,655
Total average demand	97,816	99,540	101,264	102,989	104,713	106,437
Capital Costs						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ -	$ -	$ -
O/M Costs						
Existing groundwater						
New groundwater						
Regional surface water supply						

* Schedule of capital investment and commission

BASE CASE: WCESU CONSERVATION	37	38	39	40	41	42
Year	2043	2044	2045	2046	2047	2048
Population (1.5% growth)	199,400	202,391	205,427	208,509	211,636	214,811
Total average demand (no conservation)	89,145	90,482	91,839	93,217	94,615	96,034
Total average demand (WCESU goal)	76,603	77,752	78,918	80,102	81,304	82,523
Capital Costs						
Conservation						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 30,000,000	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480
O/M Costs						
Conservation						
Existing groundwater	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 2,236,810	$ 2,270,362	$ 2,304,418	$ 2,338,984	$ 2,374,069	$ 2,409,680
Present Value						
Discounted capital costs	$ 1,739,572	$ 514,327	$ 476,229	$ 440,952	$ 408,289	$ 378,046
Discounted operational costs	$ 129,703	$ 121,897	$ 114,560	$ 107,666	$ 101,186	$ 95,096
Discounted total costs	$ 1,869,275	$ 636,224	$ 590,789	$ 548,618	$ 509,475	$ 473,141

NPV total costs

WCESU CONSERVATION AND RWH	37	38	39	40	41	42
Year	2043	2044	2045	2046	2047	2048
Population (1.5% growth)	199,400	202,391	205,427	208,509	211,636	214,811
Total average demand (no conservation)	89,145	90,482	91,839	93,217	94,615	96,034
Total average demand (WCESU conservation)	76,603	77,752	78,918	80,102	81,304	82,523
Total RW demand	3,154	3,263	3,374	3,487	3,602	3,718
Total average mains demand	73,449	74,489	75,544	76,615	77,702	78,806
Capital Costs						
Conservation						
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 9,579,480	$ 9,579,480	$ 9,579,480
O/M Costs						
Conservation						
Existing groundwater	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 2,144,724	$ 2,175,079	$ 2,205,890	$ 2,237,162	$ 2,268,904	$ 2,301,122
Present Value						
Discounted capital costs	$ 1,739,572	$ 1,610,714	$ 1,491,402	$ 440,952	$ 408,289	$ 378,046
Discounted maintenance costs	$ 124,363	$ 116,781	$ 109,662	$ 102,979	$ 96,704	$ 90,812
Discounted total costs	$ 1,863,935	$ 1,727,495	$ 1,601,065	$ 543,931	$ 504,993	$ 468,857

Municipal Perspective: NPV Calculations for RWH Systems and Regional Surface Water Supply Option

WSMP DATA	43	44	45
Year	2049	2050	2051
Total peak demand (1.5 PF)	162,241	164,828	167,414
Total average demand	108,161	109,885	111,609
Capital Costs			
Existing groundwater supply	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -
Regional surface water supply	$ -	$ -	$ -
O/M Costs			
Existing groundwater			
New groundwater			
Regional surface water supply			

* Schedule of capital investment and commission

BASE CASE: WCESU CONSERVATION	43	44	45
Year	2049	2050	2051
Population (1.5% growth)	218,033	221,304	224,623
Total average demand (no conservation)	97,475	98,937	100,421
Total average demand (WCESU goal)	83,761	85,018	86,293
Capital Costs			
Conservation			
Existing groundwater supply	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -
Regional surface water supply	$ 9,579,480	$ 9,579,480	$ 9,579,480
O/M Costs			
Conservation			
Existing groundwater	$ -	$ -	$ -
New groundwater	$ -	$ -	$ -
Regional surface water supply	$ 2,445,825	$ 2,482,512	$ 2,519,750
Present Value			
Discounted capital costs	$ 350,042	$ 324,113	$ 300,105
Discounted operational costs	$ 89,372	$ 83,994	$ 78,938
Discounted total costs	$ 439,415	$ 408,107	$ 379,043

NPV total costs

WCESU CONSERVATION AND RWH	43	44	45
Year	2049	2050	2051
Population (1.5% growth)	218,033	221,304	224,623
Total average demand (no conservation)	97,475	98,937	100,421
Total average demand (WCESU conservation)	83,761	85,018	86,293
Total RW demand	3,836	3,955	4,077
Total average mains demand	79,925	81,062	82,216
Capital Costs			
Conservation			
Existing groundwater supply	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -
Regional surface water supply	$ 9,579,480	$ 9,579,480	$ 9,579,480
O/M Costs			
Conservation			
Existing groundwater	$ -	$ -	$ -
New groundwater	$ -	$ -	$ -
Regional surface water supply	$ 2,333,823	$ 2,367,015	$ 2,400,705
Present Value			
Discounted capital costs	$ 350,042	$ 324,113	$ 300,105
Discounted maintenance costs	$ 85,280	$ 80,086	$ 75,209
Discounted total costs	$ 435,322	$ 404,199	$ 375,314

Appendix E. Calculation of Net Present Value for Societal Perspective

The Societal Perspective combines the assumptions from the Homeowners' Perspective (Appendix C) and the Municipal Perspective (Appendix D). Additional assumptions are as follows.

Additional assumptions used in NPV calculations for societal perspective

Parameter	**Value**	**Reference**
Discount rate	8% (real)	Government of Canada, 2007
Time frame	45 years	City of Guelph, 2008b
Energy intensity of water systems	Groundwater supply: 0.64 kWh/m^3 Surface supply: 0.58 kWh/m^3 Rainwater harvesting: 0.75 kWh/m^3	Maas, 2009 Maas, 2009 Average from demonstration site, Pickering et al. 2007 and Mikkelsen et al. 1999
GHG intensity	270 tonnes CO_2 e/GWh (average for all power production in Ontario)	OPG, 2007
Cost of CO_2 emissions	CAD 30.63/tonne	ECX, 2009 (Daily carbon price from April 22, 2005 to April 30, 2009, converted to CAD and averaged.)

Cost of Implementing RWH in all New Single-Detached and Multi-Attached Developments

Single Detached Homes
End-Use Scenario: outdoor use and toilets
Concrete Cistern Capacity: 5.0 m^3
Annual Water Savings: 45 m^3/system

Multi-Attached Homes
End-Use Scenario: outdoor use and toilets
Communal Concrete Cistern Capacity: 3.1 m^3/dwelling
Annual Water Savings: 32 m^3/system

	0	1	2	3	4	5	6	7
Year	2006	2007	2008	2009	2010	2011	2012	2013
Number of new single-detached	412	418	425	431	437	444	451	457
Number of new multi-attached	127	129	131	133	135	137	139	141
CAPITAL COSTS								
Single detached								
capital costs and installation	$ 2,238,507	$ 2,272,085	$ 2,306,166	$ 2,340,758	$ 2,375,870	$ 2,411,508	$ 2,447,680	$ 2,484,396
Multi-attached								
capital costs and installation	$ 365,473	$ 370,955	$ 376,519	$ 382,167	$ 387,899	$ 393,718	$ 399,624	$ 405,618
O&M COSTS AND SAVINGS								
Single detached								
cost - electricity	$ 1,113	$ 2,242	$ 3,389	$ 4,553	$ 5,734	$ 6,933	$ 8,149	$ 9,385
cost - pump replacement								
cost - maintenance	$ 12,365	$ 24,916	$ 37,655	$ 50,585	$ 63,709	$ 77,029	$ 90,550	$ 104,273
saving - water softening (salt)	$ 5,134	$ 10,345	$ 15,634	$ 21,002	$ 26,451	$ 31,981	$ 37,595	$ 43,293
saving - salvage value at end of life	$ -	$ 45,442	$ 92,247	$ 140,445	$ 190,070	$ 241,151	$ 293,722	$ 347,815
saving - cumulative salvage value								
Multi-attached								
cost - electricity	$ 249	$ 501	$ 758	$ 1,018	$ 1,282	$ 1,550	$ 1,822	$ 2,098
cost - pump replacement								
cost - maintenance	$ 3,805	$ 7,666	$ 11,586	$ 15,564	$ 19,603	$ 23,701	$ 27,862	$ 32,084
saving - water softening (salt)	$ 1,148	$ 2,313	$ 3,496	$ 4,696	$ 5,914	$ 7,151	$ 8,406	$ 9,680
saving - salvage value at end of life	$ -	$ 7,419	$ 15,061	$ 22,930	$ 31,032	$ 39,372	$ 47,955	$ 56,787
saving - cumulative salvage value								
TOTAL COST								
Total Costs	$ 2,615,229	$ 2,243,456	$ 2,239,329	$ 2,234,448	$ 2,228,792	$ 2,222,337	$ 2,215,063	$ 2,206,945

Cost of Implementing RWH in all New Single-Detached and Multi-Attached Developments

	8	9	10	11	12	13	14	15	16
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022
Number of new single-detached	464	471	478	486	493	500	508	515	523
Number of new multi-attached	143	145	147	149	152	154	156	159	161
CAPITAL COSTS									
Single detached									
capital costs and installation	$ 2,521,661	$ 2,559,486	$ 2,597,879	$ 2,636,847	$ 2,676,400	$ 2,716,546	$ 2,757,294	$ 2,798,653	$ 2,840,633
Multi-attached									
capital costs and installation	$ 411,702	$ 417,878	$ 424,146	$ 430,508	$ 436,966	$ 443,520	$ 450,173	$ 456,926	$ 463,780
O&M COSTS AND SAVINGS									
Single detached									
cost - electricity	$ 10,638	$ 11,911	$ 13,202	$ 14,513	$ 15,844	$ 17,194	$ 18,565	$ 19,956	$ 21,368
cost - pump replacement			$ 173,522	$ 176,125	$ 178,767	$ 181,448	$ 184,170	$ 186,932	$ 189,736
cost - maintenance	$ 118,203	$ 132,341	$ 146,691	$ 161,256	$ 176,040	$ 191,046	$ 206,277	$ 221,736	$ 237,428
saving - water softening (salt)	$ 49,076	$ 54,946	$ 60,904	$ 66,951	$ 73,089	$ 79,320	$ 85,643	$ 92,062	$ 98,576
saving - salvage value at end of life	$ 403,466	$ 460,708	$ 519,576	$ 580,106	$ 642,336	$ 706,302	$ 772,042	$ 839,596	$ 909,003
saving - cumulative salvage value									
Multi-attached									
cost - electricity	$ 2,379	$ 2,663	$ 2,952	$ 3,245	$ 3,542	$ 3,844	$ 4,151	$ 4,462	$ 4,778
cost - pump replacement			$ 25,322	$ 25,702	$ 26,087	$ 26,479	$ 26,876	$ 27,279	$ 27,688
cost - maintenance	$ 36,370	$ 40,720	$ 45,136	$ 49,617	$ 54,166	$ 58,783	$ 63,470	$ 68,227	$ 73,055
saving - water softening (salt)	$ 10,973	$ 12,285	$ 13,618	$ 14,970	$ 16,342	$ 17,735	$ 19,149	$ 20,584	$ 22,041
saving - salvage value at end of life	$ 65,872	$ 75,218	$ 84,829	$ 94,712	$ 104,872	$ 115,315	$ 126,048	$ 137,078	$ 148,409
saving - cumulative salvage value									
TOTAL COST									
Total Costs	$ 2,197,960	$ 2,188,084	$ 2,350,814	$ 2,341,684	$ 2,331,625	$ 2,320,613	$ 2,308,620	$ 2,295,621	$ 2,281,586

Cost of Implementing RWH in all New Single-Detached and Multi-Attached Developments

	17	18	19	20	21	22	23	24	25
Year	2023	2024	2025	2026	2027	2028	2029	2030	2031
Number of new single-detached	531	539	547	555	563	572	580	589	598
Number of new multi-attached	163	166	168	171	173	176	179	181	184
CAPITAL COSTS									
Single detached									
capital costs and installation	$ 2,883,242	$ 2,926,491	$ 2,970,388	$ 3,014,944	$ 3,060,168	$ 3,106,071	$ 3,152,662	$ 3,199,952	$ 3,247,951
Multi-attached									
capital costs and installation	$ 470,736	$ 477,797	$ 484,964	$ 492,239	$ 499,622	$ 507,117	$ 514,723	$ 522,444	$ 530,281
O&M COSTS AND SAVINGS									
Single detached									
cost - electricity	$ 22,802	$ 24,257	$ 25,733	$ 27,232	$ 28,754	$ 30,298	$ 31,865	$ 33,456	$ 35,071
cost - pump replacement	$ 192,582	$ 195,471	$ 198,403	$ 374,901	$ 380,525	$ 386,233	$ 392,026	$ 397,907	$ 403,875
cost - maintenance	$ 253,354	$ 269,520	$ 285,927	$ 302,582	$ 319,485	$ 336,643	$ 354,058	$ 371,734	$ 389,675
saving - water softening (salt)	$ 105,189	$ 111,901	$ 118,713	$ 125,627	$ 132,646	$ 139,769	$ 147,000	$ 154,338	$ 161,787
saving - salvage value at end of life	$ 980,302	$ 1,053,537	$ 1,128,748	$ 1,205,978	$ 1,285,271	$ 1,366,671	$ 1,450,225	$ 1,535,977	$ 1,623,976
saving - cumulative salvage value									
Multi-attached									
cost - electricity	$ 5,098	$ 5,424	$ 5,754	$ 6,089	$ 6,429	$ 6,774	$ 7,125	$ 7,480	$ 7,841
cost - pump replacement	$ 28,104	$ 28,525	$ 28,953	$ 29,387	$ 29,828	$ 30,276	$ 30,730	$ 31,191	$ 31,659
cost - maintenance	$ 77,955	$ 82,929	$ 87,978	$ 93,102	$ 98,303	$ 103,582	$ 108,941	$ 114,380	$ 119,900
saving - water softening (salt)	$ 23,519	$ 25,020	$ 26,543	$ 28,089	$ 29,658	$ 31,251	$ 32,868	$ 34,508	$ 36,174
saving - salvage value at end of life	$ 160,050	$ 172,007	$ 184,286	$ 196,896	$ 209,841	$ 223,131	$ 236,773	$ 250,773	$ 265,140
saving - cumulative salvage value									
TOTAL COST									
Total Costs	$ 2,266,489	$ 2,250,301	$ 2,232,992	$ 2,388,054	$ 2,371,016	$ 2,352,804	$ 2,333,387	$ 2,312,733	$ 2,290,809

	26	27	28	29	30	31	32	33	34
Year	2032	2033	2034	2035	2036	2037	2038	2039	2040
Number of new single-detached	607	616	625	635	644	654	664	674	684
Number of new multi-attached	187	190	192	195	198	201	204	207	210
CAPITAL COSTS									
Single detached									
capital costs and installation	$ 3,296,671	$ 3,346,121	$ 3,396,312	$ 3,447,257	$ 3,498,966	$ 3,551,450	$ 3,604,722	$ 3,658,793	$ 3,713,675
Multi-attached									
capital costs and installation	$ 538,235	$ 546,309	$ 554,503	$ 562,821	$ 571,263	$ 579,832	$ 588,530	$ 597,358	$ 606,318
O&M COSTS AND SAVINGS									
Single detached									
cost - electricity	$ 36,710	$ 38,373	$ 40,062	$ 41,775	$ 43,515	$ 45,280	$ 47,073	$ 48,892	$ 50,738
cost - pump replacement	$ 409,933	$ 416,082	$ 422,324	$ 428,658	$ 608,610	$ 617,739	$ 627,005	$ 636,411	$ 645,957
cost - maintenance	$ 407,885	$ 426,368	$ 445,129	$ 464,171	$ 483,499	$ 503,117	$ 523,028	$ 543,239	$ 563,753
saving - water softening (salt)	$ 169,348	$ 177,022	$ 184,811	$ 192,717	$ 200,742	$ 208,887	$ 217,154	$ 225,545	$ 234,062
saving - salvage value at end of life	$ 1,714,269	$ 1,806,905	$ 1,901,935	$ 1,999,409	$ 2,099,380	$ 2,201,899	$ 2,307,022	$ 2,414,803	$ 2,525,299
saving - cumulative salvage value									
Multi-attached									
cost - electricity	$ 8,208	$ 8,580	$ 8,957	$ 9,341	$ 9,729	$ 10,124	$ 10,525	$ 10,932	$ 11,344
cost - pump replacement	$ 32,133	$ 32,615	$ 33,105	$ 33,601	$ 34,105	$ 34,617	$ 35,136	$ 35,663	$ 36,198
cost - maintenance	$ 125,503	$ 131,190	$ 136,963	$ 142,822	$ 148,769	$ 154,805	$ 160,932	$ 167,150	$ 173,462
saving - water softening (salt)	$ 37,864	$ 39,580	$ 41,322	$ 43,090	$ 44,884	$ 46,705	$ 48,553	$ 50,430	$ 52,334
saving - salvage value at end of life	$ 279,882	$ 295,007	$ 310,522	$ 326,436	$ 342,758	$ 359,496	$ 376,659	$ 394,256	$ 412,296
saving - cumulative salvage value									
TOTAL COST									
Total Costs	$ 2,267,582	$ 2,243,017	$ 2,217,081	$ 2,189,736	$ 2,334,469	$ 2,306,801	$ 2,277,653	$ 2,246,986	$ 2,214,761

Cost of Implementing RWH in all New Single-Detached and Multi-Attached Developments

	35	36	37	38	39	40	41	42	43
Year	2041	2042	2043	2044	2045	2046	2047	2048	2049
Number of new single-detached	694	704	715	726	737	748	759	770	782
Number of new multi-attached	214	217	220	223	227	230	234	237	241
CAPITAL COSTS									
Single detached									
capital costs and installation	$ 3,769,380	$ 3,825,921	$ 3,883,310	$ 3,941,559	$ 4,000,683	$ 4,060,693	$ 4,121,603	$ 4,183,427	$ 4,246,179
Multi-attached									
capital costs and installation	$ 615,413	$ 624,644	$ 634,014	$ 643,524	$ 653,177	$ 662,974	$ 672,919	$ 683,013	$ 693,258
O&M COSTS AND SAVINGS									
Single detached									
cost - electricity	$ 52,612	$ 54,514	$ 56,444	$ 58,404	$ 60,393	$ 62,411	$ 64,461	$ 66,540	$ 68,651
cost - pump replacement	$ 655,646	$ 665,481	$ 675,463	$ 685,595	$ 695,879	$ 879,839	$ 893,037	$ 906,432	$ 920,029
cost - maintenance	$ 584,574	$ 605,708	$ 627,159	$ 648,931	$ 671,030	$ 693,461	$ 716,228	$ 739,337	$ 762,792
saving - water softening (salt)	$ 242,707	$ 251,481	$ 260,387	$ 269,427	$ 278,602	$ 287,915	$ 297,368	$ 306,962	$ 316,700
saving - salvage value at end of life	$ 2,638,566	$ 2,754,663	$ 2,873,649	$ 2,995,585	$ 3,120,532	$ 3,248,554	$ 3,379,715	$ 3,514,079	$ 3,651,714
saving - cumulative salvage value									
Multi-attached									
cost - electricity	$ 11,763	$ 12,189	$ 12,620	$ 13,058	$ 13,503	$ 13,955	$ 14,413	$ 14,878	$ 15,350
cost - pump replacement	$ 36,741	$ 37,292	$ 37,852	$ 38,419	$ 38,996	$ 39,581	$ 40,174	$ 40,777	$ 41,388
cost - maintenance	$ 179,869	$ 186,372	$ 192,972	$ 199,671	$ 206,471	$ 213,373	$ 220,378	$ 227,488	$ 234,705
saving - water softening (salt)	$ 54,267	$ 56,229	$ 58,220	$ 60,241	$ 62,293	$ 64,375	$ 66,488	$ 68,634	$ 70,811
saving - salvage value at end of life	$ 430,789	$ 449,744	$ 469,170	$ 489,078	$ 509,478	$ 530,379	$ 551,793	$ 573,731	$ 596,202
saving - cumulative salvage value									
TOTAL COST									
Total Costs	$ 2,180,939	$ 2,145,479	$ 2,108,339	$ 2,069,477	$ 2,028,850	$ 2,159,935	$ 2,118,246	$ 2,074,695	$ 2,029,236

