DEVELOPING A STANDARD METHODOLOGY FOR TESTING

FIELD PERFORMANCE OF RESIDENTIAL GREYWATER REUSE SYSTEMS:

Case Study of a Greywater Reuse System Installed in 23 Homes in Southern Ontario.

by

Madeleine Jean Craig

Bachelor of Engineering, University of Guelph, 2012

A thesis

presented to Ryerson University

in partial fulfillment of the

requirements for the degree of

Master of Applied Science

in the Program of

Building Science

Toronto, Ontario, Canada, 2015

AUTHOR'S DECLARATION FOR ELECTRONIC SUBMISSION OF A THESIS

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis including any required final revisions, as accepted by my examiners.

I authorize Ryerson University to lend this thesis to other institutions or individuals for the purpose of scholarly research.

____

Madeleine J. Craig

I further authorize Ryerson University to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

I understand that my thesis may be made electronically available to the public.

____

Madeleine J. Craig

ABSTRACT

DEVELOPING A STANDARD METHODOLOGY FOR TESTING

FIELD PERFORMANCE OF RESIDENTIAL GREYWATER REUSE SYSTEMS:

Case Study of a Greywater Reuse System Installed in 23 Homes in Southern Ontario.

Madeleine J. Craig
Master of Applied Science in Building Science
Ryerson University
2015

Using shower wastewater to flush toilets decreases the potable water demand of residential buildings, reducing pressure on existing water supplies. "Off- the-shelf" greywater reuse systems intended for single-family residential dwellings have recently become commercially available, but have variable field performance. A standard field testing methodology was developed and applied to a greywater reuse system installed in 23 homes in Southern Ontario. Performance was quantified by measuring the water balance, water quality, energy consumption, durability, maintenance requirements, installation process, economics and user satisfaction with the system. The tested system was found to save, on average, 40.9 litres per household per day, occasionally meet water quality guidelines and generally have less maintenance and durability issues than previous generations, resulting in satisfied users. However, due to low water rates and high capital costs, there is a need for government subsidization of these systems which will ultimately, reduce pressure placed on centralized water infrastructure.

ACKNOWLEDGEMENTS

Thank you to Ryerson University and my advisor, Dr. Russell Richman, for academic guidance and the opportunity to work on this project.

I would also like to thank Carl Robb at Canplas whose dedication and support made this project possible. I am also very appreciative of the homeowners who participated in this study who kindly allowed me to collect data for this research.

I would like to acknowledge the Natural Sciences and Engineering Research Council of Canada for their support through the Engage grant partnership, the MITACS Accelerate program and the City of Guelph for contributions to this project. Thank you to the greywater reuse industry, and those that have completed previous academic work that has guided this research tremendously.

Finally, thank you to my family, and friends, many of whom I met through this program, who provided the support and encouragement that I needed to complete this project.

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Current Water Issues

Due to the unpredictable weather patterns, more frequent extreme weather events and drought associated with climate change, current water sources are becoming less reliable (International Water Management Institute, 2014). It is estimated that by 2025, 45 percent of the world will be living under water stressed conditions (Daigger, 2009).

Urbanization and population growth are exacerbating the problem of water scarcity. Half of the world's population now lives in urban areas, and this value is expected to increase to two-thirds by 2050, which could lead to water shortages in urban areas, decreasing the ability to support large populations (Zadeh, Hunt, Lombardi, & Rogers, 2013). Along with an increase in building infrastructure to support the growing population, global urban water consumption is expected to increase by 62 percent from 1995 to 2025 (International Water Management Institute, 2014). Regions that are already under water-stressed conditions are not exempt from anticipated population growth, such as the state of Texas, which is expected to have a population increase of 60 percent by 2030, and is a state that already has one of the highest domestic water consumption per person in the United States (WaterSense, 2015).

The high demand placed on urban water infrastructure will require major repairs of old infrastructure, development of new water lines, and larger scale treatment plants which would increase energy and chemical use for water treatment and distribution (Croockewit, 1999), (Daigger, 2009). Additional water supplies will also be required to support the increase in water demand which can be accessed through intensive processes such as deep groundwater abstraction, desalination or importing water from far distances (Environment Agency, 2012). In order to support these costs, Canadians are already seeing an increase in municipal water rates from our low rates, relative to other developed countries (Croockewit, 1999).

Second to the United States, Canadians consume the most amount of fresh water in the world (Croockewit, 1999). Despite the myth of an abundance of natural resources, access to fresh water is limited in most regions of Canada and current finite sources must be preserved in order to ensure water security for current and future generations, as well as to protect water ecologies and the environment (Croockewit, 1999; Vander Ploeg, 2011).

Water conservation is the more reasonable and less impactful method to secure water sources and can be achieved through optimizing existing water infrastructure, changing public behaviour to use less water, and finally water reuse (Hunt, et al., 2012). Water reuse is the process of using water that has already been used and discarded, for an activity that does not require a high level of water quality. Water reuse provides an alternate water supply to reduce the pressure on our jeopardized traditional water sources (Daigger, 2009; International Water Management Institute, 2014).

1.2 Residential Water Use

The residential sector is the third largest consumer of fresh water in Canada (9 percent of national water use), following thermal-electric power generation (66 percent of water use, where some water is brackish or salt water) and manufacturing (13.6 percent of water use). The residential sector consumes more water than the agriculture sector (irrigation and livestock) as well as more than the commercial and institutional sector (Statistics Canada, 2013).

1.2.1 Ontario Water Use

According to the 2009 Canadian Municipal Water and Wastewater Survey, Ontario uses less than the national average daily residential water use per capita. On average, Canadians used 274L per capita, per day (Lcd), in residential buildings, while Ontarians use 225Lcd. This value includes all end uses in the home such as showers and laundry machines, as well as any outdoor irrigation. Residents of Newfoundland and Labrador use the greatest amount of water residentially, by consuming 395lcd, while Prince Edward Island uses only 189lcd residentially (Environment Canada, 2011). As of 2014, the population of Canada was 35 540 400, with 38.5

percent of Canadians living in Ontario (Statistics Canada, 2014). Therefore, a quick estimate can be made that Ontarians consume over three billion litres (L) of water each day domestically.

1.3 Residential End Uses

In order to determine potential savings by implementing water conservation measures into buildings, many studies have been performed to determine the domestic end uses of water such as the daily usage of potable water for flushing toilets in a home.

Aquacraft Water Engineering and Management, supported by the United States Environmental Protection Agency (U.S. EPA), performed three studies over the past decade which: (i) assessed the baseline water consumption in houses in the United States (Residential End Uses of Water Study, 1999), (ii) assessed water consumption in homes that were newly constructed to standard market performance (Analysis of Water Use in New Single Family Homes, 2011) and, (iii) studied water consumption in high-efficiency new homes, which were equipped with conservation technologies such as EPA WaterSense approved faucets (Water and Energy Savings from High Efficiency Fixtures and Appliances in Single Family Homes, 2005).

Table 1: Indoor Residential End Use data, from REUWS study (Mayer & DeOreo, 1999).

End Use	Gallons per capita per day (L/capita/day)	Percentage of Total Indoor Water Consumption
Toilet	18.5 (70.0)	26.7%
Clothes washer	15 (56.8)	21.7%
Shower	11.6 (43.9)	16.8%
Faucets	10.9 (41.3)	15.7%
Leaks	9.5 (36.0)	13.7%
Baths	1.2 (4.5)	1.7%
Dishwasher	1 (3.8)	1.4%
Other	1.6 (6.1)	2.2%

65 percent of the total indoor water use was found to be attributed to toilets, clothes washers and showers, showing the areas where improvement was needed in 1999, as highlighted in Table 1 (Mayer & DeOreo, 1999).

A more recent study in the United Kingdom found that despite increasing implementation of water efficient fixtures, toilets can use 9.5 litres per flush (Lpf), resulting in 45.6 litres per capita per day (Lcd), while showers only produced 11.9 Lcd (Fidar, Memon, & Butler, 2010).

The most current data available on Canadian residential water usage is from an online survey conducted by Dufferin Research in April 2013. 2500 residents across Canada used Environment Canada's *Water Calculator* to estimate their water use in different categories such as laundry and toilet flushing (Frank, Frank, & Hu, 2013). As this data was collected through user surveys, there is potential for poor respondent estimation and inaccuracy in the results.

The study found that an average household in Canada consumes between 753 to 793 L of water per day, domestically, with the average person consuming between 293 and 305 L. These values include outdoor consumption (irrigation), which accounts for 12 to 16 percent of the total recorded consumption. Showers were found to use 21 percent of total water consumption, while toilet flushing used 20 percent (Frank et al., 2013). This study supports the theory that, in residential buildings, shower wastewater could be reused to adequately supply water to flush toilets. The practice is less feasible in non-residential buildings due to the lack of showering and production of large volumes of greywater (Morel & Diener, 2006).

1.4 Indoor Residential Water Conservation Technologies

Through demand side water conservation technologies such as high-efficiency toilets, low flow showerheads and high-efficiency appliances, it is possible that Canadians can reduce their daily residential potable water consumption.

Inman and Jeffrey (2006) reviewed reports of demand side management campaigns and their effectiveness. The study found that replacing fixtures (toilets, shower heads and faucets) with low consumption fixtures can reduce water consumption from 9 to 12 percent, while a comprehensive retrofit including high efficient appliances can save between 35-50 percent of residential water consumption, depending on current water consumption (Inman & Jeffrey, 2006).

Aquacraft research found that retrofitting the same homes studied in the 1999 REUWS study with conserving toilets, efficient clothes washers, low flow showerheads, faucet aerators and hands free faucet controllers reduced daily household water consumption by an average of 260 L per day (39 percent water use reduction). At this point, (2005) dual flush toilet technology occasionally required double flushing, and it was found that although per capita flushing increased slightly, there was an overall reduction in consumption compared to pre-retrofits.

A cost analysis of the water conservation technologies used in the Aquacraft study is shown below in Table 2, which highlights that water efficient fixtures can have a payback of 1.5 to 6.5 years from water savings.

Table 2: Gross costs and savings of fixtures with no utility subsidies used in Aquacraft high efficiency retrofits. Adapted from Aquacraft (2005) (Aquacraft Water Engineering & Management, 2005).

		Gross Costs			**$ Savings**		**Payback**
Fixture	No.	Unit Cost	Total Cost	Water ($)	Energy ($)	Total ($)	Years
Toilets	2	$363	$726	$130		$130	5.6
Clothes Washers	1	$818	$818	$81	$42	$123	6.5
Showerheads	2	$12.50	$25	$10		$10	2.5
Faucet Aerators	3	$5	$15	$10		$10	1.5
Totals	**8**		**$1584**	**$231**		**$273**	**5.8**

The final component of Aquacraft's research, was to analyze water use in new single-family homes, built after 2001 to "standard" (meaning built to meet building code and was not focussed on water efficiency), and those built to the high-efficiency "WaterSense New Home" specification (Aquacraft Water Engineering & Management, 2011). Water consumption was lowest in high-efficiency new homes [416.4 litres per household per day (Lhhd)], and highest in homes built before 1995(670.0 Lhhd), showing improvements in available water conservation technologies (Aquacraft Water Engineering & Management, 2011). Specifically, homes built before 1995 used 171.1 L per day to flush their toilets while high-efficiency new homes used 61.3 L. No improvements were seen by using low-flow showerheads as showers in homes built before 1995 consumed 116.6lhhd, and 129.8lhhd in high-efficiency new homes. This shows that water conservation technologies have improved the water efficiency of toilets. Showers continue to use a large volume of water and if this end use is not able to be reduced, it should be reused.

1.5 Alternative Water Sources

A final method that is currently accessible to reduce potable water consumption in residential buildings is to use alternative water sources in place of potable water when high water quality is not needed. In a residential home, these sources include harvesting rainwater and reusing water from domestic sources that were not heavily contaminated by the first usage like toilet wastewater. The concept of water reuse in buildings is not new, but has taken until recently to begin to be implemented in buildings. In 1958, the United Nations wrote that “no higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade” (Surendran, 2001).

Rainwater is a relatively clean water supply but capturing technology can be expensive to install for residential buildings and does not provide a consistent reliable water source (Alliance for Water Efficiency, 2010; Domenech, March, & Sauri, 2013; Morel & Diener, 2006). Another alternative source, desalination of ocean water, requires excessive amounts of energy to produce which potentially would offset any environmental benefits from water conservation (Domenech et al., 2013).

1.5.1 Water Reuse

Water reuse options range from simple options such as diverting shower wastewater for subsurface irrigation on-site, to Direct Potable Reuse, a very complex treatment system which treats sanitary sewer wastewater to potable levels.

By treating wastewater to an appropriate level and using it a second time, pressure is reduced on high quality freshwater sources and more can be done with less freshwater (Anderson, 2003). The concept of "fit for purpose" is encouraged where reclaimed water should only be treated to the required water quality level needed for that end use. Higher water quality requires increasing levels of treatment, which have higher associated energy and cost requirements (Hui & Jiangwei, 2009; U.S. E.P.A, 2012).

1.5.2 Decentralized Water Treatment

In Canada, 86 percent of households receive water through a centralized drinking water treatment and distribution network, while only 75 percent of households rely on municipal wastewater collection and treatment (Statistics Canada, 2013). This water is transported through 1950s built infrastructure that is estimated to lose up to 20 percent of treated potable water throughout the distribution network due to leaks. In order to repair these leaks, the Canadian government is estimated to face $31 billion dollars of repair and maintenance, and $56.6 billion dollars for expansion and new infrastructure; a process which is limited spatially in dense urban areas (Brandes, Renzetti, & Stinchcombe, 2010; Gikas & Tchobanoglous, 2009; Young, 2013). As of 2010, Canadian utilities were not recovering enough money to cover these repair and expansion costs (Brandes, Renzetti, & Stinchcombe, 2010). Along with infrastructure issues, energy use of centralized systems can amount to 35 percent of total energy used by a municipality for conveyance, treatment, distribution and wastewater processing. In the United States, centralized systems total 2 percent of all national electrical energy consumption (Daigger, 2009; Elliot, 2005). This scenario has caused municipalities to re-evaluate utility budgeting and many are proposing significant rate increases for water and wastewater services (Christen, 2002).

Solutions to reduce pressure on failing and energy intensive infrastructure include (i) increasing water and wastewater service fees to cover costs for infrastructure repairs and (ii) limiting use of centralized treatment systems (Croockewit, 1999). Reducing demand on centralized systems can be done through demand side water conservation and through implementation of decentralized treatment systems.

Decentralized systems treat smaller volumes of wastewater on-site or nearby and distribute the reused water locally for non-potable applications (Gikas & Tchobanoglous, 2009). The majority of the energy used by centralized water treatment systems is used to pump potable water through the distribution network. It is possible that the energy used to treat water on-site using a decentralized system could be equal or less than the energy required for pumping, but this value is site specific (Daigger, 2009).

However, the reduced flow through traditional municipal sewers that would occur if wastewater was to be treated and reused on-site has been a focus of recent research, as sewers were designed to function properly at certain wastewater flows. Penn et al. (2013) modelled the effects of greywater reuse and low-flush toilets on the receiving municipal sewer systems, and found that the reduced velocities were still high enough to move gross solids, indicating that it is not likely that greywater reuse will lead to blockage in existing sewers. Additionally, flush volumes of 3, 6 and 9L per flush were modelled and were determined to not likely cause blockage. This allows sewers with smaller diameters to be built in new construction which has been designed with residential water conservation practices in mind (Friedler & Hadari, 2006; Penn, Shutze, & Friedler, 2013).

1.5.3 Greywater Reuse

A specific form of water reuse growing in popularity in residential buildings in North America is greywater reuse. Greywater (also, “graywater”, “gray water” and “grey water”) is defined as any domestic wastewater that is not toilet wastewater, or contain human waste (which is known as “blackwater”) (Jefferson, Palmer, Jeffrey, Stuetz, & Judd, 2004). Greywater is a cleaner source than blackwater as it has been found to have less organics and pathogens, and can be reused for practices within the home that do not require potable water. Typical examples of greywater reuse applications include toilet flushing, irrigation and in some cases laundry (Pidou, Memon, Stephenson, Jefferson, & Jeffrey, 2007). It is possible to treat greywater to a potable level, but it requires higher levels of treatment and is generally prohibited by regulations (Sharvelle, Roesner, & Glenn, 2013).

Sources of greywater in a typical home include showers, baths, laundry, sinks and dishwashers (Hodgson, 2012). However, wastewater sources from kitchens usually are high in organics and foodborne pathogens, thus dishwashers and kitchen sinks are generally not included in greywater reuse systems (Sharvelle et al., 2013).

Through reconfiguration of plumbing and the possible addition of on-site treatment, greywater can be a significant source of water for activities in the home that do not require potable water. It is a popular water conservation technique as it is an infrastructure based solution, rather than a behavioral solution (Gross A. W., 2008). In theory, users can install a greywater reuse system and continue using their fixtures and consuming water in their homes as usual. The flow of greywater reuse in a typical home which captures greywater from showers and uses it for toilet flushing is shown in Figure 1. However, greywater reuse has been found to not perform as seamlessly as the traditional municipal water supply and does require some behavioural changes (e.g. maintenance) (De Luca, 2012). The functionality issues associated with residential greywater reuse are discussed later in Section 4.1.4.

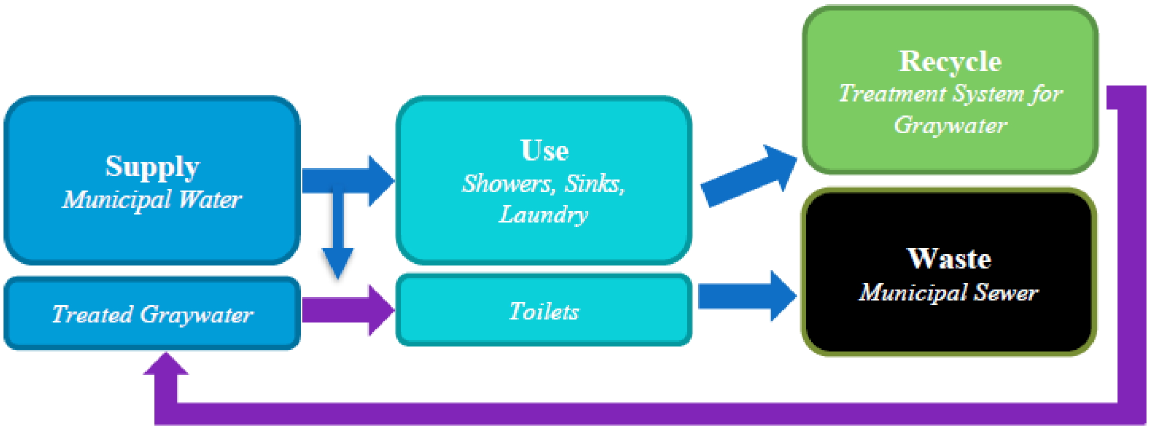


Figure 1: Schematic of flow of water and wastewater through a typical house that has been retrofitted to reuse greywater to flush toilets, from (Sphar, 2012).

Once the greywater reuse system is installed, an increase in concentration of solids and organic matter can be found in the sanitary sewer line(less dilution of pollutants). This concentration of organic matter aids with anaerobic treatment and even allows for the potential of methane biogas to be sequestered from the system. In the future, wastewater systems could generate energy rather than use it for treatment (Sharvelle et al., 2013).

1.5.3.1 Types of Greywater

Greywater quality can vary based on the wastewater origin (Christova-Boal, Eden, & McFarlane, 1996; Friedler, Kovalio, & Galil, 2005; Nolde, 2005). Therefore, based on the wastewater source, greywater is classified as either light or dark greywater.

Greywater collected from showers, baths, and bathroom sinks is referred to as “light greywater”, while greywater from all light greywater sources plus wastewater originating from washing machines, kitchen sinks and dishwashers is considered “dark” or “mixed greywater” (Friedler, Yardeni, Gilboa, & Alfiya, 2011; Sharvelle et al., 2013).

Dark greywater from kitchen sources has remnants from food which can lead to high amounts of oil and fats as well as bacteria from decaying food, to the point where the suspended solids found in kitchen greywater can be similar to the levels found in household wastewater, including toilet wastewater (Li, Wichmann, & Otterpohl, 2009).

In both greywater from kitchen and laundry sources, detergents and soaps are present in high concentrations, which can have impacts on the end use. For example, high concentrations of phosphorous or surfactants from laundry detergents can damage the soils that are receiving the greywater as irrigation, harm plants and even contaminate groundwater (Gross A. , 2005; Morel & Diener, 2006). On the contrary, if properly applied, high nutrient loads in greywater could be beneficial for crop irrigation (Mandal, Labhasetwar, Dhone, & Dubey, 2011). Non-biodegradable fibers and strong colours have also been found in laundry wastewater, leading to clogging and other reuse issues (Li et al., 2009).

Light greywater from bathroom sources is considered the least polluted greywater source, potentially due to dilution, which is why it is best-suited for reuse. Similar to laundry greywater, shower greywater also includes soaps from personal hygiene products, as well as other pollutants such as hair and body-fats. Depending on the hygiene of the people showering, bacteria such as *E.Coli* and fecal coliforms have been found to be present in light greywater (Morel & Diener, 2006). If human exposure to the reused greywater is expected, the greywater should be disinfected to reduce the risk of pathogen and virus transmission. Products like chlorine, hydrogen peroxide and UV light are examples of disinfection processes used for residential on-site greywater treatment (Sharvelle et al., 2013).

1.5.3.2 Dual Plumbing

Traditionally, all wastewater streams are combined into one pipe out of the house which flows either to a septic bed or a sanitary sewer (Isliefson, 1998). In order to reuse water within a home, first the wastewater sources must be separated. During the building design and construction process, or through a building retrofit, an additional plumbing system is incorporated that allows the wastewater from greywater sources such as showers, sinks, and potentially laundry machines, to be diverted to a treatment and storage system. In some cases greywater can flow directly to the end use (e.g. toilets which fill using bathroom sink wastewater or direct lines from showers to subsurface irrigation). The traditional blackwater plumbing system continues to collect from toilets and kitchen sinks, and flows to the sanitary sewer (Bergdolt, 2011).

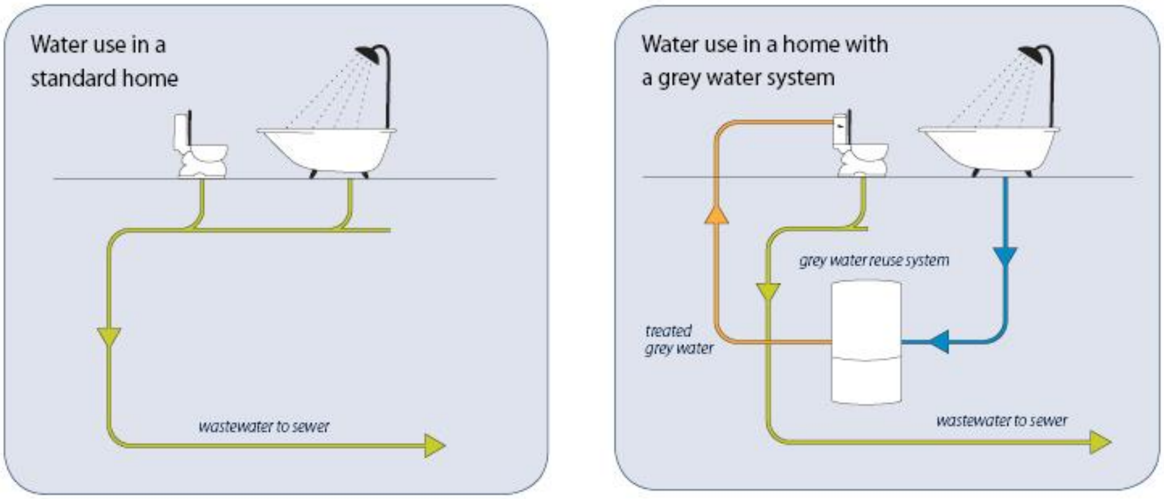


Figure 2: Water flow in a standard home (left) and water flow in home which is dual plumbed to reuse greywater (right), from (City of Guelph, 2012).

The process of creating a dual plumbing system can be very simple and the least expensive if it is incorporated into the initial design of the building and built with dual plumbing. Water scarce areas such as Tucson, Arizona have mandated that all new residential construction must be roughed-in with dual plumbing then homeowners can decide whether to utilize the greywater reuse configuration (Sheikh, 2010). The process becomes much more complicated and expensive when an existing building needs to be retrofitted with a dual plumbing system. However, by retrofitting older buildings, they can become more efficient as well as have an extended useful life, improving a city's existing building stock and potentially reducing the need for new development (Isliefson, 1998).

1.5.3.3 Public Perception and Risks

Much discussion surrounding greywater reuse and the development of regulations involves public acceptance of greywater reuse. There are health risks associated with greywater reuse as the system users can be exposed to bacteria and pathogens in poorly treated greywater used to flush their toilets. When the toilets supplied with greywater are flushed, there is potential for the increased level of bacteria particles to become airborne, and land on frequently touched surfaces in the bathroom, which could lead to illness (Sharvelle et al., 2013).

Using treated greywater for appropriate applications can reduce the risk associated with greywater reuse. For example, using shower wastewater for subsurface irrigation has a much less risk of human exposure than toilet flushing (Sharvelle et al., 2013). Further, users are much more comfortable with reusing greywater produced in their own home, to flush their own toilets, than at a larger collection level (neighborhood treatment and reuse) (Jefferson, Palmer, Jeffrey, Stuetz, & Judd, 2004). Greywater reuse for large populations such as multi-residential buildings has been found to have a greater health risk than for small populations like a single-family home (Dixon, Butler, & Fewkes, 1999).

Sharvelle et al. (2013) surveyed 38 states to gather information on experiences of greywater reuse regulations, and an interesting finding is that, of those 38 states, there had been no reported incidents of sickness associated with greywater reuse. Significant research has been done to assess risk severity for using greywater as irrigation, but more work is required to assess risk associated with exposure to greywater through toilet flushing as this affects the rate of implementation of the systems (Sharvelle et al., 2013).

1.5.3.4 Greywater Reuse in Different Countries

Due to extreme weather, droughts and population growth, many countries around the world have experience implementing water conservation technologies.

Australia, Japan and the United States are leading the way in greywater reuse, with Germany and the United Kingdom also producing research and innovative technologies (Domenech & Sauri, 2010).

Within the United States, California, Arizona, New Mexico and Texas are pushing greywater reuse and are leading the way in regulation development (Sharvelle et al., 2013). In 1992, California became the first state to normalize the use of greywater (Domenech & Sauri, 2010). It is estimated that many homes throughout the United States reuse greywater for in home activities, but as of 1999, only 2 percent of the systems were legally installed (permits are required) (Sheikh, 2010). Reuse at a greater scale than single family residential is currently under debate in the United States right now. Water conscious municipalities in the United States (Texas and California) have shown social acceptance for water reuse and have built Direct Potable Reuse (DPR) municipal water treatment plants which treat wastewater to potable drinking water standards, within the same facility. This is proving to be a financially and technically feasible option as a water source for places in drought such as California, and is expected to be a subject of future water reuse research (Raucher & Tchobanoglous, 2014).

Australia experienced a drought in the late 1990s, which significantly affected eastern Australia. Part of their conservation efforts was to offer rebates for household water conservation devices including greywater reuse systems (Sharvelle et al., 2013). Western Australia aims to recycle 30 percent of all wastewater by 2030, and 60 percent by 2060 (EMRC, 2011).

Due to large populations in concentrated urban areas, Japan has been a global leader in water reuse. Since 1992, greywater reuse has been mandatory in buildings with an area over 30 000m^2. Water reuse in Japan includes on-site systems, systems for local areas and larger district-based systems (Surendran, 2001).

Extensive research on greywater reuse systems has come out of the United Kingdom, yet implementation is not as high as expected due to relatively low water prices (compared to the rest of Europe) and a history of poor performing greywater reuse systems (Environment Agency, 2011). A study performed by South Straffordshire Water in 2004 which installed and monitored simple systems in apartments found them to be unreliable, have strong odour and water quality issues, have noise issues, and overall perform poorly. These systems were found to have a payback of 65 years and therefore were not considered a success (Environment Agency, 2011).

In Germany, greywater reuse in residential buildings has been in practice since 1989 (Nolde, 2005). Nolde (2005) notes that many municipal water distribution systems in Germany are able to distribute drinking water without the use of chlorine, so it is not realistic to use chlorine or excessive amount of energy for a residential greywater reuse system. As of 2008, water rates were much higher in Germany than in Canada, at an average of \$5.09USD/m^3 (Vander Ploeg, 2011).

Greywater reuse is not popular in cities in Canada, due to the tradition of building combined wastewater streams into one outlet to the sewer. Public health, building codes, by-laws, the impact on the environment, building infrastructure, and zoning all need to be taken into consideration when implementing greywater reuse systems in buildings (Isliefson, 1998).

Of most importance to this research is the greywater reuse pilot project that was completed by a joint partnership between the City of Guelph and the University of Guelph in Ontario. Further details of this research are explained in Chapter 2.

1.5.3.5 Existing Residential Greywater Reuse Systems

"Off the shelf" residential greywater reuse systems have recently become commercially available, allowing homeowners to install the systems without much disruption. The systems have been designed to contain all of the components for greywater treatment and the only process to implement the system is to have a plumber connect dual plumbing in the home to the system.

Commercially available greywater treatment systems are available worldwide, using different methods of treatment, resulting in varying levels of system complexity and cost. One of the least expensive and easily constructed methods is a combination of physical and chemical treatment, labelled "simple treatment systems". These simple systems are comprised of two treatment stages (coarse filtration and/or sedimentation to remove large particles, and disinfection), a way to divert the greywater from the sewer (dual plumbing), a storage tank, and a pump to distribute treated greywater to the end use (Christova-Boal, 1995; Pidou et al., 2007). Simple systems are an attractive water reuse option due to their low cost, relatively simple maintenance and their ability to treat harmful bacteria and pathogens in greywater to an acceptable reuse level (Wiles, 2013).

Other systems provide more intensive treatment through components such as ultrafiltration, membranes or biological processes. This additional treatment improves water quality, but also increases the cost for maintenance, energy requirements and the system footprint (e.g. engineered wetland) (Sharvelle et al., 2013).

There are also direct supply / diversion devices which operate under gravity and divert greywater directly from the source to a subsurface or drip irrigation system, without treatment. Sharvelle et al. (2013) provides a comparison and analysis of 17 commercially available, "off the shelf" greywater reuse systems, as of 2013. The systems were evaluated based on system maintenance, operation, energy requirements, and water quality achieved. Diversion systems (no treatment) are the most common commercially available systems as they are relatively inexpensive and easy to maintain (Sharvelle et al., 2013).

In general, developed regulations for the use of greywater to flush toilets require the greywater to be filtered and disinfected (U.S. E.P.A, 2012). Thus, simple systems are the most affordable option for single family residential greywater reuse. The following systems are current examples of simple "off the shelf", single family, residential greywater reuse systems.

1.5.3.5.1 Brac System

The Brac System was a Canadian manufactured system which used a 100µ filter as well as chlorine as a disinfectant. The system could be scaled for both residential and commercial, and had the capability of adding-on additional treatment methods (e.g. sand filtration) if a higher water quality was desired (Sharvelle et al., 2013).

In 2009, the system was installed into 24 homes in the City of Guelph as a pilot study, where the systems operated for two years. In homes that were fitted with an efficient shower and toilet, residents saved on average 16.6Lcd. The system was found to use 1.58 kWh on average to treat one metre cubed of water, which at the current energy rates in Guelph ($0.08/kWhr) was approximately $3 per year for energy (City of Guelph, 2012).

Homeowners were expected to perform system maintenance which involved frequent filter cleaning, which was between once a week and once a month, and adding chlorine. The majority of the pilot study participants rated the system with an overall “good” performance but indicated common issues such as mechanical failure, development of a biofilm in the toilet bowl, poor aesthetics and noted that the required maintenance was time consuming (City of Guelph, 2012).

Sharvelle et al. (2013) interviewed two residents who were using the Brac system. The system users indicated that they were generally satisfied but desired less maintenance. Additionally, the users noted that there were issues with the toilet bladders blistering due to chlorine contact leading to toilet leaks (Sharvelle et al., 2013).

1.5.3.5.2 Water Legacy

The Water Legacy is a system manufactured in the United States. Similar to the Brac system, it collects, filters and disinfects the greywater. However, it disinfects the greywater through a combination of UV irradiation and hydrogen peroxide (Sharvelle et al., 2013).

The manufacturer reported that the system provided insufficient removal of Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS) and turbidity, but removed *E.coli* concentration to below 1cfu/100mL, which is the systems main intent (Sharvelle et al., 2013).

Maintenance of this system requires the homeowner to refill the hydrogen peroxide approximately every four months, annual replacement of the UV bulb and annual filter cleaning (Sharvelle et al., 2013).

Again, Sharvelle et al. (2013) interviewed users who had the Water Legacy system installed for two years, and found that users “liked their systems”. The greatest found issue with the system is that water sitting in the toilet can rapidly degrade as there is no residual disinfectant from UV disinfection (Sharvelle et al., 2013).

1.5.3.5.3 Nexus eWater Recycler

Nexus, an Australian company which has expanded to North America, has developed a system that recycles greywater as well as recovers heat from the greywater drain (Nexus eWater, 2015).

The system recycles greywater from shower, bath, hand sink and washing machine drain water for use for irrigation and toilet flushing, as well as transfers heat from the untreated greywater to the hot water tank for the home. It is designed as a modular system, and can be installed as the greywater reuse system only, or the drain water heat recovery system only. The greywater system has a daily capacity of 200 gallons (757L), and can be sized for both single-family and multi-family residences. The website for the system indicates that the heat captured from the greywater drain through a heat pump process is enough to provide all of the hot water needed by the entire household. The process is similar to the refrigerant loop in a kitchen refrigerator, and has a Coefficiency of Performance (COP) of above 4 (Nexus eWater, 2015).

According to the product's website, the system includes 4 stages; a75 gallon (284L) preliminary storage tank, the tank where the greywater is treated, a hot water tank filled with fresh water that is heated by the greywater, and a final 75 gallon (284L) or 200 gallon (757L) reservoir where the treated greywater (and optional rainwater combination) is stored. The website writes that treatment includes filtration, a bubbling process which concentrates and separates contaminants, and disinfection. The system does not require any chemicals or biological culture, and disinfection is provided through UV treatment (Nexus eWater, 2015).

According to Nexus eWater's News Release on March 13, 2015, the NEXtreater home water recycler is the first system to obtain the NSF/ANSI 350 global standard for residential greywater treatment, a third-party laboratory testing standard showing the performance of the system in a simulated residential setting (Nexus eWater, 2015).

The Nexus eWater "NEXtreater" system is highlighted as being included in KB Home's "Double ZeroHouse 3.0" which are model homes featuring top of the line "cleantech", focussing on both energy and water efficiency (KB Home, 2014). Field performance results of the NEXtreater installed in the KB home are not provided, and there are no published performance assessments of the eNexus greywater reuse system.

1.5.3.5.4 Pontos Aquacycle

As of 2005, the Pontos Aquacycle modular greywater systems were very popular for single family residential buildings. These systems, which had a footprint of $0.81m^2$ and stood 1.88m tall, had a capacity of 600L/day but were not used to that full capacity by single families. Capital costs for the systems, including installation, was approximately €5000, and used between €20-€25/year for energy costs. These systems continuously met the manufacturers' water quality expectations, which were based on the EU Guidelines for Bathing Waters, to the point where the treated greywater was found to be safely used for laundry (Nolde, 2005).

Today, Pontos Aquacycle, manufactured by the German company Hansgrohe, continues to provide greywater reuse systems that function without chemical treatment. The scale of the system has grown, however, with the smallest system treating at least 2000 L of water per day, which is advertised as the greywater produced by 30 people (Hansgrohe International, 2015). These greywater reuse systems are able to meet high water quality of treated greywater through the use of extensive biological treatment. This process increases the cost of these systems, but at a larger scale (at least 30 people) and with the higher water rates in Germany, this system is economically feasible.

1.5.3.6 Overall Performance of Existing Residential Greywater Reuse Systems

In general, there are implementation issues with the currently available residential greywater reuse systems. Until recently, much of greywater reuse research has focused on the treated greywater water quality, but it has been found that there are much more to the feasibility of installing a greywater reuse system than water quality (Domenech & Sauri, 2010). The systems require frequent to excessive user involvement for maintenance, and some systems have recurrent breakdowns (De Luca, 2012; Domenech & Sauri, 2010; Environment Agency, 2011). Additionally, the systems do not meet user requirements as the water generally has an odour and has an effect on the toilet's flushing mechanisms (Isliefson, 1998). Cost of these system vary, and have been found to be "largely uneconomical for a single family dwelling", due to low potable water prices and high installation costs (De Luca, 2012; Jefferson et al., 1999; Li et al., 2009). As of right now, there is currently no standard method for testing the additional aspects of system performance beyond water quality and water savings.

1.6 Thesis Overview

Chapter 1 provides an introduction to the necessity of water conservation, an introduction to residential greywater reuse and a brief review of current "off the shelf" residential greywater reuse systems. Chapter 2 reviews significant literature pertaining to the performance of these greywater reuse systems. This chapter highlights the lack of a standard field testing methodology for performance, and outlines the research objectives of this thesis. Chapter 3 outlines the methodology of the thesis and presents how each research question was answered. Solutions to the proposed thesis questions begin in Chapter 4, which develops a standard field testing methodology of performance of residential greywater reuse systems. Chapter 5 presents the results and discussion of applying the developed testing methodology to a field study and Chapter 6 provides recommendations for further research. Conclusions are presented in Chapter 7, and Works Cited and additional Appendices are Chapters 8 and 9, respectively.

2 Significant Literature

Commercially available, packaged, "off the shelf" greywater reuse systems are available for Canadians to install into their single family homes to allow for greywater reuse; however, previous studies have found that the first generation of these systems had poor performance and that further evaluation of available greywater reuse systems is required. This research aims to develop a standard methodology to evaluate the performance of these “off the shelf” systems in residential settings, showing accurate performance data for manufacturers and consumers.

In order to develop a standard testing methodology for assessing field performance of residential greywater reuse systems, a review of existing performance guidelines, regulations and standards was completed, and is summarized below. More information about existing guidelines can be found in Appendix A: Additional Background. A review of previous field assessments of residential greywater reuse systems was also completed and is presented below.

2.1 Greywater Reuse Guidelines & Regulations

Due to the reliance on centralized water treatment systems, greywater reuse is a relatively new practice that requires regulation. Thus, standards and regulations for residential greywater reuse are being developed and have yet to be standardized across all states and provinces in North America (Sharvelle et al., 2013).

Reuse of water is limited in Ontario due to the elevated risk of contamination of drinking water. Currently, the only regulations set for greywater reuse in Ontario is within Section 7 – Plumbing and Section 8 – Sewage Systems of the newest Ontario Building Code (OBC), which came into effect on January 1, 2014. Section 7 indicates that greywater that is “free of solids may be used for the flushing of water closets, urinals or the priming of traps” (Government of Ontario, 2012).

2.1.1 Canadian Guidelines for Greywater Reuse

Health Canada addressed the lack of standards for reclaimed water in terms of plumbing and water quality requirements, and has developed the *Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing* which provides guidelines for every province to follow. The guidelines do not present recommended manufacturers that meet the guidelines.

The developed guidelines are based off of risk assessment to prevent human health issues and allow for safe greywater recycling systems. The report touches on operation and maintenance of the systems but focuses on how the systems should be set up so that proper management can occur. The guidelines do not present how frequently the system should be maintained and by whom (Health Canada, 2010).

Table 3 displays values set by Health Canada for domestic wastewater and greywater recycling specifically, and for the end use in a toilet or urinal flushing. The parameters are to be met at the point of discharge from the treatment unit, unless stated otherwise.

Table 3: Guideline values for domestic reclaimed water used in toilet and urinal flushing, adapted from the Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing (Health Canada, 2010).

Parameter	Units	Water Quality Parameters	
		Median	Maximum
BOD_5	mg/L	≤ 10	≤ 20
TSS[1]	mg/L	≤10	≤ 20
Turbidity[1]	NTU	≤ 2	≤ 5
Escherichia coli[2]	CFU/100 mL	Not detected	≤ 200
Thermotolerant coliforms[2]	CFU/100 mL	Not detected	≤ 200
Total chlorine residual[3]	mg/L	≥ 0.5	

BOD_5= five-day biochemical oxygen demand; TSS = total suspended solids
NTU = nephelometric turbidity unit; CFU = colony-forming unit
[1] Measured prior to disinfection point. Only one of TSS and turbidity needs to be monitored in a given system.
[2] Only one of *Escherichia coli* and thermotolerant coliforms needs to be monitored in a given system.
[3] Measured at the point where the treated effluent enters the distribution/plumbing system.

The guidelines make use of reference pathogens to represent major groups of pathogens in the water. *Escherichia coli* can be measured and used as a reference for bacterial pathogens as it can have severe repercussions at even low contaminations, as seen during the outbreak in

Walkerton, Ontario in 2001. Measuring *E. coli* indicates disinfection adequacy and a similar result is provided when measuring thermotolerant coliforms. The guidelines recommend, when testing solely greywater, that the thermotolerant coliforms test be performed instead of the *E. coli* test as thermotolerant coliforms can be found in excess when *E. coli* is not present (Health Canada, 2010).

The guidelines state that during the first 30 days of operation of an installed residential greywater reuse system, five samples should be taken and collected to ensure the water is meeting the parameters outlined in Table 3, where the median value of the five samples should meet the median values presented, and the maximum values should not be exceeded. This frequency of monitoring should be continued for residual chlorine, turbidity levels and TSS whereas *E.coli*, thermotolerant coliforms and BOD_5 can be tested either annually or semi-annually. This semi-annual testing should include two samples that are collected at least an hour apart from each other, where one should be less than or equal to the median values (Health Canada, 2010).