Cost of Implementing RWH in all New Single-Detached and Multi-Attached Developments

	43	44	45
Year	2049	2050	2051
Number of new single-detached	782	794	805
Number of new multi-attached	241	244	248
CAPITAL COSTS			
Single detached			
capital costs and installation	$ 4,246,179	$ 4,309,871	$ 4,374,519
Multi-attached			
capital costs and installation	$ 693,258	$ 703,657	$ 714,212
O&M COSTS AND SAVINGS			
Single detached			
cost - electricity	$ 68,651	$ 70,794	$ 72,969
cost - pump replacement	$ 920,029	$ 933,829	$ 947,836
cost - maintenance	$ 762,792	$ 786,599	$ 810,763
saving - water softening (salt)	$ 316,700	$ 326,584	$ 336,617
saving - salvage value at end of life	$ 3,651,714	$ 3,792,687	$ 3,937,067
saving - cumulative salvage value			$ 73,692,441
Multi-attached			
cost - electricity	$ 15,350	$ 15,829	$ 16,315
cost - pump replacement	$ 41,388	$ 42,009	$ 42,639
cost - maintenance	$ 234,705	$ 242,030	$ 249,466
saving - water softening (salt)	$ 70,811	$ 73,021	$ 75,264
saving - salvage value at end of life	$ 596,202	$ 619,218	$ 642,790
saving - cumulative salvage value			$ 12,031,492
TOTAL COST			
Total Costs	$ 2,029,236	$ 1,981,822	-$ 71,760,038

NPV Calculations for Societal Perspective: Considering Local Surface Water Supply

WSMP DATA		0	1	2	3	4	5	6
Year		2006	2007	2008	2009	2010	2011	2012
Total peak demand (1.5 PF)	m3/day	80,000	80,000	80,000	80,000	80,000	81,154	82,308
Total average demand		53,333	53,333	53,333	53,333	53,333	54,103	54,872
Capital Costs								
Existing groundwater supply		$ -	$ 1,907,363	$ 7,143,887	$ 6,464,375	$ 13,346,700	$ 3,565,685	$ 3,565,685
New groundwater supply		$ -	$ 25,000	$ 25,000	$ 25,000	$ 150,000	$ 632,140	$ 632,140
Local surface water supply		$ -	$ -	$ 150,000	$ 150,000	$ 150,000	$ 100,000	$ 100,000
O/M Costs				**Carbon Costs**				
Existing groundwater	per m3	$ 0.062		Energy intensity - Surface water		kWh/ m3	0.58	
New groundwater	per m3	$ 0.047		Energy intensity - Ground water		kWh/ m3	0.64	
Regional surface water supply	per m3	$ 0.080		Energy intensity - Rainwater		kWh/ m3	0.75	
				Carbon emission from electricity		tonnes/kWh	0.000270	
				Carbon cost		per tonne	$ 30.63	

BASE CASE: WCESU CONSERVATION		0	1	2	3	4	5	6
Year		2006	2007	2008	2009	2010	2011	2012
Population (1.5% growth)		114,943	116,667	118,417	120,193	121,996	123,826	125,684
Total average demand (no conservation)	m3/day	51,387	52,158	52,940	53,734	54,540	55,358	56,189
Total average demand (WCESU goal)	m3/day	51,387	51,556	51,725	51,895	52,064	52,233	52,402
Capital Costs								
Conservation			300,500	325,200	375,600	1,990,959	1,990,959	1,990,959
Existing groundwater supply		$ -	$ 1,907,363	$ 7,143,887	$ 6,464,375	$ 13,346,700	$ 3,565,685	$ 3,565,685
New groundwater supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
Local surface water supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
O/M Costs								
Conservation							$ 1,046,386	$ 86,771
Existing groundwater		$ 1,162,888	$ 1,166,718	$ 1,170,548	$ 1,174,378	$ 1,178,208	$ 1,182,038	$ 1,185,868
New groundwater								
Local surface water								
Homeowner softening (salt)		$ 14,223	$ 14,270	$ 14,317	$ 14,364	$ 14,411	$ 14,458	$ 14,505
Carbon emissions								
Ground water		$ 99,274	$ 99,601	$ 99,928	$ 100,255	$ 100,582	$ 100,909	$ 101,236
Surface water								
Present Value								
Discounted total costs		$ 1,276,386	$ 3,230,049	$ 7,505,041	$ 6,453,040	$ 12,224,179	$ 5,376,903	$ 4,376,543
NPV total costs	**$ 84,324,926**							

NPV Calculations for Societal Perspective: Considering Local Surface Water Supply

WSMP DATA	7	8	9	10	11	12	13	14
Year	2013	2014	2015	2016	2017	2018	2019	2020
Total peak demand (1.5 PF)	83,462	84,615	85,769	86,923	88,077	89,231	90,385	91,538
Total average demand	55,641	56,410	57,179	57,949	58,718	59,487	60,256	61,026
Capital Costs								
Existing groundwater supply	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 632,140	$ 632,140	$ 632,140	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ 7,215,200
Local surface water supply	$ 100,000	$ 100,000	$ 100,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
O/M Costs								
Existing groundwater								
New groundwater								
Regional surface water supply								

BASE CASE: WCESU CONSERVATION	7	8	9	10	11	12	13	14
Year	2013	2014	2015	2016	2017	2018	2019	2020
Population (1.5% growth)	127,569	129,482	131,425	133,396	135,397	137,428	139,489	141,582
Total average demand (no conservation)	57,032	57,887	58,755	59,637	60,531	61,439	62,361	63,296
Total average demand (WCESU goal)	52,572	52,741	52,910	53,079	53,249	53,418	53,587	54,391
Capital Costs								
Conservation	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	
Existing groundwater supply	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ 25,000	$ 25,000	$ 25,000	$ 150,000	$ 632,140
Local surface water supply	$ -	$ -	$ -	$ 150,000	$ 150,000	$ 150,000	$ 100,000	$ 100,000
O/M Costs								
Conservation	$ 98,814	$ 147,671	$ 565,858	$ 134,448	$ 135,447	$ 136,447	$ 137,447	$ 616,606
Existing groundwater	$ 1,189,698	$ 1,193,528	$ 1,197,358	$ 1,201,189	$ 1,205,019	$ 1,208,849	$ 1,212,679	$ 1,230,869
New groundwater								
Local surface water								
Homeowner softening (salt)	$ 14,551	$ 14,598	$ 14,645	$ 14,692	$ 14,739	$ 14,786	$ 14,832	$ 15,055
Carbon emissions								
Ground water	$ 101,563	$ 101,890	$ 102,217	$ 102,544	$ 102,871	$ 103,198	$ 103,525	$ 105,078
Surface water								
Present Value								
Discounted total costs	$ 4,015,447	$ 3,746,674	$ 3,680,443	$ 1,639,395	$ 1,520,190	$ 1,409,650	$ 1,334,722	$ 919,159
NPV total costs								

NPV Calculations for Societal Perspective: Considering Local Surface Water Supply

WSMP DATA	15	16	17	18	19	20	21	22
Year	2021	2022	2023	2024	2025	2026	2027	2028
Total peak demand (1.5 PF)	92,692	93,846	95,000	97,586	100,172	102,759	105,345	107,931
Total average demand	61,795	62,564	63,333	65,057	66,782	68,506	70,230	71,954
Capital Costs								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Local surface water supply	$ 14,000,000	$ 14,000,000	$ 14,000,000	$ 14,000,000	$ 14,000,000	$ 1,055,500	$ 1,055,500	$ 1,055,500
O/M Costs								
Existing groundwater								
New groundwater								
Regional surface water supply								

BASE CASE: WCESU CONSERVATION	15	16	17	18	19	20	21	22
Year	2021	2022	2023	2024	2025	2026	2027	2028
Population (1.5% growth)	143,705	145,861	148,049	150,270	152,524	154,812	157,134	159,491
Total average demand (no conservation)	64,246	65,209	66,188	67,180	68,188	69,211	70,249	71,303
Total average demand (WCESU goal)	55,207	56,035	56,876	57,729	58,595	59,474	60,366	61,271
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 632,140	$ 632,140	$ 632,140	$ 632,140	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ 7,215,200
Local surface water supply	$ 100,000	$ 100,000	$ 100,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
O/M Costs								
Conservation								
Existing groundwater	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332
New groundwater	$ 13,996	$ 28,202	$ 42,621	$ 57,257	$ 72,112	$ 87,190	$ 102,494	$ 102,494
Local surface water								$ 26,440
Homeowner softening (salt)	$ 15,281	$ 15,510	$ 15,743	$ 15,979	$ 16,218	$ 16,462	$ 16,709	
Carbon emissions								
Ground water	$ 106,654	$ 108,254	$ 109,878	$ 111,526	$ 113,199	$ 114,897	$ 116,620	$ 118,369
Surface water								$ 1,585
Present Value								
Discounted total costs	$ 667,494	$ 622,730	$ 581,001	$ 567,123	$ 2,054,373	$ 1,905,849	$ 1,768,107	$ 1,639,539
NPV total costs								

NPV Calculations for Societal Perspective: Considering Local Surface Water Supply

WSMP DATA	23	24	25	26	27	28	29	30
Year	2029	2030	2031	2032	2033	2034	2035	2036
Total peak demand (1.5 PF)	110,517	113,103	115,690	118,276	120,862	123,448	126,034	128,621
Total average demand	73,678	75,402	77,126	78,851	80,575	82,299	84,023	85,747
Capital Costs								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Local surface water supply	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ -
O/M Costs								
Existing groundwater								
New groundwater								
Regional surface water supply								

BASE CASE: WCESU CONSERVATION	23	24	25	26	27	28	29	30
Year	2029	2030	2031	2032	2033	2034	2035	2036
Population (1.5% growth)	161,883	164,311	166,776	169,278	171,817	174,394	177,010	179,665
Total average demand (no conservation)	72,372	73,458	74,560	75,678	76,813	77,965	79,135	80,322
Total average demand (WCESU goal)	62,190	63,123	64,070	65,031	66,006	66,996	68,001	69,021
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 7,215,200	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Local surface water supply	$ 14,000,000	$ 14,000,000	$ 14,000,000	$ 14,000,000	$ 14,000,000	$ 1,055,500	$ 1,055,500	$ 1,055,500
O/M Costs								
Conservation								
Existing groundwater	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332
New groundwater	$ 102,494	$ 102,494	$ 102,494	$ 102,494	$ 102,494	$ 102,494	$ 102,494	$ 102,494
Local surface water	$ 53,277	$ 80,516	$ 108,164	$ 136,227	$ 164,710	$ 193,621	$ 222,965	$ 252,750
Homeowner softening (salt)								
Carbon emissions								
Ground water	$ 120,145	$ 121,947	$ 123,776	$ 125,633	$ 127,517	$ 129,430	$ 131,372	$ 133,342
Surface water	$ 3,194	$ 4,828	$ 6,485	$ 8,168	$ 9,876	$ 11,609	$ 13,369	$ 15,154
Present Value								
Discounted total costs	$ 3,873,590	$ 2,453,662	$ 2,276,456	$ 2,112,102	$ 1,959,666	$ 317,834	$ 297,837	$ 279,108
NPV total costs								

NPV Calculations for Societal Perspective: Considering Local Surface Water Supply

WSMP DATA	31	32	33	34	35	36	37	38
Year	2037	2038	2039	2040	2041	2042	2043	2044
Total peak demand (1.5 PF)	131,207	133,793	136,379	138,966	141,552	144,138	146,724	149,310
Total average demand	87,471	89,195	90,920	92,644	94,368	96,092	97,816	99,540
Capital Costs								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Local surface water supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
O/M Costs								
Existing groundwater								
New groundwater								
Regional surface water supply								

BASE CASE: WCESU CONSERVATION	31	32	33	34	35	36	37	38
Year	2037	2038	2039	2040	2041	2042	2043	2044
Population (1.5% growth)	182,360	185,096	187,872	190,690	193,550	196,454	199,400	202,391
Total average demand (no conservation)	81,527	82,750	83,991	85,251	86,530	87,828	89,145	90,482
Total average demand (WCESU goal)	70,057	71,108	72,174	73,257	74,356	75,471	76,603	77,752
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Local surface water supply	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ -
O/M Costs								
Conservation								
Existing groundwater	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332
New groundwater	$ 102,494	$ 102,494	$ 102,494	$ 102,494	$ 102,494	$ 102,494	$ 102,494	$ 102,494
Local surface water	$ 282,981	$ 313,666	$ 344,811	$ 376,424	$ 408,510	$ 441,078	$ 474,134	$ 507,686
Homeowner softening (salt)								
Carbon emissions								
Ground water	$ 135,342	$ 137,372	$ 139,433	$ 141,525	$ 143,647	$ 145,802	$ 147,989	$ 150,209
Surface water	$ 16,967	$ 18,807	$ 20,674	$ 22,570	$ 24,494	$ 26,446	$ 28,428	$ 30,440
Present Value								
Discounted total costs	$ 261,566	$ 245,135	$ 229,744	$ 215,326	$ 201,820	$ 189,167	$ 177,313	$ 109,537
NPV total costs								

NPV Calculations for Societal Perspective: Considering Local Surface Water Supply

WSMP DATA	39	40	41	42	43	44	45
Year	2045	2046	2047	2048	2049	2050	2051
Total peak demand (1.5 PF)	151,897	154,483	157,069	159,655	162,241	164,828	167,414
Total average demand	101,264	102,989	104,713	106,437	108,161	109,885	111,609
Capital Costs							
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Local surface water supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
O/M Costs							
Existing groundwater							
New groundwater							
Regional surface water supply							

BASE CASE: WCESU CONSERVATION	39	40	41	42	43	44	45
Year	2045	2046	2047	2048	2049	2050	2051
Population (1.5% growth)	205,427	208,509	211,636	214,811	218,033	221,304	224,623
Total average demand (no conservation)	91,839	93,217	94,615	96,034	97,475	98,937	100,421
Total average demand (WCESU goal)	78,918	80,102	81,304	82,523	83,761	85,018	86,293
Capital Costs							
Conservation							
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Local surface water supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
O/M Costs							
Conservation							
Existing groundwater	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332
New groundwater	$ 102,494	$ 102,494	$ 102,494	$ 102,494	$ 102,494	$ 102,494	$ 102,494
Local surface water	$ 541,742	$ 576,308	$ 611,393	$ 647,004	$ 683,149	$ 719,836	$ 757,074
Homeowner softening (salt)							
Carbon emissions							
Ground water	$ 152,462	$ 154,749	$ 157,070	$ 159,426	$ 161,818	$ 164,245	$ 166,709
Surface water	$ 32,482	$ 34,554	$ 36,658	$ 38,793	$ 40,960	$ 43,160	$ 45,393
Present Value							
Discounted total costs	$ 103,330	$ 97,468	$ 91,932	$ 86,705	$ 81,769	$ 77,110	$ 72,712
NPV total costs							

NPV Calculations for Societal Perspective: Considering Local Surface Water Supply

WCESU CONSERVATION AND RWH		0	1	2	3	4	5	6
Year		2006	2007	2008	2009	2010	2011	2012
Population (1.5% growth)		114,943	116,667	118,417	120,193	121,996	123,826	125,684
Total average demand (no conservation)	m3/day	51,387	52,158	52,940	53,734	54,540	55,358	56,189
Total average demand (WCESU conservation)	m3/day	51,387	51,556	51,725	51,895	52,064	52,233	52,402
Total RW demand	m3/day	62	125	189	254	320	387	455
Total average mains demand	m3/day	51,325	51,431	51,536	51,640	51,744	51,846	51,947
Capital Costs								
Conservation			300,500	325,200	375,600	1,990,959	1,990,959	1,990,959
Existing groundwater supply		$ -	$ 1,907,363	$ 7,143,887	$ 6,464,375	$ 13,346,700	$ 3,565,685	$ 3,565,685
New groundwater supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
Local surface water supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
RWH supply		$ 2,603,980	$ 2,643,039	$ 2,682,685	$ 2,722,925	$ 2,763,769	$ 2,805,226	$ 2,847,304
O/M Costs								
Conservation							$ 1,046,386	$ 86,771
Existing groundwater supply		$ 1,161,481	$ 1,163,883	$ 1,166,263	$ 1,168,622	$ 1,170,958	$ 1,173,273	$ 1,175,564
New groundwater supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
Homeowner softening (salt)		$ 14,206	$ 14,236	$ 14,265	$ 14,294	$ 14,322	$ 14,350	$ 14,378
RWH supply		$ 11,250	$ 22,668	$ 34,258	$ 46,022	$ 57,962	$ 70,081	$ 82,382
Carbon emissions								
Ground water suppy		$ 99,154	$ 99,359	$ 99,562	$ 99,764	$ 99,963	$ 100,161	$ 100,356
Surface water supply								
RWH supply		$ 141	$ 284	$ 429	$ 576	$ 725	$ 877	$ 1,031
Present Value								
Discounted capital costs		$ 2,603,980	$ 4,491,576	$ 8,703,508	$ 7,591,339	$ 13,305,090	$ 5,690,948	$ 5,295,913
Discounted maintenance costs		$ 1,186,937	$ 1,111,839	$ 1,041,483	$ 975,570	$ 913,820	$ 1,568,125	$ 856,461
Discounted carbon cost		$ 99,295	$ 92,262	$ 85,726	$ 79,653	$ 74,009	$ 68,765	$ 63,891
Discounted total costs		$ 3,890,211	$ 5,695,678	$ 9,830,718	$ 8,646,561	$ 14,292,920	$ 7,327,838	$ 6,216,265
NPV total costs	**$ 122,609,329**							

NPV Calculations for Societal Perspective: Considering Local Surface Water Supply

WCESU CONSERVATION AND RWH	7	8	9	10	11	12	13	14
Year	2013	2014	2015	2016	2017	2018	2019	2020
Population (1.5% growth)	127,569	129,482	131,425	133,396	135,397	137,428	139,489	141,582
Total average demand (no conservation)	57,032	57,887	58,755	59,637	60,531	61,439	62,361	63,296
Total average demand (WCESU conservation)	52,572	52,741	52,910	53,079	53,249	53,418	53,587	54,391
Total RW demand	524	594	665	738	811	885	961	1,037
Total average mains demand	52,047	52,147	52,245	52,342	52,438	52,533	52,627	53,354
Capital Costs								
Conservation	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	
Existing groundwater supply	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ 25,000	$ 25,000	$ 25,000
Local surface water supply	$ -	$ -	$ -	$ -	$ -	$ -	$ 150,000	$ 150,000
RWH supply	$ 2,890,014	$ 2,933,364	$ 2,977,364	$ 3,022,025	$ 3,067,355	$ 3,113,365	$ 3,160,066	$ 3,207,467
O/M Costs								
Conservation	$ 98,814	$ 147,671	$ 565,858	$ 134,448	$ 135,447	$ 136,447	$ 137,447	$ 616,606
Existing groundwater supply	$ 1,177,833	$ 1,180,078	$ 1,182,299	$ 1,184,496	$ 1,186,669	$ 1,188,816	$ 1,190,939	$ 1,207,396
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Homeowner softening (salt)	$ 14,406	$ 14,434	$ 14,461	$ 14,488	$ 14,514	$ 14,541	$ 14,567	$ 14,768
RWH supply	$ 94,868	$ 107,540	$ 120,403	$ 332,303	$ 348,538	$ 365,016	$ 381,741	$ 398,716
Carbon emissions								
Ground water suppy	$ 100,550	$ 100,742	$ 100,931	$ 101,119	$ 101,304	$ 101,488	$ 101,669	$ 103,074
Surface water supply								
RWH supply	$ 1,187	$ 1,346	$ 1,507	$ 1,670	$ 1,836	$ 2,004	$ 2,175	$ 2,348
Present Value								
Discounted capital costs	$ 4,882,156	$ 4,543,936	$ 4,229,359	$ 2,285,158	$ 2,135,328	$ 2,005,355	$ 1,929,136	$ 1,151,598
Discounted maintenance costs	$ 808,671	$ 783,240	$ 941,979	$ 771,558	$ 722,739	$ 677,007	$ 634,166	$ 761,777
Discounted carbon cost	$ 59,363	$ 55,155	$ 51,244	$ 47,611	$ 44,235	$ 41,098	$ 38,183	$ 35,892
Discounted total costs	$ 5,750,190	$ 5,382,330	$ 5,222,583	$ 3,104,326	$ 2,902,303	$ 2,723,460	$ 2,601,486	$ 1,949,267
NPV total costs								

WCESU CONSERVATION AND RWH	15	16	17	18	19	20	21	22
Year	2021	2022	2023	2024	2025	2026	2027	2028
Population (1.5% growth)	143,705	145,861	148,049	150,270	152,524	154,812	157,134	159,491
Total average demand (no conservation)	64,246	65,209	66,188	67,180	68,188	69,211	70,249	71,303
Total average demand (WCESU conservation)	55,207	56,035	56,876	57,729	58,595	59,474	60,366	61,271
Total RW demand	1,115	1,194	1,274	1,355	1,438	1,522	1,607	1,693
Total average mains demand	54,092	54,841	55,602	56,373	57,157	57,952	58,759	59,578
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 150,000	$ 632,140	$ 632,140	$ 632,140	$ 632,140	$ 632,140	$ 7,215,200	$ 7,215,200
Local surface water supply	$ 150,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 200,000	$ 200,000
RWH supply	$ 3,255,579	$ 3,304,413	$ 3,353,979	$ 3,404,288	$ 3,455,353	$ 3,507,183	$ 3,559,791	$ 3,613,188
O/M Costs								
Conservation								
Existing groundwater supply	$ 1,224,100	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054
New groundwater supply	$ -	$ -	$ 13,045	$ 26,286	$ 39,726	$ 53,367	$ 67,213	$ 81,267
Regional surface water supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Homeowner softening (salt)	$ 14,972	$ 15,179	$ 15,390	$ 15,604	$ 15,820	$ 16,041	$ 16,264	$ 16,491
RWH supply	$ 415,947	$ 433,436	$ 451,187	$ 469,205	$ 487,493	$ 679,577	$ 701,020	$ 722,785
Carbon emissions								
Ground water suppy	$ 104,500	$ 105,947	$ 107,416	$ 108,907	$ 110,421	$ 111,957	$ 113,516	$ 115,099
Surface water supply								
RWH supply	$ 2,524	$ 2,703	$ 2,884	$ 3,068	$ 3,255	$ 3,445	$ 3,637	$ 3,832
Present Value								
Discounted capital costs	$ 1,120,867	$ 1,178,231	$ 1,104,351	$ 1,035,137	$ 970,293	$ 909,539	$ 2,180,245	$ 2,028,567
Discounted maintenance costs	$ 521,731	$ 493,198	$ 465,046	$ 438,474	$ 413,396	$ 426,959	$ 402,387	$ 379,211
Discounted carbon cost	$ 33,738	$ 31,714	$ 29,811	$ 28,022	$ 26,340	$ 24,759	$ 23,273	$ 21,876
Discounted total costs	$ 1,676,336	$ 1,703,144	$ 1,599,207	$ 1,501,633	$ 1,410,029	$ 1,361,258	$ 2,605,906	$ 2,429,655
NPV total costs								

NPV Calculations for Societal Perspective: Considering Local Surface Water Supply

WCESU CONSERVATION AND RWH	23	24	25	26	27	28	29	30
Year	2029	2030	2031	2032	2033	2034	2035	2036
Population (1.5% growth)	161,883	164,311	166,776	169,278	171,817	174,394	177,010	179,665
Total average demand (no conservation)	72,372	73,458	74,560	75,678	76,813	77,965	79,135	80,322
Total average demand (WCESU conservation)	62,190	63,123	64,070	65,031	66,006	66,996	68,001	69,021
Total RW demand	1,780	1,869	1,959	2,051	2,144	2,238	2,334	2,431
Total average mains demand	60,410	61,254	62,110	62,980	63,862	64,758	65,667	66,590
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ -	$ -	$ -	$ -	$ -
Local surface water supply	$ 200,000	$ 200,000	$ 200,000	$ 14,000,000	$ 14,000,000	$ 14,000,000	$ 14,000,000	$ 14,000,000
RWH supply	$ 3,667,385	$ 3,722,396	$ 3,778,232	$ 3,834,906	$ 3,892,429	$ 3,950,816	$ 4,010,078	$ 4,070,229
O/M Costs								
Conservation								
Existing groundwater supply	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054
New groundwater supply	$ 95,531	$ 110,009	$ 110,009	$ 110,009	$ 110,009	$ 110,009	$ 110,009	$ 110,009
Regional surface water supply	$ -	$ -	$ 25,014	$ 50,402	$ 76,172	$ 102,328	$ 128,877	$ 155,823
Homeowner softening (salt)	$ 16,721	$ 16,954						
RWH supply	$ 744,877	$ 767,300	$ 790,059	$ 813,160	$ 836,607	$ 860,406	$ 884,562	$ 1,082,602
Carbon emissions								
Ground water suppy	$ 116,705	$ 118,336	$ 118,336	$ 118,336	$ 118,336	$ 118,336	$ 118,336	$ 118,336
Surface water supply			$ 1,500	$ 3,022	$ 4,567	$ 6,135	$ 7,727	$ 9,343
RWH supply	$ 4,031	$ 4,232	$ 4,436	$ 4,643	$ 4,854	$ 5,067	$ 5,284	$ 5,504
Present Value								
Discounted capital costs	$ 1,887,534	$ 1,756,392	$ 1,634,442	$ 2,411,311	$ 2,239,896	$ 2,080,746	$ 1,932,977	$ 1,795,771
Discounted maintenance costs	$ 357,353	$ 336,738	$ 316,295	$ 299,421	$ 283,403	$ 268,201	$ 253,776	$ 257,336
Discounted carbon cost	$ 20,563	$ 19,329	$ 18,146	$ 17,036	$ 15,993	$ 15,015	$ 14,097	$ 13,235
Discounted total costs	$ 2,265,450	$ 2,112,459	$ 1,968,882	$ 2,727,768	$ 2,539,293	$ 2,363,962	$ 2,200,850	$ 2,066,343
NPV total costs								

NPV Calculations for Societal Perspective: Considering Local Surface Water Supply

WCESU CONSERVATION AND RWH	31	32	33	34	35	36	37	38
Year	2037	2038	2039	2040	2041	2042	2043	2044
Population (1.5% growth)	182,360	185,096	187,872	190,690	193,550	196,454	199,400	202,391
Total average demand (no conservation)	81,527	82,750	83,991	85,251	86,530	87,828	89,145	90,482
Total average demand (WCESU conservation)	70,057	71,108	72,174	73,257	74,356	75,471	76,603	77,752
Total RW demand	2,530	2,630	2,732	2,835	2,940	3,046	3,154	3,263
Total average mains demand	67,527	68,478	69,443	70,422	71,416	72,425	73,449	74,489
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Local surface water supply	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500	$ 1,055,500
RWH supply	$ 4,131,283	$ 4,193,252	$ 4,256,151	$ 4,319,993	$ 4,384,793	$ 4,450,565	$ 4,517,323	$ 4,585,083
O/M Costs								
Conservation								
Existing groundwater supply	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054
New groundwater supply	$ 110,009	$ 110,009	$ 110,009	$ 110,009	$ 110,009	$ 110,009	$ 110,009	$ 110,009
Regional surface water supply	$ 183,174	$ 210,935	$ 239,113	$ 267,713	$ 296,742	$ 326,207	$ 356,114	$ 386,469
Homeowner softening (salt)								
RWH supply	$ 1,110,091	$ 1,137,992	$ 1,166,312	$ 1,195,056	$ 1,224,232	$ 1,253,845	$ 1,283,903	$ 1,314,411
Carbon emissions								
Ground water suppy	$ 118,336	$ 118,336	$ 118,336	$ 118,336	$ 118,336	$ 118,336	$ 118,336	$ 118,336
Surface water supply	$ 10,983	$ 12,647	$ 14,337	$ 16,052	$ 17,792	$ 19,559	$ 21,352	$ 23,172
RWH supply	$ 5,728	$ 5,954	$ 6,184	$ 6,418	$ 6,655	$ 6,895	$ 7,140	$ 7,388
Present Value								
Discounted capital costs	$ 477,267	$ 447,194	$ 419,030	$ 392,655	$ 367,952	$ 344,815	$ 323,144	$ 302,846
Discounted maintenance costs	$ 243,321	$ 230,039	$ 217,456	$ 205,537	$ 194,249	$ 183,560	$ 173,440	$ 163,860
Discounted carbon cost	$ 12,426	$ 11,667	$ 10,954	$ 10,285	$ 9,657	$ 9,067	$ 8,514	$ 7,994
Discounted total costs	$ 733,014	$ 688,900	$ 647,441	$ 608,477	$ 571,858	$ 537,442	$ 505,098	$ 474,700
NPV total costs								

WCESU CONSERVATION AND RWH	39	40	41	42	43	44	45
Year	2045	2046	2047	2048	2049	2050	2051
Population (1.5% growth)	205,427	208,509	211,636	214,811	218,033	221,304	224,623
Total average demand (no conservation)	91,839	93,217	94,615	96,034	97,475	98,937	100,421
Total average demand (WCESU conservation)	78,918	80,102	81,304	82,523	83,761	85,018	86,293
Total RW demand	3,374	3,487	3,602	3,718	3,836	3,955	4,077
Total average mains demand	75,544	76,615	77,702	78,806	79,925	81,062	82,216
Capital Costs							
Conservation							
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Local surface water supply	$ 1,055,500	$ 1,055,500	$ -	$ -	$ -	$ -	$ -
RWH supply	$ 4,653,859	$ 4,723,667	$ 4,794,522	$ 4,866,440	$ 4,939,437	$ 5,013,528	$ 5,088,731
O/M Costs							
Conservation							
Existing groundwater supply	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054
New groundwater supply	$ 110,009	$ 110,009	$ 110,009	$ 110,009	$ 110,009	$ 110,009	$ 110,009
Regional surface water supply	$ 417,280	$ 448,552	$ 480,294	$ 512,512	$ 545,214	$ 578,405	$ 612,095
Homeowner softening (salt)							
RWH supply	$ 1,345,377	$ 1,550,329	$ 1,584,834	$ 1,619,856	$ 1,655,404	$ 1,691,485	-$ 83,995,826
Carbon emissions							
Ground water suppy	$ 118,336	$ 118,336	$ 118,336	$ 118,336	$ 118,336	$ 118,336	$ 118,336
Surface water supply	$ 25,019	$ 26,894	$ 28,798	$ 30,729	$ 32,690	$ 34,680	$ 36,700
RWH supply	$ 7,639	$ 7,894	$ 8,154	$ 8,417	$ 8,684	$ 8,955	$ 9,230
Present Value							
Discounted capital costs	$ 283,832	$ 266,020	$ 204,348	$ 192,050	$ 180,491	$ 169,628	$ 159,419
Discounted maintenance costs	$ 154,794	$ 154,201	$ 145,602	$ 137,471	$ 129,781	$ 122,512	-$ 2,569,910
Discounted carbon cost	$ 7,506	$ 7,048	$ 6,619	$ 6,215	$ 5,836	$ 5,480	$ 5,146
Discounted total costs	$ 446,132	$ 427,270	$ 356,569	$ 335,735	$ 316,108	$ 297,620	-$ 2,405,344
NPV total costs							

NPV Calculations for Societal Perspective: Considering Regional Surface Water Supply

WSMP DATA		0	1	2	3	4	5	6
Year		2006	2007	2008	2009	2010	2011	2012
Total peak demand (1.5 PF)	m3/day	80,000	80,000	80,000	80,000	80,000	81,154	82,308
Total average demand		53,333	53,333	53,333	53,333	53,333	54,103	54,872
Capital Costs								
Existing groundwater supply		$ -	$ 1,907,363	$ 7,143,887	$ 6,464,375	$ 13,346,700	$ 3,565,685	$ 3,565,685
New groundwater supply		$ -	$ 25,000	$ 25,000	$ 25,000	$ 150,000	$ 632,140	$ 632,140
Regional surface water supply		$ -	$ 80,000	$ -	$ -	$ -	$ 50,000	$ 50,000
O/M Costs				**Carbon Costs**				
Existing groundwater	per m3	$ 0.062		Energy intensity - Surface water		kWh/ m3	0.58	
New groundwater	per m3	$ 0.047		Energy intensity - Ground water		kWh/ m3	0.64	
Regional surface water supply	per m3	$ 0.080		Energy intensity - Rainwater		kWh/ m3	0.75	
				Carbon emission from electricity		tonnes/kWh	0.000270	
				Carbon cost		per tonne	$ 30.63	

BASE CASE: WCESU CONSERVATION		0	1	2	3	4	5	6
Year		2006	2007	2008	2009	2010	2011	2012
Population (1.5% growth)		114,943	116,667	118,417	120,193	121,996	123,826	125,684
Total average demand (no conservation)	m3/day	51,387	52,158	52,940	53,734	54,540	55,358	56,189
Total average demand (WCESU goal)	m3/day	51,387	51,556	51,725	51,895	52,064	52,233	52,402
Capital Costs								
Conservation			300,500	325,200	375,600	1,990,959	1,990,959	1,990,959
Existing groundwater supply		$ -	$ 1,907,363	$ 7,143,887	$ 6,464,375	$ 13,346,700	$ 3,565,685	$ 3,565,685
New groundwater supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
O/M Costs								
Conservation							$ 1,046,386	$ 86,771
Existing groundwater		$ 1,162,888	$ 1,166,718	$ 1,170,548	$ 1,174,378	$ 1,178,208	$ 1,182,038	$ 1,185,868
New groundwater								
Regional surface water supply								
Homeowner softening (salt)		$ 14,223	$ 14,270	$ 14,317	$ 14,364	$ 14,411	$ 14,458	$ 14,505
Carbon emissions								
Ground water		$ 99,274	$ 99,601	$ 99,928	$ 100,255	$ 100,582	$ 100,909	$ 101,236
Surface water								
Present Value								
Discounted total costs		$ 1,177,111	$ 3,137,825	$ 7,419,369	$ 6,373,454	$ 12,150,248	$ 5,308,226	$ 4,312,747
NPV total costs	**$ 141,798,380**							

NPV Calculations for Societal Perspective: Considering Regional Surface Water Supply

WSMP DATA	7	8	9	10	11	12	13	14
Year	2013	2014	2015	2016	2017	2018	2019	2020
Total peak demand (1.5 PF)	83,462	84,615	85,769	86,923	88,077	89,231	90,385	91,538
Total average demand	55,641	56,410	57,179	57,949	58,718	59,487	60,256	61,026
Capital Costs								
Existing groundwater supply	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 632,140	$ 632,140	$ 632,140	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ 7,215,200
Regional surface water supply	$ 50,000	$ 50,000	$ 50,000	$ 10,583,000	$ 10,583,000	$ 10,583,000	$ 10,583,000	$ 10,583,000
O/M Costs								
Existing groundwater								
New groundwater								
Regional surface water supply								

BASE CASE: WCESU CONSERVATION	7	8	9	10	11	12	13	14
Year	2013	2014	2015	2016	2017	2018	2019	2020
Population (1.5% growth)	127,569	129,482	131,425	133,396	135,397	137,428	139,489	141,582
Total average demand (no conservation)	57,032	57,887	58,755	59,637	60,531	61,439	62,361	63,296
Total average demand (WCESU goal)	52,572	52,741	52,910	53,079	53,249	53,418	53,587	54,391
Capital Costs								
Conservation	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	
Existing groundwater supply	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ 25,000	$ 25,000	$ 25,000	$ 150,000	$ 632,140
Regional surface water supply	$ -	$ -	$ 80,000	$ -	$ -	$ -	$ 50,000	$ 50,000
O/M Costs								
Conservation	$ 98,814	$ 147,671	$ 565,858	$ 134,448	$ 135,447	$ 136,447	$ 137,447	$ 616,606
Existing groundwater	$ 1,189,698	$ 1,193,528	$ 1,197,358	$ 1,201,189	$ 1,205,019	$ 1,208,849	$ 1,212,679	$ 1,230,869
New groundwater								
Regional surface water supply								
Homeowner softening (salt)	$ 14,551	$ 14,598	$ 14,645	$ 14,692	$ 14,739	$ 14,786	$ 14,832	$ 15,055
Carbon emissions								
Ground water	$ 101,563	$ 101,890	$ 102,217	$ 102,544	$ 102,871	$ 103,198	$ 103,525	$ 105,078
Surface water								
Present Value								
Discounted total costs	$ 3,956,186	$ 3,691,626	$ 3,669,329	$ 1,522,419	$ 1,411,738	$ 1,309,102	$ 1,278,271	$ 902,136
NPV total costs								

NPV Calculations for Societal Perspective: Considering Regional Surface Water Supply

WSMP DATA	15	16	17	18	19	20	21	22
Year	2021	2022	2023	2024	2025	2026	2027	2028
Total peak demand (1.5 PF)	92,692	93,846	95,000	97,586	100,172	102,759	105,345	107,931
Total average demand	61,795	62,564	63,333	65,057	66,782	68,506	70,230	71,954
Capital Costs								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000
O/M Costs								
Existing groundwater								
New groundwater								
Regional surface water supply								

BASE CASE: WCESU CONSERVATION	15	16	17	18	19	20	21	22
Year	2021	2022	2023	2024	2025	2026	2027	2028
Population (1.5% growth)	143,705	145,861	148,049	150,270	152,524	154,812	157,134	159,491
Total average demand (no conservation)	64,246	65,209	66,188	67,180	68,188	69,211	70,249	71,303
Total average demand (WCESU goal)	55,207	56,035	56,876	57,729	58,595	59,474	60,366	61,271
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 632,140	$ 632,140	$ 632,140	$ 632,140	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ 7,215,200
Regional surface water supply	$ 50,000	$ 50,000	$ 50,000	$ 10,583,000	$ 10,583,000	$ 10,583,000	$ 10,583,000	$ 10,583,000
O/M Costs								
Conservation								
Existing groundwater	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ 1,249,332	$ -
New groundwater	$ 13,996	$ 28,202	$ 42,621	$ 57,257	$ 72,112	$ 87,190	$ 102,494	$ -
Regional surface water supply								$ 1,789,116
Homeowner softening (salt)	$ 15,281	$ 15,510	$ 15,743	$ 15,979	$ 16,218	$ 16,462	$ 16,709	
Carbon emissions								
Ground water	$ 106,654	$ 108,254	$ 109,878	$ 111,526	$ 113,199	$ 114,897	$ 116,620	$ -
Surface water								$ 107,272
Present Value								
Discounted total costs	$ 651,732	$ 608,136	$ 567,487	$ 3,165,458	$ 4,460,240	$ 4,133,503	$ 3,830,749	$ 3,622,633
NPV total costs								

NPV Calculations for Societal Perspective: Considering Regional Surface Water Supply