2.1.2 Independent Testing Standards

Multiple standards have been developed to test the performance of residential greywater reuse systems. These standards require the system to be set up in a laboratory setting and be dosed with simulated greywater over a period of generally 6 months. Parameters such as construction, operation and maintenance, and effluent water quality are monitored.

The two most relevant standards for this research are *NSF/ANSI Standard 350: On-site Residential and Commercial Water Treatment Systems*, and *CSA Standard B128.3–12 Performance of non-potable water reuse systems*, which have overlapping similarities in how they quantify performance.

2.1.2.1 NSF/ANSI Standard 350 for Water Reuse Treatment Systems

The National Sanitation Foundation (NSF) is an independent and not-for-profit agency which develops standards and tests products to certify that they meet those standards (Sharvelle et al., 2013).

In July 2011, NSF released *NSF/ANSI Standard 350: On-site Residential and Commercial Water Reuse Treatment Systems* and *NSF/ANSI Standard 350-1: On-site Residential and Commercial Graywater Treatment Systems for Subsurface Discharge* (NSF, 2012). As it pertains to subsurface discharge (irrigation), Standard 350-1 is not relevant to this research.
The standard covers systems that treat all wastewater generated onsite (including toilet and kitchen waste) or systems that treat only greywater, and even more specifically, there are standards for each stream such as treating only bath water or only laundry water (NSF, 2012).

With a focus on public health and adequate water quality, NSF/ANSI Standard 350 establishes minimum requirements for the material, design, construction and performance of on-site reuse treatment systems (NSF International, 2011). It provides standards for both residential systems (less than 400L daily treated capacity) and commercially sized systems (less than 5678L (1500gal) treated capacity per day). Additionally, the standard covers on-site water reuse systems that treat greywater from either laundry or shower sources, or a combination of the two.

The certification process includes the greywater reuse system being set up in a laboratory for 26 weeks of continuous testing to show how the system performs over time. As this is a laboratory setting, the system is subject to synthetic greywater for testing and various stress tests which mimic what it would be like in a real home.

2.1.2.2 CSA Standards

Guidelines developed by Health Canada indicate that reclaimed greywater systems should follow the CSA Standard *Design and installation of non-potable water systems / Maintenance and field testing of non-potable water systems* which were developed to provide requirements for construction, operation and maintenance of non-potable water systems. CSA B128.1-06 B128.2-06 and B128.3-12 all relate to design, installation, maintenance and performance of residential greywater reuse systems. B128.1 and B128.2 indicate best practices, while B128.3 is a standard that is met by having the system tested for performance by the CSA in one of their testing facilities.

CSA B128.1-06 *Design and installation of non-potable water systems*, provides restrictions on plumbing and system installation. The standard provides details for system set-up, and specifics for backflow prevention and cross-connection tests. This standard does not discuss performance of the system (Canadian Standards Association, 2007).

CSA B128.2-06 *Maintenance and field testing of non-potable water systems*, provides guidance on how frequently the different components of the system need to be inspected. For example, the standard indicates that every 3 months, the system owner is to inspect, clean and/or replace the filter in the greywater reuse system. The system parts that require maintenance are listed in the following table and should be incorporated as points of maintenance in the developed performance testing methodology (Canadian Standards Association, 2007).

Table 4: CSA B128.2-06 Maintenance guide for non-potable water systems, from (Canadian Standards Association, 2007).

Item to be inspected	Frequency[1]	Action required
Air gaps, backflow preventers	Annually	Inspect as required by CAN/CSA-B64.10.1.
Filter systems	Quarterly	Inspect and clean or replace the filter as required.[2]
Pressure tanks	Annually	Inspect and verify operation.[2]
Pumps	Annually	Inspect and verify operation.[2]
Roof gutters, drains, and screens (rainwater-sourced systems only)	Every 6 months	Inspect, clean gutters and screens, and verify that drains are not obstructed.
Storage tanks	Annually	Inspect and clean[1] as necessary.[2] Check for leaks and repair if necessary.
Treatment systems	Every 6 months	Inspect and verify correct operation.[2]
Warning labels	Annually	Inspect and replace as necessary.

[1]Or as recommended by the manufacturer.
[2]According to the manufacturer's instructions.

2.1.2.3 Summary of Standard Laboratory Testing of Performance

Throughout reviewing the standards, it was determined that methods of testing residential greywater reuse systems are similar for both NSF Standard 350 and CSA B128.3.

Both standards quantify "performance" through water quality testing and assessment of water savings during regular operation, and when the system is under certain stressed conditions. In addition to the performance testing, the standards evaluate the use of materials, the design and construction of the system, markings used to distinguish that the system uses greywater to notify the users, and the instructions that come with the system.

Both standards require the system be set up in their testing facilities and perform various tests for 6 months. Influent and effluent water samples are taken multiple times per week, including during the various stress tests, except for NSF/ANSI 350 does not require water samples to be taken during the vacation stress test (NSF International, 2011). In both standards, it is required that the minimum 6 month testing be completed without any maintenance or routine repairs to test the system reliability.

The materials evaluation for both standards is a visual inspection of the system surfaces, edges and welding. Similarly, the design and construction testing are mostly visual inspection, where the testers assess the structural integrity of the system, the water tightness, and the systems method of overflow and diversion. Design evaluation also includes testing the noise of the system (not more than 60dbA, 6m away from the system), ensuring the mechanical components do not require maintenance, ensuring the electrical components are protected by safety devices (e.g. circuit breakers), assessing whether parts that require maintenance are accessible and an assessment of failure sensing and signaling equipment (the alarms should be audible and visible at a certain distance) (Canadian Standards Association, 2012; NSF International, 2011). In addition, the CSA B128.3-12 standard assesses the system if a blockage were to occur by capping the effluent pipe to simulate a blockage (Canadian Standards Association, 2012).

2.1.2.3.1 Steady-State Testing

Performance testing for both standards includes operating the system at the designed capacity for the majority of the six months of testing, which is where synthetic greywater is added daily in a pattern which simulates a home using the system, such as a surge of water in the morning when people are typically showering.

The base municipal water used to create the synthetic greywater must have a hardness reading between 110 – 220 mg/L and alkalinity of less than 40mg/L as $CaCO_3$. Then, products such as shampoo and toothpaste are added to simulate personal care product loading of greywater (NSF International, 2011).

2.1.2.3.2 Stress Testing

Additionally, in order to show performance as indicated by both standards, the residential shower water reuse system is also subject to stress tests which represent typical scenarios that a homeowner might incur while operating a greywater reuse system. These stress tests include a power and equipment failure test, a vacation test and a water efficiency test. CSA B128.3-12 includes all of the stress tests stipulated in NSF 350, plus additional tests.

The power and equipment failure test adds 40 percent of the system's daily loading between 5pm and 8pm, and then power to the system is turned off at 9pm for 48 hours. No additional greywater is added during the 48 hour period. After the 48 hours, 60 percent of the daily loading volume is added over a 3 hour period. The standard document does not indicate how it quantifies performance during the power outage, other than a water quality test (NSF International, 2011).

The NSF/ANSI 350 vacation stress test involves 75 percent of the system's daily hydraulic capacity being added between 7am and 2pm, and then no water is added for 8 consecutive days while the power remains being supplied to the system (NSF International, 2011). The CSA B128.3-12 vacation stress test is more rigorous, as 100 percent of the daily operating capacity is added between 6am and 9am and then no water is added for the next 13 consecutive days.

Then, on day 14, between 5and 8pm, 100 percent of its daily operating capacity is added (Canadian Standards Association, 2012).

A stress test that is specific to the NSF/ANSI 350 standard is a water efficiency test which loads the system for 7 days with synthetic greywater that is 1.4 times stronger in concentration than typically added. Additionally, the typical volume of water being added to the system is reduced by 40 percent (NSF International, 2011).

There are multiple additional stress tests that are only stipulated by the CSA B128.3 standard. First, is a test which simulates a "working-parent" with 5 consecutive stress days (simulating workdays) and then two "steady-state" days, simulating the weekend. Increased volumes of water are inputted into the system between 6am and 9am, during the week days, and the remaining volume in the daily hydraulic capacity is added between 5 and 8pm, simulating when the system owner returns home from work (Canadian Standards Association, 2012).

Another test stipulated only in CSA B128.3, is a "peak flow discharge stress test" where 200L of greywater is added to the system over a 3 minute period to simulate a bathtub water discharge. The system is also subject to an "underload" stress test, where only 50 percent of the daily capacity is added for 5 days. Similarly, the overloading stress test adds 150 percent of hydraulic capacity for 5 days. Finally, the last stress tests are cold water and hot water stress tests, where influent is added at a temperature of 10 to 15^{o}C, and 55 to 60^{o}C, respectively, for 5 day periods (Canadian Standards Association, 2012).

2.1.2.3.3 Effluent Water Quality Testing

Effluent water quality standards are more stringent for CSA B128.3-12 than for NSF/ANSI Standard 350, as compared below in Table 5.

Table 5: Summary of effluent criteria for NSF/ANSI Standard 350 and CSA B128.3-12, adapted from (Canadian Standards Association, 2012) & (NSF International, 2011).

Measure	NSF/ANSI Standard 350		CSA B128.3-12	
	Median	Single Sample Maximum	Median	Single Sample Maximum
$CBOD_5$ (mg/L)	10	25	-	-
BOD_5 (mg/L)	-	-	≤ 10	≤ 20
TSS (mg/L)	10	30	≤ 10	≤ 20
Turbidity (NTU)	5	10	≤ 2	≤ 5
***E. coli* [1] (MPN/100mL)**	14	240	Non-detectable	≤ 200
Fecal coliforms (CFU/100mL)	-	-	Non-detectable	≤ 200
pH (SU)	6.0-9.0	NA[2]	-	-
Disinfection (mg/L)	≥0.5 - ≤2.5	NA	0.5 – 2	NA
Color	MR[3]	NA	MR	NA
Odour	Non-offensive	NA	Non-offensive	NA
Oily film and foam	Non-detectable	Non-detectable	Non-detectable	NA
Energy consumption	MR	NA	-	-
Sodium Adsorption Ratio (SAR)	MR	MR	-	-

[1] Calculated as geometric mean.
[2] NA: not applicable.
[3] MR: measured and reported only.

NSF/ANSI 350 measures and records total energy consumption through a kilowatt meter, while the CSA B128.3-12 does not record energy consumption (NSF International, 2011).

In addition, CSA B128.3-12 also monitors and records temperature, pH, flow, P_{total}, TKN and ammonia (Canadian Standards Association, 2012).

Other aspects of the standard tests include assessing whether the system has sufficient marking and indication that the plumbing involved hosts non-potable water (such as using purple-coloured pipes), and an evaluation of the supporting documentation given to the system owner. It is very important that operating and maintenance instructions are clear so that the system operates as intended by the manufacturer.

2.2 Previous Assessments of Field Performance

As shown in the previous Chapter, development of regulations for greywater reuse systems is becoming more commonplace for regulating bodies. In order to meet these standards, manufacturers must show how their system performs through standardized testing. To date, the only standard tests available are developed for laboratory testing of "off the shelf" single family residential greywater reuse systems. These tests attempt to mimic greywater reuse patterns and treatment efficiency using synthetic greywater but are not able to capture the variability of greywater reuse in real life settings.

The majority of greywater reuse research to date has quantified performance by assessing only water savings and water quality associated with greywater reuse (Friedler & Hadari, 2006). Many assessments of greywater reuse have relied on estimating water savings figures and theoretical values (Antonopoulou, Kirkou, & Stasinakis, 2013).

Christova-Boal (1995) looked at the feasibility of using different combinations of laundry and bathroom greywater for irrigation and toilet flushing, at four sites in Melbourne, Australia for a 14 month testing period. Three of the four test sites were retrofit situations, while one was incorporated into the construction of the dwelling (Christova-Boal, 1995).

Overall, the performance of the systems in this research were assessed by collecting water use data through flow meters, sampling raw and treated greywater and testing water quality, evaluating the installation process, assessing multiple reusable filters, documenting maintenance of the system, and the impact on the environment and fixtures from using greywater. A final component of the study was assessing social acceptance of greywater reuse in Australia through surveys and the risks (both health and environmental) associated with greywater reuse.

Main conclusions from the study include that, although it is technically feasible to reuse greywater for toilet flushing at a single family dwelling level, it is not economically viable as installation and operation costs were high while water rates were very low. 20 years later, this continues to be an issue of concern in the greywater field. The study showed that water savings and water quality vary at different houses due to numerous household characteristics such as age of residents, number of residents and source of greywater. A final relevant point is that greywater reuse requires intensive involvement from system users for maintenance and operation, which can be time consuming (Christova-Boal, 1995).

In 2001, Surendran conducted research on greywater and rainwater reuse in the United Kingdom. At the three test houses that were equipped with flow meters, Surendran (2001) performed a mass balance and calculated that greywater from showers would only meet toilet flushing demand 37 percent of the time but if water from washing machines was included in the water reuse system, demand could be met 98 percent of the time, with the available toilet technology in 2001. Based off of the water consumption values for the three homes, Surendran (2001) built a full scale demonstration unit in a residence at Loughborough University, capturing bathing water from 50 students and treating the greywater for toilet flushing. Performance of the full system was measured in terms of water quality, water mass balance, and user's reaction to the toilet water (Surendran, 2001).

Nolde (2005) evaluated greywater reuse systems in Germany over a 15 year period. The systems evaluated used electrochemical disinfection and other treatments such as engineered wetlands, biological treatment and UV disinfection. Issues arose with the systems such as buildup blockage in pipes and toilets, as well as high capital and operation costs. It was found that a combination of sedimentation, biological treatment, and UV disinfection was the optimal solution. Every system was evaluated with the following four criteria: safety (proper installation to avoid cross-connections, and acceptable water quality), water aesthetics, social acceptance, and economic feasibility (Nolde, 2005).

A joint effort between Building Research Establishment (BRE) and Essex and Suffolk Water in 1997 tested the performance of the "Water Dynamics Well Butt System" which treats greywater with a filter and bromide, before sending the greywater to flush toilets. The systems were installed into three homes with different household characteristics such as varying ages and number of residents. Potable water savings were between 24 – 65 percent of fresh water used, and the system "worked"

39 to 83 percent of the time it was installed. There was relatively poor performance of the system at the house with seven occupants which would be expected to have the greatest potable water savings. However, it is noted that the showering habits of this house did not balance the consistent toilet flushing, as all residents would shower on one day, overflowing the tank and not provide enough water for the week to flush (Environment Agency, 2011). Water quality at the toilet tank was relatively good, with a low number of coliforms, but turbidity increased over time supporting the idea that greywater (raw or treated) cannot sit stagnant for too long (Environment Agency, 2011).

Since 2011, Colorado State University has been publishing literature on residential greywater reuse. Specifically, a greywater reuse treatment system was designed and implemented at one of the residences at the university.

Bergdolt (2011) wrote that the parameters that must be taken into account prior to installation of a greywater system are local laws and regulations, associated maintenance, existing plumbing, greywater generation, desired end use, treatment, and budget (Bergdolt, 2011).

Hodgson (2012) collected real, raw greywater from residences at Colorado State University and simulated multiple treatment technologies and toilet flushing in a lab setting. The parameters that were used by Hodgson (2012) to assess performance of the different treatment technologies were water quality and cost (including capital and operation). The goal of the research was to achieve proper disinfection while minimizing the operational costs associated with the system, including consumables, energy input, maintenance, and system cost (capital and operations). Maintenance was estimated through allotting an amount of maintenance time to each system based on the system size. Hodgson (2012) wrote that it is difficult to estimate maintenance as it is highly dependent on the durability of the treatment system (Hodgson, 2012).

Hodgson (2012) assessed the treatment systems at various scales and found that at a single family residential scale, there is a very long payback period for greywater treatment systems. This is consistent with results from the City of Guelph's (2012) study and shows that greywater reuse at a residential scale is not economically feasible with currently available treatment methods (Hodgson, 2012).

Following this research by Hodgson (2012), a residence scale demonstration unit was installed at Colorado State University. The system was connected to 14 residence rooms and was designed to process 300 gallons (1135.6 L) per day of greywater. Vandegrift (2014) monitored chlorine concentration, operational experience and through student surveys, collected user satisfaction data. It was found that occasionally there were foul odors associated with the system as well as blockage of the filter due to hair and debris causing the showers to flood. Additionally, the system encountered some errors when the power went out, including the disinfection tank being pumped dry resulting in reliance on municipal water (Vandegrift, 2014) .

Other observations included issues with the hydraulic head and the system not being at the right height to properly collect greywater through gravity.

Sphar (201) evaluated another residence scale greywater reuse project at the University of Colorado in Boulder. Sphar (2012) evaluated six components of the system: physical efficiency (water savings), economic efficiency, institutional efficiency (meets policies and regulations), social efficiency (meets users' needs), environmental efficiency and technological efficiency (system dependability and frequency of repairs) (Sphar, 2012).

As part of a greywater reuse pilot project, the City of Guelph installed greywater reuse systems into 25 houses in Guelph, Ontario (City of Guelph, 2012). Concurrently, De Luca (2012) further assessed two commercially available systems that had been installed at five of the houses.

The systems operated by collecting and treating shower greywater and redistributing it back to flush toilets throughout the houses. Of the five systems that were tested, four of the systems disinfected with chlorine tablets and a 100 micron filter sock, while the last system treated with bleach and had no filtration, but relied on settling for particle removal.

De Luca (2012) assessed the two single-family commercially available residential greywater reuse systems in terms of appropriate technology. The concept of appropriate technology is generally applied to systems being designed for the developing world, but De Luca (2012) applied the approach to assess two different greywater reuse systems installed in homes in Guelph, Ontario. Appropriate technology refers to "a science or technology considered reasonable and suitable for a particular purpose that conforms to existing cultural, economic, environmental, and social conditions" (De Luca, 2012). In summary, an appropriate technology meets certain criteria to ensure the technology will be a success in its' setting. The three main criteria that De Luca (2012) used to evaluate whether the two greywater reuse systems were appropriate technologies for the City of Guelph were (i) reliability, soundness, and flexibility, (ii) affordability and (iii) sustainability (De Luca, 2012).

The first criteria, "reliability, soundness, and flexibility" relates to whether the system meets user's expectations, is robust, and meets permit requirements. This metric is both quantitative and qualitative as it involves water quality sampling and determining how often the system produces acceptable water quality, while the soundness and flexibility metrics determine simplicity of operation and maintenance through user surveys. Under the appropriate technology criteria, De Luca (2012) evaluated greywater quality achieved by each system, water conservation achieved by the systems and performed a failure mode and effect analysis to determine the functionality of the system (De Luca, 2012).

De Luca (2012) monitored greywater reuse systems at 5 different sites for a twelve month period to show any seasonal habits. A twelve month period also allowed for a substantial collection of samples, without having to disrupt the users too frequently. System influent (raw shower water) and effluent (treated greywater) were sampled and tested to see if the system met Health Canada's *Guidelines for Reclaimed Water for Toilet and Urinal Flushing* (2010).

Major conclusions were that the raw shower water quality varied greatly in all parameters at all sites. The poorest raw shower water was found at homes which consumed the most water, and was attributed to the personal hygiene products that were used. However, with only 5 sites of data, it is difficult to draw conclusions of the influence the affecting factors such as age of residents have on water quality. It was found that in general, both treatment processes improved water quality, with reductions levels of greater than 35 percent of BOD_5, turbidity and COD being achieved. Another major conclusion is that initial raw water quality greatly influences treated water quality. For example, the site with influent with the highest water quality, had the highest effluent water quality. In general, both systems failed to meet the turbidity and BOD_5 requirements in the Health Canada Guidelines, but the fecal coliform and total chlorine residual measurements were achieved much more frequently. De Luca (2012) quantifies reliability as the frequency of which the water quality successfully meets Health Canada guidelines.

The second metric that De Luca (2012) used to assess the greywater reuse systems was affordability, which determined whether the greywater reuse system was within the means of the homeowner's financial resources. De Luca (2012) collected water savings information from 5 houses and determined the money saved based on current costs of water in Canada and the payback on investment (POI). De Luca (2012) also compared water savings that could be achieved through other water conserving methods including low flow toilets and front loading washing machines. In order to compare the different conservation methods, litres of water conserved per dollars spent on the product were compared and assessed. De Luca (2012) found that for the City of Guelph, low flush toilets are the most cost effective water conserving solution at the time.

De Luca (2012) developed a few scenarios to determine when greywater reuse is affordable, including combinations of reusing greywater for toilet flushing and outdoor irrigation.

The final metric presented by De Luca (2012) was sustainability which assesses whether the system is both environmentally sustainable as well as locally sustainable which is whether the system will continue to operate without further municipality intervention. This metric involved performing a preliminary life cycle assessment, comparing centralized and decentralized treatment systems (in terms of sustainability), collecting survey data on how the technology can be transferred on to future residents and data on user satisfaction with the greywater reuse systems.

User satisfaction with the greywater reuse systems was collected through surveys and focus groups arranged by both the City of Guelph and the University of Guelph (De Luca, 2012). These questions asked about the system's technical performance and user satisfaction as well as more general questions about the pilot study such as the acceptance of greywater reuse and experiences interacting with everyone involved in the pilot project (municipality, manufacturers, installers).

In conclusion, De Luca (2012) found that the greywater reuse technologies did not meet the developed appropriate technology criteria. One major recommendation was that the systems needed to be improved to "ensure that the systems are robust", to function well with little input and work well with toilets (no clogging, pressure loss or corrosion). This research aims to quantify these previous durability issues.

2.3 Summary of Previous Field Assessment Literature

Through reviewing previous greywater reuse literature, it was found that there are common parameters that are recorded in order to show feasibility of greywater reuse and general performance. These metrics are summarized in Table 6.

Table 6: Summary of field performance metrics of residential greywater reuse systems in previous literature.

Metrics used to assess greywater reuse system feasibility and performance	Nolde (2005)	Al-Jayyousi et al. (2003)	Morel et al. (2006)	Sharvelle et al. (2013)	CSA B128.3-12	Christova-Boal (1995)	Surendran (2001)	Friedler et al. (2006)	Mandel et al. (2011)	Mourad et al. (2011)	Bergdolt (2011)	Hodgson (2012)	Vandegrift (2014)	Sphar (2012)	De Luca (2012)
Public Health (water quality)	●	●	●	●	●	●	●	●	●		●	●	●		●
Economic Feasibility	●			●		●	●	●	●	●	●	●	●	●	●
Water Balance (water savings)				●		●	●		●	●	●		●	●	●
Social/User Acceptance	●	●	●			●	●						●	●	●
Technical Feasibility		●		●		●					●		●	●	●
Impact on the Environment		●	●			●									●
Maintenance				●							●	●			●
Regulation compliance			●								●			●	●
Water Aesthetics	●														●
Energy use												●			●
System Design					●										
System Noise					●										
Power failure					●										
Vacation mode					●										
"Work-week" testing					●										
Peak flow testing					●										

2.4 Research Problem

2.4.1 Gap in Literature

Much of performance testing for single family residential greywater reuse systems is done in labs which do not capture the variability of greywater reuse system performance, or the studies have a focus on reuse for irrigation (Hodgson, 2012). More recently, system manufacturers have been installing their systems into real homes for pilot projects to evaluate their system performance but there is no standard method developed to evaluate performance of these systems when operating in field situations.

Regulations and standards for greywater reuse are inconsistent across North America (Hodgson, 2012). There is a lack of knowledge surrounding the performance of these systems, in terms of long term reliability, costs, and how they interact with centralized distribution systems (Moglia, Cook, Sharma, & Burn, 2011).

Therefore, a standard testing methodology for the field performance of simple residential greywater reuse systems is required. This will provide a method for manufacturers, consumers and municipalities to compare systems in the same terms.

2.4.2 Research Objectives

1. Develop a standard testing methodology for performance of all packaged, commercially available residential greywater reuse systems.

2. Perform an analysis of a pilot project greywater reuse system using the developed standard testing methodology.

3. Determine any possible factors that influence the greywater reuse system performance.

2.4.3 Research Questions

1. What metrics should be tested to quantify field performance of all packaged, commercially available systems?

2. How does the studied greywater reuse system perform in the field?

3. What trends can be observed in the studied system’s performance data that can act as a reference for the performance of current simple residential greywater reuse systems?

3 Thesis Methodology

3.1 Development of Performance Metrics

Previous research has assessed the field performance of greywater reuse systems using a variety of metrics. Through literature review, it became apparent that there are several key metrics that best quantify performance and should be included in a standard field testing methodology (See Table 6). Section 4.1 presents further analysis and support behind the selected performance metrics. In Section 4.2, these selected performance metrics are presented in the developed standard field testing methodology for single family, residential commercially available greywater reuse systems.

3.2 Field Study

In order to test the developed methodology outlined in Section 4.2, the field performance methodology was applied to a pilot study of a residential greywater reuse system that had been installed in homes in Barrie, Ontario and Guelph, Ontario.

The tested system is a commercially available, packaged, “off the shelf” greywater reuse system for single family homes. The system can be installed to treat greywater from any source in the home, and be reused for any end use, but it is advertised as a system to treat shower wastewater (light greywater) to be reused for toilet flushing. The system is a second generation of greywater reuse systems, and has addressed common failures in previous systems as it features a self-cleaning filter, automatic tank emptying every 48 hours, and a user interface which allows the user to control the level of chlorination.

3.2.1 Study Locations

Greywater reuse systems were installed in 29 homes in Southern Ontario. Testing was planned for 23 of the 29 homes where the greywater reuse system was installed. Testing at House 17 began initially, but was not able to be completed due to scheduling issues. Water balance, water quality and energy use data were collected at House 11 and 22 but were not included as representative data due to extremely irregular performance, as explained in Section 5.4. The parameters that were tested at each house varied and the different testing configurations are shown below in Table 7.

Table 7: Parameters tested at each house.

House #	Location	Water Balance	Water Quality	Energy Use
1	Kitchener	●	O	●
2	Guelph	●	O	✕
3	Guelph	●	●	
4	Guelph	●	●	
5	Guelph	●	●	
6	Guelph	●	O	●
7	Guelph	●	O	●
8	Guelph	●	●	✕
9	Guelph	●	O	●
10	Guelph	●	O	●
11	Guelph	●	O	●
12	Guelph	●		●
13	Guelph	●	●	✕
14	Barrie	●		✕
15	Barrie	●	●	✕
16	Barrie	●	●	✕
17	Barrie	DNT	DNT	DNT
18	Barrie	●	●	✕
19	Barrie	●	●	●
20	Barrie	●	●	✕
21	Barrie	●	●	
22	Waubaushene	●	●	●✕
23	Toronto	◇		

O : Full water quality testing (lab testing)
✕: Belkin WeMo installed
◇: Flow meters installed
DNT: Did not test here

Figure 3 below shows the general configuration of the residential greywater reuse system in each of the test homes.

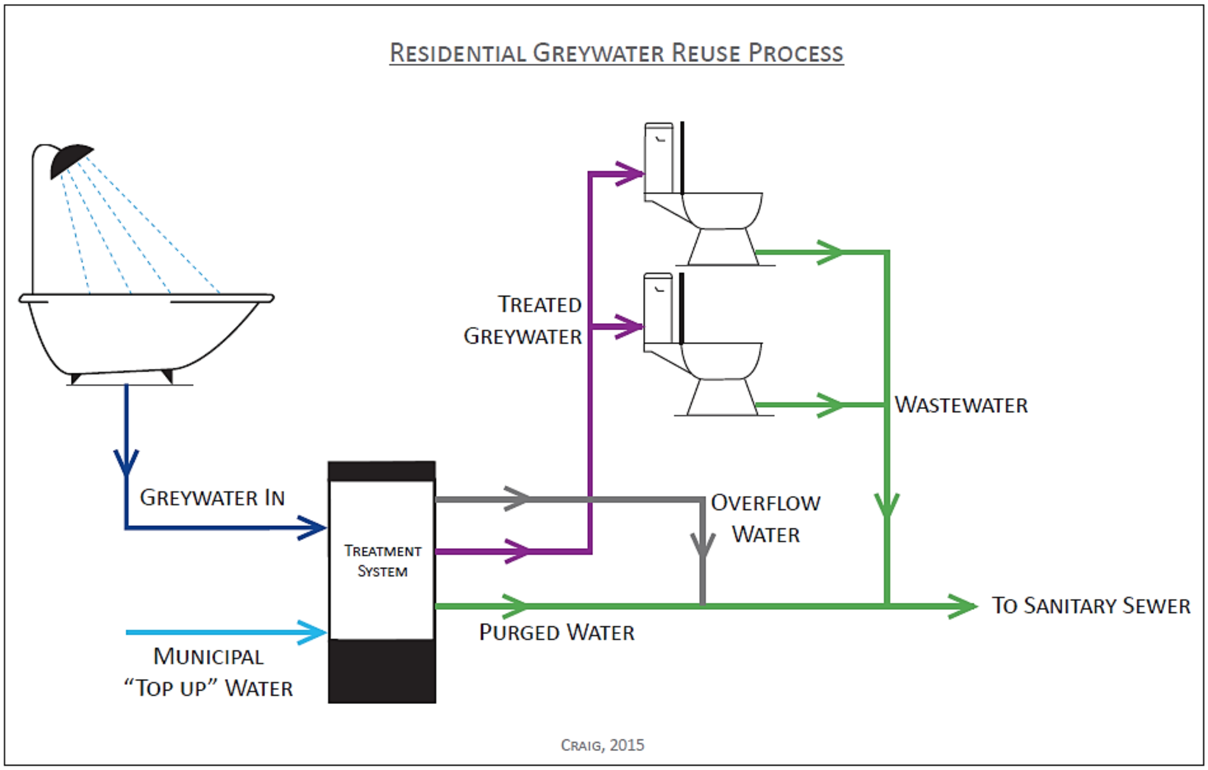


Figure 3: Configuration of the residential greywater reuse process.

3.2.2 Water Balance Testing

The case study greywater system included a program that would measure the volume and time of water flowing in and out of the holding tank, as well as indicate the source/destination of the water. The program operated by time-stamping events and storing the information on the greywater reuse system controller's memory. Then, using a microcontroller and supporting software, the data was transferred to an excel spreadsheet. The greywater reuse system's memory had the capacity to store approximately 30 days of data, after which the data needed to be transferred and cleared.

The program determined the volume of water entering and leaving the system by calculating the change in pressure using a hydrostatic pressure transducer located at the base of the tank. Based on the volume of water and whether it is added or removed from the system, the program determines whether the event was a: Flush, Chlorination (no change in overall volume), Full Purge, Mini Purge, Greywater Added, Freshwater Added, Filter Clean.

Excerpts of raw and edited data collected from the water balance program are presented in Appendix E: Water Balance Results. The raw data was placed into an excel spreadsheet which characterized each data point as a type of event, the relative day, the time and the quantity (volume in L). An event which adds water to the system is recorded as having a positive quantity of water, while an event which removes water from the system is labeled as a negative quantity.

Limitations to the program exist, which is why verification from flow meters was required. The greatest limitation to this method of quantifying water savings is that there was no way to track any overflowed water. Figure 4 shows the five key volumes that need to be recorded in order to fully assess the water balance, and Overflow (Volume 3) is not able to be captured using the pressure transducer method. For example, if a shower caused the storage tank to fill to capacity, it would begin overflowing while greywater was still continuing to be added. The overflowed water would bypass the storage tank and immediately go to the sanitary sewer, and this volume would not be recorded as there would be no change in pressure on the pressure transducer. This is a likely situation in homes where all residents shower in the morning and the greywater is not consumed at an equal rate.

Additionally, due to inevitable toilet leaking, it was required that the program not record an event until 8 seconds of water leaving the system was experienced. After 8 seconds, the software recognizes that the event is either a flush or water is being purged from the system, and begins recording the event. Therefore, each data point was documented with eight seconds worth of flow not being recorded. As per the program developer's recommendation, normalization of the data points was attempted by adding 0.5L to every recorded flush, 1L to every fresh added event and 1L to every incoming greywater event.

Another limitation is that the pressure transducer was not sensitive enough to register some "Mini Purge" events which occurs one hour after a "Greywater Added" event to remove any debris that may have settled at the bottom of the storage tank, as well as to reduce the tank water volume level from the overflow limit so that the pressure transducer was capable of sensing a new event (e.g. new incoming water).

In the case where the greywater in the tank was used by flushes, and sufficient greywater was not being added, the system automatically filled with municipal water. Initially, the program adds 20L of water, but over time, the system determines the average flush volume at that particular house and adds two times that volume. For example, a house with a dual flush toilet (3/6 L flush options), will most likely have an average flush volume of 4.5 L. When the tank runs empty, the program will add 9 L of municipal water so there is water available to flush the toilet.

In order to validate the accuracy of the data logging program, flow meters were installed on to one of the systems (House 23) to compare recorded values. Flow meters were installed on fresh municipal water coming into the system, greywater leaving the system to the toilet and wastewater being purged / overflowed from the system. Ideally, using these three flow meters, the final volume (greywater being added to the system) could have been estimated. Unfortunately, the flow meter recording overflow/purged water became clogged quickly and had to be removed. Therefore the test meters only recorded municipal water that was added, and greywater used by toilets.

Additionally, to test the sensitivity of the pressure transducer, 6 sets of tests were completed, as outlined in Table 68 in Appendix C: Field Study Testing Methodology. The tests compared a known volume of water that was added to the system to the extracted recorded data from the program. Multiple configurations were completed, with the filter in and out, and immediately after or not calibrating the pressure transducer. As a last test, water was poured directly into the tank, through the tank lid (avoiding the filter and drains).

3.2.3 Water Quality Testing

Water quality testing was performed through two methods of evaluation. Some water quality parameters were able to be measured on-site, at all houses involved in the case study, while other parameters (e.g. bacteria testing) were required to be conducted in a laboratory setting. Laboratory testing is expensive and therefore seven specific houses in Guelph were selected to have in-depth water quality testing performed to be representative of all houses in the study. From the data collected through a survey, it was found that the system was installed in homes with mostly two or four residents. Therefore, laboratory water quality samples were collected at three, two-resident homes and three, four-resident homes. One house in the study had nine residents, and was therefore included in full water quality evaluation to show how the system performed under abnormal residential loads.

In summary, water quality testing at Houses 1, 2, 6, 7, 9, 10 and 11 was performed on-site, as well as in a laboratory setting. Table 69 in Appendix C: Field Study Testing Methodology indicates the method of testing used to test each water quality parameter in both the laboratory and on-site.

Water quality samples were collected once a month from August 2014 to February 2015, except for in January, where samples were collected every two weeks. Due to testing equipment failure, samples were not collected in September 2014.

3.2.3.1 Laboratory Measurement Methodology

Maxxam Analytics provided both 500mL and 1L sample bottles that were left at each of the seven homes that were a part of the full water quality evaluation. Users were instructed to collect their shower with the following instructions:

1) At the beginning of each resident’s shower, please plug the drain and allow the bathtub to fill, while continuing to shower.

2) Allow the bathtub to fill enough so that you can fill the provided 500mL sample bottle.

3) Unplug the drain and finish showering.

4) Empty the 500mL sample from each resident's shower into the 1 L sample bottles (to create a mixed greywater sample, representative of your entire household).

It was also indicated that it was best to collect shower water as close to the planned test visit as possible, and to store the samples in the refrigerator until the test visit.

Samples were also collected from within the greywater storage tank (post filtration and chlorination) and from the toilet tank of one toilet that was frequently used and connected to the greywater reuse system.

Samples were stored in coolers with ice until they were delivered to the laboratory on the same day.

Unfortunately, system users were not always available during arranged testing times, and therefore some planned water quality samples were not collected. Full details of collected samples at each house are shown in Table 65 and Table 66 in Appendix C: Field Study Testing Methodology.

3.2.3.2 Field Testing Methodology

At every house in the field study except Houses 12 and 14, a grab sample was collected from the water stored in the greywater storage tank, from the toilet tank (water supply for toilet flushing) and from the municipal water supply (generally from the faucet in the bathroom). A portion from the collected raw shower water was also used for field testing. Samples were tested using field equipment immediately, as some parameters (e.g. free chlorine) are not stable and continue to react in the grab sample.

The length of time that the treated greywater was sitting in the toilet tank was not available, as the data logger on the greywater reuse system was not able to differentiate which toilet in the household had been flushed. It is suggested that in future greywater reuse assessments, a timer be placed on each toilet to indicate how long it has been since the last flush.

Using the LaMotteLTC3000we/wi Meter, turbidity, colour and chlorine levels of the samples were measured.

Total chlorine residual and free chlorine were measured by adding DPD reagent tablets to samples, and placing the sample into the machine. The chlorine reacts with the reagent and changes colour. The machine identifies chlorine levels by comparing the intensity of the colour of the sample to blank colourless standards. DPD tablets without iodine react with free chlorine, and DPD tablets with potassium iodide react with combined total chlorine.

Temperature and pH were collected using pen meters which were placed in the grab samples.

As previously written, equipment to test odour is not readily available, and human observations were used for this testing. The samples were recorded as either having one of the following four characteristics: Soap, Chlorine, Greywater and None. A greywater odour can be described as an offensive, septic smell, which is an indication of bacteria growth. After multiple interactions with field operating greywater reuse systems, the four odours are distinguishable and are easily identifiable.

3.2.3.3 System Purge Setting

Following CSA B128.3-12, as well as previous studies which show that greywater should not be left sitting for more than 48 hours, an automatic purge function was incorporated into the tested greywater reuse system. The water sitting in the treated greywater storage tank is emptied to the sanitary sewer every 48 hours. The 48 hour countdown would restart if the system was emptied due to regular flushing, and subsequently filled with municipal water.

In order to show how the purge function affected water quality of the system, a second version of the operating program was developed which did not have an automatic purge every 48 hours. This version was installed on the select houses in Guelph which were a part of the full water quality testing (Houses 1,2,6,7,9,10 and 11) for January and February 2015 (four weeks total operating time). Since House 11 was not available for testing for the 5th and 6th visit, the "non-purge" program could not be installed at this location. The program was also installed at House 18 for the last two weeks of testing.

3.2.4 Energy Metering

Similar to water quality and water balance, energy consumption of the greywater reuse system was monitored from September 2014 to February 2015 at houses both in Guelph and in Barrie. Energy consumption was not metered at Houses 3, 4, 5, 17, 21 and 23.

Energy usage was monitored using plug-in meters, where the system would plug in to the meter, and then the meter would plug into the wall. The meters tracked any electricity drawn by the system.

When possible, Belkin WeMo meters were used to monitor energy use as they provided power consumed over 30 minute intervals, which could show trends in energy usage relative to water balance events. For example, it was theorized that the energy consumption times could be correlated to event times and energy per event could be calculated, such as a 3am purge event consuming 0.0018kWh.

The Belkin WeMo operates by wirelessly transmitting energy consumption data from the meter to the smartphone app. In order to use the Belkin WeMo energy meter at a home, the system user had to be involved and install the Belkin app on their own smart phone. Monthly, the app exported a spreadsheet to an entered email address. This was not without problems, as the app occasionally did not work, system users did not respond, or the meter was not within WiFi ranges to operate seamlessly. Additionally, if power to the system ever shut off (home power outage), the Belkin WeMo would reset and need to be turned back on before the greywater reuse system would have power again. This interfered with the system performance and users were not satisfied.

In total, the Belkin WeMo was installed at 9 homes, but was rarely installed for the 6 month period due to the aforementioned issues. The number of days of collected data ranged from 27 days to 177 days.

At homes where the Belkin WeMo was not installed due to a lack of smart phone or wireless internet, a Kill-A-Watt meter was installed which kept a running log of energy consumption. The meter has a screen read-out of time elapsed (in hours), electricity consumption (in kWh), and current volts required by the system. This meter was much more dependable but did not provide data at the level of detail that the WeMo did. The Kill-a-Watt meter was installed at 9 homes as well. One of the homes (House 22) had both the Kill-a-Watt and WeMo installed at different times.

In order to compare the energy use of the system to other wastewater treatment methods, the energy consumption values were translated into kWh consumed / m^3 of treated water. This volume of water is the volume of treated greywater that was used to flush the toilets. Treated greywater that was purged or overflowed is not included in this calculation as the energy required to provide usable water is what is of interest. This value is then comparable to the energy used to provide municipal water, which is not purged or overflowed. Therefore, the collected energy data includes data points of energy use from purge and overflow events, but that has been included in the calculation of how much energy is consumed to produce usable water.

4 Field Testing Standard Development

4.1 Analysis of Performance Metrics of Greywater Reuse Systems

4.1.1 Water Savings

The most important metric of greywater reuse system performance is the water savings associated with the system (Vandegrift, 2014).

It has been found that household characteristics, such as the number of family members or the types of fixtures in the house can affect the water savings (Christova-Boal, 1995). In the REUWS (1999) study, it was found that an increase in the number of residents in the house led to a decrease in per capita water use (Aquacraft Water Engineering & Management, 2011). Thus, it is expected that the greatest water savings would be in the house with the most people.

Water savings can be estimated theoretically, by using historic water use records, or by multiplying typical water use figures per person per day (Mourad, Berndtsson, & Berndtsson, 2011; Sphar, 2012). However, due to the installation of efficient toilets, these estimations might be falling behind practice, and water usage metering is required to show true performance (Christova-Boal, 1995).

Previous studies have equipped the studied greywater reuse systems with flow meters on the influent and effluent pipes to establish greywater collection and use. Recordings were made frequently of the meter values and compared with previous values to determine water usage (Christova-Boal, 1995; De Luca, 2012). These volumes can be validated by having the system users fill out log sheets tracking their water consuming activities (Christova-Boal, 1995).

Recently, “smart metering” has become available which are meters that are attached to the main water line in a home that record any vibrations in the water line throughout the whole house. Different vibrations are produced from different end uses and proprietary software is able to differentiate and present water consumption from each end use.

It is important to analyze all greywater production volumes and greywater consumption volumes throughout the system, and should therefore be regarded as a water balance analysis, rather than purely water savings. Figure 4 below highlights five key volumes that should be measured when recording water savings and quantifying the water balance.