WSMP DATA	23	24	25	26	27	28	29	30
Year	2029	2030	2031	2032	2033	2034	2035	2036
Total peak demand (1.5 PF)	110,517	113,103	115,690	118,276	120,862	123,448	126,034	128,621
Total average demand	73,678	75,402	77,126	78,851	80,575	82,299	84,023	85,747
Capital Costs								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 9,579,480
O/M Costs								
Existing groundwater								
New groundwater								
Regional surface water supply								

BASE CASE: WCESU CONSERVATION	23	24	25	26	27	28	29	30
Year	2029	2030	2031	2032	2033	2034	2035	2036
Population (1.5% growth)	161,883	164,311	166,776	169,278	171,817	174,394	177,010	179,665
Total average demand (no conservation)	72,372	73,458	74,560	75,678	76,813	77,965	79,135	80,322
Total average demand (WCESU goal)	62,190	63,123	64,070	65,031	66,006	66,996	68,001	69,021
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 7,215,200	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000
O/M Costs								
Conservation								
Existing groundwater	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 1,815,953	$ 1,843,192	$ 1,870,840	$ 1,898,902	$ 1,927,386	$ 1,956,297	$ 1,985,641	$ 2,015,426
Homeowner softening (salt)								
Carbon emissions								
Ground water	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Surface water	$ 108,881	$ 110,515	$ 112,172	$ 113,855	$ 115,563	$ 117,296	$ 119,056	$ 120,841
Present Value								
Discounted total costs	$ 8,369,299	$ 6,616,072	$ 6,130,271	$ 5,680,199	$ 5,263,223	$ 3,717,769	$ 3,445,717	$ 3,193,616
NPV total costs								

NPV Calculations for Societal Perspective: Considering Regional Surface Water Supply

WSMP DATA	31	32	33	34	35	36	37	38
Year	2037	2038	2039	2040	2041	2042	2043	2044
Total peak demand (1.5 PF)	131,207	133,793	136,379	138,966	141,552	144,138	146,724	149,310
Total average demand	87,471	89,195	90,920	92,644	94,368	96,092	97,816	99,540
Capital Costs								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480
O/M Costs								
Existing groundwater								
New groundwater								
Regional surface water supply								

BASE CASE: WCESU CONSERVATION	31	32	33	34	35	36	37	38
Year	2037	2038	2039	2040	2041	2042	2043	2044
Population (1.5% growth)	182,360	185,096	187,872	190,690	193,550	196,454	199,400	202,391
Total average demand (no conservation)	81,527	82,750	83,991	85,251	86,530	87,828	89,145	90,482
Total average demand (WCESU goal)	70,057	71,108	72,174	73,257	74,356	75,471	76,603	77,752
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 9,579,480
O/M Costs								
Conservation								
Existing groundwater	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 2,045,657	$ 2,076,342	$ 2,107,487	$ 2,139,099	$ 2,171,186	$ 2,203,754	$ 2,236,810	$ 2,270,362
Homeowner softening (salt)								
Carbon emissions								
Ground water	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Surface water	$ 122,654	$ 124,494	$ 126,361	$ 128,257	$ 130,180	$ 132,133	$ 134,115	$ 136,127
Present Value								
Discounted total costs	$ 2,960,001	$ 2,743,513	$ 2,542,894	$ 2,356,979	$ 2,184,688	$ 2,025,021	$ 1,877,051	$ 643,532
NPV total costs								

NPV Calculations for Societal Perspective: Considering Regional Surface Water Supply

WSMP DATA	39	40	41	42	43	44	45
Year	2045	2046	2047	2048	2049	2050	2051
Total peak demand (1.5 PF)	151,897	154,483	157,069	159,655	162,241	164,828	167,414
Total average demand	101,264	102,989	104,713	106,437	108,161	109,885	111,609
Capital Costs							
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 9,579,480	$ -	$ -	$ -	$ -	$ -	$ -
O/M Costs							
Existing groundwater							
New groundwater							
Regional surface water supply							

BASE CASE: WCESU CONSERVATION	39	40	41	42	43	44	45
Year	2045	2046	2047	2048	2049	2050	2051
Population (1.5% growth)	205,427	208,509	211,636	214,811	218,033	221,304	224,623
Total average demand (no conservation)	91,839	93,217	94,615	96,034	97,475	98,937	100,421
Total average demand (WCESU goal)	78,918	80,102	81,304	82,523	83,761	85,018	86,293
Capital Costs							
Conservation							
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480
O/M Costs							
Conservation							
Existing groundwater	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 2,304,418	$ 2,338,984	$ 2,374,069	$ 2,409,680	$ 2,445,825	$ 2,482,512	$ 2,519,750
Homeowner softening (salt)							
Carbon emissions							
Ground water	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Surface water	$ 138,169	$ 140,241	$ 142,345	$ 144,480	$ 146,647	$ 148,847	$ 151,080
Present Value							
Discounted total costs	$ 597,658	$ 555,073	$ 515,542	$ 478,843	$ 444,773	$ 413,143	$ 383,776
NPV total costs							

NPV Calculations for Societal Perspective: Considering Regional Surface Water Supply

WCESU CONSERVATION AND RWH		0	1	2	3	4	5	6
Year		2006	2007	2008	2009	2010	2011	2012
Population (1.5% growth)		114,943	116,667	118,417	120,193	121,996	123,826	125,684
Total average demand (no conservation)	m3/day	51,387	52,158	52,940	53,734	54,540	55,358	56,189
Total average demand (WCESU conservation)	m3/day	51,387	51,556	51,725	51,895	52,064	52,233	52,402
Total RW demand	m3/day	62	125	189	254	320	387	455
Total average mains demand	m3/day	51,325	51,431	51,536	51,640	51,744	51,846	51,947
Capital Costs								
Conservation			300,500	325,200	375,600	1,990,959	1,990,959	1,990,959
Existing groundwater supply		$ -	$ 1,907,363	$ 7,143,887	$ 6,464,375	$ 13,346,700	$ 3,565,685	$ 3,565,685
New groundwater supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
RWH supply	$ 170,738,818	$ 2,603,980	$ 2,643,039	$ 2,682,685	$ 2,722,925	$ 2,763,769	$ 2,805,226	$ 2,847,304
O/M Costs								
Conservation							$ 1,046,386	$ 86,771
Existing groundwater supply		$ 1,161,481	$ 1,163,883	$ 1,166,263	$ 1,168,622	$ 1,170,958	$ 1,173,273	$ 1,175,564
New groundwater supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply		$ -	$ -	$ -	$ -	$ -	$ -	$ -
Homeowner softening (salt)		$ 14,206	$ 14,236	$ 14,265	$ 14,294	$ 14,322	$ 14,350	$ 14,378
RWH supply	-$ 51,248,727	$ 11,250	$ 22,668	$ 34,258	$ 46,022	$ 57,962	$ 70,081	$ 82,382
Carbon emissions								
Ground water suppy		$ 99,154	$ 99,359	$ 99,562	$ 99,764	$ 99,963	$ 100,161	$ 100,356
Surface water supply								
RWH supply		$ 141	$ 284	$ 429	$ 576	$ 725	$ 877	$ 1,031
Present Value								
Discounted total costs		$ 3,890,211	$ 5,695,678	$ 9,830,718	$ 8,646,561	$ 14,292,920	$ 7,327,838	$ 6,216,265
NPV total costs	**$ 168,212,516**							

NPV Calculations for Societal Perspective: Considering Regional Surface Water Supply

WCESU CONSERVATION AND RWH	7	8	9	10	11	12	13	14
Year	2013	2014	2015	2016	2017	2018	2019	2020
Population (1.5% growth)	127,569	129,482	131,425	133,396	135,397	137,428	139,489	141,582
Total average demand (no conservation)	57,032	57,887	58,755	59,637	60,531	61,439	62,361	63,296
Total average demand (WCESU conservation)	52,572	52,741	52,910	53,079	53,249	53,418	53,587	54,391
Total RW demand	524	594	665	738	811	885	961	1,037
Total average mains demand	52,047	52,147	52,245	52,342	52,438	52,533	52,627	53,354
Capital Costs								
Conservation	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	1,911,459	
Existing groundwater supply	$ 3,565,685	$ 3,565,685	$ 3,565,685	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ 25,000	$ 25,000	$ 25,000
Regional surface water supply	$ -	$ -	$ -	$ -	$ -	$ 80,000	$ -	$ -
RWH supply	$ 2,890,014	$ 2,933,364	$ 2,977,364	$ 3,022,025	$ 3,067,355	$ 3,113,365	$ 3,160,066	$ 3,207,467
O/M Costs								
Conservation	$ 98,814	$ 147,671	$ 565,858	$ 134,448	$ 135,447	$ 136,447	$ 137,447	$ 616,606
Existing groundwater supply	$ 1,177,833	$ 1,180,078	$ 1,182,299	$ 1,184,496	$ 1,186,669	$ 1,188,816	$ 1,190,939	$ 1,207,396
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Homeowner softening (salt)	$ 14,406	$ 14,434	$ 14,461	$ 14,488	$ 14,514	$ 14,541	$ 14,567	$ 14,768
RWH supply	$ 94,868	$ 107,540	$ 120,403	$ 332,303	$ 348,538	$ 365,016	$ 381,741	$ 398,716
Carbon emissions								
Ground water suppy	$ 100,550	$ 100,742	$ 100,931	$ 101,119	$ 101,304	$ 101,488	$ 101,669	$ 103,074
Surface water supply								
RWH supply	$ 1,187	$ 1,346	$ 1,507	$ 1,670	$ 1,836	$ 2,004	$ 2,175	$ 2,348
Present Value								
Discounted total costs	$ 5,750,190	$ 5,382,330	$ 5,222,583	$ 3,104,326	$ 2,902,303	$ 2,755,229	$ 2,546,331	$ 1,898,198
NPV total costs								

NPV Calculations for Societal Perspective: Considering Regional Surface Water Supply

WCESU CONSERVATION AND RWH	15	16	17	18	19	20	21	22
Year	2021	2022	2023	2024	2025	2026	2027	2028
Population (1.5% growth)	143,705	145,861	148,049	150,270	152,524	154,812	157,134	159,491
Total average demand (no conservation)	64,246	65,209	66,188	67,180	68,188	69,211	70,249	71,303
Total average demand (WCESU conservation)	55,207	56,035	56,876	57,729	58,595	59,474	60,366	61,271
Total RW demand	1,115	1,194	1,274	1,355	1,438	1,522	1,607	1,693
Total average mains demand	54,092	54,841	55,602	56,373	57,157	57,952	58,759	59,578
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 150,000	$ 632,140	$ 632,140	$ 632,140	$ 632,140	$ 632,140	$ 7,215,200	$ 7,215,200
Regional surface water supply	$ -	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 10,583,000	$ 10,583,000
RWH supply	$ 3,255,579	$ 3,304,413	$ 3,353,979	$ 3,404,288	$ 3,455,353	$ 3,507,183	$ 3,559,791	$ 3,613,188
O/M Costs								
Conservation								
Existing groundwater supply	$ 1,224,100	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054	$ 1,241,054
New groundwater supply	$ -	$ -	$ 13,045	$ 26,286	$ 39,726	$ 53,367	$ 67,213	$ 81,267
Regional surface water supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Homeowner softening (salt)	$ 14,972	$ 15,179	$ 15,390	$ 15,604	$ 15,820	$ 16,041	$ 16,264	$ 16,491
RWH supply	$ 415,947	$ 433,436	$ 451,187	$ 469,205	$ 487,493	$ 679,577	$ 701,020	$ 722,785
Carbon emissions								
Ground water suppy	$ 104,500	$ 105,947	$ 107,416	$ 108,907	$ 110,421	$ 111,957	$ 113,516	$ 115,099
Surface water supply								
RWH supply	$ 2,524	$ 2,703	$ 2,884	$ 3,068	$ 3,255	$ 3,445	$ 3,637	$ 3,832
Present Value								
Discounted total costs	$ 1,629,050	$ 1,688,549	$ 1,585,694	$ 1,489,120	$ 1,398,443	$ 1,350,530	$ 4,668,548	$ 4,339,509
NPV total costs								

NPV Calculations for Societal Perspective: Considering Regional Surface Water Supply

WCESU CONSERVATION AND RWH	23	24	25	26	27	28	29	30
Year	2029	2030	2031	2032	2033	2034	2035	2036
Population (1.5% growth)	161,883	164,311	166,776	169,278	171,817	174,394	177,010	179,665
Total average demand (no conservation)	72,372	73,458	74,560	75,678	76,813	77,965	79,135	80,322
Total average demand (WCESU conservation)	62,190	63,123	64,070	65,031	66,006	66,996	68,001	69,021
Total RW demand	1,780	1,869	1,959	2,051	2,144	2,238	2,334	2,431
Total average mains demand	60,410	61,254	62,110	62,980	63,862	64,758	65,667	66,590
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 7,215,200	$ 7,215,200	$ 7,215,200	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 10,583,000	$ 10,583,000	$ 10,583,000	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 40,000,000	$ 40,000,000
RWH supply	$ 3,667,385	$ 3,722,396	$ 3,778,232	$ 3,834,906	$ 3,892,429	$ 3,950,816	$ 4,010,078	$ 4,070,229
O/M Costs								
Conservation								
Existing groundwater supply	$ 1,241,054	$ 1,241,054	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ 95,531	$ 110,009	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ -	$ -	$ 1,813,623	$ 1,839,012	$ 1,864,782	$ 1,890,938	$ 1,917,486	$ 1,944,433
Homeowner softening (salt)	$ 16,721	$ 16,954						
RWH supply	$ 744,877	$ 767,300	$ 790,059	$ 813,160	$ 836,607	$ 860,406	$ 884,562	$ 1,082,602
Carbon emissions								
Ground water suppy	$ 116,705	$ 118,336	$ -	$ -	$ -	$ -	$ -	$ -
Surface water supply			$ 108,742	$ 110,264	$ 111,809	$ 113,377	$ 114,969	$ 116,585
RWH supply	$ 4,031	$ 4,232	$ 4,436	$ 4,643	$ 4,854	$ 5,067	$ 5,284	$ 5,504
Present Value								
Discounted total costs	$ 4,033,833	$ 3,749,851	$ 3,547,256	$ 6,300,671	$ 5,847,537	$ 5,427,150	$ 5,037,136	$ 4,692,533
NPV total costs								

WCESU CONSERVATION AND RWH	31	32	33	34	35	36	37	38
Year	2037	2038	2039	2040	2041	2042	2043	2044
Population (1.5% growth)	182,360	185,096	187,872	190,690	193,550	196,454	199,400	202,391
Total average demand (no conservation)	81,527	82,750	83,991	85,251	86,530	87,828	89,145	90,482
Total average demand (WCESU conservation)	70,057	71,108	72,174	73,257	74,356	75,471	76,603	77,752
Total RW demand	2,530	2,630	2,732	2,835	2,940	3,046	3,154	3,263
Total average mains demand	67,527	68,478	69,443	70,422	71,416	72,425	73,449	74,489
Capital Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000	$ 30,000,000
RWH supply	$ 4,131,283	$ 4,193,252	$ 4,256,151	$ 4,319,993	$ 4,384,793	$ 4,450,565	$ 4,517,323	$ 4,585,083
O/M Costs								
Conservation								
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 1,971,784	$ 1,999,545	$ 2,027,723	$ 2,056,323	$ 2,085,352	$ 2,114,817	$ 2,144,724	$ 2,175,079
Homeowner softening (salt)								
RWH supply	$ 1,110,091	$ 1,137,992	$ 1,166,312	$ 1,195,056	$ 1,224,232	$ 1,253,845	$ 1,283,903	$ 1,314,411
Carbon emissions								
Ground water suppy	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Surface water supply	$ 118,225	$ 119,889	$ 121,579	$ 123,293	$ 125,034	$ 126,801	$ 128,594	$ 130,414
RWH supply	$ 5,728	$ 5,954	$ 6,184	$ 6,418	$ 6,655	$ 6,895	$ 7,140	$ 7,388
Present Value								
Discounted total costs	$ 3,435,613	$ 3,191,307	$ 2,964,484	$ 2,753,887	$ 2,558,349	$ 2,376,786	$ 2,208,194	$ 2,051,641
NPV total costs								

NPV Calculations for Societal Perspective: Considering Regional Surface Water Supply

WCESU CONSERVATION AND RWH	39	40	41	42	43	44	45
Year	2045	2046	2047	2048	2049	2050	2051
Population (1.5% growth)	205,427	208,509	211,636	214,811	218,033	221,304	224,623
Total average demand (no conservation)	91,839	93,217	94,615	96,034	97,475	98,937	100,421
Total average demand (WCESU conservation)	78,918	80,102	81,304	82,523	83,761	85,018	86,293
Total RW demand	3,374	3,487	3,602	3,718	3,836	3,955	4,077
Total average mains demand	75,544	76,615	77,702	78,806	79,925	81,062	82,216
Capital Costs							
Conservation							
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 30,000,000	$ 30,000,000	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480	$ 9,579,480
RWH supply	$ 4,653,859	$ 4,723,667	$ 4,794,522	$ 4,866,440	$ 4,939,437	$ 5,013,528	$ 5,088,731
O/M Costs							
Conservation							
Existing groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
New groundwater supply	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Regional surface water supply	$ 2,205,890	$ 2,237,162	$ 2,268,904	$ 2,301,122	$ 2,333,823	$ 2,367,015	$ 2,400,705
Homeowner softening (salt)							
RWH supply	$ 1,345,377	$ 1,550,329	$ 1,584,834	$ 1,619,856	$ 1,655,404	$ 1,691,485	-$ 83,995,826
Carbon emissions							
Ground water suppy	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Surface water supply	$ 132,261	$ 134,136	$ 136,039	$ 137,971	$ 139,932	$ 141,922	$ 143,942
RWH supply	$ 7,639	$ 7,894	$ 8,154	$ 8,417	$ 8,684	$ 8,955	$ 9,230
Present Value							
Discounted total costs	$ 1,906,262	$ 1,779,242	$ 783,034	$ 730,610	$ 681,734	$ 636,162	-$ 2,091,880
NPV total costs							

Chapter 6 Review of Regulatory Devices Pertinent to Rainwater Harvesting in Ontario

Introduction

The previous chapters explore some of the technical and economic issues associated with rainwater harvesting and suggest that many of the concerns regarding water quality, system design and economic feasibility can be mitigated and should ultimately not serve as prohibitive barriers. However, critical to addressing these issues is the development of a comprehensive and strategic regulatory framework.

A regulatory framework is made up of three equally important and mutually reinforcing components:

1. Policy: official, high-level statements that indicate general directives and intent and thereby set expectations for future action.

2. Regulatory devices: regulations, ordinances, municipal by-laws, codes, or any legal requirement which guide implementation and enable enforcement.

3. Support mechanisms: standards, guidebooks, manuals or any educational material targeted at the end user which interprets both policy and regulation and encourages implementation; includes voluntary incentive mechanisms to encourage adoption.

Because residential RWH has largely existed only in very rural areas of Ontario, it has for the most part remained outside of the regulatory devices that govern urban development. The regulatory framework for RWH is therefore rather sparse. However, as RWH is increasingly being implemented in the urban environment, largely as part of a broader green building movement, regulatory agencies are slowing recognizing the role they must play in facilitating such practices. This chapter reviews the devices that currently make up the regulatory framework for RWH in Ontario, and specifically, in the City of Guelph. Case studies from Germany and Australia provide a comparison from jurisdictions where the practice of RWH is well established.

Supportive Policy

Broad support for both water conservation and sustainable stormwater management can be found in a number of provincial and municipal policy documents. At the provincial level, this includes the Provincial Policy Statements (2005), Green Belt Act (2004) and the recent amendment to regulations under the Water Resources Act (1990). The Places to Grow Act (2005) goes slightly further by promoting water reuse and recycling, in addition to conservation and efficiency. In Guelph, the Strategic Plan includes the objectives of water conservation and efficiency and sustainable stormwater management (City of Guelph 2005). Water conservation targets were set out in the Water Supply Master Plan (City of Guelph 2006) and reiterated in the Community Energy Plan (Garforth 2007).