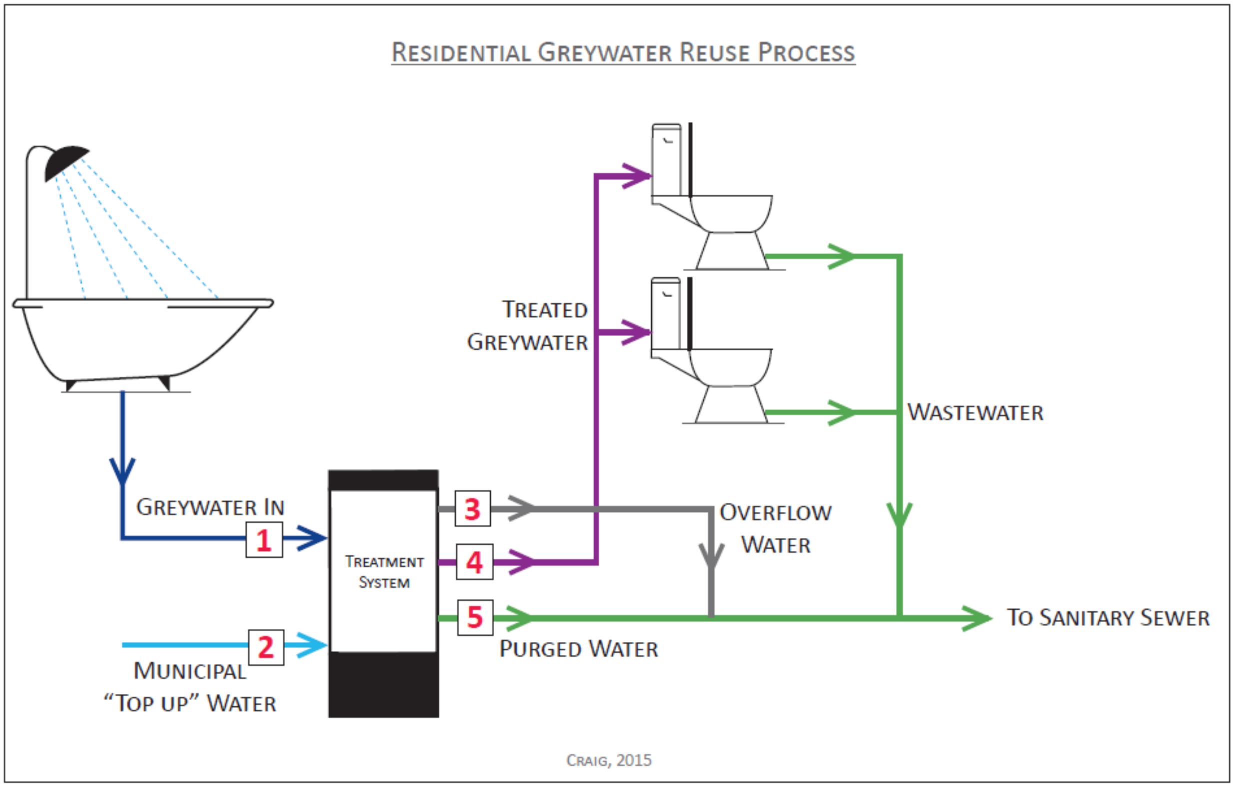


Figure 4: Residential greywater reuse process with five important volumes labelled.

When evaluating the water balance of a system, it is standard approach to consider "water in" to be equal volumes to "water out". In other terms, the greywater in to the system (Volume 1) and the municipal "top up" water (Volume 2) must be equivalent to the water consumed by the system which is either used to flush toilets (Volume 4), overflowed (Volume 3) or emptied for routine maintenance as purged water (Volume 5).

Not all volumes in and out of a greywater reuse system can be metered due to debris and particulates that could clog the rotating parts in the flow meters. When this occurs, a water balance assessment is required to estimate the remaining key volumes (De Luca, 2012).

4.1.2 Water Quality

Protection of public health must be considered when reusing greywater. Water quality of raw greywater from residential sources is well researched and has been found to be comparable to raw wastewater, thus treatment is required prior to reuse (Dixon A. M., 1999; Health Canada, 2010). In order to present the performance of the treatment by a greywater reuse system, the water quality of the influent and effluent water should be sampled to verify whether it meets applicable regulations (Morel & Diener, 2006; Vandegrift, 2014).

Table 8: Water quality parameters evaluated in guidelines and previous work on greywater reuse.

Parameter	Guidelines			Previous Work		
	Health Canada Guidelines (2010)	U.S. EPA Guidelines for Water Reuse (2012)	CSA B128.3-12 (2012)	Eriksson et al. (2002)	Hodgson (2012)	De Luca (2012)
BOD_5	●	●	●	●	●	●
Turbidity	●	●	●	●	●	●
Total Suspended Solids (TSS)	●	●	●	●	●	
Total Chlorine Residual	●	●	●		●	●
COD			●	●	●	●
Thermotolerant coliforms	●	●	●			●
pH		●	●	●	●	
E.Coli	●		●		●	
Temperature			●	●	●	
TOC			●	●		
Conductivity				●	●	
Ammonia (NH_3)			●	●		
$cBOD_5$			●			
TDS					●	
Total solids (TS)					●	
Colour			●			
Odour			●			
Total coliforms					●	
Total Kjeldahl Nitrogen (TKN)			●			
Total Nitrogen (TN)				●		
Total Phosphorus (TP)			●			
Alkalinity				●		
Oily film and foam			●			
Dissolved Oxygen					●	
DCOD					●	

Water quality assessments can involve many different tests and parameters, and those most widely used throughout pertinent literature for greywater reuse assessments are presented above in Table 8.

Following the work done by De Luca (2012) and Health Canada's guidelines for greywater reuse most comprehensively, performance of greywater reuse system treatment should be quantified by measuring:

- Biochemical Oxygen Demand (BOD_5)
- Chemical Oxygen Demand (COD)
- Total and Fecal Coliforms
- Free and Total Chlorine Residual
- Turbidity
- Colour
- Hardness
- Odour
- pH
- Temperature

4.1.2.1 Disinfection

Disinfection is the process of inactivation of microorganisms like bacteria and pathogens in water and is critical for safe greywater reuse (Winward, Avery, Stephenson, & Jefferson, 2008). Disinfection can be measured through disinfectant levels in the water, and through measuring the decrease in bacteria levels.

Chlorine is the most common disinfectant used as it is very effective in inactivating the most commonly found bacteria and viruses in water, is stable, and provides a residual disinfectant after reaction (Sharvelle et al., 2013; U.S. E.P.A., 2012). Chlorine is usually added to greywater reuse systems in the form of tablets as they slowly dissolve as greywater flows over, leading to minimal maintenance (Sharvelle et al., 2013).

Inorganic compounds such as ammonia in greywater quickly react with the free chlorine (Cl_2) in the chlorine tablets. The new reacted compounds, such as chloramine, are less effective disinfectants than free chlorine, but still provide disinfection capabilities (US EPA, 2012). This aspect of chlorine treatment permits for it to be used throughout water treatment as it will allow the water to continue to be disinfected throughout distribution and storage, preventing regrowth (U.S. E.P.A, 2012). The remaining chlorine that has reacted is considered the total chlorine residual, and according to Health Canada Guidelines for greywater reuse, should be above 0.5mg/L in treated greywater (Health Canada, 2010). The U.S. EPA (2012) and British Standard (2010) recommend a similar total chlorine residual of greater than 1.0mg/L and less than 2.0mg/L, respectively. Further information about disinfection can be found in Appendix A: Additional Background.

4.1.2.2 Indicator Organisms

Although greywater does not include toilet waste, there can be indirect fecal contamination at levels that can cause a potential health risk from showers, washbasins and laundry machines (Erikksson, Auffarth, Henze, & Ledin, 2002; Sharvelle et al., 2013).

In order to determine the efficacy of disinfection, the presence of indicator organisms can be measured. Total coliforms and thermotolerant coliforms (also known as fecal coliforms), are used to measure disinfection efficiency of a treatment system as they are indicators of the presence of other bacteria (e.g. *E.coli*) or protozoan (e.g. Giardia and Cryptosporidium) (US EPA, 2012).

One of the biggest challenges that impacts greywater reuse is how much the water quality, specifically the microbial state, can change over time while being stored (Dixon A. M., 1999). Untreated greywater should not be stored without treatment for longer than 48 hours due to growth of total and fecal coliforms (Dixon A. M., 1999; Rose, 1991).

Bacteria regrowth can occur along the distribution line from the greywater storage tank to the toilet tank, where regrowth is most probably as the water can be left stagnant in an infrequently used toilet or when system users go on vacation (Wiles, 2013). Wiles (2013) found that regrowth of indicator organisms in stagnant toilet tank greywater can be prevented for at least two days, if the chlorine residual is sufficient. A chlorine residual of at least 2.75mg/L should be reaching the toilet tank, but system users should fill their toilet tanks with potable water prior to leaving for an extended period of time as a best practice (Wiles, 2013).

4.1.2.3 Turbidity and Suspended Solids

Turbidity, the "cloudiness" of the water, and Total Suspended Solids (TSS) are indicative of the performance of the filtration of a system. Additionally, poor aesthetic water quality can affect the acceptance of greywater reuse (Jefferson et al., 2004).

Health Canada Guidelines require that only one of the two metrics needs to be monitored in a given system as they indicate the same water quality parameter (Health Canada, 2010). Suspended matter within greywater shields microorganisms from disinfection, reducing the effectiveness of treatment (Spellman & Drinan, 2000). Additionally, these particles and organic material consume chlorine without proper disinfection, thus creating a greater chlorine demand and reduces the amount of free chlorine residual remaining in the water for disinfection (Sharvelle et al., 2013). By measuring the turbidity or suspended solids in greywater, aesthetic issues as well as filtration and disinfection issues can be targeted.

4.1.2.4 Biochemical Oxygen Demand (BOD_5)

Five-day Biochemical Oxygen Demand (BOD_5) is an indicator of organic matter which consumes oxygen and adversely affects the disinfection process, leading to aesthetic problems such as poor odour and colour (US EPA, 2012). BOD_5 is measured in amount of dissolved oxygen initially and then over five days, directly correlating the amount of oxygen required by bacteria to stabilize organic matter under aerobic conditions (Spellman & Drinan, 2000). Again, the concern with organic matter is that it can shield pathogens from disinfection (Sharvelle et al., 2013);

however, the City of Guelph (2012) study shows that there is no correlation between BOD_5 and fecal coliforms.

4.1.2.5 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is an indicator of both organic and inorganic matter, which can be oxidized (Rice, Baird, Eaton, & Clesceri, 2012). It is a more complete measurement than BOD_5 as it shows the total depletion of dissolved oxygen in water (Spellman & Drinan, 2000). There is no limit according to the Health Canada Guidelines for COD, but the BOD_5/COD ratio is commonly presented in research as a measurement of greywater quality.

4.1.2.6 Colour

The colour of greywater is measured for aesthetic reasons (Spellman & Drinan, 2000). Christova-Boal (1995) documented colour, as greywater was being collected from laundry sources which was frequently brightly coloured from clothing dye. Over the long-term, this could potentially impact the fixtures such as permanently damaging the toilet bowl. Colour affects the user's acceptance of greywater reuse and ideally should have a low colour reading, measured in Colour Units (CU) (Jefferson et al., 2004).

4.1.2.7 Temperature

Temperature can affect disinfection as the warmer the water, the higher the disinfection efficacy (Spellman & Drinan, 2000). However, an increase of 10^{o}C in wastewater can lead to an increase in biological activities up to twice as much (Surendran, 2001). Documenting temperature of greywater can also support future work in drain water heat recovery.

4.1.2.8 Odour

Odour is a water quality parameter that is not standardly recorded in greywater reuse studies. However, many previous works have indicated that odour of the recycled water could influence user satisfaction (Christova-Boal, 1995). The City of Guelph (2012) found that the aesthetics of the greywater in their field study were of importance to their users. Users were not "completely dissatisfied" but were shifted from "excellent" to being "good" in terms of customer satisfaction due to aesthetics which includes odour and colour. Odour was indicated to be either a chlorine smell or an “unpleasant greywater smell”.

Complete methodology for characterizing odour has not been developed; however, current *Standard Methods* include either measuring odour through the “Threshold Odor Test”, which requires a panel of people to evaluate diluted samples, or by smelling the sample and using previously written qualitative descriptions to determine the odour (Spellman & Drinan, 2000).

Of the qualitative descriptions of odour presented in *Standard Methods*, untreated greywater could be considered to have a disagreeable, septic odour.

4.1.2.9 pH

pH is a measurement of the level of acidity. At pH values above 7.5, the disinfectant capability is greatly reduced (Spellman & Drinan, 2000). Additionally, pH of greywater can show corrosion potential (US EPA, 2012).

4.1.2.10 Water Quality Sampling Locations

In order to test the effectiveness of the greywater treatment, De Luca (2012) collected samples before treatment (from showers) and after treatment (i.e. at the point at which it enters the toilet storage tank as well as directly from the toilet bowls). De Luca (2012) also collected water samples from toilet bowls where the systems ran on potable water, to determine the bacteria levels that typically exist in toilet bowls, without greywater reuse.

Ideally, water quality testing should be performed at each toilet tank connected to the greywater reuse system as different toilets can be used more or less frequently, potentially letting greywater sit for longer.

In order to sample shower greywater, previous field studies that did not have a storage tank with untreated greywater, asked each family member to plug their tub at the end of their shower, stir the water to ensure a homogenous sample, and fill a large bottle with untreated shower greywater (Antonopoulou et al., 2013; Chaillou, Gerente, & Andres, 2011; De Luca, 2012).

4.1.2.11 Frequency of Sampling

Christova-Boal (1995) took four to six rounds of samples over the 14 week testing period. Water quality from greywater from both bathroom and laundry sources were sampled and tested six times, as well samples from receiving soils were tested 4 times, as this study was assessing the environmental impact (Christova-Boal, 1995). De Luca (2012) took grab samples either weekly or bi-weekly at five greywater reuse systems.

No variation in shower greywater quality or production has been found throughout different seasons, and therefore testing for only a portion of the year can be representative of system performance throughout the year (Aquacraft Water Engineering & Management, 2011; De Luca, 2012; Vandegrift, 2014).

4.1.3 Energy use

Treating and reusing greywater at a single family residential scale can use more energy and be more carbon intensive than municipal water treatment (De Luca, 2012; Environment Agency, 2011). Therefore, it is critical to document energy use of greywater reuse systems, and compare it to energy used by municipal water treatment. Traditionally, water treatment uses energy for two events: treatment and distribution.

Generally, for single family, residential, simple greywater reuse systems, the only point of energy consumption is the pump to send treated greywater to the toilets for flushing. In systems with a leaking toilet, the pump could be continuously running, yielding high energy (and greywater) consumption. It is possible to have gravity-fed systems, which store the treated greywater above the toilets, in order to reduce pumping energy (De Luca, 2012). This would require space in rooms other than mechanical rooms, and might not always be possible or accepted by the home owner.

Raw, untreated greywater is typically collected via gravity by installing the greywater storage tank below the height of showers, in a basement or mechanical room. However, occasionally, a shower installed in a basement or on the same floor as the greywater reuse system will require an extra sump pump to drain water from the shower into the greywater collection tank.

Depending on the system complexity, treatment can range from being passive (no energy use like wetlands) to requiring excessive amounts of energy (ozone treatment) (Sharvelle et al., 2013). Previous studies have determined the “energy intensity” of treatment water, which is defined as the energy (kWh) required to extract, treat and distribute 1m^3 of water. This rating also applies to the energy to collect and treat 1m^3 of wastewater. Energy intensity (kWh/m^3) puts energy use into a term comparable at any level of treatment (De Luca, 2012; Mass, 2009).

4.1.4 Durability

Reliability is a term that is used frequently to measure performance of greywater reuse systems. In greywater reuse research, studies refer to reliability as the system’s ability to provide ample and clean water for non-potable reuse, often basing reliability on whether the treated effluent meets local health standards (De Luca, 2012; Gross A. W., 2008). However, the NSF Standard 350 testing process refers to the ability to operate well mechanically, as “reliability” and tests reliability through having the system endure a power outage, a simulated vacation schedule, and excessive volumes of water being added (NSF International, 2011).

Through previous work and anecdotal experience, there is more to performance of a greywater reuse system than just water quality and water savings. De Luca (2012) found that all homes experienced some difficulty with their systems, with the most common issues being mechanical failures as well as a film building up in the toilet storage tank (De Luca, 2012). De Luca (2012) highlighted mechanical failures of the greywater reuse system through a Failure Mode and Effect Analysis (FMEA). It was also found that many failures involved the toilets specifically, indicating that perhaps greywater reuse systems do not perform well with certain fixtures (De Luca, 2012).

A metric is required which captures all of the previously mentioned issues and system failures. It is very important that these mechanical failures be monitored and recorded when assessing the performance of a greywater reuse system as many homeowners will not be satisfied if they install a system which has more failures than anticipated. Highlighting common mechanical failures also allows for the system manufacturers to make improvements.

As part of this thesis, this developed metric quantifying mechanical issues and system failures, as well as the ability to endure stress tests as written in NSF Standard 350, has been labelled *durability* as it is traditionally defined as the ability to exist for a significant length of time without deterioration (Merriam-Webster, 2015). Further explanation of how durability should be recorded is presented in Section 4.2.6.

Quantifying system ‘failure’ is not easily done, as there is a fine line between ‘failure’ and expected maintenance. For example, if the homeowner forgets to add more chlorine pucks, the treatment component of the greywater reuse system could be considered to be failing; however, it is due to lack of routine maintenance. Failure in the sense of the greywater reuse systems should be considered when the system does not operate as intended, beyond routine maintenance.

Log sheets can be used for users to record any irregular observations and aspects of system operation that might require repair or changes to system design (Christova-Boal, 1995).

Previous studies have found that a “thin slimy film of brownish colour” can develop in the toilet tanks, and show up occasionally in the toilet bowl (Christova-Boal, 1995; De Luca, 2012). This not only causes an aesthetic issue, it can block the flush valve from closing properly, and block supply lines. Long term effects from film buildup have not been studied but Kohler Co. (2012) evaluated the effect that different greywater reuse systems had on toilet flappers. Out of the four systems, the systems which showed the most deterioration were the systems which treated greywater with hydrogen peroxide and ultraviolet light; surprisingly more than the system which operated with chlorine (Kuru & Luettgen, 2012).

4.1.5 Maintenance

Routine maintenance of a system is required and when properly completed, allows for optimal system performance. Maintenance requirements might differ from a lab testing situation to when the system is actually operating in the field, and any discrepancies should be recorded in order to show the true performance and maintenance requirements of the system.

Maintenance levels vary based on the size of the system, the design, and the type of treatment. Beyond filter cleaning and chlorine puck addition, little maintenance is expected for current simple greywater reuse systems but previous studies have found that users have to be very willing and interested in order to perform proper maintenance due to the frequency of maintenance (Christova-Boal, 1995; De Luca, 2012).

Filter maintenance has been found to be required between once a month to once a week, and takes between 5 to 20 minutes to complete (Christova-Boal, 1995; De Luca, 2012). In order to quantify filter clogging, Christova-Boal (1995) placed pressure meters before and after the filters to capture head loss across the filter, which would increase as clogging increased.

Christova-Boal (1995) monitored their systems every week for 14 months, and performed maintenance and servicing as required. This maintenance included monitoring frequency of filter changing, the performance of each filter, and failures including odour, scum, and issues with the irrigation system. Additional toilet cleaning is sometimes required due to the installation of a greywater reuse system and should be included in maintenance requirements (Christova-Boal, 1995).

Depending on regional by-laws, there is usually an annual backflow prevention test required by the region which approve that the backflow preventer is working well and cross contamination of the municipal potable water line is not possible (City of Guelph, 2014). This is considered expected maintenance.

CSA B128.2 includes annual assessment of pumps, pressure tanks, storage tanks and warning labels as part of maintenance. Evaluation of the treatment system is expected every six months (Canadian Standards Association, 2007).

4.1.6 User Satisfaction

Social acceptance is one of the greatest barriers preventing greywater reuse from being implemented. Previous and current research has focused on the greater acceptance of greywater reuse, including regulation development (Christova-Boal, 1995).

User satisfaction is a more specific metric than social acceptance which asks the system users to indicate their acceptance with a specific system, and occasionally asks about the overall concept of greywater reuse. In order for greywater reuse systems to be successful, they must be technically simple and user-friendly (Morel & Diener, 2006).

Domènech and Sauri (2010) surveyed greywater reuse system users and in order to quantify overall perception of greywater reuse, "environmental awareness" first had to be assessed, as that could lead to some bias in answers. Assessment of environmental awareness was completed by asking questions about self-evaluation of environmental responsibility, recycling habits and value of water conservation. Homeowners which install greywater reuse systems have very different motives for greywater reuse and there is potential for biases in survey responses. Therefore, it is important to collect environmental awareness of each system user to indicate their level of bias towards greywater reuse. For example, a system user who is highly committed to reducing their environmental impact would potentially be more motivated to perform excessive maintenance for their greywater reuse system than a user who only has a greywater reuse system in their home because they moved in to a new house that was already equipped with a system.

General drawbacks stated by users of greywater reuse systems include unpleasant odours, poor water aesthetics, high maintenance costs and required maintenance/repairs (Domenech & Sauri, 2010).

4.1.7 Installation Feasibility

The installation process varies depending on whether the building is new build, where the dual-plumbing and greywater reuse system can easily be incorporated during design, or an existing structure which can be more expensive (Bergdolt, 2011; Vandegrift, 2014). It is much easier to install the system into unfinished basements, crawl spaces, or mechanical rooms, than in finished buildings (Bergdolt, 2011).

Retrofitting a residential home requires a licenced plumber, and potentially even a general contractor to repair any drywall or damages caused during the installation process as access is required to all shower and toilet plumbing throughout the house. Configuration of existing plumbing can also affect the feasibility of installation of a greywater reuse system (Bergdolt, 2011). Retrofit situations can lead to long and elaborate pipe lines throughout the system, difficulty in connecting the system to the sanitary sewer, and difficulty finding space to install the system without affecting existing services (Christova-Boal, 1995).

Generally, greywater reuse systems are located in basements as the systems are usually installed to be lower than sources of greywater to prevent backup into fixtures, and to allow gravity to aid in greywater collection. However, the location of the sewer line out of the building must also be considered (Bergdolt, 2011). In older homes, such as those in Guelph, the sewer line leaves the house at waist height in the basement, requiring the greywater systems to be elevated or for a sump pump to remove any overflow/wastewater from the greywater reuse system.

Some greywater reuse systems, specifically those used for irrigation purposes, require the greywater storage tank be installed below the ground. Depending on the type of foundation, and clearances in the basement, retrofit situation installation processes will differ. However, it must be ensured that the systems can still be easily accessible for maintenance and cleaning (Christova-Boal, 1995).

During installation, it must also be ensured that there are no cross-connections where potable water systems could be contaminated with greywater, and that any non-potable pipes are labelled with appropriate warnings. Proper installation can be verified through dying the water and tracing it throughout the greywater reuse system (Nolde, 2005)

4.1.8 Economics

In order to assess whether greywater reuse is a sensible water conservation option, the costs and benefits of the greywater reuse system need to be established (Friedler & Hadari, 2006; Hodgson, 2012; Vandegrift, 2014).

Typically, expensive decentralized greywater systems that require high capital and maintenance costs do not reach economic efficiency as the water savings are not great enough. An increase in the intensity of treatment leads to an increase in system expenses which results in a longer payback period (Sphar, 2012).

Costs associated with greywater reuse systems include (Christova-Boal, 1995):

- System cost (complexity and level of automation)
- Installation cost (materials and labour)
- Operation and maintenance costs

The capital cost of a system can vary greatly, based on the purpose and complexity of the system (Kourik, 1993). To help encourage greywater reuse implementation, some regions offer rebates to offset the capital cost of the system. The City of Guelph currently offers a $1000 incentive to homes installing a greywater reuse system (City of Guelph, 2013).

20 years ago, Christova-Boal (1995) found that installation costs ranged from $2870 to $5950 (in Canadian dollars), with the roughed-in design being one of the most cost-effective options over the retrofit sites. However, these systems were each designed for each of the four sites in the study and were expected to be higher than “off the shelf” systems.

Operation costs for single family residential greywater reuse systems is solely the cost for energy used to operate the system, as it is expected that the homeowner operates and maintains the system.

Maintenance costs include the cost for disinfectant and for any filter repairs or exchanges. Christova-Boal (1995) found that the annual cost for chlorine tablets was $24, and the disposable filters cost $5.50 per year. Annual backflow prevention inspections required by municipalities in Ontario can cost up to $150/year, which can further reduce economic feasibility and prevent greywater adoption (De Luca, 2012).

The only direct financial benefit of greywater reuse systems is the reduction in water and wastewater consumption and related payments. At a municipal level, if demand on drinking water treatment plants and wastewater treatment plants is reduced, municipalities would be able to reduce the investments needed to expand centralized treatment plants. Additionally, a reduction in drinking water demand and incoming wastewater would require less chemical treatment and energy input by municipal treatment plants.

Once the costs and benefits of a system have been calculated, an economic analysis can be performed, which calculates the payback period in which the benefits (reduced water and wastewater payments) repay the costs (capital investment, installation and maintenance and operation costs). For the system to be truly economically feasible, the payback period must be within the expected life-span of the system (Friedler & Hadari, 2006).

It is expected that implementation of greywater reuse systems will be increasing, as an increase in water rates, increases the cost effectiveness of greywater reuse systems (Nolde, 2005; Zadeh et al., 2013). Many studies found that greywater reuse systems, even with more intensive treatment, can become economically feasible when applied to multi-unit residential buildings or at a neighborhood level (Friedler & Hadari, 2006; Mandal, Labhasetwar, Dhone, & Dubey, 2011).

De Luca (2012) presented the water savings from three sites in the City of Guelph pilot project, presenting three economic scenarios: (i) best case: highest water savings with lowest costs(capital and annual), (ii) average case: average water savings with average costs and (iii) worst case: lowest found water savings with highest costs. The three sites saved 11.3m^3/yr, 14.8m^3/yr and 35.0m^3/yr. Using these values and a water/wastewater rate of \$2.43/m^3, payback on investment periods of 30 years, 24 years and 17 years were found, respectively, without including any incentives or backflow prevention costs (De Luca, 2012).

Finally, a financial comparison between greywater reuse and other water conservation technologies can be made. Through a cost comparison of other residential water conservation methods, it was found that the low flush toilet is the most cost effective way to reduce water and is a better option economically, than greywater reuse (De Luca, 2012).

4.1.9 Household Characteristics and Affecting Factors

Performance of greywater reuse systems varies based on site specific characteristics (Christova-Boal, 1995; De Luca, 2012). Specifically, the following household characteristics have been frequently mentioned in previous research as directly influencing greywater quality, potential savings and other performance metrics.

Table 9: Household characteristics which can affect performance of residential greywater reuse systems.

Metric	Potentially Influences…
Age of Residents	Water quality
Time spent in the house	Water balance, energy use
Frequency of showering	Water balance, water quality
Number of residents	Water balance
Presence of water softener	Water quality
Location of showers and toilets	Energy use, installation
Personal care products	Water quality
Showering and toilet cleaning products	Water quality
Frequency of cleaning the shower and toilets	Water quality, maintenance
Type of toilet (Conventional vs. HET)	Water balance
Roughed-in for dual-plumbing	Installation
Number of storeys	Installation

4.2 Standard Testing Methodology

Performance of single-family residential, off the shelf, greywater reuse systems has been found to be variable and unsatisfactory once the system has been installed into homes. In order to reduce satisfaction issues, improve system durability and maintenance issues as well as further promote the greywater reuse industry, a standard method to quantify the performance of these systems is required.

It is proposed that the following field testing methodology be applied in conjunction with CSA B128 laboratory testing standards, as it clearly shows how the system performs in an unpredictable field setting. The methodology is intended for the manufacturer to carry out a pilot study prior to releasing the system to the general market. The results from the pilot study are beneficial to: (i) future system buyers who should be aware of the savings and maintenance and operation required for the systems, (ii) the manufacturer and other water conservation industry members who can improve the technology moving forward and, (iii) municipalities who can provide promotions and incentives for their residents, if the performance results show that the system is an effective water saving option.

4.2.1 Development of User Profiles (Survey #1)

It is recommended that two surveys be conducted in order to quantify performance. A preliminary survey should be conducted in order to record the "base conditions" prior to installation of the greywater system, as well as household characteristics at each home as listed in Table 9. This survey should also ask questions which indicate how the system will be used at each house, by documenting current showering and cleaning habits (such as frequency of toilet bowl cleaning). The first survey that was used for the presented field study can be found in Appendix D: Surveys.

4.2.2 Testing Period

As season has not been found to influence shower greywater reuse for toilet flushing, the testing period does not need to be a specific time of year. Following laboratory standard testing methods, it is suggested that at least six grab samples be collected for water quality testing, and that at least six months of water balance and energy consumption data be collected. Ideally, one year of data would be collected for accuracy; however, this would require detailed planning and would be more invasive to the user. Frequency of maintenance requirements have decreased since previous generations, and it is therefore suggested that maintenance be tracked for at least one year to fully show annual maintenance requirements.

4.2.3 Water Balance

The specific volumes outlined in Figure 4 must be documented. These volumes can be recorded using a flow meter on each line, smart metering as previously written in Section 4.1.1, or through a developed program which documents water in and out of the greywater reuse treatment system. If possible, meters could be placed on receiving pipes from each greywater source and on each greywater use (e.g. a meter on pipes to each toilet which would show a clear indication of how much water is consumed by each fixture). If it is not possible to monitor all volumes due to instrumentation limitations, the most relevant volume to performance analysis is the amount of greywater that is used to flush the toilets, which gives the fresh water (municipal) savings.

Using a data logging program which records each event and time of event is a more thorough data collection method than flow meters which only provide an overall volume over the time period between meter readouts. Recording each event can show daily habits which can help optimize the greywater reuse process. Having users record each event manually through a log sheet can also be effective, but relies on users for accuracy and can be an invasive task for the users.

Once each volume is metered, the best way to compare water usage and savings of a system is to evaluate each volume in terms of litres per household per day (Lhhd), and litres per capita per day(Lcd). These measurements can be used to compare the results to the performance of other water conservation technologies (e.g. dual-flush toilets). Daily water savings is the volume of water used to flush the toilets that is solely greywater. Any municipal water that was added for flushing should be removed in order to provide accurate fresh water savings.
After calculating the daily values, it is then possible to determine the factors that are affecting the water balance, such as a leaking toilet or increased greywater addition due to more residents in the home. In the first user survey, users should indicate frequency of bathing, whether they typically take a bath or shower, and how much of the day is spent at home. For example, a household with two adults that shower twice per week (i.e. low greywater production) and are at home all day (i.e. high greywater consumption through flushing) would potentially have low water savings, while a house with more frequent showering and are away at work all week could have greater savings as their greywater tank would be more full and require less municipal water.

Therefore, in order to relate collected water savings field data to household habits that were documented during the first user survey, users can be categorized as high, medium or low water consumers or producers, as shown in Table 10.

Table 10: Categorization of greywater producing and consuming habits.

Frequency of showering[1]	
Once per day	High greywater producer
Every other day	Medium greywater producer
Once to twice per week	Low greywater producer

Amount of time spent at home daily	
At home all day	High greywater consumer
Away 4+ hours - work/school Part time	Medium greywater consumer
Away 8+ hours - work/school Full time	Low greywater consumer

[1] Baths require more water than showering, and users which frequently take baths can be considered high greywater producers.

Houses with a higher greywater production than level of consumption are expected to have greater savings as they are less likely to require municipal water, while houses which have a high consumption rating than production will likely have lower water savings.

4.2.4 Water Quality

4.2.4.1 Sampling Locations

Ideally, in order to show performance of the greywater reuse treatment system, grab samples would be taken immediately prior and after treatment. However, due to plumbing configurations and typical logistical restrictions that arise when dealing with home owners, the following methodology is proposed.

4.2.4.1.1 Raw shower greywater

As close to scheduled testing visits as possible, each user should be instructed to plug the tub of their shower at the beginning of their shower, and collect a water sample of at least 1 litre. Ideally, a homogenous mix from the entire shower should be collected (which would include all personal care products) but this is not a reasonable request.

Raw shower greywater should be stored in the refrigerator until tests can be made, or it can be transported in a cooler to a laboratory for testing.

4.2.4.1.2 Treated greywater

Treated greywater should be sampled from an outlet valve from the pipe that pumps greywater to the toilets throughout the house. If that is not possible, grab samples should be taken from the storage tank, post treatment.

4.2.4.1.3 Treated greywater in toilet tank

Samples of treated and distributed greywater should be taken from the toilet tank, rather than the toilet bowl, as additional bacteria can be added to the water once it fills the toilet bowl. It should be recorded whether the uses have placed chlorine pucks directly in the toilet tank for extra chlorination. If time and funds allow, water quality samples should be taken from all toilets in the home; however, one toilet tank can represent the performance of the system at each house. Testing should always be completed at the same toilet tank in the house. It would be beneficial to have a timer on the toilets to indicate time since the last flush, which would show how long water has been sitting stagnant in the toilet tank.

4.2.4.1.4 Municipal water

Municipal water samples can be collected from any faucet in the house, in order to show base water quality. It is recommended that the faucet be allowed to run for one minute as it is possible for chlorine to build up in the distribution lines if the faucets had not been used recently.

4.2.4.2 Testing Parameters

Standard Methods For the Examination of Water and Wastewater should be followed to collect and test water quality parameters (Rice, Baird, Eaton, & Clesceri, 2012). The recommended methods are outlined in Table 69 in Appendix C: Field Study Testing Methodology.

Odour at each of the four testing locations should be recorded as either: no odour, chlorine, greywater or soap. It is very important that proper observation techniques be followed such as wafting sample odours as occasionally chlorine samples can be very strong.

4.2.4.3 Vacation Mode

It is recommended that at the beginning of the study, users be asked to indicate any planned vacations. It would be optimal to have users follow any maintenance instructions for when they go on vacation, take water quality samples at all locations just prior to leaving for the extended time period, and take water quality samples again as soon as the users return home, specifically noting water quality at the toilets. This process would show water quality performance of the systems' vacation mode, as well as would provide the date information for vacations to analyze water savings, energy and durability data.

4.2.5 Energy Use

Energy use can be measured using plug-in electricity meters, which intercept the greywater reuse plug and the outlet, tracking any energy use constantly or over a period of time.

By collecting energy data over the period of study, a final energy intensity value can be calculated for each home, which is the energy used to treat greywater (kWh / m^3), which can then be compared to the energy intensity for municipal systems.

4.2.6 Durability

Durability should be assessed in two ways. First, the tester should record any noticeable failures at each test visit, through observation and discussion with the system user, if possible. Filter clogging is an aspect of durability that should be heavily monitored. A method such as tracking water flowing through the filter or pressure loss across the filter should be incorporated into testing to track filter clogging. However, visual inspection of the filter at each visit can sufficiently show build up and clogging.

Another issue that should be taken into consideration and monitored is pressure loss throughout the system. This can be monitored by tracking the time it takes to fill the toilet tanks after full and half-flushes at each site, over the period of the study. If possible, these times can be compared to toilets in the house that function with municipally supplied water, to show how the system performs relative to traditional water sources.

A checklist of common system failures that can act as a guide for performance testing is available in Appendix C: Field Study Testing Methodology.

Secondly, user's input on durability should be collected. A printed log sheet should be given to the system users to record each time an irregular system event occurred. It is recommended that the log sheet be attached to the greywater reuse system so users are visually reminded to fill in the details if an issue were to arise. User's input on durability should also be collected through the second survey (See Appendix D: Surveys).

4.2.7 Maintenance

Through user documentation during the field testing process and user surveys after the testing period, an assessment of maintenance requirements can be made. Due to the decrease in frequency of required maintenance in the current greywater reuse systems, maintenance logs should be kept for at least one year, to fully document annual maintenance requirements, including items such as annual backflow prevention testing. A log sheet attached to the greywater reuse system allows the users to record any maintenance associated with the greywater reuse system directly; however, this does not remind users to record maintenance when it is required at other points in the reuse system (e.g. more frequent toilet bowl cleaning). Therefore, it is suggested that in order to grasp a full and accurate representation of required maintenance, log sheets be attached to the greywater reuse system and at every toilet.

It is important that the tester not perform any of the required maintenance for the users during the testing period (e.g. adding chlorine pucks) as this can skew the user's perception of required maintenance.

4.2.8 Installation

The installation process of the system can be documented in terms of the cost of the installation, as well as the ease of implementation.

Using invoices from the plumbers and general contractors (if applicable) during the installation process, the cost of installation can be evaluated. The following points should be recorded at each installation site as they can greatly affect the installation process and the related installation costs:

- Number of storeys in the home
- Location of the greywater reuse system (unfinished basement, mechanical room…)
- Previously roughed-in or retrofit situation
- Number and location of showers and toilets connected to the system

Ease of implementation can be recorded through recording user's satisfaction with the system installation process, as well as interviewing the plumbers responsible for installing the system to find any common issues with installation of the system.

4.2.9 Economics

In order to provide an economic assessment of the greywater reuse system, the following details must be recorded:

Table 11: Costs and benefits associated with residential greywater reuse systems.

Costs	Explanation
Total immediate costs	• capital cost • installation cost
Annual maintenance costs	• disinfectant • filters • required backflow prevention testing
Annual operation costs	• energy usage (kWh) • local energy rates ($/kWh)
Benefits	**Explanation**
Savings from reduced water consumption	• water and wastewater savings (m^3) • local water and wastewater rates ($\$/m^3$)

As system performance varies at different sites, it is recommended that De Luca's (2012) method of economic analysis be followed and that three performance scenarios be evaluated:

the best case (highest benefits to lowest costs), the worst case (lowest benefits to highest costs) and the average case (average benefits and costs).

After calculating the costs and benefits of the system, a payback period can be determined. The payback period must be within the expected life of the system for it to be considered economically feasible. If the system is being evaluated using Canadian water rates, it is expected that the payback period will not be within the expected life of the system. Therefore, a final estimate should be made to calculate the required water rate that would have to be implemented in order for the savings from water reuse system to have a reasonable payback period.

4.2.10 User Satisfaction and Responses (Survey #2)

At the end of the field study, a second survey should be distributed to the system users to capture user satisfaction as well as performance data from the user's point of view.
The survey should collect user satisfaction with maintenance, technical performance, economics, and overall satisfaction. Environmental awareness should be documented in order to gather background on how user results could be interpreted.

A 5-point Likert scale is recommended for user satisfaction questions in the survey, with typical answers being (Marsden & Wright, 2010):

- 1 - Very Satisfied
- 2 - Somewhat Satisfied
- 3 – Neutral
- 4 - Somewhat Unsatisfied
- 5 - Very Unsatisfied

Recommendations for developing user satisfaction survey questions, and the User Survey #2 used in the field study are available in Appendix D: Surveys.

.

4.2.10.1 Environmental Awareness

Environmental awareness can be quantified by asking about other methods of water conservation practiced in the home, why they have a greywater reuse system in the home and how much waste produced in the home is recycled. Through these questions, a general sense of the user's environmental commitment can be made and taken in to account when assessing satisfaction responses.

4.2.10.2 Maintenance

Questions pertaining to maintenance should ask about the 3 most important aspects of greywater reuse system maintenance: Toilets, Disinfection products, and the Filter. The survey should aim to determine the extent of maintenance required for the system, whether the users were satisfied with the amount of effort they had to input or were capable of it, and most importantly, how had their cleaning habits changed compared to when their toilets operated with municipal water.

4.2.10.3 Technical Performance

The section of the survey dedicated to technical performance should aim to determine system durability and issues, and each user's acceptance of these technical difficulties. The system users should be able to indicate any technical issues or difficulties they experienced with the greywater reuse system, from a list of frequent issues in "off the shelf" greywater reuse systems or in a space for their own response. Users should also be asked about their satisfaction with the features of the system such as "vacation mode" or any other special features.

A final topic which should be asked in the survey is in regards to the incorporation of "state of the art" technology. For some, this could have been beneficial and added value to the system, while others could have believed it to be unnecessary and a source of frustration.

4.2.10.4 Economics

The economics portion of the survey should ask questions to determine how realistic the user believed the cost of this system and greywater reuse is. The user should be asked how likely they were to pay the capital and annual expenses, and if not at all likely, would including a government incentive increase the likelihood of installing the system. Users should be asked what an acceptable payback period would be for them to consider installing the system, and which can then be compared to the actual determined payback period of the system.

4.2.10.5 Overall Satisfaction

The final portion of the survey should ask about the overall satisfaction of the system and most importantly, would the users continue to use the system in their home.

5 Field Study Results

The standard testing methodology that was presented in the previous Chapter was applied to test the performance of a pilot residential "off the shelf" greywater reuse system. Utilizing User Survey # 1, the household characteristics were collected and used to further explain the system performance. Full descriptions of each household are presented in Appendix D: Surveys.

5.1 Water Balance

Water consumption data was collected at 22 homes, with House 23 equipped with flow meters to validate collected data accuracy. A complete account of water usage data is presented in Appendix E: Water Balance Results.

The developed data-logging program was not able to capture the overflowed volume (Volume 3 in Figure 4) and therefore an estimated water balance approach would be the only way to record the five key water volumes at the homes not equipped with flow meters. However, Section 5.1.1 below presents the inaccuracies with the recorded data and using the water balance approach was not possible.

Therefore only average volumes for greywater production, greywater consumption, freshwater required and full purge are presented. A daily average water savings value was also calculated to present how much fresh water was saved by replacing toilet water with treated greywater.

Houses 9 and 20 had newborns during the time of testing. Newborns are considered greywater producers as they produced bath water, but are not considered in greywater consumption through toilet flushing calculations.