These devices are consistent with the practice of RWH; however, they do not explicitly endorse it. The statements are largely embedded in broader planning documents and have little visibility or authority on their own. However, they provide a supportive foundation for the further development of policies that are specific to RWH.

Regulatory Devices

While formal policies are necessary to provide over-arching direction for the various levels and branches of government, there also needs to be tools for enforcement which set out minimum requirements that are consistent, accepted and binding. The most pertinent regulatory device for RWH in Ontario is the Ontario Building Code. Other support mechanisms such as standards or guidelines serve to supplement the Code and may become binding if required by the Code or other legislation.

Ontario Building Code

The Ontario Building Code is a derivative of the National Building Code of Canada, adapted to the provincial context and administered by the Ministry of Municipal Affairs and Housing. It is a rigid piece of legislation and serves as a much more detailed and more binding regulatory tool than the policy documents described above. The core objectives of the Ontario Building Code have traditionally been protecting human health and safety, ensuring accessibility for the physically disabled and providing fire and structural protection for buildings. However, amendments made to the Code throughout the 1990s indicate the evolution of a fourth objective; the protection of the environment and conservation of natural resources.

In 1993, the Code was amended to mandate the use of water efficient fixtures for toilets, faucets and showers (Sharratt et al. 1994). In the 1997 version, efficiency requirements were made even stricter for toilets. While historically the indoor use of non-potable water was strictly prohibited, in 1997, Section 7.1.5.3 was changed to allow for its use for toilet and urinal flushing in cases where the potable supply was insufficient (MMAH 2008). This applied predominantly to scarcity situations in the rural context. In 2006, this clause was further amended as part of a series of changes in the Code designed to promote energy efficiency and certain green technologies. The amendment allows for the use of non-potable water for toilet and urinal flushing regardless of the availability of potable water, effectively introducing alternative, supplementary water systems into the mainstream urban context.

Section 7.1.5.3 of the Ontario Building Code is reproduced below, as seen in both the 1997 and 2006 version (emphasis added) (MMAH 2008; Government of Ontario 2006).

1997 Amendment

(1) Except as provided in Sentence (2), every water distribution system shall be connected to a public watermain or if no public watermain is available to a potable private water supply system.
(2) *Where a supply of potable water is unavailable or insufficient* to supply water to a plumbing system, non-potable water may be used for the flushing of water closets, urinals or the priming of traps, and the piping conveying the non-potable water shall be installed in conformance with Section 7.7.

2006 Amendment
(1) Except as provided in Sentence (2), every water distribution system shall be connected

(a) to a watermain that is part of a municipal drinking-water system , or

(b) to a drinking-water system , if a watermain described in Clause (a) is not available.

(2) *Storm water or greywater that is free of solids* may be used for the flushing of water closets, urinals or the priming of traps , and the piping conveying the non- potable water shall be installed in conformance with Section 7.7.

Figure 0-1: Amendments to Section 7.1.5.3. of the OBC, Water Distribution Systems

Other sections of the Code relevant but not prohibitive to RWH are given in Figure 0-2. They cover issues such as cross connection, back flow prevention, overflow connection, and basic requirements for non-potable plumbing.

7.4 Drainage Systems
7.4.2.2. Connection of Overflows from Rainwater Tanks
An overflow from a rainwater tank shall not be directly connected to a storm drainage system.

7.6 Potable Water Systems
7.6.2.1. Connection of Systems
(1) Connections to potable water systems shall be designed and installed so that non-potable water or substances that may render the water non-potable cannot enter the system.
(2) No connection shall be made between a potable water system supplied with water from a water works approved under the Ontario Water Resources Act and any other potable water system without consent of the water purveyor.
7.6.2.4.
(8) Buildings of a residential occupancy within the scope of Part 9 are not required to be isolated unless they have access to an auxiliary water supply.

7.7 Non-potable Water Systems
7.7.1. Connection
7.7.1.1. A non-potable water system shall not be connected to a potable water system.
7.7.2. Identification
7.7.2.1. Non-potable water piping shall be identified by markings that are permanent, distinct and easily recognized.
7.7.3. Location
7.7.3.1. Pipes
(1) Non-potable water piping shall not be located
- (a) where food is prepared in a food processing plant
- (b) above food-handling equipment
- (c) above a non-pressurized potable water tank
- (d) above a cover of a pressurized potable water tank.

7.7.3.2. Outlets
(2) An outlet from a non-potable water system shall not be located where it can discharge into
- (a) a sink or lavatory
- (b) a fixture into which an outlet from a potable water system is discharged
- (c) a fixture that is used for a purpose related to the preparation, handling or dispensing of food, drink or products that are intended for human consumption.

Figure 0-2: Additional Sections of OBC Relevant to RWH

While provincial authorities administer the Building Code, municipalities are responsible for its enforcement. Municipal building inspectors are largely bound to the requirements of the Code; however, some degree of autonomy is granted through “equivalents” clauses that allow for the approval of building materials, systems or features other than those permitted in the Code. Approval for “equivalents” can be given based on past experience or thorough testing, if the municipal inspector is convinced that the performance of the proposed technology matches or exceeds that of those prescribed in the Code. Building inspectors must also interpret grey areas of the Code and have the authority to grant approvals for situations of “legal non-conformance”, which in effect contravene the Code. While this may be common for low-risk situations, such as connecting a RWH system to a storm sewer, due to the personal liability inspectors have for the approvals they grant, it is less likely to occur for situations with a higher perception of risk. Appeals to the Building Code Commission, however, can be made to seek approval of systems denied by individual inspectors.

The Code has traditionally been a prescriptive document; however, in 2006 it was restructured to be objectives-based. All applications for approval must meet a series of objectives and their associated functional statements. What were formerly prescriptive requirements are now "Acceptable Solutions". These changes are intended to make the Code more flexible and accommodating of new solutions; however, as the objectives mechanism is very new it is unclear how it will be implemented and how effective it will be.

Support Mechanisms

Support mechanisms differ from regulatory devices in that they are not legally binding. They may include standards, guidelines, best practices manuals, educational initiatives and a host of voluntary incentive mechanisms. They can be tailored to local needs and can evolve as required. They may also be legally adopted and become binding regulatory devices.

Design Standards

The Canadian Standards Association (CSA) is a non-governmental organization that develops standards for practices and products for wide a variety of industries. Standards serve as accepted, industry-wide best practices and are often made compulsory when referenced in federal, provincial or municipal legislation.

A significant milestone in the promotion of RWH is the development of new standards regarding non-potable water, recently approved by the CSA. One standard (B128.1) addresses the design and installation of plumbing systems for non-potable water and a supplementary standard (B128.2) deals with the maintenance and field testing of these systems. The standards apply to residential and commercial applications using any source of non-potable water. They do not specify permitted end uses, but suggest irrigation, toilets, bathing, laundry and heating and cooling applications as possibilities. Neither document comments on water quality or treatment, and instead makes general reference to the requirements of local authorities (CSA 2006). These standards are currently available, but are not yet legally binding in Ontario as they have not been referenced in the OBC.

Water Quality Guidelines

No water quality guidelines exist in Ontario or at the national level to govern the use of rainwater for non-potable applications. In recognition of this absence and of the likelihood of future non-potable water use, Health Canada has produced the Canadian Guidelines for Household Reclaimed Water, currently undergoing the final review process before being released. The draft guidelines are narrow in scope, pertaining only to the on-site reuse of domestic greywater for toilet flushing (Health Canada 2007). Water quality criteria are defined for three biological and two physical parameters, as well as residual chlorine requirements; however, no specific treatment mechanisms are prescribed. A detailed discussion of management issues and models is also provided. As they are still in draft form, it is uncertain if and how they may be incorporated into the Building Code and the level of authority they will obtain. It is also unclear how these standards will impact the regulation of other sources of non-potable water, such as rainwater, or end uses other than toilet flushing.

Voluntary Incentives

There are many mechanisms that can be used as voluntary incentives to promote the adoption of a practice. Rebates are one common tool for encouraging the purchase and use of specific products or services and have been used in several jurisdictions outside of Canada to promote RWH. Similarly, bylaws or other municipal requirements may indirectly serve to promote voluntary behavior. In the City of Guelph, the Outdoor Water Use Bylaw (2002) sets out domestic outdoor water use restrictions that are enforced during prolonged dry periods. The Storm Water Disposal Bylaw (1993) requires roof runoff to be retained on-site for all new single and semi-detached dwellings; however, all other buildings must connect to the municipal storm drainage system. These types of existing mechanisms can be strengthened and made more stringent to further encourage broader practices of water conservation or sustainable stormwater management, both of which may encompass RWH.

Strategic pricing structures for water, wastewater and stormwater services can also serve as an incentive for desired practices. Prices must first reflect the true cost of a service. In 2003, water utilities in Ontario recovered only 64% of their total costs (WSEP 2005); the Sustainable Water and Sewage Systems Act, passed in 2002, but yet to be enforced aims to increase this to 100%. In addition to full cost recovery, pricing structures can be designed to penalize undesirable practices. For water and wastewater, metering is required to allow for volumetric tariffs. Although not common in Ontario, structures like increasing block tariffs can then be applied, which differentially price water based on the volume consumed. Higher water prices make all conservation alternatives more cost effective and encourage their uptake. The City of Guelph achieved 100% coverage for household meters as early as the 1960s (City of Guelph 2006b); however, they charge the same rate regardless of the end use (residential, commercial or industrial) and regardless of the volume used. Guelph has had some of the lowest rates in Southern Ontario (City of Guelph 2001).

Unlike water and wastewater, municipalities do not usually impose a visible user fee for stormwater services; rather, costs are recovered through mechanisms such as development fees and property taxes. These payments could be prorated based on the volume of runoff entering the stormwater system from individual properties, thereby rewarding developers or property owners who manage stormwater on-site. They could also be developed into a visible user-fee, like water or wastewater tariffs, paid regularly by property owners. The City of Guelph has considered developing a stormwater utility that would evaluate and administer different fee structures, but to date conventional means of cost recovery for stormwater management remain in place (City of Guelph 2006b).

The restructuring of pricing structures for both water and storm water services not only allows for greater recovery of costs, but could serve as an incentive for a host water conservation and sustainable stormwater practices, including RWH.

Best Practices Documentation

Finally, but importantly, support mechanisms for a regulatory framework must include widely available documents that discuss pertinent issues. In the case of RWH, this includes health and safety issues, design, operation and maintenance issues and a description of regulatory requirements and processes, clearly outlining current best practices. Such documents can be published by government or non-government organizations, but should have broad stakeholder input. They must be designed to evolve and adapt according to local conditions and emerging best practices. As neither high level policy nor specific regulatory devices are accessible or comprehensible to the public, it is essential that supplementary, user-friendly information be widely available to promote implementation. No such documents for RWH could be found within Ontario; the closest came from the Gulf Islands in British Columbia (Stubbs 2006) and Texas (Krishna 2005).

Case Studies

While many factors influencing the development of RWH in Ontario are unique to the provincial or national context, much can be learned from parts of the world where the severity in climate patterns and development trends have necessitated water conservation measures and alternative supplies. The density of the German population and historic contamination of waterways has limited the availability of potential water resources and precipitated regulatory reform for alternative water supplies that predates current Canadian initiatives by up to 25 years. In Australia, authorities are trying to regulate and make safe the widespread, traditional practice of RWH and more formally promote it. These case studies are further explored in the following section.

Germany

In Germany, regional discrepancies in water resources, a history of severely polluted waterways and dense urban development have resulted in competition for water supplies and high water prices. As well, stormwater infrastructure is often old, over-loaded, and costly to replace. This situation has forced the development of alternative water conservation and stormwater abatement strategies such as RWH. The formal promotion of RWH began in Germany in the early 1980s and accelerated through the 1990s with the development of legislation, financial incentives and a competitive RWH industry. These advances can be instructive for the development of RWH practices in Canada.

Federal Legislation Pertinent to RWH

As in Canada, several pieces of federal legislation exist in Germany which encourage water conservation and on-site stormwater management (State of Hessen 2006). One piece of legislation that is seen to have far-reaching consequences specifically for the practice of RWH is the Regulation on General Conditions on Water Supply (AVBWasserV). As early as 1980, it was amended to permit the exemption of water users from mandatory connections to municipal water supply (Pottgen 2001).

More specific to RWH, the federal Drinking Water Ordinance (TrinkWV) outlines basic requirements. It stipulates that (i) no direct cross connection is permitted, back-up mains water must be provided to the cistern via an air gap; (ii) all non-potable pipes and outlets must be labeled; and (iii) the public health office and local water supplier must be notified of all RWH installations (König 2008). These basic requirements are supplemented by detailed standards. DIN 1989 – Rainwater Harvesting was initiated in 1997 and four specific standards have since evolved: Part 1. Planning, implementation, operation and maintenance; Part 2. Filters; Part 3. Rainwater cisterns and Part 4. Control and monitoring (DIN 2001). These standards were published in 2002 as the technical code for the RWH industry. While not legally binding, they are referenced in both the Regulation on General Conditions on Water Supply and the Drinking Water Ordinance and considered best practice for RWH in Germany (König 2008).

State and Municipal Legislation Pertinent to RWH

At the state level, the Federal State of Hessen has been a leader in the implementation of RWH. The Hessian Water Act [*HWG*] states that, where feasible, wastewater and precipitation water should be either infiltrated or utilized on-site. The Water Act also permits municipalities to pass bylaws to mandate the use of rainwater utilization systems or greywater recycling systems. Other states, such as Baden-Wuertemberg, Saarland, Bremen, Thuringen and Hamburg, have also since revised their own building regulations in a similar manner. Many cities have taken advantage of their expanded legislative authority and passed precipitation water bylaws to mandate on-site stormwater management techniques (State of Hessen 2006).

Financial Incentives for RWH

To facilitate the implementation of stormwater management requirements, RWH subsidy programs were initiated in the Federal States of Hamberg (1988) and Hessen (1992), each lasting 7 years (Köing 2005). By 2005, an additional four of the sixteen German states had developed RWH grant programs, as well as individual municipalities.

Apart from subsidies designed specifically to promote RWH, the underlying structure of water pricing in Germany is much more conducive to RWH than that in Canada. State legislation across Germany requires full cost recovery from user fees for municipal services including water, sanitary sewers and stormwater drainage (Kraemer and Piotrowski 1995). In 1999, average water prices were approximately 2.5 times higher in Germany than in Canada (WSEP 2005), allowing for more favorable amortization periods.

Like water rates, sewer discharge fees are also more aggressive in Germany. Separate stormwater charges must be applied when the cost of stormwater management is considered no longer “insignificant” (Kraemer and Piotrowski 1995). This has been defined as 15% of total municipal sewer costs. A survey of German municipalities suggests that 16% charge a separate stormwater management rate, based primarily on the portion of sealed surfaces. Many municipalities then discount this fee when rainwater is captured for on-site use. 14% of respondents gave one-time rebates for RWH construction and 6% offered ongoing rebates for rainwater use (Kraemer and Piotrowski 1995). König (2008) suggested that as of 2000, half of all municipalities had volume-based stormwater fees.

German RWH Industry

In addition to supportive legislation and financial incentives, the wide-scale implementation of RWH requires technical expertise and commercially available products. The early development of RWH practices in Germany has allowed for the establishment of a robust industry to provide for these requirements. More than 100 commercial manufactures of RWH equipment compete in the German market and collectively installed over 100,000 tanks and 600,000 m^3 of storage capacity in the 1990s (Herrmann and Schmida 1999). As well, all hydraulic software on the German market now includes the consideration of rainwater use.

Australia

Like Germany, RWH is much more established in Australia than in Canada. It is a longstanding practice, particularly in the rural interior where the population is very sparse and municipal water infrastructure is not common. For example, between 1994 and 2001, 51% of households in the state of Southern Australia had rainwater tanks and 36% used their tanks as the primary source of drinking water (AGDHA 2004). Values for the entire country were 16% and 13%, respectively. On the national level, much of the activity surrounding RWH is attempting to manage an already common practice. On the state level, RWH is being further promoted within the greater context of environmental building practices.

Federal RWH Initiatives

Federal support for RWH is explicit in the National Plumbing and Drainage Code, AS/NZS 3500. The Code has a section dedicated to RWH which specifies requirements such as tank material, backflow prevention, overflow systems and signage (AS/NZS 2003). Permitted end uses are not specified; rather reference is made to local health authorities. It also clearly refers to the “Guidance on the Use of Rainwater Tanks” as an authoritative source of information. This document was produced by the federal Department of Health and Aging in consultation with state health departments. It is a comprehensive document that offers guidelines for the design, construction and maintenance of RWH systems and thoroughly explains potential health hazards and preventative measures (AGDHA 2004). The guidelines recognize the extensive use of RWH systems for potable consumption and provide information to users to ensure such practices are executed safely. However, it recommends only hot water services, bathing, laundry, toilet flushing and irrigation where municipal mains are available.

State-Wide RWH Initiatives

Two state-wide building initiatives are of specific interest for their ability to combine compulsory regulatory requirements with voluntary participation in order to achieve greater water, energy and greenhouse gas savings.

BASIX is an environmental initiative introduced in 2004 by the government of New South Wales as a regulation under the Environmental and Planning Assessment Act (NSW Government 2008). The regulation requires a prescribed level of greenhouse gas reduction and water and energy conservation in all new single and multi-dwelling residential buildings as a prerequisite for obtaining a development approval. Applicants choose the most appropriate options from a variety of environmental building features and a web-based evaluation tool ensures that the proposed developments meet specific energy, water and greenhouse gas targets. Current targets include 25% reduction in greenhouse gas emissions, 40% reduction in energy consumption and up to 40% reduction in water consumption (depending on geographic location of development). Rainwater tanks for toilet, laundry and outdoor applications are one option strongly encouraged in the BASIX program.

The State of Victoria introduced a similar program in 2004 also designed to decrease the energy and water consumption of buildings (Government of Victoria 2008). The 5-Star Program is being implemented through amendments to the Building Code of Australia, Victoria Appendix, and applies to all new single and multi-dwelling residential buildings. The program makes it compulsory for all new residences to achieve a certain level of energy efficiency and requires the installation of either a solar water heater or a rainwater tank serving all sanitary fixtures.

These examples show how flexibility can be incorporated into performance-based regulatory structures so that affected parties can choose how to meet the defined objectives. Both of these programs, however, were introduced with significant educational outreach for both the building industry and homeowners.

Municipal RWH Initiatives

One ambitious municipal initiative in Queensland, Australia is the Pimpama Coomera Water Futures Plan. The area is anticipated to be the next urban growth corridor in that region and the population is expected to grow from 5000 to 150,000 over the next 50 years (Gold Coast Water 2004). This growth, however, is taking place in the context of ongoing water shortages. The City Council undertook a comprehensive and unconventional planning process to meet urban water needs in an integrated, synergistic, and sustainable manner. Key principles include matching water use with required quality level and utilizing both centralized and on-site systems. The use of rainwater is an integral part of the Master Plan and is expected to replace 25% of current potable water demand through use in bathrooms fixtures (other than toilets), laundry and hot water applications. Other elements include centralized greywater recycling facilities for toilets and outdoor use, xeriscaping and on-site stormwater retention. These features will become mandatory criteria for development in this region (Gold Coast Water 2004).

Key Learnings

Key learnings to be taken from the German and Australian case studies include:

1. The importance of authoritative, comprehensive and non-regulatory support documentation to supplement regulatory measures;
2. The advantages of flexible, performance-based regulatory structures to give affected parties alternatives choices in meeting defined environmental objectives;
3. The need for proactive, integrated water services planning for new urban growth;
4. The need for appropriate price structures for both water and stormwater services to make RWH systems economically attractive to property owners; and
5. The need for a competent, local RWH industry of system designers, manufacturers and builders.

Conclusions

While the regulatory framework for RWH in Ontario and in Guelph is currently wanting, there are encouraging signs that the relevant authorities are aware of the growing interest in RWH and of the need for intervention to accelerate progress. At both the provincial and municipal level there is broad policy support for water conservation and efficiency as well as for sustainable stormwater management practices, both of which are conducive to RWH.

The Ontario Building Code is the primary regulatory device governing RWH and is advanced in that it allows for minimal use of rainwater in the home; however, compared to international case studies, its restriction on end uses (toilet flushing) may be unnecessarily conservative. The CSA standards for non-potable water and the Health Canada guidelines for household reclaimed water are emerging regulatory devices which indicate a regulatory response; however, because they are both very new, it is unclear how exactly they will impact the practice of RWH.

Despite these developments, there appears to be a lack of user-oriented support mechanisms and incentives for RWH. No relevant guidelines, best practices manual or similar support documents could be found in Ontario, nor do they seem to exist at the federal level. Further, current pricing structures and municipal by-laws are weak in their ability to encourage water conservation and sustainable stormwater management. There is significant scope for all of these devices to be strengthened to more strongly encourage practices such as RWH. Examples from both Germany and Australia provide insight on the importance of these support mechanisms and how they can be further developed.
The development of comprehensive, proactive and consistent regulatory framework is key to the wide-spread implementation of RWH to ensure that the greatest possible benefits are achieved and that standards of public health maintained. The following chapter discusses some of the main shortcomings of the existing regulatory framework and offers suggestions for its advancement.

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Chapter 7 Evaluation of Regulatory Framework for Rainwater Harvesting in Ontario

Introduction and Objectives

While RWH was common in Ontario prior to the advent of centralized water supply systems, it is today seen mostly in rural areas where centralized systems do not exist and on-site supplies are limited. The practice developed organically and has largely remained outside of the regulatory devices that govern urban development. However, RWH is now entering the urban environment, riding largely on the coat tails of the green building movement. As RWH is increasingly implemented in Ontario cities it is challenging the existing regulatory framework. It is demanding the re-evaluation of not only the specific clauses that govern such practices, but of the very assumptions and values upon which the processes of policy development rest.

This chapter reports the results of a qualitative research study. The immediate objectives of this study were to identify the regulatory and non-regulatory barriers impeding the widespread implementation of RWH, as experienced by local stakeholders in Guelph and surrounding areas, and to seek their insight for overcoming these barriers. The broader goal of this work, however, was to use RWH as a means of exploring the meaning of "progressive policy" and the role of regulation in advancing innovative solutions to critical urban issues such as sustainable water management. It is hoped that the discussion provided in this paper will stimulate debate among both policy makers and technical practitioners and that the outcome of this debate will be reflected in future policy developments for sustainable water management.

A "regulatory framework" includes all binding and voluntary instruments created by different government and non-government authorities, which jointly serve to guide or control targeted activities. This includes policy, regulatory devices and support mechanisms. This entire framework was considered in the evaluation of barriers and opportunities for RWH.

Method

The study consists of exploratory research that uses experimental case studies and interviews to gather both direct and anecdotal data, respectively. The data are then contrasted and correlated to reveal significant issues affecting the individual perspectives represented as well as general trends from the data set as a whole. The two methods of data collection are described below.

Experimentation

Three RWH systems were installed at residential sites in Guelph to serve as case studies for the project. As described in Chapter 3, these systems were used primarily to evaluate different RWH technologies and associated design issues and to monitor system performance.

The process of designing, installing and seeking municipal approval for three demonstration sites also served as a means of observing first-hand the barriers associated with the implementation of RWH, as well as allowing for speculation about potential remedies. Preliminary hypotheses developed from this experience were used as a starting point for the further exploration of barriers and incentives via key-informant interviews.

Key Informant Interviews

Throughout the development of the demonstration sites and the course of the project in general, the researchers for this project interacted and collaborated with many individuals and organizations who are also involved in the implementation of RWH. A series of semi-structured interviews was conducted with a cross-sectoral representation of these stakeholders to gather their collective insights.

Key Informants

Sixteen informants from Guelph and surrounding areas were selected based on their previous experience with RWH and their anticipated involvement in the future, categorized as follows:

Administrators

- Municipal water conservation officers (3)
- Municipal building inspectors (3)

Practitioners

- Architects (2)
- Engineers (2)
- Builders (1 custom builder, 1 production developer/builder)

Suppliers

- Manufacturer of plastic cisterns and supplier of Australian RWH accessories (1)
- Manufacturer of concrete cisterns and supplier of German RWH accessories (2)
- Manufacturer of concrete cisterns (1)

Municipal representation was sought from water conservation officers and building inspectors because they play a key role in promoting RWH to the public and ensuring its safe and appropriate implementation, respectively. In addition, they interact frequently with the public and can thus gauge attitudes and trends both within the local administration and in the community in general. At the time of interviewing, none of the water conservation officers were engaged in RWH programs or projects (except one, who was a partner in this project), but all were actively investigating its feasibility and considering ways to facilitate its uptake. Of the building inspectors, two had personally dealt with several applications for RWH over the past few years and one had only limited experience with a single application.

Practitioners included individuals who have actually designed and installed RWH systems as part of their commercial practices. They would be one of the end users of any programs or regulations developed for RWH. Their hands-on experience working with clients, designing systems, sourcing parts, applying for permits and coordinating installations allow them insight into a broad range of technical, administrative and social issues. Of the participants in this category, the engineers and architects had implemented anywhere from two to "about a dozen", RWH systems in the past few years, including residential, commercial and institutional applications. The builders had installed 1-2 systems each. All respondents reported a growing demand for RWH from their clientele.

Suppliers of RWH systems are the stakeholders with the greatest commercial interest in RWH and are thus the most actively engaged in its promotion. While RWH constitutes only a small portion of the scope of work for many of the respondents, for suppliers it is a principle activity. Two of the companies represented manufacture plastic and concrete tanks, respectively, and import RWH components from abroad. The RWH division of the company was new in both cases and at the time of the interviews they had few installations. The third company manufactures concrete tanks for a variety of purposes with no specialization in RWH.

While the degree of current engagement varies, all of the participants have some interest, exposure and involvement in RWH and are important stakeholders in its widespread implementation.

Research Questions

Each interview began with a discussion of the respondent's past, present and future anticipated involvement with the implementation of RWH. Several questions were then asked to determine the level of familiarity each respondent has with the pertinent regulatory devices. Following the collection of this background information, the remainder of the interview focused on the following core questions.

1. What are the regulatory and non-regulatory barriers impeding the widespread implementation for RWH?
2. What can be done to overcome these barriers and further encourage the widespread implementation for RWH?

The full schedule of questions is given in Appendix A. All interviews were conducted in-person by the author. Approval for this work was granted by the University of Guelph Research Ethics Board.

Content Analysis

Content analysis of the interview data involved the following steps.

1. Transcribe each interview verbatim.
2. Extract relevant points from each transcript into a summary document.
3. Compile list of issues raised by all participants.
4. Categorize the issues as either barriers or solutions. Within these two categories, group issues as either over-arching regulatory issues, specific Building Code issues or non-regulatory issues.
5. Cross-reference each transcript summary with the list of issues. Rate each issue as [0] = not mentioned or insignificant; [1] = significant; or [2] = very significant, for each transcript.

Following this process, each participant was given the opportunity to review the results of their interview and the ranking assigned to each issue. They were asked to confirm or amend the rankings according to their personal judgment. Twelve of the sixteen participants responded to this request. From this confirmed data, major themes were identified for the group as a whole as well as for each category of respondent. The following section presents the results of the interviews, followed by a discussion of the broader trends and implications.

Results

The results of the interviews are separated into three sections. First, barriers to the widespread implementation of RWH are presented, as identified by the respondents. Second, their recommendations for addressing these barriers are given. Finally, a brief tally of the level of familiarity with CSA Standard B.128 reported by the participants is shown.

Each of the participants in the study draws from different experiences and offers a unique perspective. The architects and water conservation officers, for example, are generally more concerned with "big picture" issues such as municipal planning trends or infrastructure pressures, while inspectors or suppliers deal on a daily basis with the detailed technical issues. Therefore, while some of the concerns are shared by all perspectives, others are unique to certain categories of participant or to individual respondents.

Upon analysis of the data, two respondents stand out as being inconsistent with the group. First, all but one of the participants are fully supportive of RWH and think it should be further promoted; however, one respondent from the practitioners category was wary of RWH and does not promote it in his own practice. He merely accommodates it when requested. Second, one of the suppliers currently works for the given company but has years of experience working in the area of municipal and provincial administration. His responses seemed to reflect a government perspective to a greater extent than the interests of a commercial enterprise. The results presented here include the responses of these two participants; however the agreement achieved may have been greater if more representative respondents had been identified.

Possibly the most important result observed throughout the interviews was the unanimous agreement among all respondents that interest in RWH exists and is growing. It is with this encouragement that the barriers and opportunities are explored.

What are the barriers to widespread implementation of RWH?

Figure 0-1 presents the total score for each of the identified barriers, representing a composite of the responses from all of the participants.

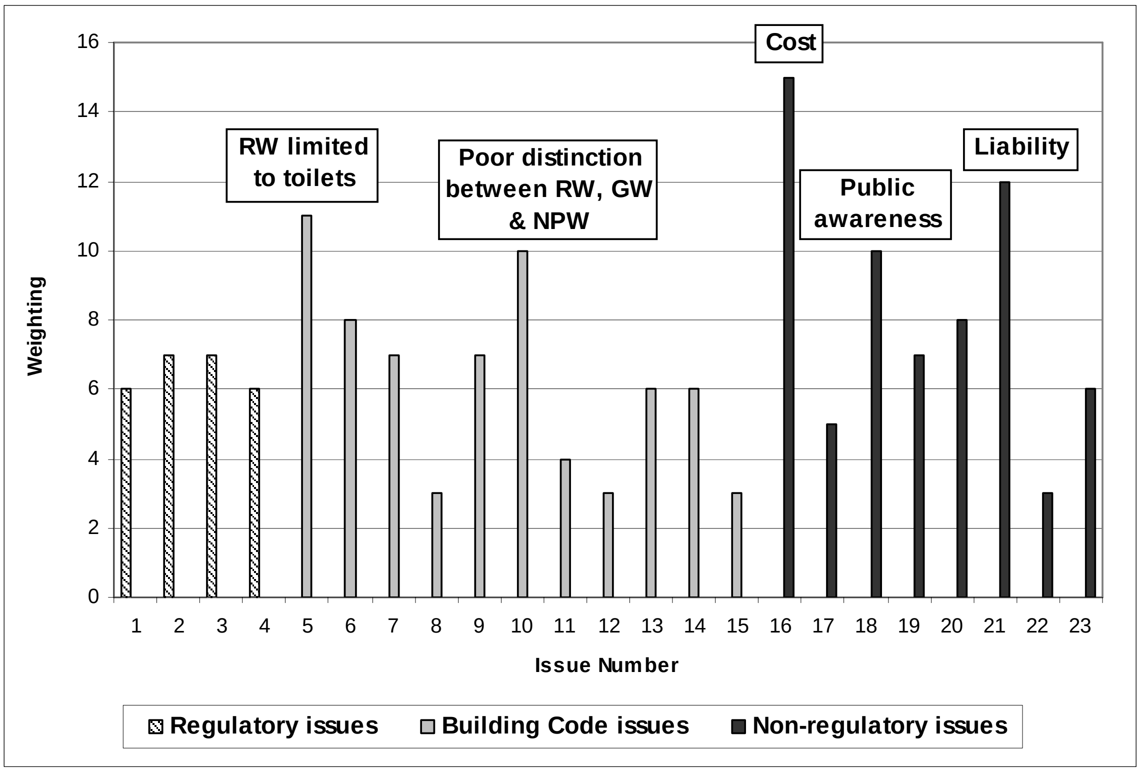

Figure 0-1: Interview results identifying the barriers to widespread implementation of RWH

Table 0-1 defines each of the issues referenced in Figure 0-1 and shows the total score obtained from all respondents, as well as the distribution of responses in each category. In Table 0-1, dark grey shading indicates issues where more than half of the respondents in that category considered it as either significant or very significant (ie. > 3 out of 6 administrators and practitioners and >2 out of 4 suppliers). Light grey shading is shown where exactly half of the respondents considered it to be either significant or very significant. Considering both the frequency and intensity of response, dark grey can then be said to represent very significant issues while light grey represents significant issues. The significance rating assigned to each issue based on the researchers' observations from the demonstration sites is indicated in the "Case Study" column. Throughout the remainder of the chapter, issue numbers are referenced in square brackets [X] as they are discussed.

Table 0-1: Barriers identified for implementation of RWH and distribution of significant rankings for each category of respondent.

Category	Issue No.	Barriers Identified by Respondents	Total Score	Municipal Significance			Practitioners Significance			Suppliers Significance			Case Study
				0	1	2	0	1	2	0	1	2	
Regulatory Barriers	1	Provincial inertia and culture of risk aversion in MMAH	6	4	0	2	5	0	1	4	0	0	1
	2	Lack of awareness about existing regulatory devices	7	5	1	0	6	0	0	1	0	3	0
	3	Inconsistency in interpretation of existing regulatory devices	7	5	1	0	4	2	0	1	2	1	0
	4	Ambiguity surrounding permitting process and requirements	6	4	2	0	4	1	1	3	1	0	0
OBC Barriers	5	Indoor use of rainwater limited to toilets	11	2	2	2	3	2	1	3	1	0	2
	6	Lack of details and/or clarity	8	3	3	0	4	1	1	2	2	0	1
	7	Refers to rainwater as "storm sewage" - negative connotation	7	4	2	0	4	1	1	2	2	0	0
	8	Absence of reference to CSA Standard B.128	3	5	1	0	6	0	0	2	2	0	0
	9	Ambiguity wrt backflow prevention, inappropriate requirements	7	4	2	0	5	1	0	1	2	1	1
	10	Inadequate differentiation between greywater, rainwater and non-potable water	10	2	2	2	4	2	0	2	2	0	1
	11	Prohibits the connection of a RWH system to storm sewers	4	6	0	0	5	1	0	2	1	1	0
	12	Relevant clauses scattered & buried - onerous to interpret wrt RWH	3	5	0	1	5	1	0	4	0	0	0
	13	Requires connection to municipal water supply, if existing	6	5	1	0	3	1	2	4	0	0	0
	14	Ineffectiveness of approving exceptions (ie.pilots), or using objective based approach	6	4	2	0	3	2	1	4	0	0	0
	15	Inadequate specifications for non-potable pipe identification	3	5	0	1	6	0	0	3	1	0	0
Non-Regulatory Barriers	16	Cost, lack of business case	17	1	2	3	3	1	2	2	2	0	2
	17	Health and safety	5	4	1	1	5	0	1	4	0	0	0
	18	Lack of environmental awareness and commitment among public	10	4	2	0	4	0	2	2	0	2	1
	19	Lack of experience & familiarity with RWH among stakeholders	7	5	0	1	4	2	0	2	1	1	1
	20	Lack of information, data and research for policy makers	8	4	1	1	4	2	0	2	1	1	1
	21	Liability	12	0	3	3	4	1	1	4	0	0	1
	22	Lack of practical, how-to information for end users	3	5	1	0	5	1	0	3	1	0	2
	23	Availability of products and materials	6	5	0	1	4	1	1	3	1	0	1

Note: Significance rating (0 – 2) and total score are in ascending order: a higher score indicates greater significance.

Overall Trends

Cost [16] was identified as the most significant barrier, supported most strongly by the municipal representatives but agreed upon by all categories. Liability [21] was the second highest ranked concern; however there was very little convergence. It was expressed as very significant for municipalities but insignificant for the majority of practitioners and suppliers. Two specific Building Code issues made up the third and fourth most significant concerns. The limitation on end uses [5] and the inadequate differentiation between rainwater, greywater and non-potable water [10] were again most strongly expressed by the municipal perspective, but also supported by the practitioners and suppliers, respectively. The lack of environmental awareness among the public [18] also emerged as a significant concern; however with a very high degree of variance from the respondents. It was expressed most strongly by the suppliers and the architects but seen as insignificant by a majority of municipal representatives.

Trends within each Respondent Category

The municipal representatives identified the highest number of barriers as being very significant. Their principal concerns for cost and liability reflect the municipal role in promoting and providing incentives for RWH and their responsibility for ensuring it is implemented in a safe and appropriate manner.

Responses from the practitioners showed the highest degree of variability, due largely to the fact that the group was comprised of three sub-categories: builders, architects and engineers. Overall, the builders expressed the most concerns (14 each) while on the other extreme, one architect and one engineer expressed very few (4 and 6, respectively). There was therefore little agreement among the latter two sub-groups, with the exception that both architects felt environmental awareness among the public [18] is a critical issue while the two engineers agreed that cost is a primary concern [16]. The architects and engineers generally identified broad concerns which relate to the uptake of RWH in the future, but did not feel immediately impeded to any great extent. Contrarily, the two builders expressed significant frustration with the existing regulatory framework and its current interpretation and implementation [3, 4].

The suppliers represent the smallest group, having only four respondents, compared to the six participants in each of the other two categories. The group has unique concerns, demonstrated by the fact that their top three barriers received little agreement from either of the other groups. Only the builders seemed to share their concerns. Their primary issues express frustration with the lack of awareness among building professionals and municipal authorities with respect to regulatory requirements for RWH, as well as inconsistency in their interpretation [2,3]. In general, the suppliers are more concerned with immediate barriers faced for specific installations and to a lesser extent about longer term issues pertaining to widespread implementation.

In general, the municipal perspective dominates the overall selection of the most critical issues. They felt very strongly about several issues while the practitioners were in general more satisfied with the current situation. The low number of respondents for the suppliers category made their input less influential in the overall score. For this reason, the results from each category of respondent were viewed independently, in addition to assessing the consolidated results.

How can these barriers be overcome?

Figure 0-2 presents the list of solutions identified collectively by all of the respondents. Comparing this data to Figure 0-1, participants felt stronger about potential solutions than about existing barriers and offered a wide range of responses. While the principle barriers identified were largely non-regulatory in nature, the solutions offered represent overarching regulatory issues, specific Building Code changes, and non-regulatory opportunities.