Table 12 shows the categorization of each house as either a high, medium or low greywater producer (based on showering habits) and greywater consumer (time spent at home used to estimate daily flushing). The ideal situation for greywater reuse would be a home that is producing the same amount of greywater that is consumed within the home, meaning their flushing demand can be completely supplied by their shower water without overproducing shower wastewater. Houses with high flushing demands would have the greatest reduction in environmental impact by reducing their fresh water demand, and are the target candidates for greywater reuse.

Of interest is House 13, which is considered a medium greywater producer and a high consumer as the residents plus additional employees work out of the home during the day and would flush the toilet more frequently.

Table 12: Categorization of each field study house as a high, medium or low greywater producer and consumer.

Producer / Consumer	House #
High / High	1, 8
High / Medium	7, 9, 14, 16
High / Low	2, 3, 5, 6, 11, 15, 19, 20, 22
Medium / High	13
Medium / Medium	4, 18
Medium / Low	12, 21
Low / High	-
Low / Medium	10
Low / Low	-

5.1.1 Validation of the Water Balance Program

Validation of the water balance program was completed in two ways; through flow meters at House 23 and through addition of a known volume into the system and correlating recorded volumes.

Figure 5 compares the recorded flow meter volumes, versus the recorded program volumes (diagonal line fill) for both the meter on the greywater used to flush line and the meter for municipal water added. Complete recorded values are presented in Table 67 in Appendix C: Field Study Testing Methodology.

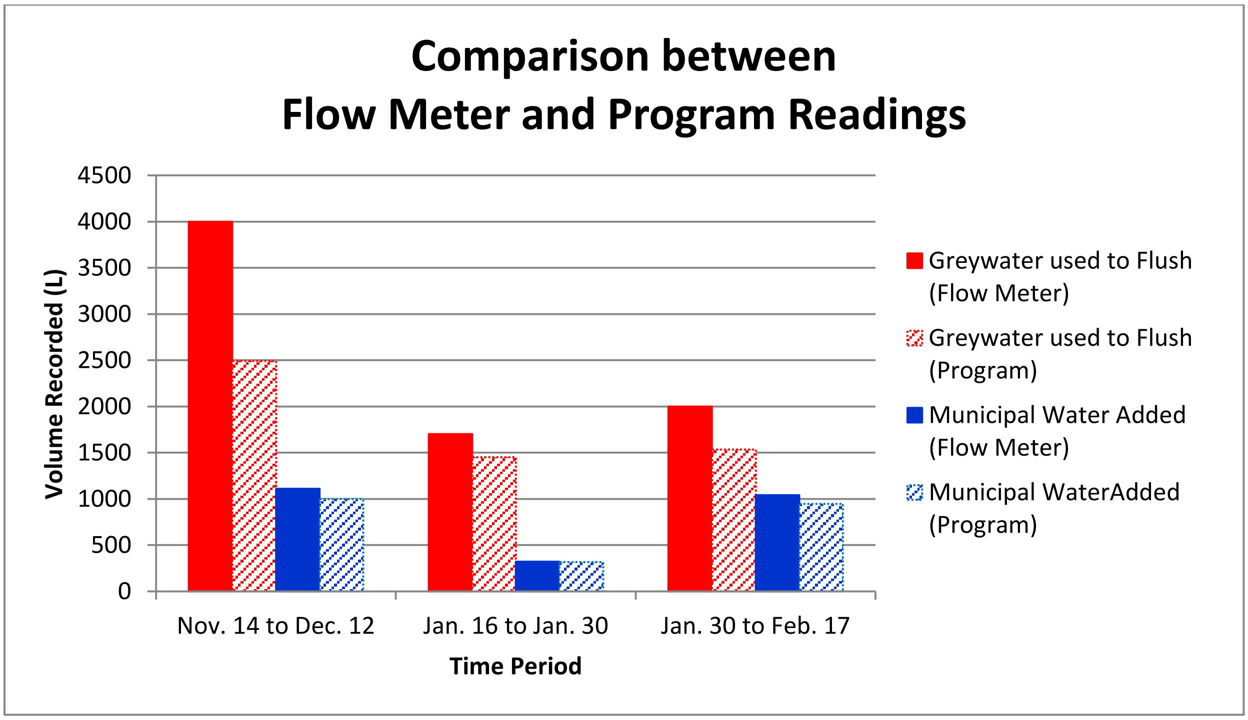


Figure 5: Comparison between flow meter readings and recorded program data at House23, over 3 time periods.

Despite correcting the recorded program data to account for the eight second leaking toilet delay by adding 0.5L to every recorded flush, 1L to every fresh added event and 1L to every incoming greywater event, the program still appeared to be recording less greywater consumption relative to the flow meter consumption values. By comparing the greywater volume measurements, it was found that the flow meter volumes were between 15 to 38 percent greater than the program readings, while the flow meter on the municipal water line was between 1 to 10 percent greater than the program readings. It appears that the municipal readings are more accurate, relatively, but an explanation for this is not available.

Through the second method of program validation testing, known volumes of water were poured directly into the greywater storage tank. In the final test using this method, 50L was poured directly into the storage tank (bypassed filter) but the system only recorded 38.250L (11.750L difference). This difference could be attributed to the eight second delay set on the program recording. This finding supports the previous validation method finding that the program records less volume than the flow meter, and is potentially underestimating consumption and production volumes. It is suggested that the eight second leaking toilet delay be eliminated from future water balance recording which will allow the full volume of events to be monitored. Then, the researcher can review the data and remove any data points that have an extremely small volume as estimated leaking toilet errors.

5.1.2 Greywater Production

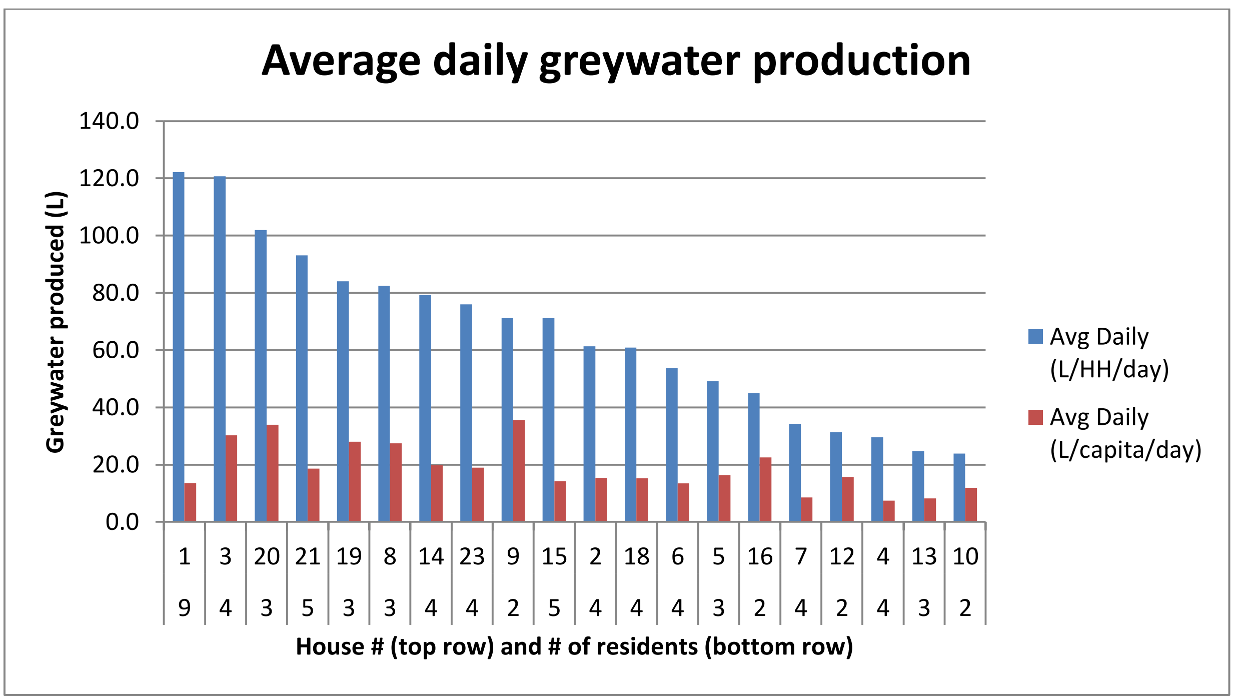


Figure 6: Average daily greywater production, in terms of Lhhd and Lcd.

Figure 6 shows average daily greywater production volumes per household, and per resident living at each house. On average, the houses in this study produced 65.8 L of greywater per household per day (18.8L per capita per day), collecting only from the showers in the homes. Due to overflowing, there is potential for these values to be underestimated but this is less likely in homes with lower average daily greywater production volumes.

Depending on the number of residents, the number of showers per household per day ranged from an average of 0.7 showers per day (House 7) to 3.2 showers per day (House 1). Overall, the houses in the study showered 1.9 times per day, with an average shower volume of 34.8 L. Each resident showered on average 0.5 times per day. Average shower events ranged from 22.9L at House 6 to 56.1L at House 19. Full shower analysis values are presented in Appendix E: Water Balance Results.

Additionally, as shown in Table 13, the number of showers per resident per day did not vary each month, indicating that greywater production from showers is a consistent source and does not vary seasonally.

Table 13: Summary of monthly shower averages.

Time Period	# of showers/ HH/day	Std. Dev. (#)	# showers/ capita/day	Std. Dev. (#)	Avg. shower volume (L)	Std. Dev. (L)
Oct - Nov	1.88	1.10	0.52	0.25	33.34	9.98
Nov - Dec	1.93	0.87	0.54	0.22	34.09	10.09
Dec - Jan I	1.85	0.75	0.52	0.21	35.65	8.43
Jan I - Jan II	1.82	0.85	0.51	0.23	34.90	10.64
Jan II - Feb	1.89	0.80	0.55	0.24	33.33	12.33
Overall Avg.	**1.87**	**0.86**	**0.53**	**0.23**	**34.85**	**10.47**

5.1.3 Greywater Consumption

Figure 7 shows average daily greywater consumption through toilet flushing at each of the field study houses. These values are the amount of water that was required to flush the toilets, which includes both greywater from showers and any freshwater that was required to be added (Freshwater added analysis is provided in Section 5.1.4). Overall, the toilets in this field study used an average of 72.3 Lhhd for flushing (21.3 Lcd). House 16 was the only house in the study that had a functioning toilet in the home that was not connected to the greywater reuse system. The children in the home used this toilet and were not included in the resident count for greywater consumption.

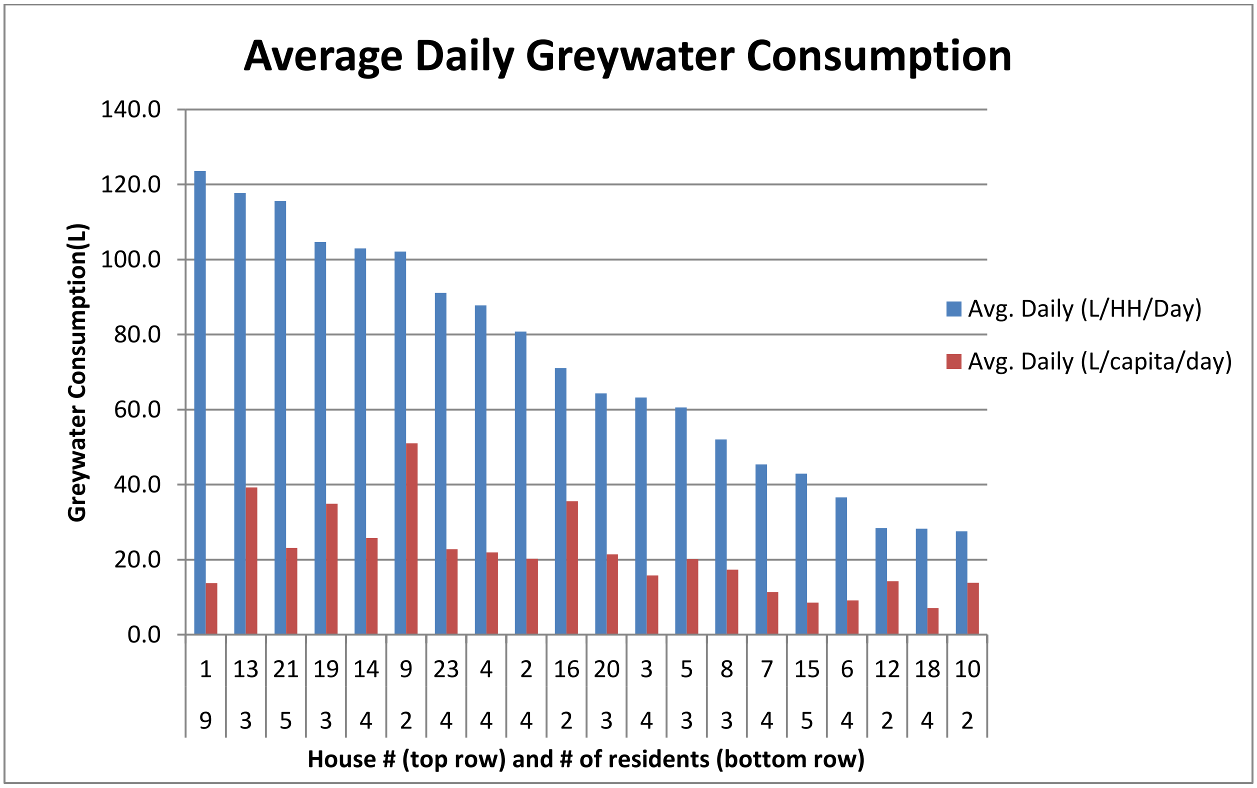


Figure 7: Average daily greywater consumption through toilet flushing, in terms of Lhhd and Lcd.

House 1, which has 9 residents and 3 dual flush toilets (which consume either 3 or 6L of water depending on the flush selection) consumed the most greywater through flushing.

House 9 consumed the most, per person, in the home, consuming 51.1Lcd with their two conventional toilets; these models can have the ability to consume 13L or more with each flush.

Figure 8 below highlights the potential trend that as the number of residents increases, the average daily consumption volume increases, which is expected due to an increase in flushing frequency.

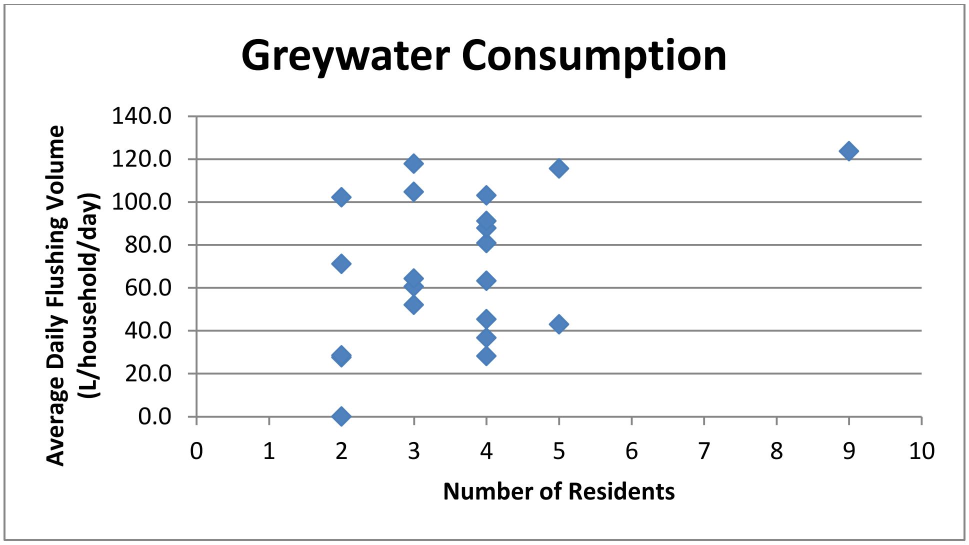


Figure 8: Average daily greywater consumption in the test homes.

Similar to monthly average shower volumes shown previously in Table 13, average toilet flushing values shown in Table 14 did not vary seasonally and therefore greywater consumption for toilet flushing can be considered a consistent draw on greywater sources. Additional details of flushing frequency can be found in Appendix E: Water Balance Results.

Table 14: Summary of monthly average toilet flushing at all houses.

	Avg. # of flushes/HH/day	Std. Dev. (#)	Avg. # flushes/capita /day	Std. Dev. (#)	Avg. flush volume (L)	Std. Dev. (L)
Oct - Nov	13.52	9.95	3.83	2.73	5.07	1.87
Nov - Dec	17.07	21.29	5.09	7.11	5.29	2.09
Dec - Jan I	12.37	4.99	3.44	1.25	5.23	1.76
Jan I - Jan II	11.55	5.11	3.21	1.20	6.02	2.53
Jan II - Feb	12.04	5.78	3.34	1.40	5.99	2.44
Overall Average	**13.31**	**11.10**	**3.78**	**3.50**	**5.52**	**2.23**

It is of interest to note how the different types of toilets consumed water, relative to how they are marketed, as shown below in Table 15.

The data shows the traditional toilets at House 9 (advertised as potentially consuming more than 13L per flush) occasionally outperformed the High Efficiency Toilets (less than 4.8L per flush). The following Table provides a summary of the toilet consumption, while details of toilet performance at each house can be found in Table 82 in Appendix E: Water Balance Results.

Table 15: Average flush volumes for different toilet types in the field study.

Type of Toilet (Lpf)	Avg. flush volume (L)[2]
13+ L	8.1
Low Flush Toilet (6 - 12)	8.9
Dual Flush (3/6)	8.3
HET (<4.8)	6.5[1]

[1]Includes values from House 13, which potentially had leaking toilets(see Section 5.1.6.1).
[2]Performance values were only collected from homes with one toilet type throughout all bathrooms in the home.

The best performing home in terms of greywater consumption was House 10 which had one HET, and had an average flush volume of 3.5L.

A dual-flush toilet, should either consume 3 or 6L per flush, depending on which flush volume is pressed. This research shows that of the seven houses that had only dual flush toilets, five had average flush volumes of greater than 6, indicating that these toilets may consume more water than advertised.

Figure 9 shows the balance between greywater produced daily from showers and water (both greywater and municipal “top up” water) consumed through toilet flushing at each of the field study houses. It can be seen that House 13 had the highest “overconsumption” volume, which was expected as House 13 has additional employees working out of the house during the day, flushing the toilet, but not providing shower greywater. House 4 was the next highest over-consumer relative to the amount of greywater they were producing, which can be attributed to only three of the four showers in their home being connected to the greywater reuse system. Additionally, House 4 has one resident who is at home all day, further offsetting the production/consumption balance at this house. House 1 (nine residents) had the most balanced greywater production to consumption volumes, only consuming, on average, 1.4L more greywater to flush than their house was producing through showering. House 3 (four residents), were considered high producers/low consumers, and had the greatest over-production volume.

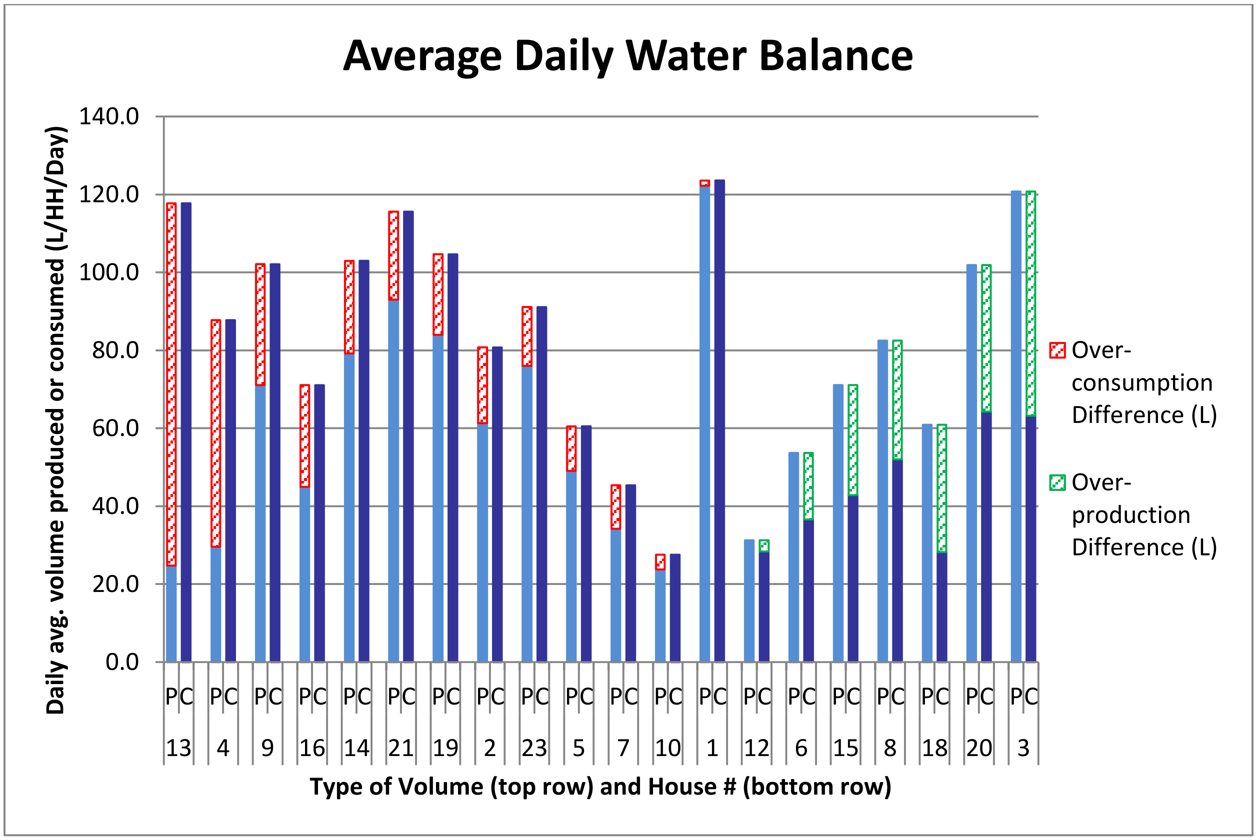


Figure 9: Comparison between greywater production volumes ("P") and greywater consumption volumes ("C") at each house in the field study.

5.1.4 Freshwater Added

Every system required municipal water to be added either to refill after the tank emptied for purging, or in order to satisfy the flushing requirements (see Table 83 in Appendix E: Water Balance Results). House 11 and 22 recorded that more fresh water was added than was used for flushing, indicating their system was purging too frequently, had a leaking toilet or was inaccurately recording. Due to the other durability and performance issues with House 11 and 22, they were removed from some results as they were not representative of water savings, energy or water quality.

Figure 10 shows the overall volume of municipal water that was added to the system, relative to the volume of water that was used to flush toilets, when the systems were operating with the purge setting. As presented earlier, House 13 was consuming much more water to flush their toilets than greywater was being produced, thus leading to municipal water being high percentage of water used to flush.

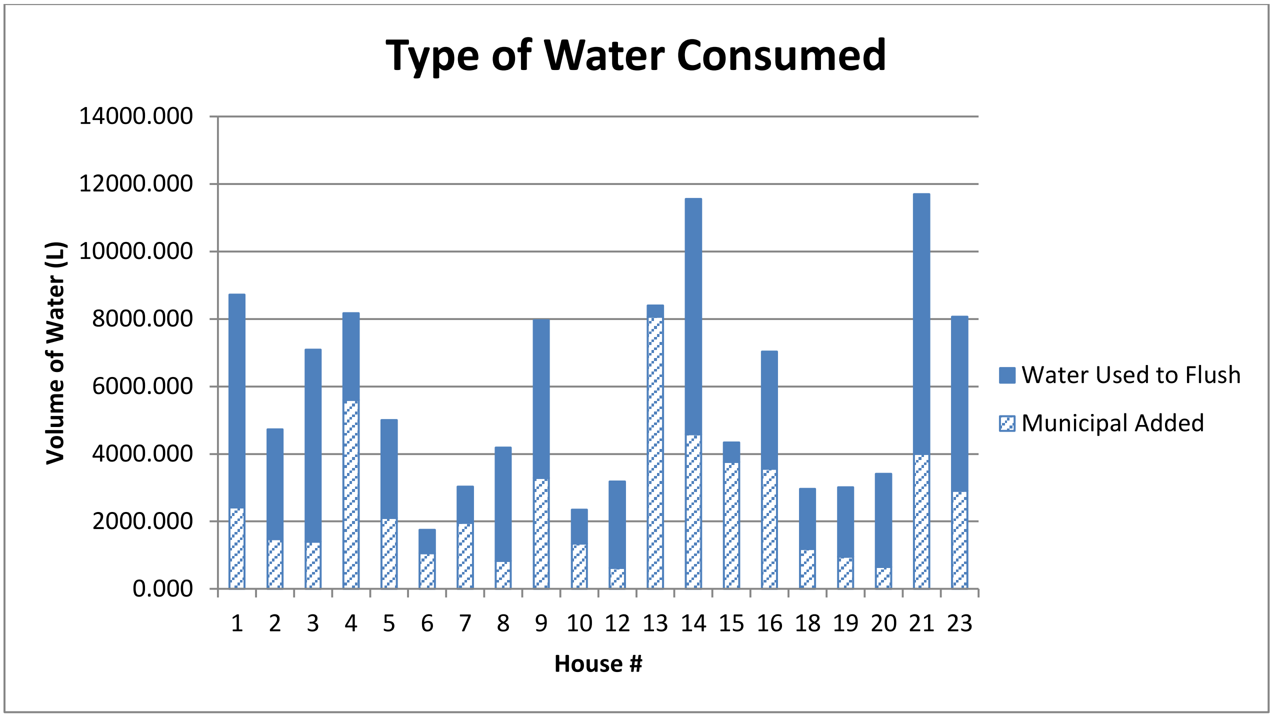


Figure 10: Municipal water added to the system (L) versus the volume of water used to flush toilets (L), when the system was operating with the purge setting.

On average the systems required 44.3 percent of the flush water to be provided by municipal water. This was greatly reduced to 21.0 percent when the systems operated without the purge function. These average results are much better, environmentally, than Christova-Boal (1995) which required 72-88 percent of water used to flush toilets to be municipal water, but comparable to De Luca (2012) which had between 4.24 to 26.7 percent of flush water be provided by municipal water. The found results did vary largely between homes, and it is always important to look at the found values for each home and the factors that are affecting their water balance (e.g. number of residents).

5.1.5 Purged water

Figure 11 shows how the percentage of the water that was municipal water that was used to flush decreased when the purge setting was removed, as greywater was never emptied from the tank and was available as a water source for flushing.

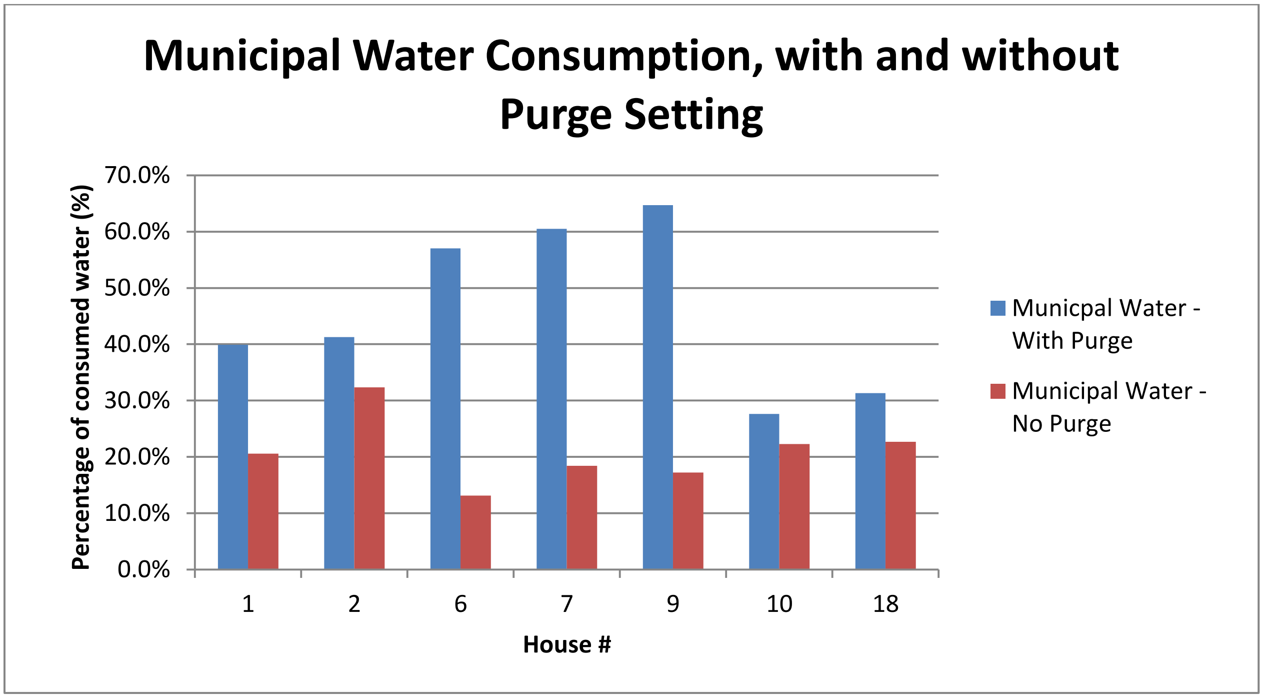


Figure 11: Municipal water consumption, as a percentage of water used to flush, when the system was operating with and without the purge setting.

When the system was operating with the purge setting, volumes that were discarded ranged between 4.6L per household per day (House 4, consume much more than produce greywater), and 81.4L per household per day (House 20, produce more greywater than consume). The overall average daily purged volume for all of the houses was 32.6L, when the system was operating with the purge function which emptied the tank every 48 hours, and 12.2L when the system was operating without the purge (which still includes mini-purge events and filter cleaning). A full account of purged volumes is presented in Table 85 in Appendix E: Water Balance Results.

Figure 12 shows how only a fraction of the water typically sent to the sanitary sewer was discarded when the system stopped purging the tank water every 48 hours, reducing unnecessary water disposal.

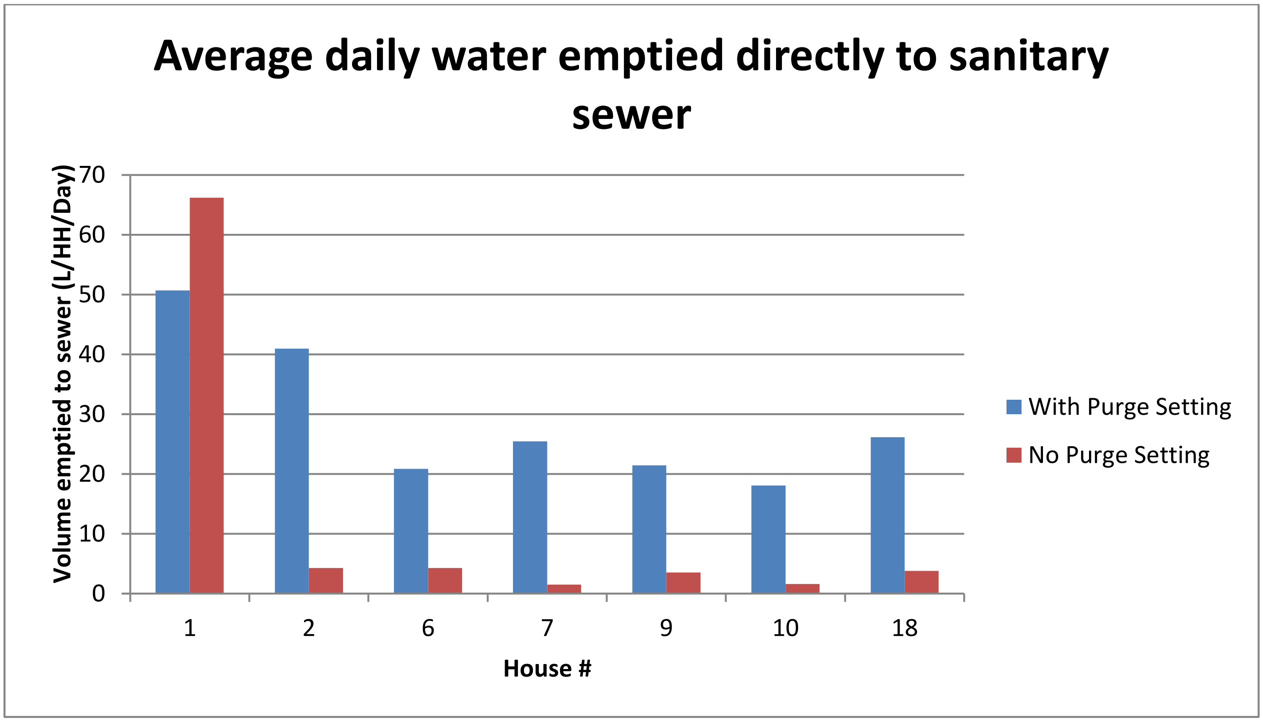


Figure 12: Average water volume emptied daily, directly to sanitary sewer through purge setting, filter cleaning and mini-purge events.

House 1 (9 occupants) had greater volumes removed from the system after removing the purge function. This could be explained by the presence of more water in the storage tank consistently, resulting in the volume to be mini-purged to reduce overflowing, rather than the system being emptied every 48 hours. In this situation the mini-purge code should be optimized for such high usage and demands.

In the second user survey, users who had their system equipped to operate without the purge function were asked to rate different effects of not having the purge setting. A comparison between user satisfaction to the system with and without the purge function is presented below in Table 16.

Table 16: User Survey responses showing satisfaction with the system operating with and without the purge function.

Rate your level of satisfaction with…	1 Very Satisfied	2 Somewhat Satisfied	3 Neutral	4 Somewhat Unsatisfied	5 Very Unsatisfied
water quality at your toilets when the system did purge the stored greywater every 48 hours.	**8**	4	5	-	-
water quality at your toilets when the system did NOT purge the stored greywater every 48 hours.	**4**	2	1	-	1
water savings of the system when the system did purge the stored greywater every 48 hours.	5	**6**	4	2	0
water savings of the system when the system did NOT purge the stored greywater every 48 hours.	3	1	**4**	-	-

Results show that, of the users that responded about their system operating without the purge function, users were equally happy with the water quality in the toilet bowl regardless of whether their system had the purge function or not. The majority of users responded as "neutral" towards water savings of the system without the purge function. It is speculated that there was not enough test time for the system users to develop an opinion on water savings of the system without the purge function.

House 9 was very unsatisfied with the water quality associated with the purge setting as a thick black bacteria ring started to grow in their toilet tank, despite chlorine addition. The user commented that there should be a purge setting, but every 48 hours is too frequent. Other users agreed with this sentiment, and it is therefore suggested that an automatic tank drain occur once a month to clear any residue in the system.

In houses where water quality was not an issue, users commented that they are glad the system is operating without emptying, as it seemed like a waste of water to empty every 48 hours.

House 20 found that when their system was operating without the purge function, their water quality improved. This result, which mostly occurred at every home but was not recorded, is likely because the same greywater would be chlorinated multiple times potentially leading to higher chlorine levels.

The “no-purge” testing time was only four weeks which perhaps was not a long enough period for users to notice the difference in water savings, explaining the selection of “neutral” improvements to water savings as shown in Table 16. It is recommended that future testing operate systems with and without purge functions for the entirety of the pilot study to show differences.

5.1.6 Average Daily Water Savings

Average daily water savings were calculated for each house, which was the balance of total water used to flush toilets, less the fresh water added in order to flush the toilets. Generally, this was a positive value, and on average, saved 40.9Lhhd. Daily savings ranged from 10.3 to 96.9 Lhhd, depending on household characteristics (e.g. number of residents) and the elimination of the purge setting. These results are the most accurate and indicative water balance results from this study as the limitations due to overflowing did not affect this calculation.

House 1 saved, on average, 90.8L of municipal water per day by reusing greywater instead of fresh municipal water to flush toilets. When House 1 operated without the purge function (water collected was stored and never emptied), average daily water savings for the house increased to 96.9L.

Figure 13 shows how daily average water savings for the system ranged from 90.8 L per day to 10.3 L per day. House 13, featured at the right of the graph, shows a negative average daily water savings, as this house was, on average, consuming more municipal water to flush their toilets, than available greywater.

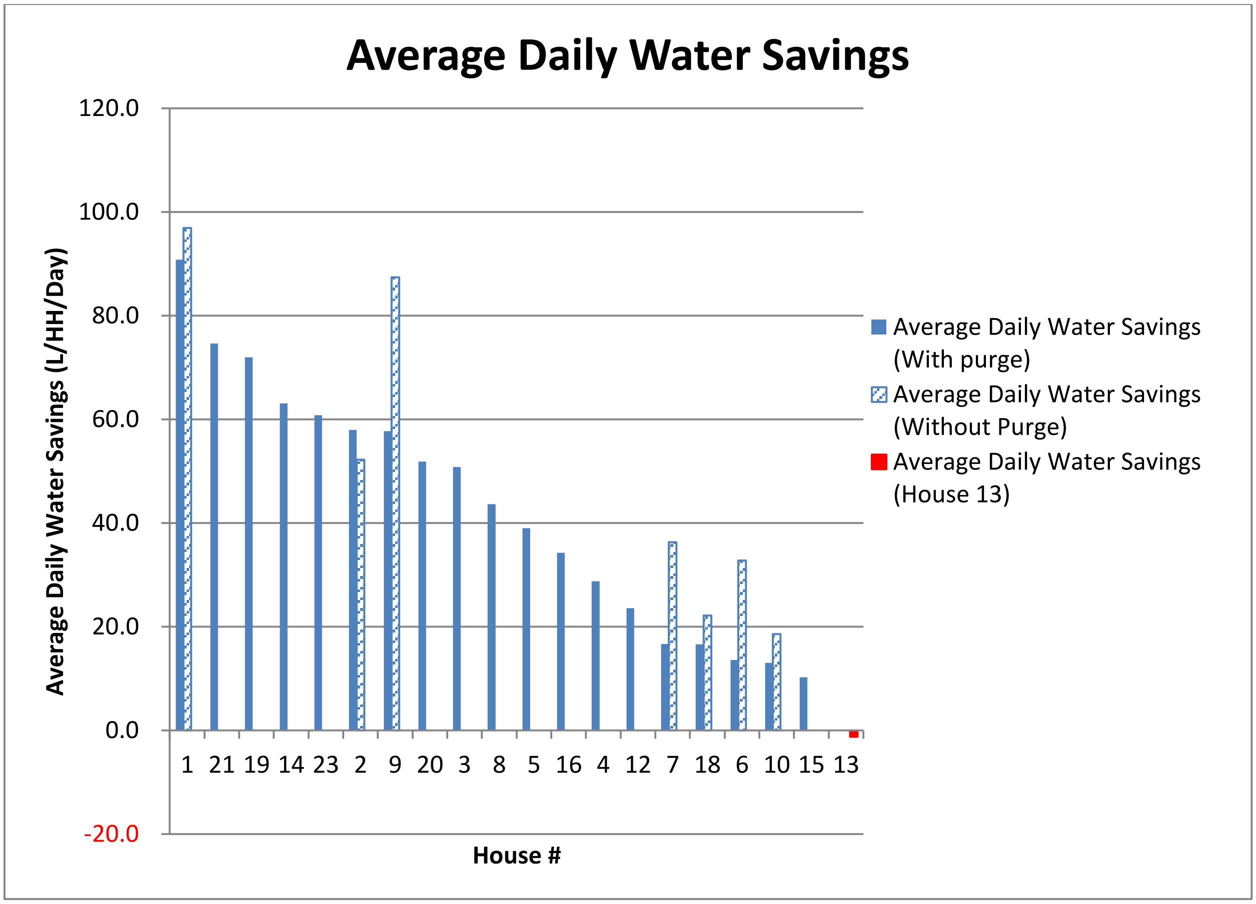


Figure 13: Average Daily Water Savings for each house in the field study.

Every home saw an increase in daily average water savings when the purge setting was removed, except for House 2, which saw a decrease. This is believed to be due to the small sample size of when the system was operating without the purge setting.

Figure 14 below shows how the number of residents can have an impact on average daily water savings. Data from House 13 has been removed for this presentation due to their varying number of residents. The data suggests greater daily water savings may be connected to an increase in the number of residents, although further study is required to verify this. Occupant behaviour could also influence daily water savings and could be considered in future performance research. Figure 14 also shows how when the systems operated without the purge function, average daily water savings were higher.

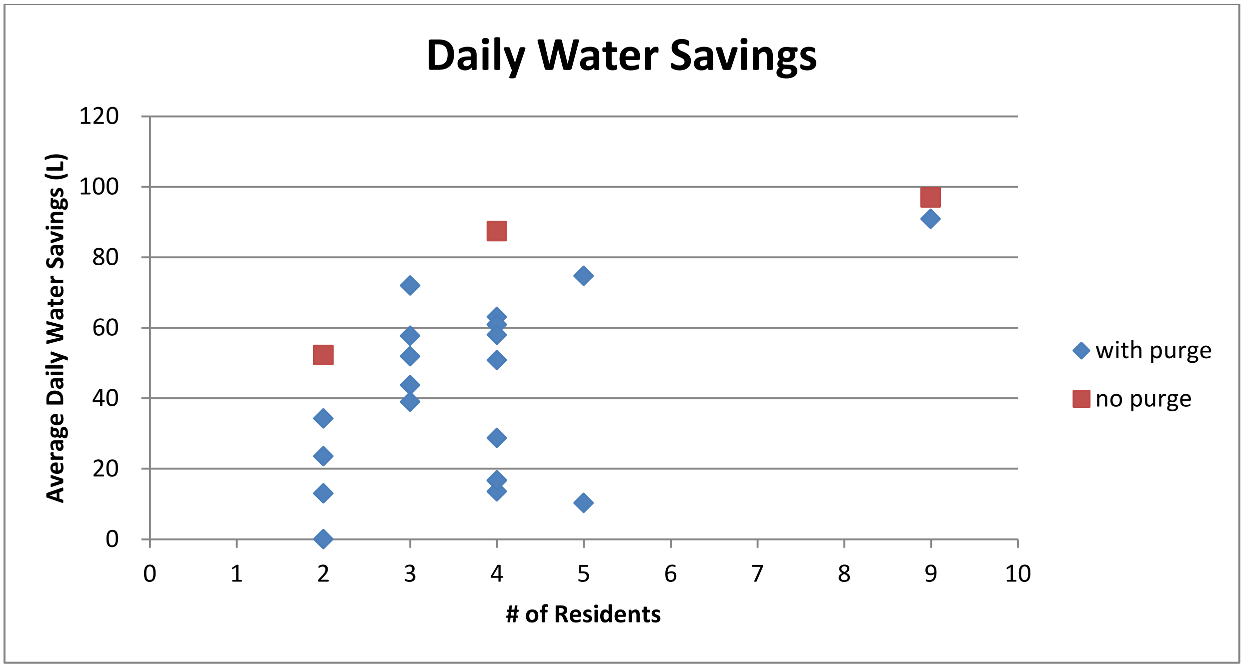


Figure 14: Average daily water savings (L) at each home, compared to number of residents in each home.