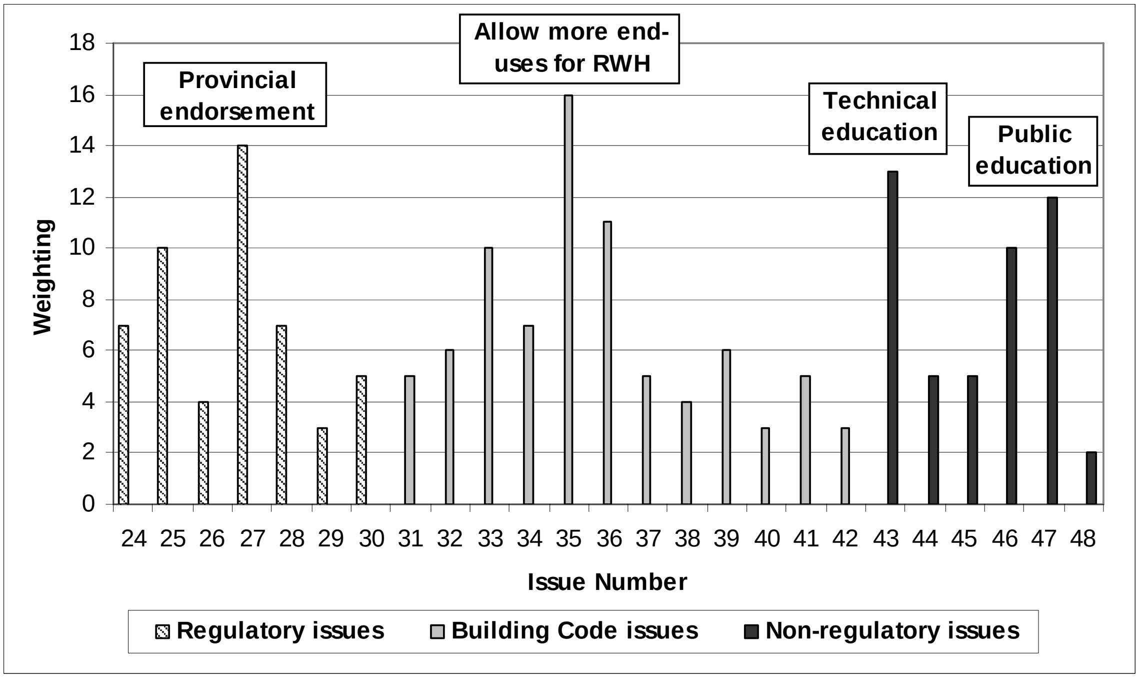

Figure 0-2: Interview results suggesting means of overcoming barriers to widespread implementation of RWH

Table 0-2 presents all of the identified solutions, their total score, the distribution of responses for each category and the significance rating observed through the case studies. The dark and light grey shading represents very significant and significant issues, respectively, as define above for Table 0-1.

Table 0-2: Solutions identified for implementation of RWH and distribution of significant rankings for each category of respondent

Category	Issue No.	Solutions Identified by Respondents	Total Score	Municipal Significance			Practitioners Significance			Suppliers Significance			Case Study
				0	1	2	0	1	2	0	1	2	
Regulatory Solutions	24	Municipal policy endorsement and/or guidelines	7	5	0	1	4	0	2	3	1	0	1
	25	Financial incentives	10	4	2	0	2	4	0	1	2	1	1
	26	Accelerated development approvals	4	5	0	1	5	1	0	3	1	0	0
	27	Provincial policy endorsement and/or guidelines	16	2	0	4	3	2	1	3	0	1	2
	28	Certification process for equipment or manufacturers	7	5	1	0	5	1	0	1	1	2	0
	29	Establishment of water quality criteria for non-potable end uses	3	4	2	0	6	0	0	3	1	0	0
	30	Encourage or mandate non-potable water for irrigation	5	4	2	0	3	3	0	4	0	0	0
OBC Solutions	31	More details and clarity	5	3	3	0	6	0	0	2	2	0	0
	32	Update terminology, use "rainwater" not "storm sewage"	6	5	1	0	4	1	1	2	2	0	0
	33	Dedicated section on RWH, separate from greywater	11	1	4	1	4	2	0	2	2	0	2
	34	Better distinguish greywater, rainwater and non-potable water	7	5	1	0	3	3	0	1	3	0	0
	35	Allow for more uses of rainwater	16	2	2	2	2	1	3	2	1	1	2
	36	Specify requirements for treatment (in Code or referenced standard)	12	3	3	0	2	4	0	2	2	0	2
	37	Specify requirements for installation (in Code or referenced standard)	5	4	2	0	5	1	0	2	2	0	1
	38	Clarify requirements for backflow prevention	4	4	2	0	5	1	0	3	1	0	1
	39	Reference CSA Standard B.128	6	3	3	0	5	0	1	3	1	0	0
	40	Re-evaluate water requirements for buildings	3	5	1	0	5	1	0	3	1	0	0
	41	Remove requirement to connect to municipal supply	5	5	1	0	4	1	1	3	1	0	0
	42	Allow connection of RWH system to storm system	3	6	0	0	4	2	0	3	1	0	0
Non-Regulatory Solutions	43	Technical education for building professionals and trades	14	1	4	1	3	3	0	1	2	1	2
	44	Manual of best practices	5	4	1	1	5	0	1	4	0	0	2
	45	Further research and testing	5	3	3	0	6	0	0	3	0	1	1
	46	Quantification of municipal level impact (economics, water demand)	10	3	3	0	2	3	1	2	2	0	1
	47	Public education	12	3	3	0	4	2	0	0	1	3	1
	48	Develop RWH industry association	2	5	1	0	6	0	0	3	1	0	0

Note: Significance rating (0 – 2) and total score are in ascending order: a higher score indicates greater significance.

Overall Trends

The generation of solutions produced a greater degree of agreement among the different categories of respondents than the identification of barriers. Three of the top five priorities received support from all three categories of respondents. These were expanding the permissible end uses of rainwater [35], technical education for the building industry [43] and treatment specifications in the Code [36]. All of the top eight solutions were supported by at least two categories. The need for provincial endorsement [24] was the second most critical issue, despite lacking support from suppliers. It was by far, the number one issue for municipal representatives. Only one issue was viewed as very significant by one category and insignificant by the other two. This was the suggestion for product or installer certification, recommended by the suppliers [28].

Trends within Each Category

As liability is the barrier that most directly affects building inspectors, their priorities focused principally on augmenting the Building Code to give them more guidance for approving RWH systems [31-42]. Also cognoscente of municipal liability issues, the conservation officers were unanimous in their strong desire for provincial leadership and direction, via the Building Code and otherwise. Both groups also agreed about the need for technical education and training [43].

As with the barriers, the recommendations offered by the practitioners showed significant variance, with the builders again offering the greatest number of suggestions. The need to expand the allowable end uses beyond toilets [35] was their first priority, followed by the quantification of municipal level impacts [46] and provincial endorsement [27]. Financial incentives [25] (derived in part from the quantification of the municipal level impacts of widespread RWH [46]), treatment requirements [36] and prohibiting potable water for irrigation [30] were all agreed upon by the two architects as significant; however, neither saw any issue as very significant. There was no agreement among the two engineers as they have differing views about RWH in general.

Public education [47] was the most important recommendation put forth by the suppliers, expressed unanimously by all four respondents. This was followed by product certification [28], technical education [43] and financial incentives [25], all considered very significant. Several Building Code issues emerged as significant, reflecting the suppliers' intimate knowledge of the Code and their frustration with its limitations.

What level of influence has the CSA B.128 Standard Achieved?

CSA Standard B.128 was published in May, 2006, to provide guidance for the design, installation and permitting of non-potable water systems, including RWH. Interview participants were asked about their familiarity with the standard to indicate the level of penetration and influence it had gained in the year or so since its release. Their responses are summarized in Table 0-3.

Table 0-3: Degree of familiarity with CSA Standard B.128 among respondents

Degree of Familiarity	Number of Respondents
Unaware of standard	3
Aware standard exists	6
Familiar with content	7
Committee member	4

Nine of the sixteen respondents were not familiar with the content of the standard. Of the seven people who were knowledgeable, four were on the technical committee that developed the standard. Discounting the committee members, the standard had effectively reached only 3 of the participants.

The low level of penetration is largely due to the fact that the standard is so new. Also, only a portion of the respondents had been involved in a RWH project since its release, and of those, each in a different capacity. Not all of the participants would have actually required that level of technical information. However, of the people familiar with the standard, the majority agreed that it is largely unknown and stressed that it must be referenced in the Building Code before it will be recognized and enforced.

Synthesis of Results

This study originally sought to examine the policy context for RWH by identifying and exploring regulatory barriers; however, it was the non-regulatory barriers that emerged as the greatest priorities for the respondents. Many non-regulatory barriers, however, have regulatory solutions and the relationship between the two spheres cannot be neatly delineated. Further, each barrier has many possible solutions and each solution can help to address several barriers. The following table elaborates on the key issues and trends that arose from the interviews and case studies and attempts to explain their interrelation. A full discussion of these issues, as well as a list of specific Building Code concerns, is presented in the appendix at the end of this chapter.

Table 0-4: Synthesis of major issues from survey results

Issue[1]	Barriers		Opportunities	
	Convergence	Divergence	Convergence	Divergence
Cost (13/16)	• High cost as major barrier to demand • Limited use of rainwater permitted in Code prevents better cost performance • Lack of technical capacity and familiarity with RWH among building professionals serves to exacerbate cost barrier • tradespeople who increase the price of installation • engineers who over-design systems • delayed approvals processes	• Cost not a significant barrier (1 Builder)	• Full cost recovery in water sector will improve payback • Financial incentives needed • exemption from wastewater fees • tax deferral on capital investment for RWH • reduced development fees • in approval process, give priority to development applications with environmental features • Municipalities have responsibility for incentives due to the benefit they receive from widespread implementation • Public education necessary to increase willingness to pay	• Incentives not needed. If restrictions on end use are removed, RWH will become economical (ie. in rural context where it may replace a private well) and commercial interests will drive demand. (1 Builder)
Public Awareness (12/16)	• Lack of environmental consciousness and awareness about water issues leads to low demand for RWH and low willingness to pay • Lack of awareness exists among both the public, government and members of the building sector	• Significant awareness and demand already exists, but it is impeded by restrictive regulation. (1 Conservation Officer) • Demand limited by economic performance, not by lack of awareness. (1 Builder)	• Public education necessary to "grow" demand • Increasing demand will encourage market development, allow for economies of scale and ultimately create enough pressure on government agencies to achieve regulatory reform (ie. allowing more end uses for rainwater in OBC and active encouragement of RWH)	• Regulatory reform should be led from the top and should not need to be driven from the bottom Progressive regulation facilitates awareness and leads to higher demand. (1 Conservation Officer) • Public education not needed. If restrictions on end use are removed, RWH will become economical (ie. in rural context) and commercial interests will drive demand. (1 Builder)

Issue[1]	Barriers		Opportunities	
	Convergence	Divergence	Convergence	Divergence
End Use (10/16)	• Restrictions on permissible end uses (toilet flushing) in OBC limits potential water savings and increases financial payback period • Significant interest/demand from end users for additional applications for rainwater • Expansion of end uses in OBC represents tangible provincial endorsement	• No interest observed for additional end uses beyond toilet flushing (1 Engineer)	• Expanding permissible end uses is the most important change that can be made to the OBC • Indoor use to include laundry, potentially potable applications • Additional end uses must be accompanied by more design specifications, especially for treatment, either in Code itself or referenced in Code • Separation of greywater and rainwater in Code important before further end uses or design requirements can be specified • Discouraging or banning potable water use for irrigation as feasible next step	• The level of public awareness around safe use of non-potable water is not sufficient to promote additional uses. (1 Engineer)
Liability (8/16)	• Liability is most significant issue for municipal representatives • Municipality is responsible for ensuring safety and efficacy of what they promote. In absence of guidelines from higher authorities, they are liable for any information they give out or recommendations they make. • Building inspectors personally liable for the approvals they grant, specifically ones which contravene the Code or require interpretation of the Code. • Results in conservative decisions.	• Liability not a significant issue for architects, engineers or suppliers. They can design the systems to mitigate risk to their own satisfaction and to that of the Code. • Engineers ultimately responsible for health and safety, not municipal inspectors. (1 Engineer)	• As the Code is legally binding, enforceable and comes from provincial authorities, it is the most effective mechanism for alleviating municipal liability concerns • Detailed design requirements in Code, specifically with respect to quality and treatment, are necessary to minimize liability	• There is currently not enough knowledge or experience to develop detailed design standards. (Engineer) • Too much regulation may inhibit the uptake of RWH; information is preferred over regulation (2 architects, 1 supplier) • Broader policy support at the municipal level may encourage inspectors to approve innovation that goes beyond the Code. (1 Builder)

Issue[1]	Barriers		Opportunities	
	Convergence	Divergence	Convergence	Divergence
Technical Capacity Building (11/16)	• Lack of familiarity with RWH among municipal staff, the building industry and homeowners in general • Causes resistance, hesitation and cost escalation at every step of the implementation process • tradespeople who increase the price of installation • engineers who over-design systems • delayed approvals processes	•	• Technical training specifically on RWH for all stakeholders • Training to include technology as well as regulatory processes • Training needs to encourage changes in attitudes and values, with respect to environmental stewardship	•
Provincial Endorsement (8/16)	• Provincial endorsement necessary to assist municipalities in promoting RWH on a wide scale • Lack of provincial endorsement increases liability concerns for municipalities • Lack of provincial endorsement undermines the legitimacy of RWH and exacerbates resistance from municipal and building professionals	• As little provincial intervention as possible is desired (2 Architects)	• Improving the OBC to better promote RWH is the most impacting form of endorsement • Expand the allowable uses for rainwater • Develop dedicated section for RWH • Informational material for end users • Implementation strategies or best practices for municipalities	•

1. Value in parenthesis represents the number of respondents who discussed each issue as either a barrier or a solution, out of a total of sixteen respondents.

International Examples

In addition to the insight provided by local stakeholders, the case studies from Australia and Germany reviewed in Chapter 6 offer concrete examples of how the barriers identified in this study can be addressed.

High Cost:
While still a substantial cost, RWH is more economically attractive in both Germany and Australia than in Canada. This can be attributed to higher water tariffs and specific RWH incentive programs and the existence of a mature RWH industry. Volume-based storm water fees have also served as a significant incentive in Germany. Australia further benefits from the fact that their climate allows for above-ground plastic tanks, which are much less expensive to install than the buried tanks required in a cold climate.

Lack of Public Awareness:
In Australia, public awareness about water and conservation seems directly related to scarcity issues and the multi-year drought affecting many regions. This awareness is reinforced through aggressive government conservation initiatives. This situation, combined with the historic use of RWH systems in rural Australia, has granted the practice a high level of acceptance. Germany in general is well known for environmental innovation and leadership and a lack of public awareness has not been a significant barrier to the uptake of RWH (König 2008). Further, in both countries, higher water tariffs help foster public awareness about water issues and the value of conservation.

Liability:
In both Germany and Australia, federal legislation defines three basic requirements for RWH: (i) cross connection requirements or restrictions; (ii) labeling of pipes; and (iii) notification to public health office and local water provider (AS/NZS 2003; König 2008). In Germany, these requirements are supplemented by the DIN technical standards that not binding, but are considered to be best practices and are strongly endorsed by federal authorities. Following these standards alleviates liability concerns (König 2008). In Australia supplemental information for end users is provided by various government agencies at the federal and state level, outlining best practices and recommendations. These documents state that installation, operation and maintenance of RWH systems are the responsibility of the end users and not the local authorities, even in cases where RWH is mandated.

Permitted End use:
In Germany, end use is defined in the DIN standards and not in legislation. The standards permit the use of rainwater for irrigation, toilet flushing and laundry, as well as a variety of industrial applications (König 2005). Acceptance of rainwater for these uses has been largely based on water quality research, showing that the recommended treatment strategies produce a sufficiently high level of water quality for the given applications. Rainwater is thus not subject to water quality guidelines and there is no requirement for testing or monitoring of water quality (König 2008).

In Australia, acceptable end uses for rainwater are largely based on traditional practices. Government authorities clearly encourage the use of rainwater for irrigation, toilet flushing and laundry, as well as hot water applications (Australian Government 2004); however, end use is not defined in the federal building code. Drinking rainwater is not advised when a municipal supply is available, but it is also not prohibited (Australian Government 2004). Government agencies offer extensive information on designing and operating systems to ensure a high level of water quality for all possible end uses.

While many social, environmental and economic factors differ significantly between these case studies and the Canadian context, several of the implementation strategies used abroad can be adapted and applied locally. From these examples, many of the solutions offered by the interview participants appear both feasible and effective.

Discussion

Throughout the study, it became evident that significant divergence exists among stakeholders with respect to what the purpose of a regulatory framework should be and what form it should take. Table 0-5 attempts to delineate this variation into four different categories for regulatory development.

Table 0-5: Summary of four types of regulatory development revealed during the study

Purpose	Characteristics	Development	Tools
Limit liability	• Detailed and clear such that no interpretation is required • Restrictive and conservative • Inflexible and prescriptive specifications • Accommodates a practice, but does not encourage it	• Reactionary - driven by demand from end users • Created by higher (provincial) authorities, limited participation of stakeholders	• Specifications in Code or other legally binding devices • No need for additional information outside of Code as only legal requirements affect decision making
Manage risk	• Detailed • Restrictive, conservative • Inflexible and prescriptive specifications • Accommodates a practice, but does not encourage it	• Reactionary - driven by demand from end users • Created by higher (provincial) authorities • Demands significant research or evidence for advancement • Very slow to develop	• Water quality criteria • Treatment specifications • Product or installer certification
Encourage innovation	• Seeks to facilitate development of technical, market, and institutional capacity • Open, flexible, adaptive • Minimal requirements • Objectives-based • Values experimentation • Requires judgment • Focus on information over regulation	• Proactive - initiated by higher (provincial) authorities • High level of stakeholder participation in development of regulation and support documentation • Looks to other jurisdictions for best practices and considers local, grassroots trends	• Broad policy support at provincial and municipal level • Minimal requirements to cover basic health and safety • Best practices manuals, can be regionally specific and updated as required • Demonstration sites • Technical training
Encourage adoption	• Seeks to facilitate wide spread behavior change • Visible, accessible, user-friendly • Requires sufficient technical, market, and institutional capacity to be in place	• Initiated by higher (provincial) authorities • Endorsed by municipal authorities • May be reactionary and driven by severity of local water situation, or may be proactive in anticipation of future water insecurity	• Broad policy support at provincial and municipal level • Implementation guidelines and strategies for municipalities • Strong education campaign • Information and guidelines for end users • Aggressive incentive programs • Embedded in green building programs • Mechanisms for mandating installations

While most interview respondents saw the need for policy to be multi-functional, several specific tendencies were observed. Most ardently, the inspectors felt that the purpose of regulation, and specifically the Building Code, is to minimize both personal and municipal liability. The conservation officers recognized this concern, but strongly felt that a regulatory framework must also encourage widespread adoption and provide tools for municipalities to facilitate uptake. All respondents identified the mitigation of risk as an important objective for regulatory development. While this was a priority for many of the practitioners, the architects felt it could be achieved with minimal intervention. They clearly favored regulation that gave them the most freedom for innovation.

Although the existing regulatory framework for RWH in Ontario is very sparse, what does exist seems largely focused on alleviating liability and minimizing risk. The few clauses in the Code are restrictive and conservative and while it does accommodate RWH, there are no mechanisms to encourage it. Little support specific to RWH could be found in provincial or municipal policy documents and there is little to no information available for end users. The CSA standard exists, but it is largely unknown, un-influential and inaccessible. Contrarily, in the Australian and German case studies, mechanisms are in place to minimize health and safety risks and alleviate liability, but the focus seems to be on encouraging both innovation and adoption.

Conclusions

One definitive conclusion arising from this study is that interest in RWH is growing and needs to be addressed. Based on opinions expressed in the interviews, it should not only be accommodated, but actively promoted. While uptake will increase naturally due to increases in environmental awareness, water rates and water use restrictions, for example, intervention is necessary to build capacity and accelerate this process. Municipalities are seen to have a significant role in facilitating the uptake of RWH because widespread implementation directly impacts their own infrastructure and operations. They are a key to addressing issues of cost and public acceptance. Provincial agencies are also important to the widespread implementation of RWH because of the authority and influence they have. They have a particularly critical role in advancing the Building Code and alleviating liability issues for other stakeholders. While these barriers are substantial, many practical solutions are available, as identified by local stakeholders and as demonstrated by international experiences.

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Appendix

Discussion of Barriers and Solutions Identified by Interview Respondents

This study originally sought to examine the policy context for RWH by identifying and exploring regulatory barriers; however, it was the non-regulatory barriers that emerged as the greatest priorities for the respondents. Many non-regulatory barriers, however, have regulatory solutions and the relationship between the two spheres cannot be neatly delineated. The following discussion elaborates on the key issues and trends that arose from the interviews and case studies and attempts to explain their interrelation.