Daily average water savings were not found to vary greatly from month to month, and therefore no significant impact from seasons can be shown in this study, as presented in Table 17.

Table 17: Average daily water savings of all houses, by month of study.

Time Period	Daily average water savings With Purge (L/HH/day)	Daily average water savings No Purge (L/HH/day)
Oct – Nov	35.688	-
Nov – Dec	37.285	-
Dec - Jan I	38.166	-
Jan I - Jan II	45.587	50.027
Jan II – Feb	44.152	58.036
Overall Average	40.176	54.032

5.1.6.1 Leaking Toilets

House 13 used more water to flush than produced greywater which was due to additional system users throughout the day from the in-house office, as well as a leaking toilet. Table 18 shows how through October to December, House 13 had a very high frequency of flushing data points recorded. This greatly reduced as the leaking toilet was fixed. Additionally, the average flush volume was very small, indicating a leaking toilet.

Table 18: Analysis of toilet flushing at House 13.

Time Period	# of Flushes over Time period	# of Days in Time Period	Average # of Flushes per day	Average Flush volume (L)	Daily Average Water Savings (L)
Oct - Nov	676	8	84.5	2.744	-10.584
Nov - Dec	673	7	96.1	2.772	-26.399
Dec - Jan I	380	36	10.6	5.565	6.253
Jan I - Jan II	136	15	9.1	6.191	5.675
Jan II - Feb	106	15	7.1	6.960	19.017

This shows that despite the overall average daily water savings for House 13 being -1.208L (indicating shower greywater did not provide enough water to flush the toilets), the system was able to save water once the leaking toilet was fixed.

5.1.7 Water Balance Summary

Table 19 shows a summary of the key volumes found in this field study, as daily averages. The water balance varied greatly at each house depending on their household characteristics which should be considered when reviewing average values.

Table 19: Summary of daily average key volumes, at the household and per capita level.

	With Purge		No Purge	
Volume	**L/HH/day**	**L/capita/day**	**L/HH/day**	**L/capita/day**
Greywater In	65.8	18.8	-	-
Municipal "top up" water	31.7	9.7	13.5	3.7
Water used to flush toilets	72.3	21.3	-	-
Water purged/emptied	32.6	8.9	12.2	1.9
Overflowed	-	-	-	-

5.2 Water Quality

5.2.1 Laboratory Testing Results

5.2.1.1 Biochemical Oxygen Demand (BOD_5)

The samples were recorded as “Not Detected” BOD_5 levels. These sample values were represented as 0mg/L in averaging calculations. Additionally, a value of “>58mg/L” was changed to 59 mg/L. Full BOD_5 measurements are available in Appendix F: Water Quality in Table 88.

As shown below in Table 20, the highest average BOD_5 levels in raw shower greywater were found at House 2 and House 9, which is expected, as children are present at those sites, specifically a newborn at House 9. However, BOD_5 levels in shower water at another house with two young children (House 7) were consistently low; enough that 100 percent of the raw shower water samples met Health Canada Guidelines of a maximum BOD_5 of 20mg/L.

Aside from House 7, BOD_5 levels ranged significantly in raw untreated greywater and rarely met the Health Canada greywater reuse guidelines of a maximum of 20 mg/L, indicating that raw greywater quality is variable and that treatment is necessary for reuse. These findings are slightly lower than results from De Luca (2012), which found that the average BOD_5 levels for untreated greywater ranged between 78.6 to 317.3mg/L.

When the system was operating with the purge function, average BOD_5 values for samples taken directly from the greywater reuse system storage tank (post filtration and disinfection) were slightly more consistent and of higher quality than raw shower greywater, with average values ranging from 21 mg/L to 60 mg/L. On average, 38 percent of the samples taken directly from the greywater reuse system storage tank met Health Canada Guidelines for BOD_5.

Table 20: Summary of BOD_5 laboratory results from samples taken from bathtubs (BT), greywater reuse system storage tanks (GS) and toilet tanks (TT).

		Sample Location	H1	H2	H6	H7	H9	H10	AVG
With Purge	% that meet HCG Max (20mg/L)	BT	0%	20%	0%	100%	0%	0%	**20%**
		GS	40%	40%	0%	67%	40%	40%	**38%**
		TT	20%	25%	0%	67%	20%	50%	**30%**
	Average (mg/L)	BT	76	122	44	3	136	65	**74**
		GS	30	36	32	57	60	21	**39**
		TT	36	55	36	51	67	18	**44**
No Purge	% that meet HCG Max	GS	50%	50%	100%	50%	0%	50%	**50%**
		TT	0%	50%	100%	50%	0%	50%	**42%**
	Average (mg/L)	GS	44	42	3	25	92	24	**38**
		TT	72	36	3	29	69	40	**41**
Number of Residents			9	4	4	4	3	2	-
Children Present?			Yes	Yes	Yes	Yes	Yes	No	-

Again, House 9 had the highest average BOD_5 level in treated greywater, which is consistent with literature findings that the poorer the influent water quality is to begin with, the poorer the water quality of the treated water will be (De Luca, 2012).

BOD_5 levels were more variable once the greywater reached the toilet tank, with a similar average value of 44mg/L, but with a range of average BOD_5 from 18 to 67mg/L. Success rate of samples that met Health Canada Guidelines was reduced to an average of 30 percent from 38 percent at the greywater reuse system storage tank. This is perhaps due to toilet tank water sitting in the toilet tank for a period of time, prior to sampling. Again, House 9 had the highest BOD_5 level at the toilet tanks, while House 10 had the lowest BOD_5. BOD_5 levels were very low at House 11(not presented in the results), and this was attributed to House 11 potentially leaving their by-pass valve open, allowing their system to be mostly municipal water. Average BOD_5 levels were lower than De Luca's findings (2012), which found that the two studied greywater systems had average BOD_5 levels at the toilet tank inlet between 73.7 and 119.9 mg/L. This indicates that although the system only meets Health Canada guidelines 38 percent of the time in terms of BOD_5, greywater reuse treatment technology is improving. In general, when the system was operating with the purge function, houses with fewer residents and no children present had lower BOD_5 levels at their toilet tank.

When the system was operating without the purge function for four weeks, percentage of samples from the greywater reuse system and the toilet tank that met Health Canada Guidelines, increased relative to when the system was operating with the purge function. However, the average BOD_5 values between the two operating methods were similar but there were only 2 samples without the purge function, and therefore this result is limited. The data shows that removing the purge function did not have a significant impact on BOD_5 levels in greywater treatment.

5.2.1.2 Chemical Oxygen Demand (COD)

Similar to the BOD_5 results, any result that was presented as “Not Detected” by the laboratory was changed to zero for average calculations. Full COD results are shown in Appendix F: Water Quality in Table 89. Table 21 shows average COD results for samples from raw shower greywater (BT), treated greywater (RS) and treated and distributed greywater (TT).

Table 21: Summary of COD laboratory results of samples from bathtubs(BT), greywater reuse system storage tanks(GS) and toilet tanks(TT).

		Sample Location	H1	H2	H6	H7	H9	H10	AVG
With Purge	Average (mg/L)	BT	138	161	76	8	199	111	**115**
		GS	83	65	68	86	134	50	**81**
		TT	79	122	62	102	124	52	**90**
	BOD_5/COD Ratio	BT	0.55	0.76	0.58	0.39	0.68	0.58	**0.59**
		GS	0.36	0.56	0.47	0.66	0.45	0.41	**0.49**
		TT	0.46	0.45	0.58	0.50	0.54	0.35	**0.48**
No Purge	Average (mg/L)	GS	155	41	29	69	150	86	**88**
		TT	145	75	21	82	165	89	**96**
	BOD_5/COD Ratio	GS	0.28	1.01	0.11	0.36	0.61	0.27	**0.44**
		TT	0.49	0.48	0.14	0.35	0.42	0.45	**0.39**
		Number of Residents	9	4	4	4	3	2	-
		Children Present	Yes	Yes	Yes	Yes	Yes	No	-
		Use of “natural” care products?	Yes	No	Yes	No	Yes	Yes	-

Similar to the BOD_5 levels, average COD levels in the untreated greywater with the purge function, were lower than De Luca's (2012) findings, which found COD levels in untreated greywater to range between 171.8 to 670.3mg/L. Values in the toilet tank were also lower, with an average of 90mg/L for all sites, while the average for both systems tested in De Luca's (2012) study were 164.8 and 195.8 mg/L.

Highest COD levels were found again consistently throughout the treatment process at House 9, which could potentially be due to the use of "natural" personal care products. One of the products used by House 9 for their newborn, listed oatmeal as one of the ingredients which could have led to high COD levels. House 7 did not indicate using natural products in their shower, and had the lowest COD levels but the connection between personal care products and COD levels requires further investigation.

When the system was operating without the purge function, average COD levels increased at three houses, and decreased at three houses. A change (increase or decrease) in COD levels in the greywater reuse storage tank resulted in the same change at the toilet tank, when the purge function was removed.

Table 21 also shows the BOD_5/COD ratio, and shows how the average value decreases through treatment and distribution when the system is operating with the purge function. Once the purge function was removed, BOD_5/COD ratio only decreased through the treatment system at three of the six houses where this comparison was available.

Previous work found that the raw, untreated shower greywater had a ratio of approximately 0.50, which these results are consistent with, but also found an increase in ratio after treatment (De Luca, 2012) (Santos, Taveira-Pinto, Cheng, & Leite, 2012). Although the results from this research are contradicting to previous work, it supports the theory that biodegradable and non-biodegradable matter does not respond to filtration and disinfection at the same treatment rate.

5.2.1.3 Total and Fecal Coliforms

Of the 34 raw, untreated shower greywater samples collected for this study, 24 samples (70.6 percent) initially met the Health Canada Guidelines for fecal coliforms prior to treatment (shown as highlighted cells in Table 22). It is a possibility that the samples users collected were not representative of all residents, as this level of fecal coliforms was unexpected. For example, House 2 and House 7 have young children and would be expected to have high fecal coliform measurements. Table 23 presents the total coliform measurements in raw greywater.

Table 22: Laboratory measurements of fecal coliforms in raw, untreated shower greywater samples.

Raw Greywater	**Fecal Coliforms (CFU/100mL)**					
Month/Year	**House 1**	**House 2**	**House 6**	**House 7**	**House 9**	**House 10**
08/14	240	<10	-	<10	50	>200000
10/14	-	-	-	-	4400	-
11/14	<10	60	1200	<10	18000	>200000
12/14	-	-	-	-	710	10
01/15 I	10	<10	>200000	<10	110	5400
01/15 II	20[2]	<10	>200000	<10	40	<10
02/15	<10	<10	-	<10	100	<10
% meet HCG	**80%**	**100%**	**0%**	**100%**	**57%**	**60%**
# of Residents	9	4	4	4	3	2
Children Present?	Yes	Yes	Yes	Yes	Yes	No

[1] Samples highlighted represent samples that meet HCG maximum value of 200 CFU/100mL.

Table 23: Laboratory measurements of total coliforms in raw, untreated shower greywater samples.

Raw Greywater	**Total Coliforms (CFU/100mL)**					
Month/Year	**House 1**	**House 2**	**House 6**	**House 7**	**House 9**	**House 10**
08/14	44000[1]	3100	-	80	210	>200000
10/14	-	-	-	-	18000[1]	-
11/14	10[1]	290[1]	24000	<10	18000[1]	>200000
12/14	-	-	-	-	820[1]	640[1]
01/15 I	10[1]	<10[1]	>200000	<10	490[1]	26000[1]
01/15 II	20[1]	<10[1]	>200000	<10	3400[1]	150[1]
02/15	<10	<10[1]	-	<10	4600[1]	5200[1]
# of Residents	9	4	4	4	3	2
Children Present?	Yes	Yes	Yes	Yes	Yes	No

[1]Values reported may be biased low due to overgrowth.

Health Canada Guidelines (HCG) recommend that samples from the treatment unit meet a maximum of 200 CFU/100mL. Of the 24 samples taken from greywater reuse systems operating with the purge function, 22 samples met HCG, as shown in Table 24.

Table 24: Laboratory measurements of Fecal Coliforms of samples from the greywater reuse system storage tanks.

Greywater Reuse System		Fecal Coliforms (CFU/100mL)					
	Month/Year	**H1**	**H2**	**H6**	**H7**	**H9**	**H10**
With Purge	**08/14**	<10[1]	<10	<10	10	<10	<10
	10/14	<10	-	-	-	<10	-
	11/14	<10	<10	<10	<10	<10	22000
	12/14	10	<10	-	-	<10	<10
	01/15 I	>200000	<10	<10	20	<10	<10
	% meet HCG	**80%**	**100%**	**100%**	**100%**	**100%**	**75%**
No Purge	**01/15 II**	340	<10	4400	<10	<10	<10
	02/15	<10	<10	-	<10	<10	<10
	% meet HCG	**50%**	**100%**	**0%**	**100%**	**100%**	**100%**

[1] Samples highlighted represent samples that meet HCG maximum value of 200 CFU/100mL.

Table 25 below shows total coliform levels in the greywater storage tank. Health Canada does not stipulate a limit for total coliforms in their guidelines.

Table 25: Laboratory measurements of Total Coliforms of samples from the greywater reuse system storage tanks.

Greywater Reuse System		Total Coliforms (CFU/100mL)					
	Month/Year	**H1**	**H2**	**H6**	**H7**	**H9**	**H10**
With Purge	**08/14**	<10	<10	<10	10	2100[1]	<10
	10/14	<10	-	-	-	<10	-
	11/14	<10	<10	<10	<10	<10	28000[1]
	12/14	18000	<10	-	-	<10	<10
	01/15 I	>200000	390	160	>200000	10	<10
No Purge	**01/15 II**	50000	10	5000[1]	40	<10	<10
	02/15	<10[1]	<10	<10	<10	<10	<10

[1]Values reported may be biased low due to overgrowth.

The spike in fecal coliforms at House 1 is due to the lid on the chlorine chamber being stuck and the users were unable to add more pucks until the end of January. Similarly, the users at House 10 and House 6 had forgotten to add chlorine pucks yielding empty chlorine chambers at the November 2014 visit and second January visit, respectively. This is further discussed in Section 5.4. It was found that when there was an elevated fecal coliform levels in the greywater reuse system tank due to lack of available chlorine for treatment, there was also a related high level at the toilet tanks, as shown below in Table 26.

A very high result of >200000 CFU/100mL was collected from the greywater reuse system storage tank at House 7, while the system was operating with the purge function, due to a lack of chlorine maintenance. Total chlorine residual was found to be 0.00mg/L at both the greywater reuse system and the toilet tank at House 7 during the first January 2015 visit. It is of interest to note that at this test visit, fecal coliforms in the greywater reuse system storage tank met Health Canada Guidelines with a value of 20 CFU/100mL while the sample from the toilet tank was >200000 CFU/100mL, indicating that without the presence of chlorine, fecal coliforms can grow rapidly.

Table 26: Laboratory measurements of Fecal Coliforms of samples from toilet tanks.

Toilet Tanks		**Fecal Coliforms (CFU/100mL)**					
	Month/Year	**H1**	**H2**	**H6**	**H7**	**H9**	**H10**
With Purge	**08/14**	<10[1]	<10	<10	<10	<10	<10
	10/14	20	-	-	-	<10	-
	11/14	<10	<10	<10	<10	<10	13000
	12/14	<10	<10	-	-	<10	<10
	01/15 I	700	18000	<10	>200000	<10	<10
	% meet HCG	**80%**	**75%**	**100%**	**67%**	**100%**	**75%**
No Purge	**01/15 II**	>200000	<10	5600	<10	<10	<10
	02/15	<10	<10	-	<10	<10	<10
	% meet HCG	**50%**	**100%**	**0%**	**100%**	**100%**	**100%**

[1] Samples highlighted represent samples that meet HCG maximum value of 200 CFU/100mL.

Table 27: Laboratory measurements of Total Coliforms of samples from toilet tanks.

Toilet Tanks		Total Coliforms (CFU/100mL)					
	Month/Year	H1	H2	H6	H7	H9	H10
With Purge	08/14	6000	<10	3500	10	80[1]	10
	10/14	>200000	-	-	-	<10	-
	11/14	>200000	240	220	<10	20000[1]	24000[1]
	12/14	12000	19000[1]	-	-	10	<10
	01/15 I	>200000	>200000	<10	>200000	<10	<10
No Purge	01/15 II	>200000	20	5600[1]	>200000	2000[1]	<10
	02/15	56000	130000[1]	<10	20000[1]	<10	<10

[1]Values reported may be biased low due to overgrowth.

Table 24 and Table 26 show that when there was chlorine available in the chlorine chamber for disinfection, fecal coliforms met Health Canada Guidelines, regardless of whether the system was operating with or without the purge function. This indicates that this system does not require the stored treated greywater to be emptied every 48 hours as it can provide adequate disinfection, assuming proper maintenance is performed. Having a high success rate of meeting the Health Canada Guidelines of ≤200 CFU/100mL is comparable to De Luca(2012) in which 89.9 percent of samples from the manufactured off the shelf system met HCG.

5.2.2 Field Testing Results

5.2.2.1 Free and Total Chlorine

Chlorine readings in raw, untreated shower water were not included. It is possible that chlorine residual could remain in the collected shower water from municipal treatment, explaining why some raw shower water samples were found to have chlorine readings. However, it is more likely that the process of shaking the DPD tablet in the sample during measurement caused suds to form, creating a false colour change. This could have resulted in compromised chlorine readings for shower water samples.

As shown in Table 28, average base municipal free chlorine readings were higher in Barrie than in Guelph, perhaps due to the houses’ location to the water treatment plant. Average free chlorine levels were found to be 1.87mg/L and 2.41 mg/L in the greywater reuse system storage tank, in Guelph and Barrie respectively, giving an overall average of 2.06mg/L for the greywater reuse system tank. Available free chlorine diminished to an overall average of 1.22mg/L in the toilet tanks when the system was operating with the purge.

Average free chlorine values were slightly higher in the systems operating without the purge, and the relationship of being higher in the greywater reuse system storage tank than in the toilet tank is still present. It can be expected that the values are slightly higher in the systems operating without the purge function as it is the same water continuously circulating through the chlorinating chamber.

Table 28: Summary of average free chlorine field results.

Free Chlorine Averages (mg/L)		With Purge			No Purge	
Sample Location		M	GS	TT	GS	TT
Guelph	House 1	0.21	0.29	0.45	1.10	0.04
	House 2	0.03	2.13	0.24	2.40	0.82
	House 3	0.12	3.32	3.87	-	-
	House 4	0.02	1.10	0.14	-	-
	House 5	0.07	4.38	0.70	-	-
	House 6	0.03	1.42	0.27	2.46	2.91
	House 7	0.35	0.01	0.31	1.88	0.15
	House 8	0.21	2.03	0.19	-	-
	House 9	0.05	1.63	0.49	1.62	2.81
	House 10	0.10	1.96	2.65	4.18	2.66
	House 13	0.78	2.29	1.29	-	-
	AVG	0.18	1.87	0.96	2.27	1.56
Barrie	House 15	0.05	0.06	1.41	-	-
	House 16	0.02	2.78	2.00	-	-
	House 18	0.04	5.93	3.95	0.43	0.11
	House 19	0.49	1.29	0.82	-	-
	House 20	0.11	3.26	1.25	-	-
	House 21	0.27	1.11	0.69	-	-
	AVG	0.16	2.41	1.69	-	-
Overall Average		**0.18**	**0.17**	**2.06**	**1.22**	**2.01**

Table 29 shows when the systems were operating with the purge setting every 48 hours, 77 percent of the greywater reuse system storage tank samples met the Health Canada Guidelines recommended value of at least 0.5mg/L total chlorine. Total chlorine values were generally high in the greywater reuse system, with values ranging from 0.00 mg/L to 13.75 mg/L, with an average value of 3.05mg/L.

Table 29: Summary of average total chlorine field results.

Total Chlorine (mg/L)			With Purge						No Purge			
Sample Location		Mode chlorine setting	% of Samples that meet HCG Max			Average (mg/L)			% of Samples that meet HCG Max		Average (mg/L)	
			M	GS	TT	M	GS	TT	GS	TT	GS	TT
Guelph	H1	4	20%	50%	67%	0.30	0.69	1.56	100%	0%	1.33	0.08
	H2	4	0%	67%	33%	0.06	2.71	0.57	100%	50%	2.94	0.97
	H3	2	0%	100%	100%	0.18	4.40	5.32	-	-	-	-
	H4	2	0%	40%	20%	0.08	1.56	0.33	-	-	-	-
	H5	3	0%	100%	50%	0.13	6.28	1.18	-	-	-	-
	H6	4	0%	100%	50%	0.08	2.30	0.65	50%	50%	3.18	3.77
	H7	3	25%	50%	50%	0.46	0.45	1.25	100%	50%	2.76	0.44
	H8	3	17%	83%	17%	0.28	3.80	0.37	-	-	-	-
	H9	4	0%	75%	100%	0.11	2.43	1.24	100%	100%	3.34	3.56
	H10	3	0%	75%	67%	0.14	2.88	4.14	100%	100%	5.30	1.10
	H13	4	100%	100%	100%	0.86	2.56	1.67	-	-	-	-
	AVG	4	**15%**	**76%**	**59%**	**0.24**	**2.73**	**1.66**	**92%**	**58%**	**3.14**	**1.65**
Barrie	H15	4	0%	17%	67%	0.14	0.11	3.54	-	-	-	-
	H16	4	0%	100%	100%	0.05	4.45	3.89	-	-	-	-
	H18	4	0%	100%	80%	0.10	7.97	6.99	100%	0%	0.85	0.40
	H19	3	50%	100%	67%	0.56	2.06	1.58	-	-	-	-
	H20	2	0%	100%	80%	0.19	5.41	2.31	-	-	-	-
	H21	4	40%	60%	80%	0.36	1.76	1.01	-	-	-	-
	AVG	4	**15%**	**79%**	**79%**	**0.23**	**3.63**	**3.22**	-	-	-	-
Overall Average		**4**	**15%**	**77%**	**66%**	**0.24**	**3.05**	**2.21**	**93%**	**50%**	**2.81**	**1.47**

At the 6 houses that operated without the purge function for two weeks, chlorine levels at the greywater reuse system were similar, ranging from 0.00mg/L to 7.49mg/L. 92 percent of the greywater reuse system samples met Health Canada Guidelines, but this is smaller sample size than the systems that operated with the purge function. Average values of total chlorine residual were 3.05mg/L and 2.81mg/L, with and without the purge function, respectively, indicating that the purge function does not greatly affect the total chlorine levels in the greywater reuse system storage tank.

An average total chlorine residual of 2.21mg/L in the toilet tanks is within the ideal range of chlorine residual to prevent pathogenic regrowth in toilets, and is close to previously found values in toilet tanks (De Luca, 2012; Vandegrift, 2014)

Total chlorine residual readings at the toilet tank were lower than in the greywater reuse system tank, as the chlorine reacted as a disinfectant. The average total chlorine in the toilet tank with the purge function was 28 percent less than the total chlorine at the greywater reuse system, while the total chlorine was reduced 48.8 percent from the greywater reuse system tank to the toilet tank when the system was operating without the purge function. This perhaps indicates a higher bacteria and particle level in the greywater in systems without the purge function, as more chlorine was consumed during distribution.

5.2.2.2 Turbidity

Table 30 shows that when the systems were operating with the purge function, they rarely (20 percent of the samples) met Health Canada's Guideline maximum of 5.00 NTU at the greywater reuse system storage tank, with an average of 16.19 NTU. Additionally, Health Canada Guidelines requires the maximum value be met prior to disinfection which is not accessible in this study.

The average turbidity at the toilet tank of systems operating with the purge was 14.99 NTU, which is a minor improvement from the storage tank samples; potentially showing some sedimentation between filtration/disinfection and distribution. This value of 14.99 NTU was much better than the average from De Luca's work of 32.12 NTU.

Turbidity at the greywater reuse system storage tank improved when the systems were operating without the purge function, and had an average value of 10.92 NTU, but the turbidity at the toilet tanks was relatively close to when it was operating with the purge function, and have an average of 14.57 NTU.

Table 30: Summary of turbidity measurements.

	With Purge								No Purge			
	% of Samples that meet HCG Max				Average (NTU)				% of Samples that meet HCG Max		Average (NTU)	
Sample Location	M	BT	GS	TT	M	BT	GS	TT	GS	TT	GS	TT
H1	100%	0%	20%	20%	0.26	23.72	12.15	12.69	0%	0%	10.23	26.80
H2	100%	0%	50%	0%	0.57	47.62	13.89	19.19	50%	50%	12.18	18.05
H3	100%	17%	17%	25%	0.37	18.71	12.11	7.93	-	-	-	-
H4	100%	0%	0%	60%	0.40	45.03	15.38	5.54	-	-	-	-
H5	100%	0%	17%	0%	0.13	69.15	24.89	15.99	-	-	-	-
H6	100%	0%	0%	0%	0.28	7.30	7.47	7.37	50%	50%	3.75	3.74
H7	100%	80%	33%	0%	0.32	2.02	32.65	48.78	50%	50%	6.39	10.09
H8	100%	0%	14%	0%	0.43	47.32	16.19	24.36	-	-	-	-
H9	100%	0%	20%	20%	0.41	32.71	20.03	14.82	0%	0%	19.85	19.15
H10	100%	14%	40%	40%	0.22	21.42	7.29	7.56	0%	0%	12.63	13.75
H12	100%	17%	83%	57%	0.25	30.67	4.25	5.58	-	-	-	-
H15	100%	0%	0%	0%	0.15	69.70	32.32	28.53	-	-	-	-
H16	100%	0%	17%	33%	0.32	22.70	14.60	7.85	-	-	-	-
H18	100%	0%	0%	0%	0.14	36.92	12.71	10.36	0%	0%	11.40	10.42
H19	100%	20%	20%	0%	0.59	16.85	8.81	15.23	-	-	-	-
H20	100%	25%	0%	0%	0.62	119.27	18.68	11.51	-	-	-	-
H21	100%	0%	17%	33%	0.95	121.32	21.76	11.61	-	-	-	-
AVG	100%	10%	20%	17%	0.38	43.08	16.19	14.99	21%	21%	10.92	14.57

House 7 had the highest average turbidity values at both the greywater reuse system and at the toilet tank, when the system was operating with the purge function. Perhaps this high turbidity level contributed to low chlorine levels in the greywater reuse system and toilet tank. Turbidity values decreased for House 7 when it was operating without the purge function.

5.2.2.3 Colour

It was found that colour measurements were highest in raw, untreated greywater, and improved with treatment. The average colour measurement of the greywater was greatly reduced from 599.33 cu to 240.85 cu, after treatment as shown below in Table 31. The samples collected when the systems were operating without the purge function have a lower average value for colour at the greywater reuse system (181.06 cu) than when the system had the purge function, but the average colour at the toilet tanks is slightly higher than with the purge function.

Table 31: Summary of average colour results for municipal, bathtub, greywater reuse system and toilet tank samples.

Average (CU)	With Purge	No Purge
M	**36.88**	**-**
BT	**599.33**	-
RS	**240.85**	**181.06**
TT	**270.13**	**279.18**

Table 90 in Appendix F: Water Quality shows details of colour measurement at each location. In general, colour of raw, untreated greywater was the highest, with two samples reaching 3448 cu and 3850 cu at Houses 20 and 21, respectively. This could be attributed to these houses using more natural soaps and shampoos.

5.2.2.4 Hardness

Despite hard water in Guelph (Region of Waterloo, City of Guelph, 2012), three of the 13 houses in Guelph did not have a water softener. Water is considered soft, when it is below 17 mg/L as $CaCO_3$, slightly hard between 17.1 – 60 mg/L, moderately hard between 61 – 120 mg/L, hard between 121 – 180 mg/L and very hard over 180 mg/L (Region of Waterloo, City of Guelph, 2012). Average hardness of municipal water at Houses 7, 10 and 13 was found to be 377.5, 405 and 310 mg/L as $CaCO_3$, respectively. Houses 18, 19 and 20 in Barrie did not have water softeners and the municipal water was found to have average hardness readings of 107.5, 162.5 and 110 mg/L as $CaCO_3$, respectively.

Hardness was as expected in the houses in Guelph without a water softener, but no correlation can be made between hardness and system maintenance issues, as discussed later in 5.4.

5.2.2.5 Odour

Results from odour testing of the four grab sample locations of the greywater reuse system are presented Figure 15 and shown in more detail in Table 92 in Appendix F: Water Quality.

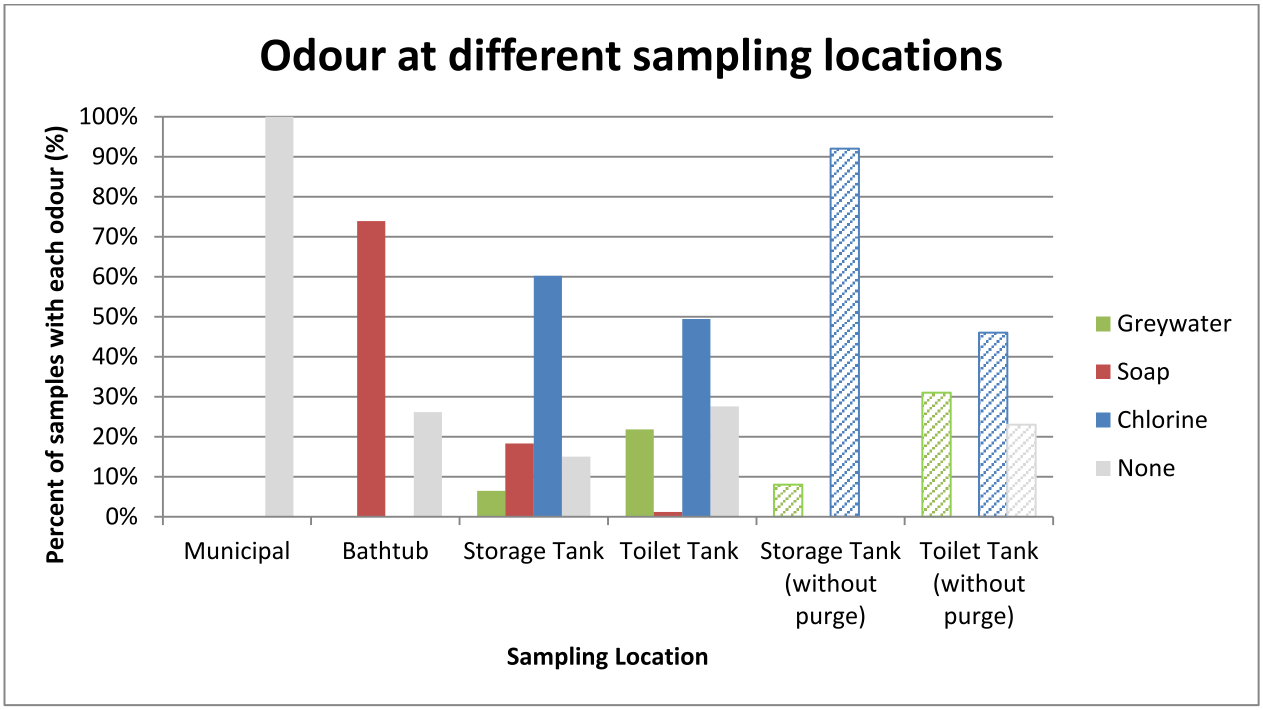


Figure 15: Percentage of odours recorded at each sampling location.

100 percent of the municipal samples had no odour. This was important to test as some houses had relatively high levels of total chlorine residual in their municipal water. The majority (74 percent) of bathtub samples had a soap odour, as expected, and the remaining had no odour. There is potential for bathtub samples to have a greywater odour if the samples were stored for too long prior to sampling, indicating bacteria growth.

60 percent of samples taken at the Greywater reuse system when the system was operating with the purge function had a chlorine odour, which was lower than when the system did not purge, when 92 percent of the samples had a chlorine smell. This is potentially due to the high circulation of the stored greywater through the chlorinator. This measurement is of importance as the system odour could spread throughout the room when the system is installed and not be appropriate for all users. For this reason, it is recommended that in future testing, an odour assessment in the mechanical room also be made.

It is of importance to note that the greywater odour at the toilet tank increased from 22 percent of the samples to 31 percent of the samples, when the system was operating without the purge. As written in the user survey discussion, 8 of the 17 user survey respondents indicated they experienced a noticeable greywater odour at their toilet tank, and 7 of the 17 also indicated a chlorine odour at their toilet tank.

5.2.2.6 pH

Average pH values were found to be greater than 7 throughout the system, which is comparable to previous studies. Values in the toilet tank, as well as without the purge function are slightly more basic than municipal values, indicating chlorine and personal care products potentially increase pH levels in greywater.

Table 32: Summary of pH measurements.

	With Purge		No Purge	
Sample Location	**# of Samples**	**Average**	**# of Samples**	**Average**
M	86	7.58	-	-
BT	76	7.74	-	-
RS	71	7.53	13	7.85
TT	67	7.68	11	7.83

5.2.2.7 Temperature

Table 33 shows the average temperatures of the greywater throughout the treatment system. Average storage tank system values of a temperature of 22.6 ^{o}C is important as this shows there is potential for drain water heat recovery, as this is slightly higher than room temperature.

Table 33: Summary of temperature measurements.

	With Purge		No Purge	
Sample Location	**# of Samples**	**Average**	**# of Samples**	**Average**
M	106	22.74	-	-
BT	89	16.25	-	-
RS	91	22.61	13	18.85
TT	87	20.19	13	18.06

5.2.3 Water Quality Summary

Table 34 and Table 35 provide a summary of the most important water quality values found when assessing the performance of the studied system, with and without the purge setting.

Table 34: Summary of recorded water quality at the greywater reuse system storage tank, with the purge setting.

Greywater reuse system tank	With Purge			Health Canada Guidelines		
Parameter	**Average**	**# of Samples**	**Max.**	**Average**	**Max.**	**% Met**
BOD_5 (mg/L)	39	24	160	≤10	≤ 20	38%
COD (mg/L)	81	24	230			
Fecal Coliforms (CFU/100mL)	<10[1]	24	>200 000	ND[4]	≤ 200	92%
Total Coliforms (CFU/100mL)	<10[1]	24	>200 000			
Free Chlorine (mg/L)	2.06	51	9.08			
Total Chlorine (mg/L)	3.05	76	13.75	≥ 0.5		77%
Turbidity (NTU)	16.19	91	58.10	≤ 2	≤ 5	20%
Colour (cu)	240.85	91	923			
Odour	Chlorine[2]	93	60%[3]			
pH	7.53	71	8.5			
Temperature (^{o}C)	22.61	91	37.6			

[1]Mode value.
2Majority of recorded odours at greywater reuse system tank.
[3]Percent of recorded odours that were chlorine.
[4]ND: Not detected.

Table 35: Summary of recorded water quality at the greywater reuse system storage tank, without the purge setting.

Greywater reuse system tank	No Purge			Health Canada Guidelines		
Parameter	**Average**	**# of Samples**	**Max.**	**Average**	**Max.**	**% Met**
BOD_5 (mg/L)	38	12	100	≤10	≤ 20	50%
COD (mg/L)	88	12	250			
Fecal Coliforms (CFU/100mL)	<10[1]	11	4 400	ND[4]	≤ 200	75%
Total Coliforms (CFU/100mL)	<10[1]	12	50 000			
Free Chlorine (mg/L)	2.01	13	5.13			
Total Chlorine (mg/L)	2.81	13	7.91	≥ 0.5		93%
Turbidity (NTU)	10.92	13	24.60	≤ 2	≤ 5	21%
Colour (cu)	181.06	13	327			
Odour	Chlorine	13	92%[3]			
pH	7.85	13	8.3			
Temperature (^{o}C)	18.85	13	29.0			

[1]Mode value.
2Majority of recorded odours at greywater reuse system tank.
[3]Percent of recorded odours that were chlorine.
[4]ND: Not detected.

Adding greywater collected from bathroom sinks would not likely impact overall water quality of this system due to dilution from the large volume of shower greywater, but analysis is recommended as part of future research as bathroom sink greywater has been found to have poorer water quality than shower greywater (Jefferson, Palmer, Jeffrey, Stuetz, & Judd, 2004).

5.3 Energy Use

The presented values reported in kWh/m^3 correlate recorded energy data to recorded water consumption. Houses 2, 11, 13, and 22 had water balance and energy metering issues and were omitted from overall energy intensity results.Table 36 provides a summary of the average energy consumption at each home, and the corresponding energy intensity (kWh/treated m^3).

Table 36: Summary of energy consumption for all homes, sorted by highest energy intensity to lowest.

House #	Meter	Energy Consumption (Average kWh/day)	Greywater used to Flush (m^3)[1]	Percentage water used to flush that is Municipal (%)[2]	Energy Intensity (kWh/m^3)[3]
18	WeMo	0.070	3.360	44.96	2.763
12	Kill-a-watt	0.07	3.183	19.59	2.37
15	WeMo	0.084	4.336	96.75	2.354
10	Kill-a-watt	0.05	3.063	48.91	1.53
8	WeMo	0.078	4.186	20.10	1.422
6	Kill-a-watt	0.06	2.886	13.13	1.39
7	Kill-a-watt	0.04	4.359	50.54	1.17
20	WeMo	0.067	3.410	18.93	0.909
16	WeMo	0.064	7.027	50.65	0.885
1	Kill-a-watt	0.09	13.214	20.60	0.75
9	Kill-a-watt	0.07	11.126	34.41	0.68
14	WeMo	0.071	11.546	36.86	0.668
19	Kill-a-watt	0.07	3.007	31.61	0.61
Overall Average		0.069			1.346

[1]This volume indicates volume from the storage tank that was used to flush the toilets. This could include both greywater and municipal water.
[2]This volume assumes that 100% of municipal water that was added to the storage tank was used to flush (i.e. not purged).
[3]Energy used to treat all water used to flush the toilets (including greywater and municipal).

Energy intensity (kWh/m^3) of this system ranged from 0.61 to 2.763 kWh/m^3. These results are in line with the findings from De Luca (2012) which found the electrical intensity to be 1.3, 1.85 and 3.7 kWh/m^3 at the sites in the previous study. However, this indicates that energy intensities for this system can be higher for this system than found values for municipally sourced water (0.68 – 1.11kWh/m^3) (Mass, 2009), further supporting the need for research into residential greywater reuse at greater scales (i.e. multi-unit buildings). It is important to note the percentage of water that is used to flush that is municipally added water as this indicates which water is then being treated twice for one end use (treated municipally and by the greywater reuse system for toilet flushing), which is wasted energy.

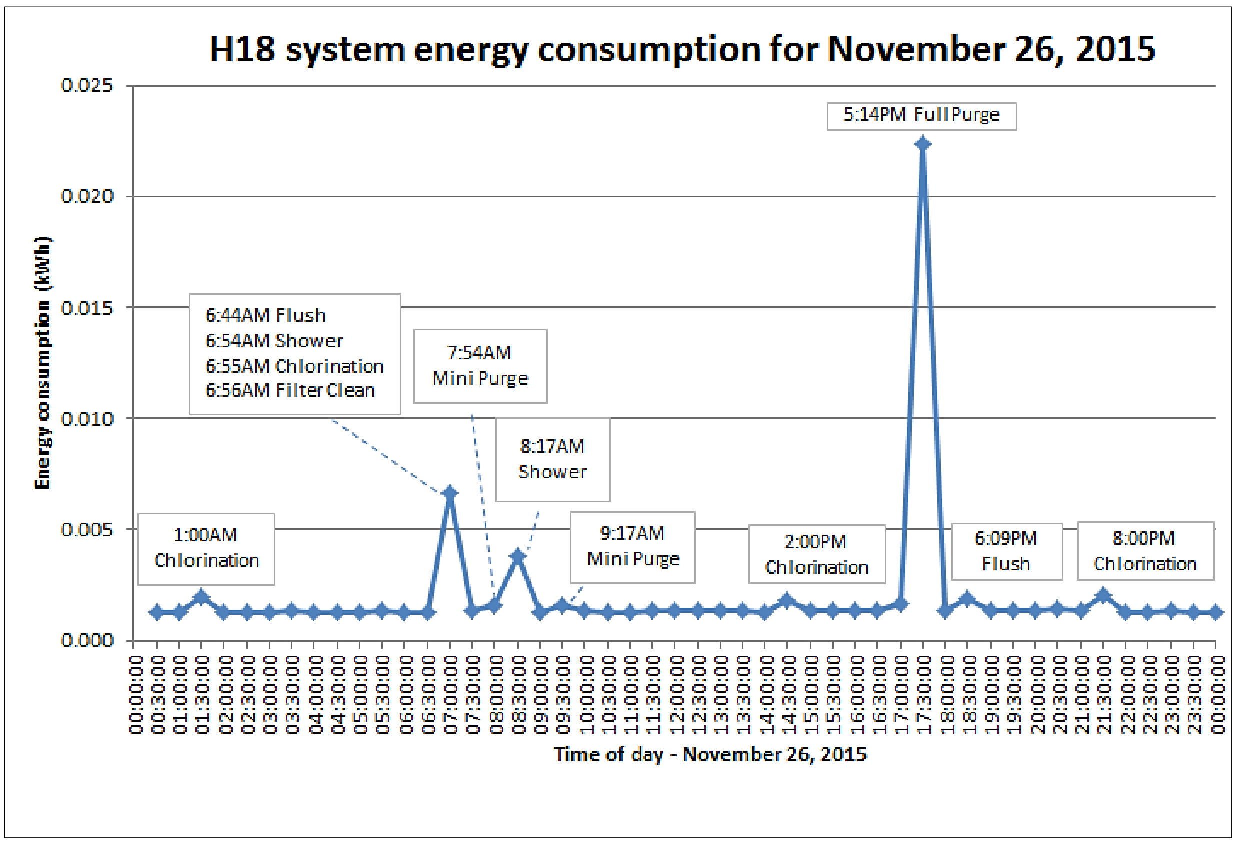


Figure 16: Detailed energy and correlating water consumption data for House 18 on November 26, 2015.

A more in depth analysis of the energy consumption results can be made at a house-by-house level. Using data collected every 30 minutes by the WeMo meters, an in-depth analysis was performed at House 18 due to the completeness of the energy and water balance data.

Energy and water balance data was aligned and analyzed from November 12, 2014 to December 9, 2014. Through this analysis, it is possible to line up water balance events with energy demands, as shown above in Figure 16. Another example of detailed energy consumption for House 16 is presented in Figure 24 in Appendix G: Energy Results.

The following table is a summary of the greywater reuse events that occurred over the 27 days of data. The WeMo meter presented an energy usage value for a 30 minute time frame, which was representative of the event that occurred during that time frame, unless more than one event occurred, in which that energy data was disregarded.

Table 37: Total energy use and average energy use for each event at House 18, for November 12, 2014 to December 9, 2014.

Type of Event	# of Events over time period	Total Energy (kWh)	Average Energy/event (kWh)
Chlorination	52	0.07283	0.00140
Mini Purge	21	0.03047	0.00145
Flush	103	0.18288	0.00178
Fresh Added	1	0.00122	0.00122
Full Purge[1]	5	0.11153	0.02231
Shower Event[2]	13	0.05816	0.00447
Standby	1049	1.21339	0.00116

[1]This includes the energy used to add fresh water to the tank after emptying through a “full purge” event.
[2]This includes greywater being added, and the immediate chlorination and filter cleaning that happens after the system detects a “shower” event.

Of all the events, the full purge uses the most energy per event, while chlorination and fresh water added use the least. Figure 17 below further illustrates the energy use by the various events of system installed at House 18. The total energy use for the presented time period was 1.67kWh.

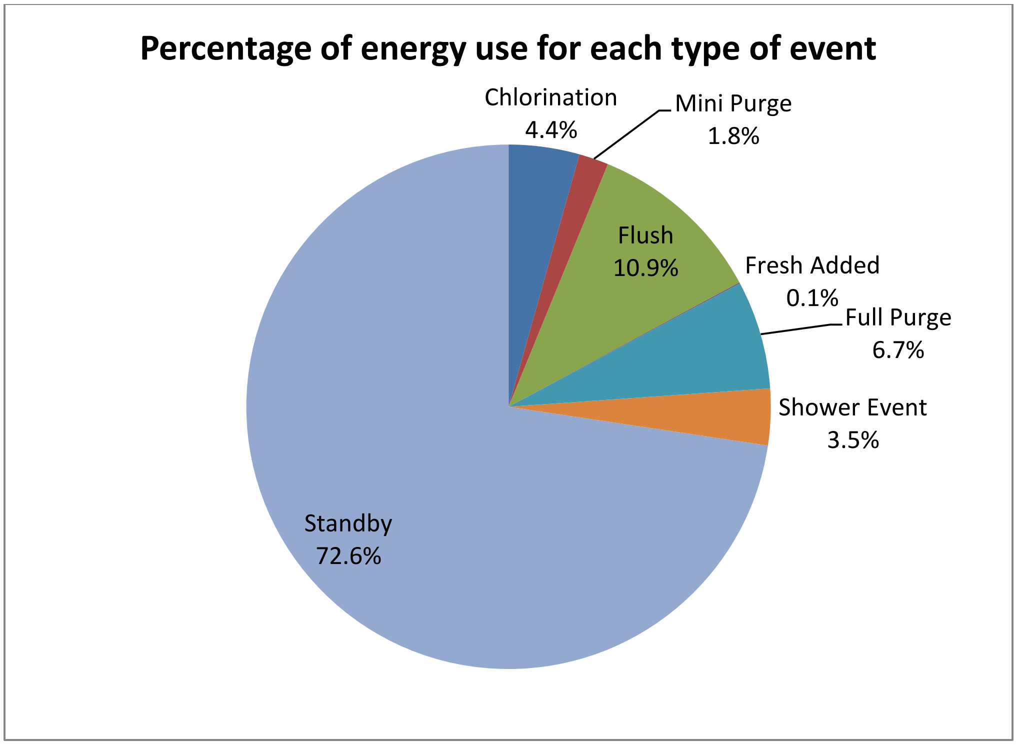


Figure 17: Energy use breakdown, for House 18 from November 12, 2014 to December 9, 2014.

It is of importance to note that the majority of the energy used by the system is when it is in "standby" mode. This is expected however, as the system spends, on average, 98.99 percent of a day in standby mode. The system at House 18 was operating, on average, 15 minutes per day and was on standby mode for the remainder.

When the system is "On", it consumes 23.90 percent of daily energy use. On average, the system used 0.01612kWh operating daily events and 0.05133 kWh (76.10 percent) on standby. This is a point of further research and recommends further product development to reduce standby energy use.

Through evaluation of energy use by each event, energy intensity (i.e. kWh to treat one m^3 of greywater) for an average shower event can be calculated. An average energy consumption value for shower events was recorded, as well as an average value for chlorination (which occurs every six hours between shower events). Assuming that greywater being added to the system requires no energy, the energy consumption for a shower event is solely for chlorination and filter cleaning. Therefore, the difference in averages of the shower event energy and chlorination energy is the energy used for filter cleaning. Table 38 shows the determined values, and by comparing the energy use to the average volume for a shower event, the energy intensity for treatment of one shower event can be calculated. However, the system continues to chlorinate after this initial treatment, and therefore these values are perhaps not representative of complete treatment of greywater.

These values are much lower than previously calculated energy intensities and show that individual shower treatment (chlorination and filter cleaning) has a much lower energy intensity than municipal systems (0.68 – 1.11kWh/m^3) (Mass, 2009). These results suggest that if the system could reduce other energy demands such as full purge, standby, and pumping to flush, the system would be more energy efficient than municipal treatment.

Table 38: Evaluation of energy use by each treatment event.

Event	Average event energy usage (kWh)	Average volume for each event (m^3)	Average Energy Intensity for each event (kWh/m^3)
Shower Event	0.004474	0.0525	0.0851
Chlorination	0.001401		0.0267
Filter Clean	0.003073		0.0585

In Ontario, energy rates range based on season, and by time of use. At the time of this study, energy rates ranged from \$0.077/kWh and \$0.14/kWh depending on when electricity is used during a peak time or not (Ontario Energy Board, 2015). Using a weighted average, energy costs can be taken as \$0.095/kWh. Calculations for this can be found in Appendix G: Energy Results in Table 93.

Taking average daily energy use of the systems, the average daily operating cost can be found, as shown in Table 39. It is assumed that the life span for the system is 10 years (Hodgson, 2012; Seiders, et al., 2007).

Therefore, the operating costs associated with energy use can be estimated for the life span of the system. On average, the energy cost for operating this system for 10 years is $24.65.

Table 39: Energy use operating costs based on daily average energy use for all systems.

House #	Meter	Average kWh/day	Average $ / day	Estimated $/year	Estimated $/10 years
1	Kill-a-watt	0.09	0.009	3.11	31.08
2	WeMo	0.054	0.005	1.88	18.76
6	Kill-a-watt	0.06	0.006	2.18	21.76
7	Kill-a-watt	0.04	0.004	1.55	15.46
8	WeMo	0.078	0.007	2.71	27.11
9	Kill-a-watt	0.07	0.006	2.29	22.90
10	Kill-a-watt	0.05	0.005	1.67	16.73
12	Kill-a-watt	0.07	0.007	2.49	24.90
13	WeMo	0.121	0.011	4.20	41.97
14	WeMo	0.071	0.007	2.47	24.71
15	WeMo	0.084	0.008	2.91	29.09
16	WeMo	0.064	0.006	2.23	22.27
18	WeMo	0.070	0.007	2.41	24.10
19	Kill-a-watt	0.07	0.007	2.55	25.47
20	WeMo	0.067	0.006	2.34	23.35
Overall AVG		0.071	0.007	2.46	24.65

The only other user characteristic that could influence energy consumption is toilet location and therefore required pump pressure to supply greywater. There is potential for the pump to require more energy to pump water to higher floors. This could be researched in the future. This 30-minute interval time stamping also shows how habits change on weekdays versus weekends. For example, a home with two adults who work traditional work weeks, shower before 8am, Monday through Friday, and shower later on Saturday and Sunday. These habits could be used for treatment scheduling and is also potential area for further research.

5.4 Durability

5.4.1 Failure

At each test visit, the durability of the system was assessed by checking each point of potential failure. Table 40 shows the frequency of which a certain failure occurred with the system, at each of the houses. Failure frequency was calculated by counting the failures that occurred at each house, at least one time. A description of each failure and more detailed durability results for each house can be found in Appendix H: Durability Assessment in Table 94.

Table 40: Durability Assessment of the greywater reuse system.

Failure	Failure Frequency	
Film Buildup in toilet tank	16 of 20	80%
Flashing notifications	17 of 23	74%
Corrosion	13 of 23	57%
Incorrect time on screen	12 of 23	52%
Clogged greywater filter	11 of 22	50%
External Water Leakage	9 of 23	39%
Broken Screen	6 of 23	26%
Insufficient Pressure	5 of 23	22%
Toilet Flush Valve issues	5 of 23	22%
Pump issues	4 of 23	17%
Clogged pump filter	2 of 23	9%
Limited access to chlorine	2 of 23	9%
Insufficient water supply	1 of 23	4%
Deteriorated toilet flush valve	1 of 23	4%
Fragmented text on screen	1 of 23	4%
Flooding / Overflow	0 of 23	0%
Limited access to filter	0 of 23	0%

According to observations made at each test visit, it was found that the most common failure in the systems was film build-up in the toilet tanks which could lead to the toilet tanks not working properly (e.g. clogged flush valves) as well as potentially leading to damaged toilet fixtures. User survey results shown in Table 42 indicated that users also indicated that tank build-up was the most frequent failure. For multiple reasons, the flush valves had to be replaced in five houses during the study. Flush valves were replaced in at least one toilet in Houses 1, 8, 15, 19 and 22 due to leaking. House 8 was the only house that was previously connected to a greywater reuse system and therefore does not clearly show that it was the previous system that affected the flush valves. There is potential that these systems had buildup in their flush valves or leaking flappers prior to the study, but this was not documented. Further research in to effects of greywater reuse on flush valves is recommended.

The second most common failure, according to observation data, was unnecessary screen notifications (occurred at 74 percent of the houses). 57 percent of the test houses showed signs of corrosion, specifically on the screws around the greywater tank lid. Many of these failures were repaired easily and were addressed during the testing period by the manufacturer.

Common failures in previous “off the shelf” system field studies included loss of pressure in the pump as well (De Luca, 2012). In this pilot study, 22 percent of the systems experienced loss of pressure to pump greywater to the toilets. It could have been beneficial to track the amount of time it took for the toilets to refill after flushing at each site, to show pressure loss over the period of the study, as completed by previous studies (Christova-Boal, 1995).

De Luca (2012) also found corrosion issues, filter blockage and toilet flush valves not being able to maintain a tight seal due to build-up and deterioration. More details about the filter performance in this system can be found below in Section 5.4.2 below.

Of note, House 12 had excessive issues with their toilets. Prior to the installation of the greywater reuse system, the house was equipped with two pressure assist toilets. One of the two toilets (top floor) would not pressurize properly which prevents the ability to flush. Despite having two plumbers assess the pressure issues, the toilet would not flush properly and was replaced with a dual flush toilet. It is not speculated that these issues were caused by the greywater reuse system as House 14 also had pressure assisted toilets and did not experience any issues. Further research is recommended to assess the performance of greywater reuse systems connected to pressure assisted toilets to show the compatibility.

Additionally, House 22 had many issues with their toilets leaking, their pump continuously pulsating and clogging of both the primary greywater filter and the secondary filter before the pump at the base of the tank. This system is the only system that operated on well water rather than municipal water and it is believed that their source water had fine sand particles that were potentially causing filter and pump issues. The manufacturer was investigating further reasoning behind their continuous pump failures.

Five users indicated pump issues throughout the installation of their system, and noted that every four to six months the pump can lose air and become noisy.

Finally, it was common for houses that had screen interface issues to have screen issues more than once. The screen component would go blank and stop working repeatedly at Houses 8,9,11 and 22 indicating an electrical issue, which the manufacturer continues to investigate. The control panel circuit board showed signs of burning, as pictured in Figure 25 in Appendix H: Durability Assessment.

The unfortunate aspect of this failure is that it is beyond the scope of a typical plumber repair and requires a service technician from the manufacturing company to resolve. Through the user survey, House 11 indicated that they were "somewhat unsatisfied" with the display screen user interface as it malfunctioned at a time when many guests were visiting. In this instance, all components of the system shut down, and greywater was not being pumped to toilets throughout the house. The configuration of plumbing did not allow for the users to switch back to municipal water plumbing leaving the users without a direct fillable water source for the toilets.

With the other screen failures, the greywater reuse system was still operating as normal, but the users were not able to control any functions as the screen readout would be blank or the buttons would stop working. House 8 had to have their screen replaced multiple times and indicated that they were "very unsatisfied" with the user interface.

Overall, 41 percent of users were very satisfied with the user interface, and 24 percent indicated they were each somewhat satisfied and neutral.

Table 41: User survey responses to satisfaction with incorporation of "State of the Art" technology.

Rate your level of satisfaction with the display screen user interface.				
1 Very Satisfied	2 Somewhat Satisfied	3 Neutral	4 Somewhat Unsatisfied	5 Very Unsatisfied
7	4	4	1	1

Another frequent comment made by users through the user survey is that they would like for the system to have a read out of the current tank balance, as the tank is opaque and the water level cannot always be easily seen. Users also specified that it would be beneficial for the screen readout to indicate the true water saved value. Currently, the system indicates a water saved value which is the amount of water used by flushing. This should be offset to account for fresh water that has been added.

Along with observational data taken during field testing, users were asked in the second survey to comment on system performance and difficulties. Users were given the option to choose multiple issues. The value of this process was to capture any failures that were not visible to the tester during visits (e.g. Noise).

Through the user survey, user's also noted that the most frequent technical issue with the system was film build-up in the toilet tank. A noise nuisance was also indicated by nine system users. This could be verified in future testing through noise meters which can measure the noise produced by the system when operating. Through discussion with system users at test visits, it was noted that if any plumbing connected to the system was loose, it would rattle throughout the house when the pump turned on.

Table 42: User survey durability assessment.

Did you experience any of the following technical issues or difficulties with your greywater reuse system?	
Film buildup in toilet tank	13
Noise nuisance	9
Unpleasant "greywater" odour at toilets	8
Chlorine odour at toilets	7
Film buildup in toilet bowl	7
Unable to flush toilets (pump issues)	7
Screen malfunctions	5
Pump issues	5
Unable to flush toilets (no water in greywater storage tank)	4
Flooding	3
None	1
Improper installation	1
Other:	3
Other: frequent alarms, vibration in walls due to retrofit tubing and air gaps when water levels were low, toilets not flushing strongly	

As the system was installed in each city by two plumbing companies that were trained installers, it was not surprising that incidents with installation were low. However, a cleaning cloth was left behind by one of the installers at one house and was later found blocking the pump in the system.

Users were asked to indicate whether they had experienced any of the listed failures with their system, yielding results which give a “yes or no” as to whether a failure had occurred. It is recommended that in future testing, users be asked to rate the severity of the problem from a scale from one to five, with five being severe, and any ratings above three be considered a “failure”, following the assessment example set by Fittschen (1997).

5.4.2 Filter Performance and film build-up

Filter blockage and frequent cleaning was a significant drawback to previous generations of greywater reuse systems. Although “self-cleaning”, the filter in the greywater reuse system still became clogged with a thin transparent film.

Incorporated into the system's programming was an alert which notified the user when less than 70 percent of a known volume from the filter cleaning process did not pass through the filter. The program did have issues with unnecessary notifications, but the filters on some systems were blocked, without any explanation as to why. Possible reasons for the film build-up were speculated as due to the use of natural-based personal care products, the reaction of these natural products with chlorine or use of hard water without a softener.

In this study, the use of hygienic products that were advertised as "natural" did not necessarily correlate to filter build-up issues. Additionally, a connection cannot be made between the use of a water softener and whether the system experienced filter build-up (see Table 96 in Appendix H: Durability Assessment). This is most relevant in Houses 1 through 13 which are in Guelph, which has notably hard water which could lead to calcification.

It was also found that the filter at the base of the system which filters any debris before the pump, could become clogged for an unknown reason (shown in Figure 26 in Appendix H: Durability Assessment). This was not included as user maintenance, but affected Houses 5 and 22 during the study period.

A sample of the build-up on the pump filter at House 22 was further analyzed by the Agriculture and Food Laboratory at the University of Guelph for further analysis. It was speculated that the build-up was due to soap reacting with hard water, but this was not the case. Their report indicated that aside from hair, fibers, plastic and metal dust particles, the build-up surprisingly contained protein. The only source of protein that could be traced throughout the greywater reuse system was in the natural shampoos used in this house, which had "hydrolyzed wheat protein".

Of the nine houses that indicated use of "natural hygiene products", five experienced filter build-up issues. Therefore, further research into the possible connection between natural hygienic products and buildup on fine greywater reuse filters is recommended.

5.4.3 Stressed Situations

5.4.3.1 Vacations

The greywater reuse system was equipped to enter "vacation mode" when greywater was not added to the system or used to flush toilets for 48 hours. When the system entered vacation mode, the system would purge the water in the system, fill with fresh municipal water, and continue to circulate that water through the chlorinator every 6 hours until greywater was added again.

There were 5 instances where the water balance data showed that users went on vacation, and the system should have entered vacation mode, as shown in Table 43. Ideally, as outlined in Section 4.2.4.3, planned vacations would have been previously recorded and the results could have been compared to the expected days.

Table 43: Durability assessment of the greywater reuse system when the users went on vacation.

House	Time Period	Proper Vacation Mode operation?	Notes & Failure explained
5	Jan II - Feb	No	User turned municipal water off. System did not record any events (including chlorination) during the vacation period.
10	Dec - Jan I	No	User turned municipal water off. System did not record any events (including chlorination) during the vacation period.
14	Dec - Jan I	Yes	
15	Nov - Dec	No	System still purged tank volume every 48 hours.
23	Jan II - Feb	Yes	User filled with municipal water and opened system bypass.

Of the 5 known opportunities to operate in "vacation mode", the system only operated in vacation mode twice. This lack of proper vacation events could be due to two factors: (i) users turned the municipal water off, and the system stopped chlorinating and (ii) the systems did not have the most up to date version of the program installed at this time.

When asked in the user survey about the performance of the system's vacation mode, 11 users responded as going on vacation as shown in Table 44. It is recommended that in future studies, a detailed log be kept of when users are away for more than 48 hours.

Table 44: User survey assessment of vacation mode.

Rate the system performance when you went on vacation.					
1 - Very Satisfied	**2 - Somewhat Satisfied**	**3 - Neutral**	**4 - Somewhat Unsatisfied**	**5 - Very Unsatisfied**	**N/A**
6	2	2	1	-	6

Please comment on the water quality in the toilet bowl when you returned from your vacation.[1]	
Unusually cloudy	1
Unusually clear	3
Strong unpleasant "greywater" odour	3
Strong chlorine odour	1
Excessive buildup in toilet bowl	-
Excessive buildup in toilet tank	1
No difference	**4**
Other:	-

[1] Users could select more than one response to this question.

Of the users that went on vacation during the pilot study, the majority were very satisfied with vacation mode, and most noticed no difference to when they were at home flushing the toilets as usual. However, there were users that were less satisfied with the water quality when they returned and further improvements to vacation mode are recommended.

Before leaving for seven days, House 16 filled their toilets and the greywater reuse system with municipal water, and wrote in the user survey that when they returned, there was no difference between the toilets connected to the greywater reuse system and the systems connected to municipal water.

House 9 wrote in the user survey that as their system had experienced flooding before (prior to the start of the pilot study testing) and they were hesitant to leave it operating while away and unplugged it.

5.4.3.2 Power Outage

This system was equipped with a battery that was intended to turn on when external power was cut from the system. However, every time the systems were unplugged, this back up power supply source did not work in any of the units, and therefore, any time the power went out, the system would not function. This could lead to stagnant water in the greywater storage tank creating a habitat for bacteria growth.

Through the user survey, the majority of the system users indicated that the system restarted with no issues after a power outage. However, House 11 did indicate that the system had to be manually restarted after a power outage, but this could be due to other issues with their control panel, as explained in Section 5.4.1. House 20 noted that after a power outage, their “water saved” volume reset to zero, which, although not crucial to operation, could lower the user’s satisfaction with water savings.

Multiple users indicated that they would like a battery to operate the system when the power goes out for extended periods of time, indicating that the battery currently connected to the system does not function when the power goes out.

5.5 Maintenance

Log sheets were distributed to the system users to record maintenance when it was performed; however, few users completed the maintenance sheets. The best source of data for maintenance was to check the status of system at each test visit. However, these frequent visits might have impacted the sense of awareness of the greywater system in the user’s home and the frequency of required maintenance might have increased.

5.5.1 Toilet Maintenance

Using greywater to flush traditional toilets was found to lead to additional toilet maintenance including cleaning the toilet tank (reservoir that holds water for toilet flushing) and the potential for more frequent toilet bowl cleaning, as build-up occurs easily.

However, through the second user survey, it was found that the majority of users (53 percent) found no change in frequency of cleaning their toilet bowls that were connected to the greywater system, relative to when their systems were operating using municipal water. 24 percent of users indicated they clean their toilet bowls more frequently, and 24 percent also indicated they clean their toilet bowls less frequently than when their system operated using municipal water. This comparison was made by asking the system users to indicate how frequently they clean their toilet bowls in both the first and second survey. It is possible that users did not properly estimate how frequently they performed toilet cleaning without the greywater reuse system, as many had been equipped with a greywater reuse system for multiple years. Most users indicated that they had to clean their toilet bowls once a week.

82 percent of users indicated they did not need to change the strength of cleaning product they used to clean their toilet bowls, while the remaining indicated needing to increase the strength of product they used. The most common products used to clean the toilets operating with the greywater reuse system were regular strength toilet bowl cleaners. 4 houses indicated using “natural” cleaning products, and 3 more use just vinegar and/or a toilet brush. These results show that strong chemicals are not necessarily required for cleaning toilets when they are connected to greywater reuse systems.

Cleaning the toilet tank is a maintenance task that is traditionally not required as toilet maintenance. 29 percent of users indicated not having to ever clean the toilet tanks, but the remaining users recorded some cleaning was required as scum/mould can build up and affect the flush valves. Additionally, some users noted that black mould would grow in the toilet tank and flush into the toilet bowl and not be aesthetically pleasing. House 5 indicated having to clean their toilet tank once a week, while the remaining users recorded cleaning their toilet tanks every month (3 users), every 2-3 months (4 users) and every 6-12 months (2 users). The final two users indicated they only had to clean their toilet tanks when the chlorine in their greywater reuse system ran out leading to water quality issues.

Table 45 shows the distribution of user responses to questions relating to toilet maintenance. As toilet tank cleaning is not a normally practiced part of toilet maintenance, the reasoning behind checking the toilet tank was asked. The most common answers were an unpleasant odour in the toilet bowl, and excessive build-up in the toilet bowl. Users deduced these issues were due to toilet tank fouling.

Table 45: Toilet Maintenance assessment by users in User Survey #2

What prompted you to clean the toilet tank(s)?[1]				
Unpleasant odour in toilet bowl	**Excessive buildup in toilet bowl**	**Toilet wasn't flushing properly**	**Regular Maintenance**	**Other**
7	**7**	4	2	2
Other:	System notified users of leak, lead them to check the toilet tank.			

Rate the impact this greywater reuse system has had on your toilets and their components.				
1 No impact on toilets	**2 Minor impact on toilets**	**3 Neutral**	**4 Major Impact on toilets**	**5 Severe (caused damage to toilets)**
2	**8**	4	2	1
4 - Major Impact on toilets:	Potential impact on flush valves for pressure-assisted toilets. Severe mould buildup inside the toilet tank.			
5 – Severe (caused damage to toilets):	Light flush button (dual flush toilet) sticks on all toilets now. Flush valve replaced in one toilet, but now leaking again.			

[1]Users could select more than one response to this question.

Toilets were not designed to operate using greywater and thus the impact greywater has on toilets is of great interest. A difficulty that arose with assessing impact from this system was that all systems in Guelph had been previously operating using a different greywater reuse system. Therefore, it is not absolute if durability issues (build-up, part deterioration, etc.) were due to this system or the previous system.

Regardless, eight users (47 percent) indicated a “minor impact on toilets” from the system, while only two users indicated no impact. Two users (12 percent) indicated major impact on the toilets: (i) indicated that the system did not function with pressure-assisted toilets, which as previously mentioned, was not confirmed to be due to the greywater reuse system and (ii) excessive mould growth and build-up in the toilet tank. House 1 indicated severe damage to their fixtures occurred, and explained that the “light flush” button in all of their toilets now sticks when they flush. This could be due to build-up in the toilet tank.

House 1 also had issues of toilet leaking and found that replacing their flush valve resolved the leaking issue but only temporarily. It is of importance to note that House 1 has excessive use with 9 residents showering and flushing, and was not able to refill their chlorine in the greywater reuse system for an extended period due to a jammed lid. This resulted in poor water quality and odour at the toilet being very strong leading the users to put chlorine pucks directly in to the toilet tank. It is speculated that a combination of build-up in the flush valve which prevented the flush valve from closing properly, and deterioration of rubber parts in the flush valve due to excessive chlorination led to a leaking toilet in this instance. In total, flush valves needed to be replaced at 5 toilets, which could have been caused by many factors including chlorination and build-up issues.

In summary, when the greywater reuse system is chlorinating properly, build-up in the toilet tank is manageable and there is little difference in toilet bowl maintenance practices. User satisfaction with toilet maintenance was not asked directly, but can be seen in overall satisfaction with maintenance in Section 5.8. As this study only tracked performance for 6 months, long term impact on fixtures could not be documented and require further investigation.

5.5.2 Chlorine Refilling

The studied greywater reuse system provides a flashing notification to check the chlorine chamber every three months as a reminder to the home owner. However, at each test visit, the system was reprogrammed and the three month countdown was reset. This interfered with the proper evaluation of water quality performance and maintenance requirements as the homeowners occasionally forgot to add chlorine pucks and their water quality deteriorated. This also shows that system users require a system prompt to maintain the system. Through tests visits and user surveys, it was found that the majority of the systems (65 percent) had to refill their chlorine pucks every 2-3 months, meeting manufacturer specifications. Houses 4, 10 and 21 indicated only having to replace their chlorine pucks every 5-6 months but this is believed to be underestimated as the chlorine pucks were replaced by the tester during test visits. Two other houses indicated they were unsure of chlorine refilling requirements as the test visits interrupted the schedule.

House 22 indicated having to replace their chlorine pucks once a month, and had unusual system performance. Initially, House 22 was using small chlorine pucks which had too much filler content and not enough available chlorine. After switching to pucks where at least 90 percent of the product was available chlorine present as Trichloro-s-triazinetrione, there was a minor improvement in water quality at House 22. This system continued to have pump and toilet leaking issues, and overall poor performance.

The manufacturers directed users to add chlorine pucks intermittingly to the toilet tanks to resolve any water quality issues (odour and buildup). The field testing and user survey did not record how many users were adding chlorine pucks to their toilets. House 1 indicated having to add a chlorine puck to their toilet tanks every two weeks.

Chlorine pucks that are advertised for pool treatment were used in the greywater reuse system. Two sizes of chlorine pucks are readily available for use, a small “mini puck” of 50 g and a large puck of 200 g. Anecdotally, the system manufacturer found that using the mini pucks allowed for more surface area in the chlorinating container, allowing for more greywater contact. Additionally, the filler part of the large chlorine pucks would occasionally block the holes where water would spray into the chlorinating container, causing issues. A correlation between water quality and chlorine puck size could not be made with this data but it is recommended for future research.

Chlorine could be added to the system through a screw top lid at the top of the system. Unfortunately, this lid became stuck on a few systems preventing new chlorine from being added. Overall, six houses were very satisfied with the procedure to add chlorine, four were somewhat satisfied, and three were neutral. House 15 indicated somewhat unsatisfied but did not indicate why, but can be assumed that this low rating was due to a tight lid.

Table 46: Satisfaction with chlorine maintenance for the studied greywater reuse system.

Rate your level of satisfaction with the procedure to add chlorine to this greywater reuse system.				
1 - Very Satisfied	**2 - Somewhat Satisfied**	**3 - Neutral**	**4 - Somewhat Unsatisfied**	**5 - Very Unsatisfied**
6	4	**6**	1	-

5.5.3 Self-Cleaning Filter

The filter used in the studied greywater reuse system was equipped with a self-cleaning process, which used greywater to wash the filter after a shower, removing any filter debris or build-up to the sanitary sewer. The intent was that this self-cleaning process would greatly reduce the frequency of which system users have to manually clean the filter themselves, compared to previous generations of greywater reuse systems.

Table 47: Frequency of filter maintenance for the studied greywater reuse system.

How frequently did you have to clean the filter?						
Every 2 weeks	**Once a month**	**Every 2-3 months**	**Every 5-6 months**	**Once a year**	**Never**	**Other**
-	2	5	**6**	-	2	2
Other:	Uncertain, Pilot study interfered					

However, the filters do become clogged (50 percent of homes experienced filter issues) and require maintenance more frequently than anticipated. The manufacturer indicated that filter maintenance would be required every six months, which was accurate for six of the system users (35 percent). However, five users (30 percent) found that the filter required maintenance every two to three months. Two users indicated that they did not yet have to clean the filter, and two users were unsure as the frequent test visits interfered with regular maintenance. System users indicated in the survey that the greatest reason why they completed filter maintenance was due to screen notifications, which could have been falsely notifying them, while the second highest result in the user survey as reasoning behind checking the filter was by system users who were sensitive to the water level in the greywater reuse system tank. The users realized that the water level was very low when it was expected to be higher, and found that the filter was clogged and raw greywater was bypassing the system. 53 percent of survey responses indicated that cleaning the filter could be done with light scrubbing and water, while 24 percent needed the cleaning product CLR. Other responses used vinegar or dish soap.

Satisfaction with filter maintenance was not directly asked, but additional comments about filter maintenance indicated that although filter maintenance was not bad, the system was not completely “self-cleaning” as advertised. Another common user comment was that the filter lid was not quickly removed and should be easily accessible.

Overall, system users indicated that they were between neutral and very satisfied with the maintenance of the system, except for House 1 which indicated “very unsatisfied”. The system at House 1 had a stuck chlorine lid, poor water quality requiring the addition of chlorine pucks to toilet tanks, leaking toilets as a result of greywater reuse and frequent system notifications and alerts leading to excessive user maintenance. House 1 wrote that this system was advertised as having less maintenance than previous generations, but in this situation, it was not.

Table 48: User satisfaction with maintenance required for the studied greywater reuse system.

Rate your level of satisfaction with all maintenance required for this greywater reuse system.				
1 - Very Satisfied	**2 - Somewhat Satisfied**	**3 – Neutral**	**4 - Somewhat Unsatisfied**	**5 - Very Unsatisfied**
7	4	5	-	1

5.6 Installation

5.6.1 Economics

All of the houses in Guelph had been a part of the previous greywater testing projects and therefore had already had their plumbing retrofitted to allow for greywater reuse. One company out of Guelph was set with the task of replacing the existing greywater reuse systems with the greywater reuse system, and did not divide each replacement to its own invoice. As an average value, each replacement process cost $862.44, and it is estimated that half of that charge was for removal of the old system and half is for installation of the new system.

Based on the invoices from the plumbing company that installed the greywater reuse system into existing homes that were not dual-plumbed for greywater reuse, the ease of installation could be measured. It became evident that a "basic greywater reuse installation" required: (i) roughing-in a drain from the showers and baths in the house to the location where the greywater reuse system would be located (such as the mechanical room), (ii) roughing-in a water supply line from the greywater reuse system to toilets and (iii) installing and connecting the greywater reuse system. It is important to note how many stories are in the home as extending the plumbing to bathrooms on higher floors can add to costs. Full details about the cost of all installations and repairs are shown in Table 97 in Appendix J: Economics.

Table 49 shows that "basic" installs were the least expensive, with an average installation cost of $1568.13 for a single story bungalow. Once an additional story was added, prices of installation increased to levels between $2269.24 to $2912.26. These installations were not as straightforward as the single story installations and two of the three homes required extra work such as moving the washing machine.

Retrofitting a house to be dual-plumbed requires access to the plumbing by cutting holes in the drywall at various points throughout the house. The repairs of these access points are quite costly as they require a secondary tradesperson (contractor) and usually result in dry-wall repair, painting, textured finish work (e.g. stucco ceilings) and clean up. These repairs cost between $1025.00 to $2621.60, depending on the contractor and the amount of work. These repairs greatly increased the cost of installation and show the advantage of building homes with dual plumbing, rather than retrofitting.

Table 49: Assessment of greywater reuse system installation into existing homes, built without dual-plumbing.

House	House type	Installation	Repairs	Total[1]	Notes
19	Single story bungalow	1123.38	-	1123.38	Basic installation.
E[2]	Single story bungalow	2012.88	-	2012.88	Basic installation.
15	Two story home	2269.24	-	2269.24	Basic installation.
16	Two story home	2756.40	-	2756.40	Extra work re-routing washing machine drain.
14	Two story home	2912.26	-	2912.26	Extra work re-routing shower drain in bathroom.
20	Single story bungalow	1818.86	1260.00	3078.86	Basic install and repairs included dry-wall repair and painting.
F	Single story bungalow	2063.45	1025.00	3088.45	Basic install and repairs included dry-wall repair, painting, and building bulkhead for drain.
18	Two story home	1740.10	2621.60	4361.70	Two days for installation, and repairs included dry-wall repair with textured finish.
17	Two story home	2179.76	2214.80	4394.56	Relocated laundry sink in basement to make room for the greywater reuse system, and repairs included dry-wall and trim repair, and painting.
21	Two story home	2393.89	2245.00	4638.89	Basic install and dry-wall repair with textured finish, and building bulkhead.

[1]All costs include 13% Ontario sales tax (HST).
[2]Additional invoices were available for houses where the system was installed, beyond Houses 1 through 23. These houses were labelled A through F.

Compared to a home that previously had a greywater reuse system installed ($862.44), retrofitting a home with dual-plumbing and a greywater reuse system can be between 23 to 81 percent more expensive. The overall average cost of installation of this system in houses involved in the pilot study was $1677.71. In comparison, it was cheaper than Christova-Boal's (1995) assessment which ranged between $2871 to $5946 Australian Dollars, 20 years ago, which at the time was approximately equivalent to Canadian Dollars (Antweiler, 2015).

5.6.2 Ease of installation

Many of the homes in Guelph are older buildings and were built with the wastewater line draining to the basement and leaving the building at waist height. The studied greywater reuse system relies on gravity to manually empty the tank, which is not possible if the sanitary sewer level is higher than the base of the tank. Options are to have a pump the water up to the sanitary sewer or some systems were just not equipped with a manual purge option.

Results from the user survey showed that there was only one instance of issues with installation, and it was due to a misplaced cloth getting stuck near the pump. One user indicated that installation was very easy, because they have an unfinished basement, and that perhaps it would be different if their basement was finished. Every house that was a part of this pilot study either had an unfinished basement or a mechanical room. Overall, 14 of 17 users indicated they were "very satisfied" with the installation process when asked during the second online survey.

5.7 Economics

5.7.1 Capital Cost

The capital cost of this residential greywater reuse system is $2 499.00, which is considered to be the worst case. Assuming the system users receive a $1 000.00 rebate for installing the system, the price would be $1 499.00 and this is considered the best case scenario. A rebate off $500.00 towards the capital cost is considered the average case.

5.7.2 Installation

Installation for this system in the pilot study ranged from $862.44 to $4638.39, depending on whether the system was previously dual-plumbed, number of stories in the house and whether repairs were required. The average installation cost for this system into the pilot study homes was $1677.71, with approximately half of the homes being dual-plumbed from previous greywater reuse.

5.7.3 Annual Maintenance and Operating Costs

A 10 year life-span was estimated for the residential greywater reuse system (Hodgson, 2012; Seiders et al., 2007).

It was found that on average, three chlorine pucks had to be added every two to three months, which averages to approximately 35 large chlorine pucks per year. These super pucks are sold at Canadian Tire for $43 for a 7kg supply. Each chlorine puck is 200grams; therefore, average annual cost for chlorine maintenance is $17.69. Following these calculations, the best case scenario is replacing chlorine pucks every five to six months, which costs $8.04 annually, and the worst case, replacing chlorine pucks every month, adds up to $44.23 annually.

Annually, users are expected to pay for a municipal backflow prevention testing which is $150 each year in Guelph. This was considered to be the worst case, while Barrie's backflow prevention test of $35 annually was considered to be the average case. The best case for this component of annual maintenance would be no fee associated with testing.

The highest found energy consumption by the system was at House 22, which consumed 0.18kWh per day, on average. The average energy consumption was 0.077kWh per day, and the best energy consumer was House 7, which used 0.04kWh per day. Assuming the average rate for Ontario energy as $0.095/kWh, the cost for operating the system for 365 days a year would be $1.55, $2.68 and $6.30 for the best, average and worst case scenario, respectively.

5.7.4 Savings from Greywater Reuse

When House 1 was operating without the purge setting, they had the highest water savings (96.9L/day) and are considered the best case scenario. On average, the system saved 26.0L/day operating with the purge, the value which will be used for economic analysis, and 49.5L/day operating without the purge. In the worst cases, the system actually consumed more water than greywater was produced and did not offer any savings. The lowest found savings were at 10.3L/day at House 15.

Based on the Ontario water rate analysis available in Appendix B: Projected Water Rates for Municipalities in Southern Ontario, the current average rate for water and wastewater can be estimated as \$3.15 per metre cubed. In terms of greywater reuse economics, the best case for water rates is the highest water rates, as this will lead to the shortest payback period. Therefore, the best case is in London, where the combined water and wastewater rate is \$4.44/m^3, and the worst case scenario is in Peel, where the combined water rate is \$2.03/m^3. Based on the rough estimates presented earlier a projected average combined rate for 2022 is \$4.47/m^3.

5.7.5 Economic Analysis

Table 50 shows the estimated best, average and worst case scenarios for the greywater reuse system, and presents a payback period for each of the scenarios. It was estimated that water rates would increase from the 2015 rates by five percent annually (see Table 64 in Appendix B: Projected Water Rates for Municipalities in Southern Ontario), but an increase in energy costs or other inflated items were not considered. Full calculations are in Appendix B: Projected Water Rates for Municipalities in Southern Ontario.

Table 50 shows that in the best case scenario, the water savings would not be great enough to pay back the subsidized immediate costs within a reasonable time frame (10 years). The majority of survey respondents indicated that five years was an acceptable payback period for them to consider installing a greywater reuse system (Figure 28 in Appendix J: Economics).

Table 50: Economic analysis of the studied greywater reuse system.

	Best Case	Average Case	Worst Case
Capital Cost ($)	$1,499.00	$2,000.00	$2,499.00
Installation Cost ($)	$862.44	$1,677.71	$4,638.39
Total immediate cost ($)	**$2,361.44**	**$3,677.71**	**$7,137.39**
Water Savings (L/house/day)	96.906	26.045	10.265
Annual Water Savings (m^3)	35.371	9.506	3.747
2015 Combined Water Rate ($/$m^3$)	$4.44	$3.15	$2.03
Annual Savings ($)	**$157.05**	**$29.95**	**$7.61**
Annual Maintenance ($)	$8.04	$52.69	$194.23
Annual Operation ($)	$1.55	$2.68	$6.30
Total annual Costs ($)	**$9.59**	**$55.37**	**$200.53**
Payback Period (years) (assuming 5% annual water rate increase)	**11**	**43**	**52**

Table 51 below shows the financial incentives that would be required for the five, ten and 20 year payback periods to be met, under each scenario. For most scenarios, the financial incentive required to have the simple payback period be anything less than a 20 year payback period would require the incentive to be more than the capital and installation cost, highlighted as “NF” in the following table.

Table 51: Required financial incentives for the system to have a 5, 10 or 20 year payback period, including 5% combined water rate increases.

	Best Case	Average Case	Worst Case
Incentive for 5 year Payback	$1351.00	NF[1]	NF
Incentive for 10 year Payback	$236.00	NF	NF
Incentive for 20 Year Payback	NR[2]	3832.00	NF

[1]NF: Not feasible. Incentive required would be more than the capital and installation costs.
[2]NR: Not required. Payback period for the greywater reuse system is within time period without financial incentive.

The user survey responses, shown in part in Table 52, show support for a government provided financial incentive. Users were more likely to install the greywater reuse systems if there was a $1000 incentive for the system, but were still likely to pay for the immediate and annual expenses associated with the system.

Table 52: User responses to economic feasibility survey questions.