Demand

The strongest and likely most important trend made obvious throughout the interviews represents neither a barrier nor a solution. It is simply the opinion, expressed by all sixteen participants, that interest in RWH is growing and will continue to accelerate in the future. Several participants noted that, due to many of the barriers identified in this study, this interest has not yet manifested itself as full-fledged demand; however, the growth of this interest and inevitability of both the need and demand for RWH was largely unquestioned.

Cost

The issue of cost was discussed by thirteen of the sixteen participants, representing all categories except the sub-category of builders. While it emerged as the most significant issue impeding the widespread implementation of rainwater harvesting; several mechanisms, both active and passive, were suggested as means to address it.

Barriers Identified

The high price of RWH is attributed largely to the capital costs associated with each system. Typical buried concrete RWH systems currently range from $6000 tot $10,000, which is ultimately born by the homeowner. High cost produces low demand, which in turn perpetuates high costs. As experienced in the case studies, most systems being installed are one-off systems with no economies of scale. Low demand means minimal market development, few locally available specialized RWH components, a dependency on imported equipment or custom design and installation. The benefits of optimization, standardization and scale have yet to be realized.

This initial cost burden is exacerbated by low municipal water tariffs, making for exceeding long pay-back periods. Two participants pointed to the limited end-use of rainwater as a further constraint on economic performance as additional water savings, and thus cost savings, could be realized if more end-uses were permitted. A link between cost and liability was also mentioned as both designers and regulators would tend toward more conservative, and therefore more expensive, designs in order to ensure all health and safety concerns are mitigated to the maximum possible degree. All of these issues manifest themselves as a barrier to RWH because the resulting cost of RWH exceeds the public's willingness to pay for it. Even for individuals with a high level of environmental consciousness, there are many household conservation products that offer a greater environmental impact per dollar of investment that would potentially be more attractive than RWH.

Recommended Solutions

Five participants predicted that the economic performance of RWH will inevitably improve as full cost recovery is implemented in the public sector and water and wastewater rates increase. Public education about water issues in general and RWH specifically, was seen to contribute to an increased willingness to pay among early adopters of the technology and allow for a further decrease in system cost as greater economies of scale are achieved.

In the end, however, over half of the participants articulated the need for financial incentives to accelerate the uptake of RWH systems until such time that these other factors become significant. Specifically, it was strongly felt that the widespread implementation of RWH would greatly benefit municipalities, in terms of lessening the burden on existing water supplies and mitigating stormwater impacts, and as such they should be responsible for the provision of financial incentives. The expected benefit to the municipality should be quantified and used as a basis for determining the value of these incentives. Different forms of incentives suggested by respondents include exemption from wastewater fees or a tax deferral on capital investment for property-owners with RWH systems and reduced development fees for developers installing systems. One innovative suggestion made by two participants was to give priority to development applications that include RWH (or environmental features in general) and streamline their approval process. Currently, the approval process for applications with environmental features is longer than normal due to the lack of familiarity on the part of the approval body, resulting in lost revenue for the developer. Progressive developers are thus penalized for environmental stewardship instead of being rewarded. By implementing a policy to move environmental applications to the front of the approvals line, municipalities can offer significant financial savings to the developers at no cost to themselves.

Ultimately, if the cost of RWH systems decreases, current interest will grow into high demands as affordability allows individuals to act on their environmental persuasions.

Lack of Environmental Awareness

Twelve of the sixteen participants discussed environmental consciousness and the lack public awareness about water issues as a major impediment to the widespread uptake of RWH, expressed as a very significant concern for 5 of the respondents [18, 47]. Greater awareness was desired primarily to increase demand for RWH.

Barriers Identified

The level of environmental commitment among the general population was seen to be too low to produce the financial commitment needed to implement RWH on any significant scale. Why go through all the trouble and expense when, as one respondent said, "you can just turn on the tap?". The resulting low level of demand then hinders efforts to encourage more progressive regulatory development and may serve to justify the status quo.

Apart from awareness about environmental issues in general and RWH in specific, one engineer extended the need for awareness to the management of non-potable water at the household level. He cautioned against prematurely introducing rainwater or greywater into the home without proper education about how to use it and what safety measures are required. Significant changes in behavior and attitudes would be necessary, he suggested, if non-potable water is used for applications such as laundry or hose-bibs.

Recommended Solutions

Public education was the most obvious means of increasing environmental awareness and cultivating a culture of conservation and was a priority for the majority of respondents. Both municipal and provincial entities were seen to have a role in educating the public about water issues, as a broader context for their active endorsement and promotion of RWH [24, 27].

Those advocating for more environmental education targeting the public generally felt that greater awareness is necessary to cultivate demand for RWH and that this demand will in turn encourage market development, bring costs down, and most importantly, create enough pressure to produce the regulatory changes needed to facilitate widespread uptake. Necessary regulatory reform included expanding the list of permissible end uses for rainwater and developing more detailed design requirements or guidelines, for example [35, 36, 37]. In this case, education and awareness are seen to be the bottleneck to widespread implementation.

Two opinions emerged contrary to this rationale. The custom builder suggested that it is not public awareness that is holding back demand, but rather poor economic performance caused by the limitation on end-use in the OBC. Referring primarily to the rural context, he speculated that if RWH is permitted for all household applications, it could have the potential to completely replace alternative water sources, such as a well, and eliminate the redundancy in infrastructure that results when rainwater is used as a supplementary source. RWH would then be a cost competitive alternative to conventional on-site water supplies, and demand would grow in response to its economic advantage. He suggested that public education is required where there is no business case, but in the rural context, the uptake of RWH could be driven by commercial interests if the regulations permit.

In a similar vein, one water conservation manager felt that a significant level of awareness does exist among developers, builders, municipal governments and the general public. It is the provincial government, and specifically the bureaucrats responsible for the OBC, that lag behind in terms of understanding public expectations and emerging markets. He rejects the argument that regulatory change should be in response to massive public demand and instead holds governments responsible for recognizing beneficial trends and taking leadership in their promotion and implementation. In the case of RWH, the most impacting way for them to do this is through the Building Code. Under these two rationales, the lack of a progressive regulatory framework, and specifically the limitation on end-uses for rainwater, is seen to be the bottleneck to the widespread implementation of RWH. Public awareness and demand are then the natural product of progressive policy.

While it was well recognized that public education is important to “grow demand”, the current limitation on end-uses is seen to impede existing demand and inhibit the economic drivers that could perpetuate future demand.

Limitation on Permissible End-Use

The limited use of rainwater for toilet flushing, as prescribed by the Building Code, was viewed by 10 of the 16 respondents as a major barrier to the widespread adoption of RWH and the expansion of permissible applications was the strongest of all recommendations. Participants largely agree that allowing more uses is both necessary and inevitable.

Barriers Identified

Expanding the permissible end-uses in the Code [35] is a critical issue because, as will be shown in Chapter 5, current constraints prevent the maximum water savings from being achieved and reduce the economic performance of each system. As one respondent said, “If we are going to do this, we can’t just go part way”. It is also important because it represents tangible endorsement of RWH by provincial authorities [27]. The municipal water conservation officers stressed the importance of provincial endorsement in gaining buy-in throughout their organizations, particularly the planning, building and engineering departments. Instead of having to convince each division independently, provincial endorsement, particularly via a device as practical and thoroughly enforced as the Building Code, would provide the authority and influence to refute any resistance from within the municipal administration. This would allow the conservation staff to focus on implementation, instead of battling the institutional resistance that naturally accompanies change.

Recommended Solutions

Three people suggested that irrigation is a logical and relatively straightforward place to begin promoting or even mandating RWH [30]. A policy that no potable water shall be used for outdoor use is thought to be feasible, with one respondent suggesting that non-potable water is already a cost competitive option for the irrigation of many commercial sites. Laundry was generally identified as the next most appropriate application inside the home, and indeed many examples, including the project's demonstration sites, already exist. Four respondents, including two building inspectors, even suggested the possibility of potable end-uses such as showering. At a broader level, the need to re-evaluate the clause in the Code that requires households to connect to the municipal system was raised by four participants, who felt mandatory connection should not be imposed [41].

Overall, the respondents' suggestions for expanded uses of rainwater represent broader trends including the diversification of water sources, an increase in risk tolerance with respect to water quality and the redistribution of responsibility for water management. All are important considerations that merit further attention as the water sector evolves to include technologies such as RWH.

The desire to expand the permissible applications for RWH beyond toilet flushing was accompanied by the recognition that additional end-uses produce an increased level of risk that must be mitigated. Fourteen of the participants discussed the need for more details in the Code [31, 36, 37], primarily to address minimum safety requirements. Many of these comments emphasized in particular the need for treatment or water quality specifications [36]. The building inspectors all suggested that greywater and rainwater must first be separated and given dedicated sections of the Code before additional applications can be permitted [33]. This separation will also serve to better differentiate greywater, rainwater and non-potable water, which was seen to be unclear by 10 of the participants [10, 34]. After separating the two sources, appropriate end uses, design requirements and treatment concerns can be defined for each. As greywater is of much lower quality than rainwater, the constraints with respect to end use and treatment requirements are more severe. Unless the two are dealt with separately, the limitations for greywater would govern, thus impeding the use of rainwater.

Contrary to the desire for more specifications, both architects cautioned against over-regulating, suggesting that too many requirements or restrictions may actually impede the uptake of RWH.

Recognizing the need for additional end-uses for RWH and identifying a possible strategy for permitting these applications provides a relevant context for the following discussion of liability. Liability becomes increasingly significant with each additional end-use and was recognized as a major barrier by many of the study participants.

Liability

Liability [21] emerged as the second most important barrier for the large-scale implementation of RWH; however the concern was largely concentrated in a single category. Eight of the sixteen respondents discussed liability issues, six of whom represented the municipal category. As municipalities are a key stakeholder, it is important that the issue of liability, their predominant concern, be addressed.

Barriers Identified

Conservation officers expressed concern about municipal liability when endorsing something that isn't clearly regulated. They can't actively encourage practices that are prohibited in the Building Code and are hesitant to promote anything that is subject to ambiguity or controversy. They are responsible for ensuring the safety and efficacy of what they promote and in the absence of guidelines from higher authorities, the municipality itself is liable for any information they give out or recommendations they make. They want to promote, implement and enforce higher level directives, but bear too much liability to develop those directives themselves. They eagerly looked to provincial or federal bodies for general endorsement of RWH [27], recommended implementation strategies, and most pertinently, expanded end-uses [36] and detailed design requirements [37] in the Building Code. They want to encourage RWH but at this time there is little for them to actually promote, short of making everything up themselves.

While conservation officers are very conscious of municipal liability, building inspectors have the added concern of personal liability. They stressed repeatedly that they personally bear legal responsibility for the approvals they grant and that it is their job to minimize civil liability. If the applications they approve are in compliance with the Code, then they are not liable for any consequences that may result. However, they are responsible for the consequences of any "legal non-conformances" that they permit and for the interpretation of more ambiguous parts of the Code. While the inspectors all expressed support for RWH and the desire to approve more progressive uses of rainwater, they all felt constrained to more conservative decisions due to the liability they face. This was clearly the issue that impacted them the most.

In addition to the municipal employees, the developer strongly felt that any ambiguity in the Code increases their liability. They need a clear Code to fully understand what the minimum standards are, to assess whether those standards are sufficient and to be confident that they are able to meet them. Having a building inspector approve a system may remove their legal responsibility, but not the personal responsibility they have to their customers. As the developers do not have the technical expertise to design their own systems, they depend on the Code to ensure a minimum level of safety. Further, liability issues tend to delay the permitting of environmental features, further discouraging developers. The severity of these liability concerns increase proportionately with the scale of implementation they realize. As developers are key to widespread uptake of RWH in new developments, their liability issues must also be addressed.

Contrary to these perspectives, the engineers and architects who design RWH systems and the manufacturers who sell RWH products did not express significant concern over liability issues. They better understand the systems they promote, as well as the associated risks, and are able to design the technology to mitigate risk to their own satisfaction and to that of the Code. While this may to over-design and subsequent cost escalation, it does alleviate liability concerns.

Recommended Solutions

The most highly recommended means of minimizing liability and the resulting tendency for excessive precaution is to develop detailed specifications for RWH systems either in the Code itself or as a document referenced in the Code. Specifically, a dedicated section of the Code for RWH [33] and the detailing of treatment requirements [36] were two of the top three recommendations made by the municipal inspectors. Essentially, inspector would like clear-cut criteria that remove the need for interpretation or judgment. All of the inspectors discussed the need to work within the framework of the Code as it is the only legally binding document that defines personal and municipal liability. As seen by the low level of familiarity among inspectors with the CSA B128 standard, documents outside of the Code are given secondary consideration and risk having only minimal impact on decision-making.

As a starting point, individuals familiar with the CSA B128 standard recommended making reference to it in the Code [39]. Three of the suppliers recommended a mandatory certification process for products and/or installers [28], which could further serve to minimize liability for both inspectors and developers. However, this may further complicate the bureaucratic process. In addition to more detailed specifications in the Code, two respondents recommended a manual of best practices [44] to explain the requirements of the Code and promote consistent interpretation. One engineer countered all of these suggestions by pointing out that there is not enough knowledge or experience with RWH, among either practitioners or policy makers, to have detailed design specifications. While this may be true, discussion throughout the interviews suggests that sufficient experience exists to make at least some increment of improvement over and above the specifications currently found in the Code. One municipal representative stressed emphatically that the technical expertise exists and that in fact it is entirely a bureaucratic challenge.

It was also suggested by respondents other than the municipal representatives that liability issues could be eased through broader policy support [24]. Even in the absence of Code changes, municipalities could adopt policy positions that actively promote alternatives like RWH, creating a more open environment for inspectors to utilize the objectives-based approach of the Code and support innovation that transcends the Code. However, as stressed by the building inspectors, ultimately “the Code rules”. Such initiatives may serve to educate and create demand, but would likely have minimal impact on the ability of inspectors to work outside of the Code.

The fact that the 2006 version of the Building Code adopts an objectives-based approach was raised as an opportunity to allow inspectors to approve more innovative RWH systems, without taking on additional liability. Both an inspector and a builder stressed however, that the final decision rests with the Chief Building Inspector, who is under no obligation to approve applications even if the objectives and functional statements are categorically met. As this approach is very new, none of the inspectors were certain if or how it could be used to advance the practice of RWH and there was in general little known experience with the use of the objectives mechanism. It seems that, like most regulatory devices, it will largely be subject to interpretation.

In general, the liability quagmire is that everyone wants to do it, but no one wants to be responsible for it. Ultimate responsibility is seen to largely rest with the Ministry of Municipal Affairs and Housing and the Ontario Building Code and limitations at that level are considered a significant bottleneck to the widespread uptake of RWH.

Technical Capacity Building

One final theme that warrants further discussion is the current lack of technical capacity for RWH. The need for technical training received the third highest overall score among the solutions offered, expressed by eleven of the sixteen participants. It is ranked highly because it relates closely to several of the other key issues, including public education, expanded end-uses and liability.

Barriers Identified

Respondents thought that the idea of RWH was foreign for many people, whether municipal staff, the building industry or homeowners in general. This lack of familiarity was reported for the technology itself [19], as well as for the regulatory tools and procedures that govern it [2,4]. It is compounded by the ambiguity of both the technical and administrative requirements [6, 4, 12, 9] for RWH such that even individuals who are familiar with RWH may have different interpretations of how it can be implemented [3]. Further, the low level of environmental awareness discussed above means that few people would value RWH enough to want to deal with the barriers associated with its implementation [18].

This lack of interest, familiarity and clarity was reported to cause hesitation and resistance at every step in the design and installation process. In the case of inspectors, it causes permitting delays, the imposition of unnecessary requirements or the potential for refusal altogether. Resistance from tradespeople was cited by means of over-pricing the work or otherwise dissuading customers from pursuing RWH. A lack of knowledge and experience among engineers or designers was also mentioned, resulting in the natural tendency to over-design to compensate for uncertainties. All these sources of hesitation or resistance collectively serve to impede the uptake of RWH, due to both the immediate cost escalations incurred, as well as more generally to the lack of technical assistance or administrative support.

Recommended Solutions

Technical training about RWH was suggested for the various stakeholders in order to increase familiarity and minimize resistance [43]. While training must include issues such as system design, end applications, and risk management, several respondents stressed that it should also include discussion of the regulatory procedures and devices affecting RWH so as to increase consistency in their interpretation and application [2, 3, 4]. Two respondents suggested that it must go beyond technical issues and encourage changes in values and attitudes, with respect to environmental stewardship [18].

Technical capacity and thus training and education will become increasingly important as the permissible end uses for rainwater are expanded beyond toilet flushing and correspondingly, as the technical requirements become increasingly sophisticated. While the associated liability issues will be most concretely alleviated by the specification of design requirements in the Building Code, a greater understanding of risk and risk management can be achieved through technical education. This may provide a level of comfort for inspectors, municipalities, the building industry and end users that allows for a broader range of experimentation. The ultimate goal is to develop technical capacity among practitioners and end-users and institutional capacity among the regulating authorities such that innovation can be encouraged.

Building Code Clauses Identified as Problematic for RWH

Section	Clause	Concern
7.1.5.3.	(1) Except as provided in Sentence (2), every water distribution system shall be connected, (a) to a water main that is part of a municipal drinking water system or, (b) to a drinking water system, if a water main described in (a) is not available.	- Requires connection to municipal system, if existing - A RWH system with advanced treatment to produce potable quality water would appear to be acceptable under Part (b); however in one respondent's experience, RWH was still limited by building inspector to toilets despite the absence of a municipal line and the provision of advanced treatment
7.1.5.3.	(2) Storm sewage or greywater that is free of solids may be used for the flushing of water closets, urinals or the priming of traps.	- Referring to rainwater as "storm sewage", which gives a very negative connotation - Limited use of rainwater for toilets - Considers rainwater and greywater jointly
7.1.5.5.	Private sewers and private water supplies pipes should be installed according to the MOE…Guidelines for the Design of Water Distribution Systems…	- This document does not seem to be readily available and can therefore not be evaluated
7.2.10.10.	Except as provided in Sentence (2) back siphoning and backflow preventers shall be certified to , (m) CAN/CSA-B64.10 "Manual for the Selection and Installation of backflow Prevention Devices".	- Rainwater is considered to be an auxiliary water supply and is therefore classified under CSA-B64.10 as an extreme hazard, requiring reduced pressure back-flow protection - It was suggested that isolation is not required if there is no cross connection between the mains supply and the rainwater supply (ie. if the tank is filled with mains water via an air gap, during dry periods), and if all lines are well labeled. An air gap should be the recommended means of supplying water during dry periods, with no further backflow prevention required.
7.6.2.4.	(8) Buildings of residential occupancy within the scope of Part 9 are not required to be isolated unless they have access to an auxiliary water supply.	
7.4.2.2.	An overflow from a rainwater tank shall not be directly connected to a storm drainage system	- Prohibits connection of cistern to stormwater management system (whether private, onsite system or municipal infrastructure) - Due to both design and site limitations, connection to this infrastructure is often necessary
7.6.2.1.	(2) No connection shall be made between a potable water system supplied with water from a drinking water system and any other potable water system without the consent of the water purveyor.	- It was suggested that if, during dry periods, municipal water is provided to the cistern via an air gap and not a cross connection, the consent of the water purveyor would not be required
7.7.1.1.	(1) A non-potable water system shall not be connected to a potable water system.	- Not clear if this statement means that a cross connection that is protected with a reduced pressure backflow preventer is also prohibited
7.7.3.2.	(1) An outlet from a non-potable water system shall not be located where it can discharge into, (b) a fixture into which an outlet from a potable water system is discharge	- This clause may preclude the use of rainwater for the cold service to a washing machine, when the hot water is provided by mains water