How likely are you to pay…	1 Very Likely	2 Somewhat Likely	3 Neutral	4 Somewhat Unlikely	5 Very Unlikely
...the capital cost to have this system in your home?	1	**6**	4	4	2
...the annual expenses to have this system in your home?	**5**	**5**	4	2	1
...for a system in your home, if the capital cost was subsidized by a government incentive of $1000?	**7**	**7**	-	2	1

5.8 User Satisfaction Survey

After completing site visits collecting water quality samples, water balance data and energy data, a second survey was sent to the system users to gather information on their experience with the system and determine whether users enjoyed having the system in their home. The survey was sent to the main contact at each household. An explanation of the survey can be found in Section 4.2.10 and all survey questions are available in Appendix D: Surveys.

17 of the 20 users that were asked to complete the satisfaction survey responded. Houses 14, 17, and 23 were not included in user satisfaction data collection.

It should be noted that most test houses in Barrie were users that had direct ties with the manufacturers, such as a family member working for the company. Therefore, user satisfaction results could be biased from these houses. It should also be noted that the greywater reuse systems had been installed and operating for more than a year at some houses prior to the beginning of the pilot study testing, which could sway users results when trying to recall their experiences with municipal systems before the greywater reuse system. Average values or most common responses are presented below but with such a small and diverse sample of field study participants, the opinions about the system performance often varied.

5.8.1 Environmental Awareness

Table 53 shows the results from the four environmental awareness questions in the survey.

Table 53: Results from Environmental Awareness survey questions

House #	Involved in previous study?	# of practiced water conservation methods[1]	How did user get a system?	Primary reason for GW reuse?	Recycle in the home?
1	No	7	Approached by manufacturer.	To use less fresh water.	3 - Neutral
4	Yes	5	Approached by manufacturer.	To adopt innovative technology.	2 - Mostly everything
5	Yes	1	Home-builder recommended a system.	To adopt innovative technology.	3 - Neutral
6	Yes	5	Actively searched for a system.	To use less fresh water.	3 - Neutral
8	Yes	6	Moved in to home with a system.	To save money on water bills.	3 - Neutral
9	Yes	1	Home-builder recommended a system.	To save money on water bills.	2 - Mostly everything
10	Yes	5	Approached by manufacturer.	To use less fresh water.	2 - Mostly everything
11	No	2	Moved in to home with a system.	To save money on water bills.	3 - Neutral
12	Yes	6	Moved in to home with a system.	To use less fresh water.	2 - Mostly everything
13	Yes	3	Other: Supplier/installer for the manufacturer.	To use less fresh water.	1 - Everything
15	No	1	Approached by manufacturer.	To save money on water bills.	4 - Some things
16	No	4	Approached by manufacturer.	To save money on water bills.	2 - Mostly everything
18	No	3	Approached by manufacturer.	To adopt innovative technology.	2 - Mostly everything
19	No	5[2]	Approached by manufacturer.	To save money on water bills.	2 - Mostly everything
20	No	7	Approached by manufacturer.	To save money on water bills.	2 - Mostly everything
21	No	5	Approached by manufacturer.	To use less fresh water.	2 - Mostly everything
22	No	7	Actively searched for a system.	To use less fresh water.	2 - Mostly everything

[1] Users were given the option of selecting 8 water conservation methods, and/or indicating other methods.
[2] House 19 noted an "other" method of water conservation which was using municipal water at off-peak times.

It can be read that users that practice a higher amount of water conservation methods, actively searched for a greywater reuse system, are using greywater reuse systems to conserve fresh water and recycle most to all of the waste in their home have a high environmental awareness, like House 13 or 22.

Users that indicated that they do not practice many water conservation methods beyond greywater reuse, came to have a greywater reuse system in their home by methods such as moving in to a home with a system already installed, are using the greywater reuse system for financially reasons and recycle little waste in their home can be considered to have a relatively low environmental awareness (e.g. House 5 or 15). In summary, Table 53 shows that the study participants had a broad range of motives and environmental awareness which could have influenced their satisfaction responses.

5.8.2 Overall Satisfaction

Table 54 below shows the user satisfaction with various aspects of the greywater reuse system. Generally, the majority of the users were very satisfied to neutral for most of the response.

Table 54: Satisfaction with various performance details of the studied greywater reuse system.

Rate your level of satisfaction with …	1 Very Satisfied	2 Somewhat Satisfied	3 Neutral	4 Somewhat Unsatisfied	5 Very Unsatisfied	N/A
water aesthetics at the toilet bowl.	**8**	4	5	-	-	-
water savings of the system.	5	**6**	4	2	-	-
process to by-pass greywater reuse and access municipal water to flush your toilets.	**7**	1	1	-	-	8
any noise produced by the greywater reuse system.	3	5	**6**	2	1	-
energy use of the system.	**7**	5	5	-	-	-
the greywater reuse system aesthetics.	**12**	3	2	-	-	-
how long it took to install this greywater reuse system.	**14**	1	2	-	-	-

Table 55 shows that most users were overall, very satisfied and somewhat satisfied with this greywater reuse system and 12 of the 17 respondents will continue to have the system in their home.

Table 55: Overall satisfaction with the studied greywater reuse system.

Rate your level of satisfaction with the overall performance of this greywater reuse system.					
1 Very Satisfied	2 Somewhat Satisfied	3 Neutral	4 Somewhat Unsatisfied	5 Very Unsatisfied	
8	6	2	-	1	
Have you noticed a change in your water bill since installing this greywater reuse system?					
1 Major water savings	2 Minor water savings	3 No change	4 Minor increase in water usage	5 Major increase in water usage	Unsure
2	5	2	1	-	**7**
Do you believe that this greywater reuse system provides a reliable water supply to flush your toilets?					
1 Strongly Agree	2 Somewhat Agree	3 Neutral	4 Somewhat Disagree	5 Strongly Disagree	
13	3	1	-	-	
Rate how much you agree with the following statement: " I would recommend this greywater system to someone else"					
1 Strongly Agree	2 Somewhat Agree	3 Neutral	4 Somewhat Disagree	5 Strongly Disagree	
8	6	1	1	1	
Would you continue to have this system in your house?					
1 Yes, definitely	2 Possibly	3 Unsure	4 Not unless some improvements are made.	5 No, never again	
12	4	-	1	-	
Changes needed in order to keep system?	"Toilet tank fouling needs to be resolved, without the need for chlorine pucks in the tank. Chlorine vapour needs to be minimized in the bathroom, and should ideally not occur in the bathroom at all." - House 1				

In the user survey, one user wrote that it would be beneficial to include a remote tank level readout somewhere (perhaps even incorporate online) so that the users can make behavioural changes to optimize water savings, such as showering before a party where there would be excessive flushing.

5.9 Summative Discussion

5.9.1 Application of Standard Testing Methodology to Field Study

Actual water savings and economic feasibility could be considered the most important metrics of assessment of this greywater reuse system, as little data has been presented previously on the true field performance of residential greywater reuse systems, in Southern Ontario. On average, the homes in this study did produce roughly the same amount of water (65.8Lhhd) as were consumed by flushing toilets (72.3Lhhd) which shows that greywater is a sufficient water supply for toilet flushing in homes. Further, when the automatic purge setting was removed from the system, municipal water demand decreased.

Unfortunately, the high capital ($2499) and installation costs (ranging from $862.44 to $4638.39), do not allow for a reasonable payback period as the average water savings combined with low water rates does not provide a strong return. This supports De Luca's (2012) conclusion that installation of a low flow toilet is a much more economic method of water conservation.

For example, House 9 was found to be the highest water consumers for flushing in the study. There are two adults and one infant (not included as a flushing resident) at House 9, and they are equipped with 2 conventional toilets which traditionally can use 13+L of water per flush. The water balance found that the average flush for these conventional toilets was actually 6.661L, and that this household flushes on average 14.27 times per day.

Dual flush toilets are advertised as having three or six litre flush volumes, with an average of 4.5 L. This rating was found to be relatively accurate as most measured flush volumes at house with dual flush toilets ranged between 4.2 L and 4.9 L. If House 9 were to retrofit their conventional toilets with dual flush toilets, there would reduce their water consumption by 37.9 L, daily (14.27 flushes/ day x 4.5L/flush = 64.22 L, compared to 102.1 L currently). Savings of approximately 38 L is significant, when the system at House 9 was found to save 58 L, on average per day, when operating with the purge (the setting at which the users preferred due to build up growth in their toilet tanks).

In summary, retrofitted with two dual flush toilet for $400-$600, can save 38 L a day for House 9. House 9 was retrofitted for greywater reuse in a previous study, but it could be assumed that installation and repairs for this house (two storeys) would have cost at least $2269.24 based on invoice data. Including the capital cost for the system, the overall greywater reuse option for this house is $4,768.24, in order to save 58 L per day. At this point, greywater reuse does not make financial sense, unless it is subsidized by municipalities. By reducing the capital costs of a greywater reuse system through subsidization, onsite treatment and residential reuse of wastewater would become feasible. This would reduce the pressure placed on deteriorating municipal infrastructure and would reduce the total amount of energy and chemical treatment required to municipal treat water and wastewater.

In cases like House 1, which had 9 residents, saved 96.9 L of fresh water per day, and was already equipped with dual-flush toilets, the installation of a greywater reuse system makes sense, but for environmental and conservation efforts only at this time. Perhaps in the future when technology improves, capital costs are reduced, and water rates increase, the simple payback period could be within the estimated life span and become a more financially viable option. Additionally, the grand-scale environmental benefits of water conservation were not accounted for in the economic analysis and should be considered when assessing the simple payback period.

In terms of water quality, average found BOD_5, and turbidity measurements after treatment in the greywater reuse system tank did not meet Health Canada Guidelines. Chlorine residual did however on average exceed required chlorine levels, and when adequate chlorine levels were present, fecal coliforms regularly met required levels, at the greywater reuse storage tank. Fecal coliforms at levels not meeting Health Canada Guidelines were slightly more common at the toilet tank as the chlorine was beginning to be diminish but still met guidelines very frequently. Although water quality measurements were relatively good, 8 of 17 users still experienced an unpleasant greywater odour in the bathrooms, and film buildup was very common. Therefore, treated greywater does not perform the same as municipal water in toilet flushing, but if users are willing to accept the toilet tank maintenance and potential for odours, it generally meets water quality guidelines.

This greywater reuse system was advertised as having a self-cleaning filter, and would require very little maintenance input from the system users. 50 percent of the users still found that they had filter issues, with two of the survey respondents indicating that they have to manually clean the filter once a month due to film buildup, blocking greywater from passing through. Five respondents noted having to clean the filter every two to three months, and six respondents indicated having to clean the filter every five to six months. The manufacturer had advertised that the filter needed to be maintained annually, and therefore it was found that it has to be cleaned much more frequently than anticipated. However, 16 of the 17 user respondents indicated that they were between 1-Very Satisfied and 3-Neutral with all maintenance required for this greywater reuse, indicating that although some maintenance is required, users think it is a reasonable amount.

This greywater reuse system was found to use more energy to treat and distribute greywater throughout a home than centralized water treatment. However, chlorination and filtration of the greywater did not use more energy than centralized water treatment, and it is possible that if the pumping efficiency and standby operations improved, the residential greywater reuse system could use less energy than current centralized systems.

Although an exact comparison cannot be made, it appears that users are generally more satisfied with this greywater reuse system than previous generations, as 14 of the 17 survey respondents indicated a level 1-Very Satisfied and 2-Somewhat Satisfied for overall system performance. This shows that despite the durability and maintenance issues associated with this system (mainly buildup in the toilet tanks and filter issues), the residential greywater reuse technology is improving and is becoming more user friendly. This will lead to further adoption of the practice.

Applying the developed standard testing methodology to the field study highlighted performance issues with the greywater reuse system that the manufacturer was then able to resolve. The manufacturer responded to the system's durability assessment by improving the filter design, repairing faulty controllers, implementing corrosion resistant screws, replacing frequent faulty water seals, resolving pressure issues and replacing the chlorine lid to prevent access issues. Toilet flush valves that were found to be leaking were replaced, but the typical greywater reuse issues of buildup and flapper degradation due to chlorine were not resolved in this field study.

The standard testing methodology showed where water savings were greatest in the field study providing the manufacturer with details for their target market. Water balance analysis also proved that the system did not necessarily require a full purge every 48 hours leading to increased water savings.

5.9.2 Evaluation of Developed Standard Testing Methodology

By applying the standard testing methodology that was developed in the first part of this thesis to a case study, it was shown that the suggested metrics can successfully grasp the overall field performance of a residential greywater reuse system. The results of the field study showed that the developed methodology was an effective method for collecting the water savings associated with the system, the water quality of the greywater treated by the system, and the energy consumption of the system, which can be considered the most relevant performance criteria.

Water savings were found to vary greatly for each test system and showed the relationship that an increase in residents led to an increase in daily savings. However, the results also highlight that occupant behaviour can influence system performance and could be considered in future studies assessing greywater reuse system performance.

Durability issues might differ for future generations of the greywater reuse systems; however, the presented checklist of failures can be used as the base for future system testing and be expanded upon depending on technology improvements.

Improvements to the method of collecting maintenance requirements were made throughout field testing and are therefore not reflected in the field study results. By evaluating maintenance for at least one year, as suggested in the developed methodology, a complete annual account of required maintenance for a greywater reuse system will be available.

Using invoices for evaluation of the installation process effectively showed how the installation process is highly variable depending on each house's setup. Ease of installation and interviewing plumbers could be a more important part of future field studies as the systems might become more complex resulting in a more difficult installation process.

Evaluating the simple payback of the system was an effective method to show the financial reality of greywater reuse, but is a very rudimentary method of economic analysis. This method does not take into account inflation (other than an estimated 5 percent annual water rate increase), and does not capture the non-quantifiable environmental savings, such as reducing freshwater consumption. The developed methodology for economic analysis could be expanded by further presenting how the system economics change in more varied scenarios using statistical methods such as beta distribution.

The method for quantifying user satisfaction successfully showed the field study participant's responses to the system. A more in-depth method would have included asking user's opinion and documenting anecdotal responses throughout the testing process, rather than solely via a conclusive online survey. However, the results from the user survey provide standard averaged feedback which can be compared to the results from the application of the method to other greywater reuse systems. The developed methodology gathered the user's environmental awareness by asking about water conservation and recycling methods within the home. Other user characteristics such as education level and background could potentially influence occupant behaviour and the overall performance of the system in each home.

It is recommended that the developed methodology be applied for each new greywater reuse system before it becomes commercially available on the market, similar to CSA B128 and NSF 350. It is expected that further variations of the methodology will be required for more complex systems using treatment methods beyond disinfection and filtration.

Overall, the developed methodology accurately captured the core greywater reuse system performance metrics of water savings, water quality and energy consumption, while also presenting the less tangible performance issues of the greywater reuse systems once they are installed in to a home such as durability, maintenance requirements and user satisfaction.

6 Further Work

Throughout this research, it was found that there is a lack of research on greywater reuse across Canada, as well as a lack of Canadian guidelines permitting greywater reuse. It is suggested that future research aim to develop guidelines in order to further the implementation of the systems.

One of the greatest found durability issues of the greywater reuse system is the buildup that forms in the toilet tanks, which can cause issues with the flush valves. Further investigation is required into the long term effects from greywater reuse on toilets.

This research showed that there are tools available to collect very detailed and correlated residential energy and water consumption data. This data can be very important to determining specific water and energy consumption habits throughout the homes (e.g. consistently showering at peak energy times), and could help promote behavioural modification.
A final recommendation for future research is that an analysis be completed which compares the expenses for a municipality to provide a rebate for residential greywater reuse versus the expenses for treatment and distribution (including infrastructure repairs and expansion) of residential water and wastewater.

7 Conclusions

Current water usage in Canada is unsustainable and requires a paradigm shift change in order to support expanding populations, reduce pressure on failing infrastructure and maintain water availability during variable weather conditions. Residential buildings are one of the top consumers of potable water and many studies such as work by Aquacraft have shown the breakdown of water end uses in buildings. These studies also indicate the success of installing indoor residential water conservation technologies in reducing water consumption while maintaining user satisfaction. Residential greywater reuse systems are included in available water conservation technologies but available systems have had poor performance.

In order to show the field performance of these off the shelf systems, a standard method for quantifying field performance first had to be developed. Through literature review of previous field assessments and laboratory testing standards, the following metrics were determined as the best indicators of field performance: water balance, water quality, energy use, durability, maintenance, installation, economics and user satisfaction with the system. A standard testing methodology was developed with the eight selected performance metrics at the core with the intention of being a methodology that manufacturers could apply to their system prior to marketing.

The developed methodology was then used to quantify performance of a greywater reuse system that was installed in 23 homes in Southern Ontario, from August 2014 to February 2015.

The greywater reuse systems were equipped with a program which tracked water coming in and out of the system using a pressure transducer. The following key volumes were able to be tracked using the program: (i) greywater coming in to the system, (ii) municipal "top up" water, (iii) water used to flush toilets and (iv) water purged/emptied from the storage tank. Any water that overflowed the storage tank was not able to be tracked. One system was also equipped with flow meters in order to validate the accuracy of the pressure transducer and program. It was found that the flow meter values were recording volumes between 1 to 38 percent greater than the program, indicating that the program readings were potentially underestimated.

Water savings and water quality varied largely between each home in the field study, with some household characteristics directly influencing the performance, such as the number of residents at home during the day. However, occupant behaviour could potentially affect the performance of the system and should be further documented in future research. Overall, the daily average water savings of the studied greywater reuse system ranged between 10.3 Lhhd to 96.9 Lhhd, with a study average of 40.9 Lhhd. Monthly and seasonal changes did not affect the daily water savings of this system.

Water quality was sampled and tested at four locations through the system's treatment train to show performance including: (i) base municipal water quality, (ii) raw shower water (untreated greywater), (iii) treated greywater in the storage tank, and (iv) stored treated greywater in the toilet tank. Samples for BOD_5, COD, total coliforms and fecal coliforms were transported to a laboratory for testing, while free and total chlorine, turbidity, colour, hardness, odour, pH and temperature were taken on-site. Water quality varied greatly at each home as well as throughout the greywater treatment process. When compared to Health Canada Guidelines for greywater reuse to flush toilets, 92 percent of the samples taken from the system storage tank met fecal coliform requirements. 77 percent, 38 percent and 20 percent of the samples from the storage tank met guidelines for total chlorine, BOD_5 and turbidity, respectively.

The studied system was found to consume, on average, 0.069kWh/day and was only recorded as operating for 15 minutes per day, with the remaining time spent on system standby. 73 percent of the system's energy use was consumed by operating on standby. The energy intensity of the system was found to be 1.346 kWh/m^3 indicating that this system is less energy efficient than municipal treatment. However, if the manufacturer would be able to reduce the amount of energy consumed by the system on standby, the system could potentially be a more efficient treatment option than large scale, municipal treatment.

The durability assessment of the system showed the most common failures were film buildup in the toilet tanks which could lead to blocked flush valves and subsequent toilet leaking, flashing notifications and finally, screw corrosion. Some users also indicated through the user survey that the system was a noise nuisance as well as yielded unpleasant greywater or chlorine odours at the toilets. The system was advertised as having a "self-cleaning" filter which was found to be an improvement from previous system generations but still became clogged at some homes requiring extra maintenance. A thorough analysis of the system performance when the users were on vacation was not available, but the majority of the users that did go on vacation during the study indicated that they were very satisfied with the system performance while away. In the circumstance of a power outage, the backup battery did not work and the system would not operate until power was turned back on. The manufacturer was able to address some of the durability issues during the study and was able to improve their system based on the found failures.

Maintenance for the system was recorded using log sheets and through the conclusive user survey. For a house equipped with this greywater reuse system, required maintenance included cleaning the toilet bowls once a week, cleaning the toilet tanks every two to three months due to an odour and film buildup, replacing the chlorine every two to three months and cleaning the filter every five to six months. Some houses experienced more frequent buildup and clogging of the filter and were required to clean their filter every two to three months. Overall, users were between neutral and very satisfied with the maintenance required with this system which is an improvement from previous generations of greywater reuse systems.

Installation of the system was assessed by evaluating the installation invoices as well as through assessing the ease of installation by asking the user’s opinion on the process. Interviews with the plumbers were not completed but are recommended in future research as a method to quantify ease of installation. Depending on whether the home was equipped with a dual plumbing system initially and the number of storeys in the home, the cost of installation for this system ranged between $860.00 to $2750.00. For houses with more difficult installations and more required repairs from general contractors post-installation, the total installation costs escalated up to $4640.00. Each home in this study had a mechanical room or a basement, and 14 of the 17 survey respondents indicated that they were very satisfied with the installation process.

An economic assessment of the studied system was completed by reviewing the costs and benefits of the system. System costs included total immediate costs, annual maintenance costs, and annual operation costs while the economic benefit was the savings associated with reducing water consumption. The intent of the economic analysis was to show a simple payback period and whether the system could reach economic efficiency where the payback period is within the lifespan of the system, which in this case, was estimated to be ten years. Since performance ranged widely in terms of water savings, three economic scenarios were presented. The best case (high water savings, low costs), the average case (average water savings, average costs) and the worst case (low water savings, high costs) were assessed for the studied system and were found to have a payback period of 11, 43 and 52 years, respectively, assuming an annual 5 percent water rate increase. This estimate shows that the system does not reach economic efficiency under the presented scenarios. The majority of survey respondents indicated that an acceptable payback period for the system was five years which would, in the best case, require a rebate of $1350 off of the system's capital cost. This method provides a simple economic assessment of the greywater reuse system and does not fully account for factors such as inflation and unquantifiable environmental benefits.

The last step in assessing the performance of the greywater reuse system was to collect the user satisfaction with the system which was completed via an online survey. The survey first attempted to collect each user's environmental awareness by asking about topics such as waste recycling in the home. These results were taken in to consideration when reviewing the user's responses but it was found that there was a broad range of users in the study with varying levels of environmental awareness. The majority of survey respondents indicated they were very satisfied with the overall performance of the greywater reuse system and 12 of the 17 respondents would "definitely" continue to have the system in their home after the study. One respondent, House 1 which was operating with nine residents, was overall, not satisfied with the system and indicated that major improvements to the system would be required in order to keep the system in their home.

In summary, the methodology developed to test field performance of "off the shelf", single family, residential greywater reuse systems successfully captured performance data when it was applied to a field study. The methodology can be applied to simple treatment systems (filtration, chlorination and light sedimentation) but will require expansion as more complex systems are developed. It is proposed that the standard testing methodology be used by greywater reuse system manufacturers in conjunction with standard laboratory testing to present a complete assessment of the system's performance under varying conditions. Homeowners and municipalities will also greatly benefit from the application of the developed testing methodology as it will allow for a clear and comparable review of available systems.

Works Cited

Alberta WaterSMART. (2014). *Water Reuse in Alberta - Overview of Water Reuse: Regulatory Framework and Case Studies.* Calgary: Alberta WaterSMART.

Alliance for Water Efficiency. (2010). *On-Site Alternate Water Sources & Use Introduction*. (Alliance for Water Efficiency) Retrieved July 10, 2015, from http://www.allianceforwaterefficiency.org/Alternative_Water_Sources_Intro.aspx

Anand, C., & Apul, D. (2011). Economic and environmental analysis of standard, high efficiency, rainwater flushed, and composting toilets. *Journal of Environmental Management, 92*, 419-428.

Anderson, J. (2003). The environmental benefits of water recycling and reuse. *Water Science and Technology, 3*(4), 1-10.

Antonopoulou, G., Kirkou, A., & Stasinakis, A. S. (2013). Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physiochemical methods. *Science of the Total Environment, 454-455*, 426-432.

Antweiler, W. (2015). *Foreign Currency Units per 1 Canadian Dollar, 1948-2014, Pacific Exchange Rate Service*. Retrieved August 8, 2015, from University of British Columbia: http://fx.sauder.ubc.ca/etc/CADpages.pdf

Aquacraft Water Engineering & Management. (2005). *Water and Energy Savings from High Efficiency Fixtures and Appliances in Single Family Homes.* Washington: US EPA.

Aquacraft Water Engineering & Management. (2011). *Analysis of Water Use in New Single Family Homes.* Salt Lake City: Salt Lake City Corporation and US EPA.

Bergdolt, J. H. (2011). *Graywater Reuse Guidance and Demonstration using a constructed wetland treatment system.* Fort Collins: Colorado State University.

Brandes, O. M., Renzetti, S., & Stinchcombe, K. (2010). *Worth Every Penny: A Primer on Conservation-Oriented Water Pricing.* Victoria: University of Victoria.

CAG Consultants. (2013, August). *Code for Sustainable Homes Case Studies: Volume 4.* Retrieved December 27, 2013, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/230271/Code_Case_Studies_Volume_4_-_final.pdf

California Office of Administrative Law. (2015). *California Code of Regulations: Title 22.* Sacramento: California Office of Administrative Law.

Canada Green Buiding Council. (2012, April 30). *LEED Canada for Homes 2009.* Retrieved October 15, 2013, from http://www.cagbc.org/AM/PDF/LEED_Canada_for_Homes_2009_RS+addendum_EN.pdf

Canada Mortgage and Housing Corporation. (2002). *Report on Rainwater Harvesting and Grey Water Reuse for Potable and Non-potable Uses.* Ottawa: Canada Mortgage and Housing Corporation.

Canada Mortgage and Housing Corporation. (2010, May 6). *The Now House*. (Government of Canada) Retrieved December 28, 2013, from http://www.cmhc-schl.gc.ca/en/inpr/su/eqho/noho/index.cfm

Canada Mortgage and Housing Corporation. (2012). *EQuilibrium Housing InSight: EchoHaven Water Conservation Measures.* Ottawa: Canada Mortgage and Housing Corporation.

Canada Mortgage and Housing Corporation. (n.d.). *CMHC's Healthy House in Toronto is...* (Government of Canada) Retrieved December 27, 2013, from http://www.cmhc-schl.gc.ca/en/co/maho/yohoyohe/heho/hehoto/hehoto_001.cfm

Canada Mortgage and Housing Corporation. (n.d.). *The EQuilibrium Sustainable Housing Demonstration Initiative*. (Government of Canada) Retrieved December 28, 2013, from http://www.cmhc-schl.gc.ca/en/inpr/su/eqho/eqho_008.cfm

Canadian Passive House Institute. (2013). *Requirements*. (Canadian Passive House Institute) Retrieved October 17, 2013, from http://www.passivehouse.ca/requirements/

Canadian Standards Association. (2007). *CSA B128.1-06 Design and Installation of non-potable water systems.* Mississauga: Canadian Standards Association.

Canadian Standards Association. (2007). *CSA B128.2-06 Maintenance and field testing of non-potable water systems.* Mississauga: Canadian Standards Association.

Canadian Standards Association. (2012). *CSA B128.3-12 Performance of non-potable water reuse systems.* Mississauga: CSA Group.

Chaillou, K., Gerente, C., & Andres, Y. (2011). Bathroom Greywater Characterization and Potential Treatments for Reuse. *Water Air Soil Pollution, 215*, 31-42.

Christen, K. (2002). Decentralized wastewater management gains momentum. *Water Environment & Technology, 14*(12), 26-30.

Christova-Boal, D. (1995). *Installation and Evaluation of Domestic Greywater Reuse Systems.* Victoria: Victoria University of Technology.

Christova-Boal, D., Eden, R. E., & McFarlane, S. (1996). An investigation into greywater reuse for urban residential properties. *Desalination, 106*, 391-397.

City of Guelph. (2012). *Guelph Residential Greywater Field Test Final Report.* Guelph: City of Guelph.

City of Guelph. (2013, September 17). *Greywater Reuse Pilot*. (City of Guelph) Retrieved June 30, 2015, from http://guelph.ca/living/environment/rebates/greywater-reuse-pilot/

City of Guelph. (2014). Understanding Greywater Reuse. *AWC Reuse Symposium.* Calgary.

City of Guelph. (2015). *Water and Wastewater Rates Overview.* Guelph: The City of Guelph.

Croockewit, J. (1999). *Residential Water Conservation: Application and Relevance in British Columbia.* Burnaby: Simon Fraser University.

Daigger, G. T. (2009). Evolving Urban Water and Residuals Management Paradigms: Water Reclamation and Reuse, Decentralization, and Resource Recovery. *Water Environment Research, 81*(8), 809-823.

De Luca, M. (2012). *Appropriate Technology and Adoption of Water Conservation Practices: Case Study of Greywater Reuse in Guelph.* Guelph: University of Guelph.

Department of Communities and Local Government. (2010, November). *Code for Sustainable Homes*. (United Kingdom Government) Retrieved December 27, 2013, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/5976/code_for_sustainable_homes_techguide.pdf

Dixon, A. M. (1999). Measurement and modelling of quality changes in stored untreated grey water. *Water, 1*, 293-306.

Dixon, A., Butler, D., & Fewkes, A. (1999). Guidelines for Greywater Re-Use: Health Issues. *Water and Environment Journal, 13*(5), 322-326.

Dolnicar, S., & Schafer, A. (2009). Desalinated versus recycled water - public perceptions and profiles of the accepters. *Journal of Environmental Management, 90*(2), 888-900.

Domenech, L., & Sauri, D. (2010). Socio-technical transitions in water scarcity contexts: Public acceptance of greywater reuse technologies in the Metropolitan Area of Barcelona. *Resources, Conservation and Recycling, 55*, 53-62.

Domenech, L., March, H., & Sauri, D. (2013). Degrowth initiatives in the urban water sector: A social multi-criteria evaluation of non-conventional water alternatives in Metropolitan Barcelona. *Journal of Cleaner Production, 38*, 44-55.

Elliot, R. (2005). *Roadmap to Energy in the Water and Wastewater Industry.* Washington: American Council for an Energy-Efficient Economy.

EMRC. (2011). *Reuse of Greywater in Western Australia.* Belmont: EMRC.

Environment Agency. (2011). *Greywater for domestic users: an information guide.* Bristol: Environment Agency.

Environment Agency. (2012). *The case for change - current and future water availability.* Bristol: Environment Agency.

Environment Canada. (2006). *Atlantic Canada Wastewater Guidelines Manual for Collection, Treatment, and Disposal.* Halifax: Government of Nova Scotia.

Environment Canada. (2011, May 30). *2011 Municipal Water Use Report – Municipal Water Use 2009 Statistics.* Retrieved August 6, 2013, from Environment Canada: http://www.ec.gc.ca/doc/publications/eau-water/COM1454/survey2-eng.htm

Erikksson, E., Auffarth, K., Henze, M., & Ledin, A. (2002). Characteristics of grey wastewater. *Urban Water, 4*, 85-104.

Fidar, A., Memon, F., & Butler, D. (2010). Environmental implications of water effiicient microcomponents in residential buildings. *Science of the Total Environment, 408*, 5828-5835.

Frank, A., Frank, R., & Hu, F. (2013). *Canadian National Household Water Usage Study.* Ottawa: Dufferin Research.

Friedler, E., & Gilboa, Y. (2010). Performance of UV disinfection and the microbial quality of greywater effluent along a reuse system for toilet flushing. *Science of the Total Environment, 408*, 2109-2117.

Friedler, E., & Hadari, M. (2006). Economic feasibility of on-site greywater reuse in multi-storey buildings. *Desalination, 190*, 221-234.

Friedler, E., Kovalio, R., & Galil, N. (2005). On-site greywater treatment and reuse in multi-storey buildings. *Water Science and Technology, 51*(10), 187-194.

Friedler, E., Yardeni, A., Gilboa, Y., & Alfiya, Y. (2011). Disinfection of greywater effluent and regrowth potential of selected bacteria. *Water Science and Technology, 63*(5), 931-940.

Fung, A., Zhang, D., Barua, R., Safa, A. A., Tanha, K., Shami, K., et al. (2011). *The Archetype Sustainable Houses: Overview of Design and Monitoring Systems.* Toronto: Toronto and Region Conservation Authority.

Gikas, P., & Tchobanoglous, G. (2009). The role of satellite and decentralized strategies in water resources management. *Journal of Environmental Management, 90*, 144-152.

Government of Ontario. (2008, April 1). *Ontario Regulation 453/07 Financial Plans.* Retrieved July 15, 2013, from Safe Drinking Water Act, 2002: http://www.e-laws.gov.on.ca/html/regs/english/elaws_regs_070453_e.htm

Government of Ontario. (2012, November 2). *2014 Ontario Building Code Act.* Retrieved December 16, 2013, from http://www.e-laws.gov.on.ca/html/source/regs/english/2012/elaws_src_regs_r12332_e.htm

Government of Ontario. (2012, November 6). *Building Code Act, 1992.* Retrieved April 2, 2013, from Service Ontario E-laws: http://www.e-laws.gov.on.ca/html/regs/english/elaws_regs_060350_e.htm

Gross, A. (2005). Environmental impact and health risks associated with greywater irrigation: A case study. *Water Science and Technology, 52*(8), 161-169.

Gross, A. W. (2008). Reliability of small scale greywater treatment systems and the impact of its effluent on soil properties. *International Journal of Environmental Studies, 65*(1), 41-50.

Haarhoff, J., & Van der Merwe, B. (1996). Twenty-Five years of Wastewater Reclamation in Windhoek, Namibia. *Water Science and Technology, 33*(10-11), 25-35.

Hansgrohe International. (2015). *Pontos AquaCycel 2500 Specifications*. (Hansgrohe Group) Retrieved June 18, 2015, from https://pro.hansgrohe-int.com/4282.htm

Health Canada. (2010). *Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing.* Ottawa: Minister of Health.

Hodgson, B. (2012). *Development of a Cost Effective and Energy Efficient Treatment System for Graywater Reuse for Toilet Flushing at the Multi-Residential Scale.* Fort Collins: Colorado State University.

Hui, Y., & Jiangwei. (2009). Study on Decision-Making of Reclaimed Water Reuse in Water-Ample Urban. *International Conference on Management and Service Science.* Wuhan.

Hume, I. (2012, September 27). *IHBC Technical Sub-Committee Paper: French Drains.* Retrieved December 27, 2013, from http://www.ihbc.org.uk/guidance_notes/docs/tech_papers/French%20Drains.pdf

Hunt, D. V., Lombardi, R. D., Farmani, R., Jefferson, I., Memon, F. A., Butler, D., et al. (2012). Urban futures and the code for sustainable homes. *Engineering Sustainability, 165*(1), 37-58.

IAPMO. (2012). *2012 Uniform Plumbing Code.* Ontario: International Association of Plumbing and Mechanical Officials.

IAPMO. (2015). *IAPMO Z1207-20yy - Small-Scale Residential Greywater Recycling Systems DRAFT.* Ontario: International Association of Plumbing and Mechanical Officials (IAPMO).

Inman, D., & Jeffrey, P. (2006). A review of residential water conservation tool performance and influences on implementation effectiveness. *Urban Water Journal, 3*(3), 127-143.

International Code Council. (2012). *International Plumbing Code 2012.* Washington: International Code Council.

International Living Future Institute. (2012, May). *Living Building Challenge 2.1.* Retrieved December 23, 2013, from https://ilbi.org/lbc/LBC%20Documents/lbc-2.1

International Water Management Institute. (2014). *Strategy 2014 2018: Solutions for a water-secure world.* Colombo: International Water Management Institute.

Isliefson, D. (1998). *Protocols for pre-design assessment of greywater reuse retrofit in urban redevelopment: An opportunity/constraint analysis method for existing buildings.* Winnipeg: The University of Manitoba.

Jefferson, B., Laine, A., Parsons, S., Stephenson, T., & Judd, S. (1999). Technologies for domestic wastewater recycling. *Urban Water, 1*, 285-292.

Jefferson, B., Palmer, A., Jeffrey, P., Stuetz, R., & Judd, S. (2004). Greywater characterisation and its impact on the selection and operation of technologies for urban reuse. *Water Science and Technology, 50*(2), 157-164.

KB Home. (2014, February 26). *KB Home's 'Double ZeroHouse' is a Model of Water and Energy Efficiency*. (KB Home) Retrieved April 8, 2015, from http://investor.kbhome.com/releasedetail.cfm?ReleaseID=828549

Kourik, R. (1993). *Gray water use in the landscape: how to help your landscape prosper with recycled water.* Occidental: Metamorphic Press.

Kuru, B., & Luettgen, M. (2012). *Is gray-water reuse ready for prime time? A study of gray-water technologies.* Kohler: Kohler Co.

Li, F., Wichmann, K., & Otterpohl, R. (2009). Evaluation of appropriate technologies for grey water treatments and reuses. *Water Science & Technology, 59*(2), 249-260.

Li, F., Wichmann, K., & Otterpohl, R. (2009). Review of the technological approaches for grey water treatment and reuses. *Science of the Total Environment, 407*, 3439-3449.

Mandal, D., Labhasetwar, P., Dhone, S., & Dubey, A. S. (2011). Water conservation due to greywater treatment and reuse in urban setting with specific context to developing countries. *Resources, Conservation and Recycling, 55*, 356-361.

Marsden, P. V., & Wright, J. D. (2010). *Handbook of Survey Research.* Bingley: Emerald Group Publishing Limited.

Mass, C. (2009). *Greenhouse Gas and Energy Co-Benefits of Water Conservation.* Victoria: POLIS Project on Ecological Governance.

Mayer, P. W., & DeOreo, W. B. (1999). *Residential End Uses of Water.* Boulder: Aquacraft, Inc. Water Engineering and Management.

Merriam-Webster. (2015). *Merriam-Webster Online Dictionary: Durable*. (Encyclopaedia Brittanica) Retrieved June 3, 2015, from http://www.merriam-webster.com/dictionary/durable

Moglia, M., Cook, S., Sharma, A. K., & Burn, S. (2011). Assessing Decentralised Water Solutions: Towards a Framework for Adaptive Learning. *Water Resource Management, 25*, 217-238.

Morel, A., & Diener, S. (2006). *Greywater Management in Low and Middle-Income Countries.* Dubendorf: Swiss Federal Institute of Aquatic Science and Technology (Eawag).

Mourad, K. A., Berndtsson, J. C., & Berndtsson. (2011). Potential fresh water saving using greywater in toilet flushing in Syria. *Journal of Environmental Management, 92*, 2447-2453.

Muthukumaran, S., Baskaran, K., & Sexton, N. (2011). Quantification of potable water savings by residential water conservation and reuse - A case study. *Resources, Conservation and Recycling, 55*, 945-952.

Nexus eWater. (2015, March 13). *News Release: Nexus eWater is World's First Company to Obtain NSF/ANSI Certification for Residential Grey Water Treatment.* Retrieved April 8, 2015, from http://cdn2.hubspot.net/hub/409087/file-2622223065-pdf/blog-files/NexuseWaterNSF-ANSI350pressrelease_final1.pdf?t=1427486261776

Nexus eWater. (2015). *Products: Home Water Recycling Products Which Also Generate Energy*. (Nexus eWater) Retrieved April 8, 2015, from http://www.nexusewater.com/products

Nolde, E. (2005). Greywater recycling systems in Germany - results, experiences and guidelines. *Water Science and Technology, 51*(10), 203-210.

NSF. (2012, December 19). *NSF/ANSI Standard 350 for Water Reuse Treatment Systems: Questions & Answers.* Retrieved April 9, 2015, from http://www.nsf.org/newsroom_pdf/ww_nsf_ansi350_qa_insert.pdf

NSF International. (2011). *NSF/ANSI 350 - 2011: Onsite Residential and Commercial Water Reuse Treatment Systems.* Ann Arbor: NSF International.

Ontario Energy Board. (2015, April 29). *Electricity Prices*. (Ontario Energy Board) Retrieved April 30, 2015, from http://www.ontarioenergyboard.ca/OEB/Consumers/Electricity/Electricity+Prices

Penn, R., Shutze, M., & Friedler, E. (2013). Modelling the effects of on-site greywater reuse and low flush toilets on municipal sewer systems. *Journal of Environmental Management, 114*, 72-83.

Pidou, M., Memon, F. A., Stephenson, T., Jefferson, B., & Jeffrey, P. (2007). Greywater recycling: A review of treatment options and applications. *Engineering Sustainability, 160*, 119-131.

Popplewell, B. (2008, March 1). Toronto man builds environmental dream house. *The Toronto Star*.

Queen's Printer BC. (2012). *BC. Reg. 87/2012 - Municipal Wastewater Regulation.* Victoria: Queen's Printer.

Raucher, R. S., & Tchobanoglous, G. (2014). *The Opportunities and Economics of Direct Potable Reuse [White Paper].* Alexandria: WateReuse Research Foundation.

Region of Waterloo, City of Guelph. (2012). *My Water Hardness*. Retrieved August 8, 2015, from Water Softener Facts: http://watersoftenerfacts.ca/my-water-hardness

Rice, E. W., Baird, R. B., Eaton, A. D., & Clesceri, L. S. (2012). *Standard Methods For the Examination of Water and Wastewater.* Washington: American Public Health Association.

Rose, J. (1991). Microbial quality and persistence of enteric pathogens in graywater from various household sources. *Water Resources, 25*(1), 37-42.

Santos, C., Taveira-Pinto, F., Cheng, C., & Leite, D. (2012). Development of an experimental system for greywater reuse. *Desalination, 285*, 301-305.

Seiders, D., Ahluwalia, G., Melman, S., Quint, R., Chaluvadi, A., Liang, M., et al. (2007). *Study of Life Expectancy of Home Components.* Washington: National Association of Home Builders.

Sharvelle, S., Roesner, L., & Glenn, R. (2013). *Treatment, Public Health and Regulatory Issues Associated with Graywater Reuse: Guidance Document.* Alexandria: WateReuse Research Foundation.

Sheikh, B. (2010). *White Paper on Graywater.* Alexandria: WateReuse Association.

Spellman, F. R., & Drinan, J. (2000). *The Drinking Water Handbook.* Lancaster: Technomic Publishing Company, Inc.

Sphar, K. M. (2012). *The Challenges to Implementing Decentralized Water Reuse: A Greywater Recirculation Case Study in Boulder, Colorado.* Boulder: University of Colorado.

Statistics Canada. (2013, December 11). *The demand for water in Canada*. (Government of Canada) Retrieved January 6, 2014, from http://www.statcan.gc.ca/pub/16-201-x/2010000/part-partie3-eng.htm

Statistics Canada. (2014, September 26). *Population by year, by province and territory*. (Government of Canada) Retrieved June 23, 2015, from http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/demo02a-eng.htm

Surendran, S. S. (2001). *The development of an in-house greywater and roof water reclamation system for large institutions, during 1994 to 1998.* Loughborough: Loughborough University.

Tal, T., Sathasivan, A., & Kirshna, K. B. (2011). Effect of Different Disinfectants on Grey Water Quality during Storage. *Journal of Water Sustainability, 1*(1), 127-137.

Toronto Region Conservation. (2009). *The Archetype Sustainable House*. (Toronto Region Conservation) Retrieved November 6, 2013, from http://www.sustainablehouse.ca/the-house/water.dot

U.S. E.P.A. (2012). *2012 Guidelines for Water Reuse.* Washington: United States Environmental Protection Agency.

US EPA. (2012). *2012 Guidelines for Water Reuse.* Washington: United States Environmental Protection Agency.

Vandegrift, J. (2014). *Implementation of Graywater Reuse in the State of Colorado.* Fort Collins: Colorado State University.

Vander Ploeg, C. G. (2011). *Water Pricing: Seizing a Public Policy Dilemma by the Horns - Canadian Water Policy Backgrounder.* Calgary: Canada West Foundation.

Veritec Consulting Inc. (2008). *Region of Durham Efficient Community Final Report.* Mississauga: Durham Region.

WaterSense. (2015, June 25). *Tomorrow & Beyond*. (U.S. EPA) Retrieved July 1, 2015, from http://www.epa.gov/watersense/our_water/tomorrow_beyond.html

Watson & Associates Economists Ltd; Dillon Consulting. (2012). *Towards Full Cost Recovery: Best Practices in Cost Recovery for Municipal Water and Wastewater services.* Mississauga: Association of Municipalities of Ontario.

Wiles, K. (2013). *Investigation of pathogen disinfection and regrowth for a low cost graywater reuse treatment system for toilet flushing.* Fort Collins: Colorado State University.

Winward, G. P., Avery, L. M., Stephenson, T., & Jefferson, B. (2008). Chlorine disinfection of grey water for reuse: Effect of organics and particles. *Water Research, 42*, 483-491.

World Health Organization. (2006). *WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater.* Geneva: World Health Organization.

Young, R. (2013). *Saving Water and Energy Together: Helping Utilities Build Better Programs.* Washington: American Council for an Energy-Efficient Economy.

Zadeh, S. M., Hunt, D. V., Lombardi, D. R., & Rogers, C. D. (2013). Shared Urban Greywater Recycling Systems: Water Resource Savings and Economic Investment. *Sustainability, 5*, 2887-2912.

Appendices

Appendix A: Additional Background

Water Reuse

Figure 18 shows how wastewater can be reused with different levels of treatment, for different purposes.

Figure 18: Treatment technologies are available to achieve any desired level of water quality, from U.S. EPA 2012 Guidelines for Water Reuse (U.S. E.P.A, 2012).

Table 56 below, adapted from the U.S. EPA 2012 Guidelines for Water Reuse recommends levels of treatment for different end use purposes. The table shows that with increasing levels of treatment, the reused wastewater becomes more acceptable for human contact, but also increases in cost (U.S. E.P.A, 2012). It is not included in this table, but it is also possible that energy use would increase as level of treatment increases.

Table 56: Types of reuse appropriate for increasing levels of treatment, adapted from the U.S. EPA 2012 Guidelines for Water Reuse (U.S. E.P.A, 2012).

	Increasing Levels of Treatment→			
Treatment Level	**Primary**	**Secondary**	**Filtration and Disinfection**	**Advanced**
Processes	Sedimentation	Biological oxidation and disinfection	Chemical coagulation, biological or chemical nutrient removal, filtration and disinfection	Advanced carbon, reverse osmosis, advanced oxidation processes, soil aquifer treatment, etc.
End Use	No Uses Recommended	Surface irrigation of orchards and vineyards	Landscape and golf course irrigation	Indirect potable reuse including groundwater recharge of potable aquifer and surface water reservoir augmentation and potable reuse
		Non-food crop irrigation	Toilet Flushing	
		Restricted landscape impoundments	Vehicle washing	
		Groundwater recharge of nonpotable aquifer	Food crop irrigation	
		Wetlands, wildlife habitat, stream augmentation	Unrestricted recreational impoundment	
		Industrial cooling processes	Industrial systems	
Human exposure	Increasing Acceptable Levels of Human Exposure→			
Cost	Increasing Levels of Cost→			

There are many different applications for water reuse. Reclaimed water is the term given to municipal wastewater that has been collected and treated to a certain water quality at a centralized treatment plant and redistributed for various end uses (U.S. E.P.A, 2012). Reclaimed water can be treated to the desired level and reused for agriculture and landscape irrigation, various industrial applications such as cooling in power plants, urban applications like fire protection or toilet flushing. Reclaimed water can also be used for environmental and water resource application, such as groundwater recharge (Gikas & Tchobanoglous, 2009). Using reclaimed water for non-potable applications is more popular in some regions, such as Florida which has been reusing water for irrigation since the late 1980s, with more than 50 percent of domestic wastewater being reused (Canada Mortgage and Housing Corporation, 2002)In a rare but increasingly popular case, wastewater can be treated to supplement potable water supply (Haarhoff & Van der Merwe, 1996).

Currently, areas such as Singapore are looking at separating wastewaters into different streams, and taking different treatment methods for each (Daigger, 2009). This approach might be the best option as many cities in North America are unnecessarily treating all wastewater streams at the same high efficiency level. Many municipalities collect and treat residential wastewater and stormwater using combined sewers. Chemicals and energy are being wasted to treat stormwater, as it is much cleaner than residential wastewater (Anand & Apul, 2011).

At this point, there is no clear indication which of centralized or decentralized water and wastewater treatment systems is the best option, but perhaps the best solution is a combination of both, keeping a centralized treatment system for blackwater, in order to mitigate associated health risks (Daigger, 2009).

Public Perception of Greywater Reuse

Jefferson (2004) conducted a survey to assess the English and Welsh attitudes toward water reuse and found that 88 percent of respondents were willing to reuse greywater in their home, but that decreased to 50 percent when reused at a neighbourhood or large institution (e.g. hospital) level, due to perceived health risk (Jefferson et al., 2004). Dixon et al. (1999b) confirms that there is a greater risk of reusing greywater at a larger population level, as outlined in Table 57.

Table 57: Qualitative risk associated with greywater, adapted from (Dixon, Butler, & Fewkes, 1999).

	Lower Risk	Intermediate Risk	Higher Risk
Population	Small population (residential)	-	Large population (multi-residential/commercial)
Exposure	No body contact (subsurface irrigation)	Some contact (toilet flushing/bathing)	Ingestion (drinking)
Dose-response	<1 virus or bacteria per sample	-	>1 virus per sample >106 bacteria per sample
Delay before reuse	Immediate reuse	Reused within hours	Reused within days

In Jefferson's study (2004), poor aesthetic water quality (strong colour, turbid water, and high suspended solids) only minimally affected acceptance of greywater reuse. Turbidity was found to be the biggest deterrent for public acceptance, with suspended solids and colour having the middle and least significant effect, respectively on whether the greywater was accepted. Respondents were most likely to reuse greywater for toilet flushing, and decreased in acceptance for washing the car, watering the garden and lastly, as expected, drinking (Jefferson et al., 2004).

Similarly, Muthukumaran (2011) found that users were most likely to reuse greywater for irrigation, but less than 35 percent of respondents were willing to reuse greywater, as shown in Figure 19.

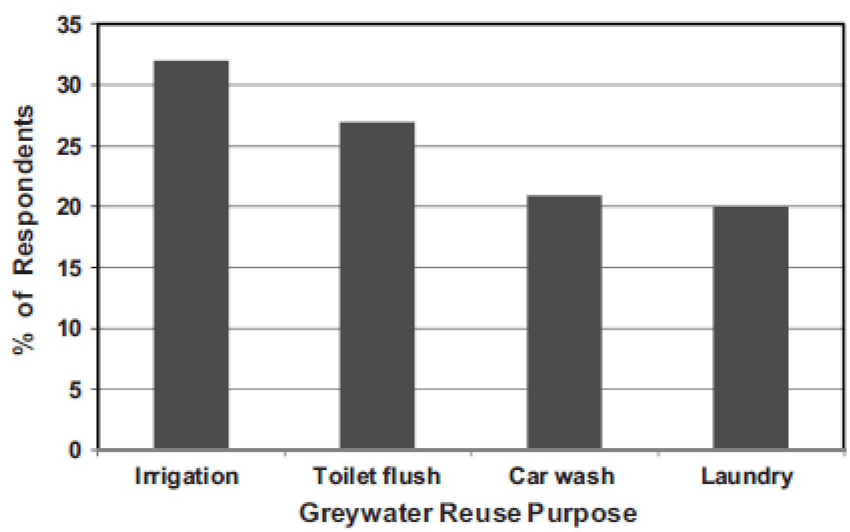


Figure 19: Willingness to use greywater for different activities, from (Muthukumaran, Baskaran, & Sexton, 2011).

Christova-Boal (1995) assessed social acceptance in their study through telephone surveys of 300 people, 990 mail surveys and personal interviews of the four homes which had the test greywater reuse systems installed. These social surveys assessed general perception, education required for the general public to accept greywater reuse, concerns with greywater systems. The proposed study aims to find only the user satisfaction of the system, and overall social acceptance of the system is beyond the scope of this study (Christova-Boal, 1995).

In 2009, Dolnicar and Schafer compared public acceptance of recycled water versus desalinated water in Australia. This is a valuable study as it firstly had to assess the public understanding of recycled water and desalination before it could quantify their assessment of the two water sources. Dolnicar and Schafer (2009) distributed a 30 minute online survey to 1000 people, and used a five-point scale to measure acceptance as this method had been successfully used previously (Domènech & Sauri, 2010).

The study found that the three main concerns associated with these alternative water sources were health concerns, environmental concerns (traditionally, desalinated water is very energy intensive to produce) and cost. Additionally, the study found that age, gender, education, occupation and media usage affected acceptance of the alternative water sources. Income, state of residence, size of the city of residence, frequency of watching TV, and number of years lived in Australia did not influence acceptance. The "strong accepters" of desalinated and recycled water were generally older, with a mean age of 44-46, educated beyond secondary school, watched state run television programming, and in this case, were more men than women. The study concludes that those who were more informed (through media outlets such as the newspaper) were more accepting of recycled and desalinated water (Dolnicar & Schafer, 2009).

Sharvelle et al. (2013) highlight that significant research has been done to assess risk severity for using greywater as irrigation, but more work is required to assess risk associated with exposure to greywater through toilet flushing (Sharvelle et al., 2013). The topic of acceptance and risk is beyond the scope of this research, but heavily affects the rate of implementation of the technology. It is recommended that further investigation into these issues be completed.

Green Building Rating Systems

Existing green rating systems were evaluated in order to determine what performance metrics were considered important in the "sustainable building" industry.

Leadership in Energy and Environmental Design (LEED) has a green rating system with Canadian specifications for residential buildings with up to 3 stories. Water Efficiency LEED credits are awarded for water reuse, an efficient irrigation system and efficient indoor water use. Energy LEED credits are given for efficient hot-water distribution, an efficient domestic hot water system and high efficiency appliances, which meet ENERGY STAR (Canada Green Buiding Council, 2012).

The Living Building Challenge does not have specifications for water fixtures as the rating system requires 100 percent of the building's water needs to be supplied from precipitation or "natural closed loop water systems" which could mean using well water and returning waste to a septic tank. Additionally, 100 percent of the wastewater (stormwater and sewage) must be treated on-site. The Living Building Challenge makes case-by-case exceptions depending on local building regulations. Energy for a Living Building Challenge building must be completely supplied by on-site renewable energy (International Living Future Institute, 2012).

Passive House does not have specifications on water use but it does require that the total primary energy demand of the building is a maximum 120 kWh/m^2a (Canadian Passive House Institute, 2013). This includes energy that would be required for the water reuse treatment systems and domestic hot water heaters.

In the United Kingdom, the national standard for sustainable design is the voluntary *Code for Sustainable Homes*. The code presents different levels of efficiency that can be met, with the lowest level permitting consumption of less than 120 Lcd. The only restrictions on indoor water use is that it must be less than 120 Lcd, and that can be met any way (Department of Communities and Local Government, 2010).

The UK Government publishes Case Studies of houses that were built to meet the Code for Sustainable Homes, most recently in August 2013. In their Case study 16: Bramble House, Ashford, Kent, solar water heating was utilized. However, it was found that tenants found the controls for operating the solar water heating to be too complicated and did not use the system optimally (CAG Consultants, 2013).

The majority of the case studies indicated the use of low-flow fixtures and dual-flush toilets. Case Study 17: Forresters Fold, Dudley, West Midlands which were 2-4 bedroom single family dwellings also included low volume baths. A resident in this case study building indicated that there had been no change in performance with the low-flow/high efficiency water fittings relative to older models. The building also used rainwater harvesting systems. One of the contractors indicated that some tenants were having difficulty understanding the rainwater harvesting system. The rainwater harvesting systems were the only source for flushing toilets. Pumps for rainwater harvesting systems seemed to be a source of complaints as they tended to fail. Failure of the pump left some houses without flushing toilets and in need of an expensive and difficult repair as they pumps were located below ground. Additionally, there were no watermains connected in case of overriding so the systems were completely unavailable when the pump failed. Specialist contractors were needed for repairs, which the client reported as a difficult person to find (CAG Consultants, 2013).

Examples of Canadian Buildings which focus on Water Conservation

Healthy House

Healthy House was a design competition developed by CMHC in 1991. The winner for Toronto was a 1 700 square foot semi-detached house which uses one-tenth of the water that a typical household uses. It achieves this by using rainwater, low-volume toilets, low-flow showerheads and aerated faucets (Canada Mortgage and Housing Corporation).

The house does not require municipal water nor does it release waste into the sewer systems, an investment that will pay back the cost for the house, which was 12 per cent more than a traditional house to build. Rain and snow are water sources, and are filtered through sand and activated charcoal and then disinfected with ultraviolet light. Similarly, wastewater produced by the house undergoes anaerobic digestion through a Waterloo Biofilter, passes through a sand filter and activated carbon, and is finally disinfected with ultraviolet light. This water is clean and is recycled up to five times to flush toilets and wash clothes. Any excess water is used for subsurface irrigation (Canada Mortgage and Housing Corporation). A detailed diagram of the water system in the house is shown in Figure 20.

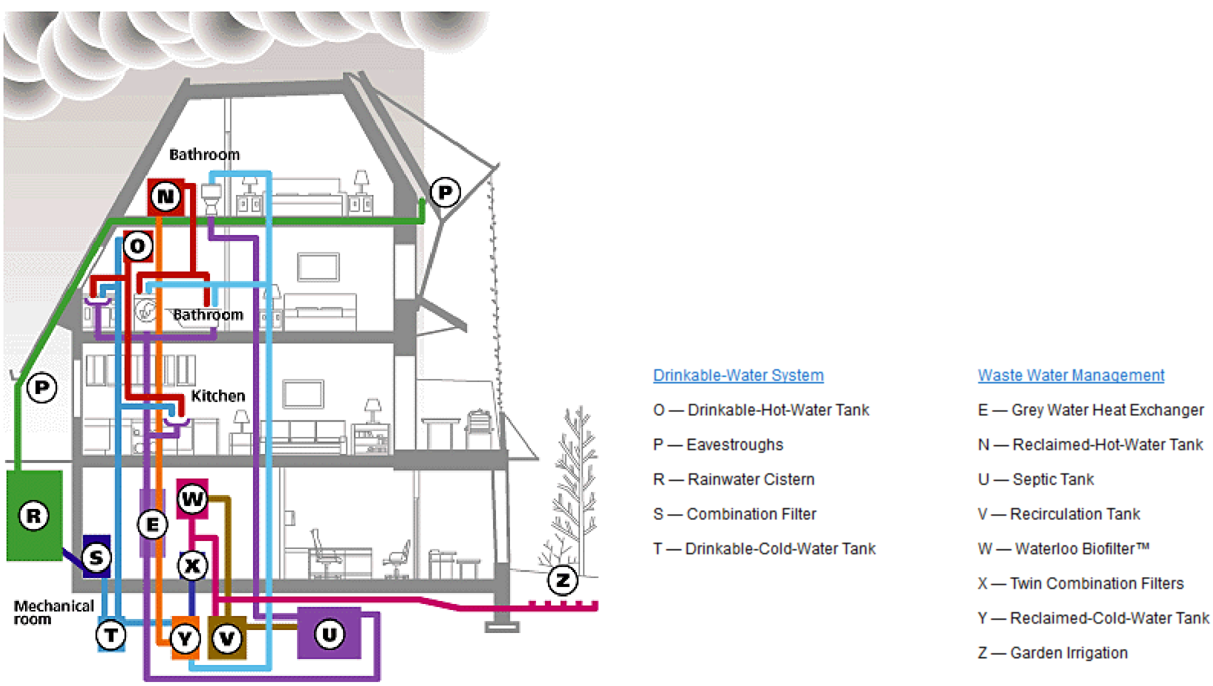


Figure 20: Water System for Toronto Healthy House (CMHC, 2013).

An article published in 2008 in the Toronto Star, indicates that the owners are happy with the performance of the house, despite the rainwater cistern almost going dry one summer, and the occasional clogging of the wastewater composter (Popplewell, 2008).

Kortright Centre Archetype Sustainable Houses

The Archetype Sustainable Houses located at the Kortright Centre in Vaughan, Ontario include dual-flush toilets, low flow faucets and showerheads, hands free fixtures, and ENERGY STAR washers and dishwashers. Collected rainwater is treated using filtration, as well as the houses are surrounded by French drain systems which collect water for toilet flushing (Toronto Region Conservation, 2009). A french drain system is a trench that surrounds the building with gravel or weeping tile installed at the bottom, allowing water to be drained rapidly, protecting the concrete foundation (Hume, 2012). Sewage is treated through a wetland wastewater treatment system. The building was designated a LEED for Homes Platinum in 2010 as well as is ENERGY STAR Certified (Toronto Region Conservation, 2009).

The house maximizes heat from hot water through using a radiant heating system and a drain water heat recovery system. House A has a green roof, and a Brac greywater system (150 litre barrel, filtration, chlorination and pump). Rainwater is collected in House B and stored in a 10 000 litre underground cistern and a 170 litre rain barrel. Potable water is obtained from wells on the property and there is no connection to municipal water services. The buildings include ENERGY STAR appliances. Energy consumption data has been monitored but water consumption data has yet to be collected. Further evaluation is expected at the Archetype House (Fung, et al., 2011).

Region of Durham Efficient Community (2008)

Durham region worked with Tribute Communities, Natural Resources Canada (NRCan) and the Federation of Canadian Municipalities (FCM) to build an “Efficient Community” at the junction of Audley and Taunton Roads in Ajax, Ontario. The project quantified potential water, energy, gas and CO_2 savings by using a high-efficiency upgrade option in half of the 175 homes, while the remaining half received the builder’s typical fixtures and appliances and was the control group. The high-efficiency upgrade included efficient plumbing fixtures, ENERGY STAR dishwashers, clothes washers and fridges, and landscape packages (Veritec Consulting Inc., 2008).

The study found that the high efficiency new homes saved 132 Lhhd; equivalent to saving 66Lcd indoors which is a 22.3 percent reduction in water use relative to the builder's typical new home. Additionally, the high efficiency new homes reduced electricity usage by 13 percent (2.6 kWh per household per day) and reduced natural gas usage by 9.1 percent (0.59m^3 per household per day). The majority of the natural gas savings (0.30m^3 per day) was saved by reducing water consumption thus also reducing the amount of hot water heating. The high efficiency homes reduced carbon dioxide production (through water, electricity and natural gas usage) by 10.7 percent, which is 1.19 tonnes per household per year. In the Region of Durham, this correlated to utility cost savings of approximately $200 per year and a payback period for the upgrades of 3.4 years (Veritec Consulting Inc., 2008).

More specifically, the study found that hot water demand was reduced by 9.2 percent (17 Lhhd); 6 L of which was attributed to a reduction in hot water use for clothes washers. Cold water use for clothes washers also reduced by 41 percent (42 Lhhd) (Veritec Consulting Inc., 2008).

An interesting finding from the study was that water demands from dishwashers were actually greater in the houses with high efficiency dishwashers (50.4 percent more; 6.8 Lhhd).The study argues that this is because the people who opted to have energy efficient appliances in their homes are those who are more environmentally aware and would choose to use their dishwasher more rather than hand wash their dishes. The paper even suggests that this demographic is more likely to have meals at home (requiring dishes to be washed) rather than eating out at restaurants (Veritec Consulting Inc., 2008).

CMHC EQuilibrium Sustainable Housing Demonstration Initiative

CMHC developed the EQuilibrium initiative to design sustainable housing across Canada. It focuses on factors such as energy efficiency, resource conservation and affordability. The initiative is a design competition which picked 15 designs across Canada which incorporated technologies and strategies to reduce the environmental impacts of homes. CMHC presented predicted performance and it is expected that a follow up with performance reports of all of the built homes will be completed soon (Canada Mortgage and Housing Corporation, 2010).

Case Study: Now House (Toronto, ON)

The Now House is a 60 year old wartime house that has been retrofitted to meet EQuilibrium principles. It includes upgraded insulation, new windows, ENERGY STAR appliances, a solar hot water system, a wastewater heat recovery system and installation of photovoltaics. The house focuses on energy reduction and not on water consumption as it is predicted that the 4-person house will consume 1 340 L per day which is 335Lcd, a number near average Canadian consumption (Canada Mortgage and Housing Corporation, 2010).

Case Study: EchoHaven (Calgary, AB)

EchoHaven located in Calgary, Alberta does focus on water conservation and utilizes rainwater harvesting for clothes washing, toilet flushing and irrigation. The house is a new, one storey single family detached home in the community of Rocky Ridge that is intended to have 25 sustainable homes, developed by Echo-Logic Lands (Canada Mortgage and Housing Corporation, 2012). The house includes the following water conserving measures (Canada Mortgage and Housing Corporation, 2012):

- Water-efficient fixtures,
- Dual-flush toilets,
- A dishwasher which uses 12.6 L per cycle,
- A clothes washing machines which uses 5.9 L per cycle,
- Greywater collection and treatment at the community level for outdoor irrigation,
- Landscaping with native plants to reduce irrigation
- Rainwater harvesting for indoor and outdoor use and
- Stormwater is captured and stored on site.

A final interesting technique used in the EchoHaven home is the process of condensing water that is removed by the clothes dryer, and using that water for irrigation. CMHC expected that the EchoHaven home will reduce water consumption by 72 per cent relative to a typical Calgary home. Figure 21 below clearly represents water use and the path of water reuse in the

EchoHaven home. The house draws from a combination of the municipal system and their well, and eventually does release blackwater to the municipal wastewater system (Canada Mortgage and Housing Corporation, 2012).

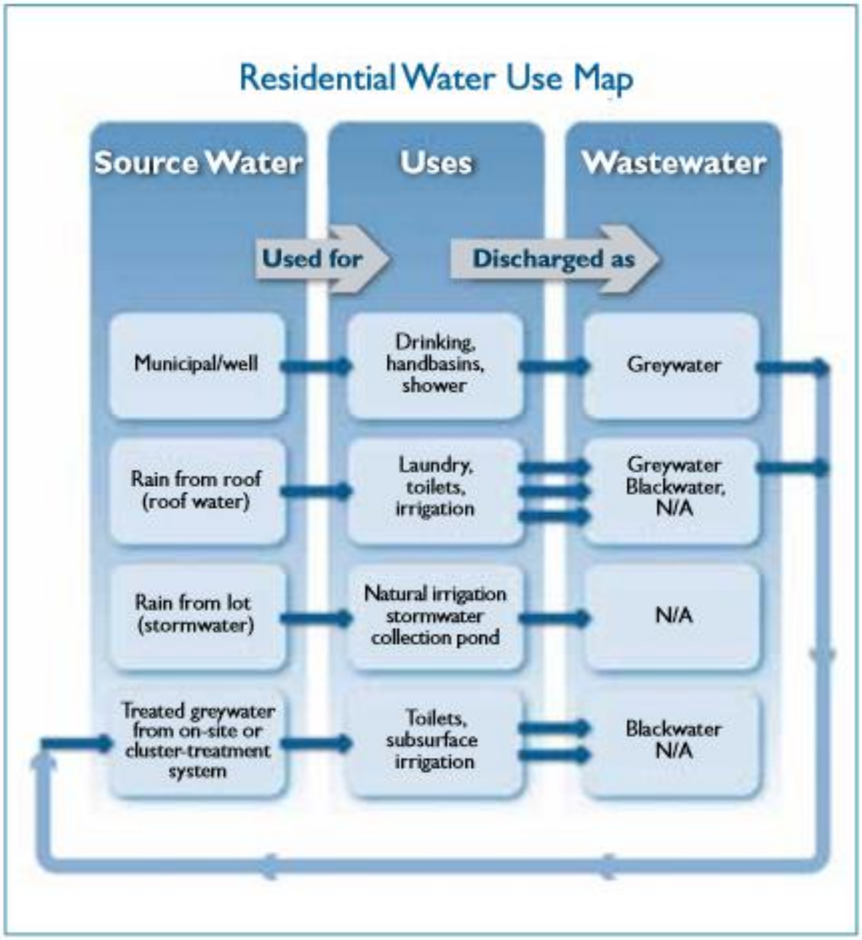


Figure 21: Water use flow at EchoHaven site, from (Canada Mortgage and Housing Corporation, 2012).

Greywater Reuse Guidelines & Regulations

Sharvelle et al. (2013) developed a Microsoft Access tool for the United States which links greywater reuse regulations to the available systems that would meet the specific regulations. A synopsis of the regulations states that in general, regulations are implemented in a tiered approach where there are minimal requirements when there is low-exposure to the greywater, like irrigation, and more intensive and stricter regulations when there is more exposure to the greywater, such as while flushing the toilet. Although greywater is a cleaner source than blackwater, no regulations permit the residential reuse of greywater for direct potable reuse, despite treatment levels. Some regions have developed Best Management Practices (BMPs) to ensure greywater reuse is approached properly, while others have strict regulations with water quality requirements (Sharvelle et al., 2013).

It is interesting to note that Arizona and California are the two states leading the way in greywater reuse, and have taken different regulatory paths. In Arizona, it is permitted to have a greywater reuse system with a capacity of less than 400gpd, without a permit. While in California, their regulations are much stricter and a permit is required for all systems (Sharvelle et al., 2013). The intent behind greywater reuse regulations is to protect public health by ensuring greywater is treated to a safe level and that there are barriers limiting exposure to the greywater (Sharvelle et al., 2013).

There is potential for greywater to host pathogens and viruses, and there is the risk that the user could come into contact with the greywater through splashing while flushing, or through volatilization while flushing, where the pathogens and viruses become airborne and could be inhaled or attach to frequently touched surfaces. This is why it is important to properly disinfect and ensure there is an appropriate residual disinfectant in the toilet (Sharvelle et al., 2013).

British Columbia is currently the only province which has developed a reclaimed water standard named the *Municipal Sewage Regulation*. Guidelines have been developed in Alberta and for the Atlantic Provinces, but no regulations other than the Ontario Building Code are set in Ontario (Health Canada, 2010).

Ontario Building Code

After the most recent revision of the Ontario Building Code, greywater recycling systems were permitted in residential settings. However, these standards only state that "storm sewage or greywater that is free of solids may be used for the flushing of water closets, urinals or the priming of traps" (Government of Ontario, 2012). The OBC mainly regulates the plumbing setup and system location, and does not regulate maintenance or testing parameters after installation, or quality that the recycled effluent must meet.

One of the biggest changes pertaining to indoor water conservation to the 2014 Ontario Building Code is the reduction in maximum flow for shower heads and water closets in Residential Occupancy. Previously, all shower heads could have a maximum flow of 9.5 litres per minute (lpm). This new code restricts showerheads in residential settings to 7.6 lpm (Government of Ontario, 2012). Additional maximum flows are presented in Table 58.

Table 58: Maximum Flow Rates for Water Supply Fittings, adapted from OBC (2014) Table 7.6.4.1 (Government of Ontario, 2012).

Fitting	Maximum Flow (L/min)	Test Pressure (kPa)
Lavatory Faucet	8.35	413
Kitchen Faucet	8.35	413
Shower Heads in *Residential Occupancy*	7.6	550
Shower Heads in *Other Occupancies*	9.5	550

Similarly, the maximum water consumption for urinals is now 1.9 Lpf, whereas it had previously been 3.8 lpf (Government of Ontario, 2012). Water consumption per flush cycle for toilets remains the same for most buildings, except for buildings with residential occupancies. All maximum consumptions for sanitary fixtures are presented in Table 59.

Table 59: Maximum Water Consumption per Flush Cycle for Sanitary Fixtures, adapted from OBC (2014) Table 7.6.4.1.A&B (Government of Ontario, 2012).

Fixture	Maximum Water Consumption per Flush Cycle, LPF	Maximum Water Consumption per Flush Cycle, LPF (Residential Occupancies)
Water Closet (Tank Type)	6.0	4.8
Water Closet (Direct Flush)	6.0	4.8
Urinal (Tank Type)	1.9	1.9
Urinal (Direct Flush)	1.9	1.9

It is noted that dual flush toilets with cycle options of both 4.1lpf and 6.0lpf are acceptable in residential occupancy buildings (Government of Ontario, 2012).

These changes will greatly reduce residential water consumption, and contribution to sanitary sewers. It is expected that by reducing showerhead maximum flow, fresh water consumed by showers will be reduced, affecting the water balance required for toilet flushing with treated greywater. This requires further analysis.

Further changes in the OBC which reduce potable water consumption are the laws which permit using rainwater for laundry, and allowing greywater to be used for subsurface irrigation, which amounts to 16 percent of freshwater consumption during summer months (Frank et al., 2013).

British Columbia

British Columbia is one of the only provinces making progress on municipalities using reclaimed water for non-potable applications. British Columbia follows the *Municipal Sewage Regulation* which permits flushing toilets and urinals with reclaimed water but does not permit "closed-loop" systems where greywater that is produced within a building be used within the same building (Queen's Printer BC, 2012).

Alberta

According to the *Alberta Building and Plumbing Code*, reusing greywater to flush toilets is not permitted. It is, however, permitted to use greywater for outdoor irrigation (Alberta WaterSMART, 2014).

Atlantic Canada

In Atlantic Canada, reclaimed water use follows the *Atlantic Canada Wastewater Guidelines Manual for Collection, Treatment, and Disposal*, but has a focus on irrigation and does not discuss closed-loop greywater reuse (Environment Canada, 2006).

WHO Guidelines

The World Health Organization (WHO) has developed guidelines for safe use of wastewater, excreta and greywater. However, they are intended to be used as a framework for reuse of wastewater for agriculture and aquaculture, and do not have guidelines for indoor toilet flushing (World Health Organization, 2006).

USA Regulations

As previously noted, there is no consistency between greywater reuse regulations in the U.S. and limits on total and fecal coliforms for greywater used to flush toilets are highly variable between states, showing confusion on acceptable limits for water quality (Hodgson, 2012). According to Sharvelle et al. (2013), research to date does not provide enough guidance on appropriate water quality limits and more research is required to determine optimal guidelines (Sharvelle et al., 2013).

As of 2013, 20 states have greywater reuse regulations while many more have adopted the Uniform Plumbing Code (UPC), the International plumbing code or the National Standards Plumbing Code (Sharvelle et al., 2013).

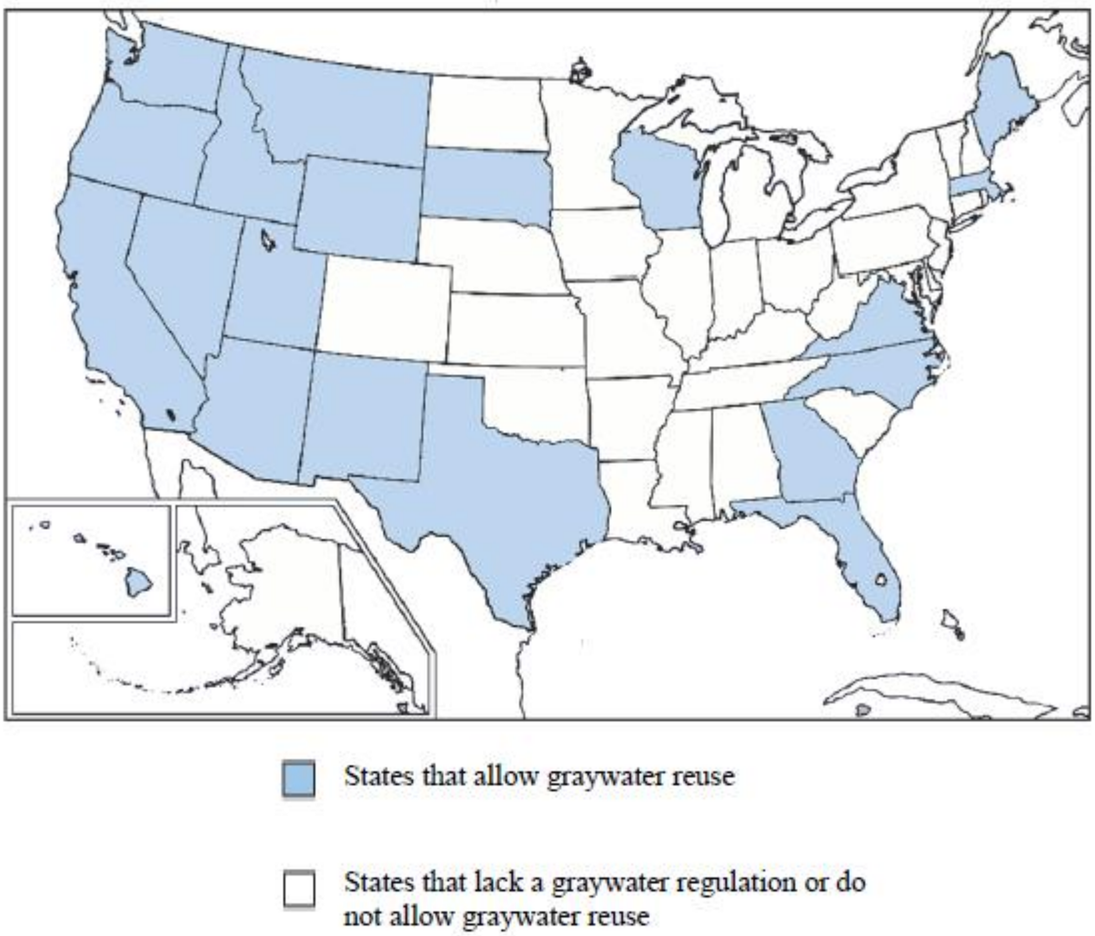


Figure 22: Map of states in the United States that have a greywater regulation, from (Sharvelle et al., 2013).

Additionally, most states require each jurisdiction to have their own regulations that are similar or even stricter than the state level regulations (Sharvelle et al., 2013). Li et al. (2009) provide a summary of wastewater reuse standards from different countries, while Sharvelle et al. (2012) provide a complete summary of the requirements of each regulation in the United States.

California Code of Regulations - Title 22

California was the first state to develop greywater reuse regulations, in 1994. Title 22 of the California Code of Regulations is often a point of discussion in greywater reuse as many other standards followed the code for guidance when developing their own regulations.

According to Section 60307 of Title 22, recycled water can be used for flushing toilets and urinals, if it first undergoes tertiary treatment and disinfection. According to Section 60301.230, disinfected tertiary recycled water is water that has been filtered and subsequently disinfected through chlorine disinfection or a process that removes and/or inactivates 99.999 percent of F-specific bacteriophage MS2 or polio virus. Total Coliform measurements should have a median MPN (most probable number) of less than 2.2/100mL, and should never exceed a MPN of 23/100mL (California Office of Administrative Law, 2015). Coagulation does not need to be used, as long as turbidity of the effluent treated greywater does not exceed 2 NTU, and the influent turbidity never exceeds 10 NTU.

U.S. EPA Guidelines for Water Reuse

The U.S. EPA first published guidelines on water reuse in 1980, with updates in 1992 and 2004. Each set of guidelines has built upon previous versions, and the 2012 guidelines are the most current version of U.S. EPA Guidelines on Water Reuse.

This document provides guidelines on various reuse applications, including urban and agriculture applications, reusing for environmental purposes such as groundwater recharge, industrial reuse and potable reuse. Using reclaimed water to flush toilets and urinals is considered unrestricted urban reuse, as public exposure is likely, and is discussed in detail in the 2004 document.

The document focuses on the treatment of reclaimed water for reuse, but does present guidelines on unrestricted urban reuse, which includes toilet flushing. The 2012 guidelines suggest that unrestricted urban reuse of reclaimed water require secondary treatment, filtration and disinfection in order to be used to flush toilets. Secondary treatment of greywater might be excessive for its purpose of flushing toilets; however, the water quality standards that the guideline suggests, as shown in Table 60, are relevant and should be met through greywater treatment.

Table 60: Unrestricted urban reuse water quality guidelines from the U.S. EPA 2012 Guidelines for Water Reuse (U.S. E.P.A, 2012).

Reuse Application	**Unrestricted Urban Reuse**			**Monitoring requirements**
Reuse Water Quality Guidelines	Fecal Coliforms	CFU/100 mL median	<1[1,2]	Daily
	BOD	mg/L	≤10	Weekly
	pH	(90 per cent)	6-9	Weekly
	Turbidity	NTU	≤2	Continuous
	30 min chlorine residual	mg/L	≥1	continuous

[1] Unless otherwise noted, recommended coliform limits are median values determined from the bacteriological results of the last seven days for which analyses have been completed.
[2] The number of fecal coliform organisms should not exceed 14/100mL in any sample.

Additionally, the reclaimed water should be odorless, clear and contain no measurable levels of pathogens. The guidelines recommend that fecal coliforms be used as indicator organisms, rather than total coliforms as they are a better indicator of fecal contamination (U.S. E.P.A, 2012).

The guidelines propose that *Giardia* and *Cryptosporidium* could also be monitored, but they have been found within acceptable limits at water reuse operations throughout the United States, and thus do not require limitations. Similarly, there are no guidelines on viruses as disinfection generally works well (except for Adenoviruses which have built up a resistance to UV), as well as there are no documented cases of viral disease in the United States resulting from water reuse operations. Additionally, the testing methods for viruses in water are expensive, take an excessive amount of time, and are not able to indicate whether the viruses are activated or inactivated (U.S. E.P.A, 2012).

International Plumbing Code

The most recent version of the IPC (International Plumbing Code) was released in early 2015 by the International Codes Council. The intent of the IPC is to provide a standard code for countries, states and local jurisdictions to use as a base framework, and then add their own specific amendments (Sharvelle et al., 2013).

The IPC provides detailed information on the design and installation of plumbing and fixtures, and specifically has a section on greywater recycling systems. The 2012 code covers the materials, design, construction and installation process of greywater systems that are to be used to flush toilets and urinals, as well as subsurface irrigation.

The code indicates that greywater reuse systems must be equipped with a filter, and disinfectant such as chlorine, iodine or ozone. The code also stipulates details such as there must be makeup water available to the greywater system, and that all greywater shall be dyed blue or green before supplying to the fixtures. A very important detail that is referenced frequently from the IPC is that the retention time of greywater in the system must be limited to 72 hours (International Code Council, 2012).

Specifications for water quality or disinfection dosing are not included in the IPC.

Uniform Plumbing Code

The 2012 Uniform Plumbing Code (UPC) provides details on reusing greywater for irrigation purposes only (IAPMO, 2012).

United Kingdom Guidelines

In the United Kingdom, greywater reuse follows the British Standard 8525-1:2010, which is a code of practice to be used for guidance and recommendations and is not a specification. Similar to the previously mentioned standards, there are details on system plumbing, design, and maintenance, as well as water quality guidelines for each greywater reuse application. The standards are listed below in Table 61, and are similar to North American guidelines.

Table 61: Water Quality Requirements for Toilet Flushing in the United Kingdom, adapted from (Sharvelle et al., 2013).

	Health Risk Parameter				System Operation Parameter		
End Use	E.coli (#/100mL)	Intestinal Enterococci (#/100mL)	Legionella Pneumophila (#/100mL)	Total Coliforms (#/100mL)	Turbidity (NTU)	pH	Disinfection (mg/L)
Toilet Flushing	250	100	NR[1]	1000	<10	5-9.5	Chlorine <2.0 Bromine <5.0

[1]NR: Not regulated.

The British Standard also includes a suggested maintenance schedule, which is very similar to the Canadian standards (CSA B128.2-06),

Australia Greywater Regulations

Similar to the United States, greywater regulation throughout Australia varies by state) but most have adopted the Australian/New Zealand Standard (AS/NZS) 3500 (Sharvelle et al., 2013).

In Australia, greywater reuse is permitted for toilet flushing, irrigation and laundry reuse. In order to be commercially available, greywater reuse systems in Australia must first undergo a 26-week monitoring process which shows that the system meets state water quality requirements (Sharvelle et al., 2013).

Some states such as New South Wales require a licensed professional to visit, maintain and repair the greywater reuse systems, and all states require backflow prevention tests. Greywater quality requirements for reuse in toilet flushing are very similar to North American standards (Sharvelle et al., 2013).

Independent Testing Standards

IAPMO (The International Association of Plumbing and Mechanical Officials) is set to publish a standard entitled "Small-Scale Residential Greywater Recycling Systems" (IAPMO Z1207) and will present requirements for single-family residential households reusing greywater for toilet flushing and subsurface irrigation. Similar to NSF/ANSI Standard 350, the standard presents details on appropriate materials to be used in the construction of the system, and a testing methodology for the simulated-use laboratory testing of the greywater system (IAPMO, 2015).

Disinfection

There are multiple methods for disinfection that could be used in packaged, commercially available residential greywater reuse systems. Total chlorine, chloramine and hydrogen peroxide are commonly suggested as disinfectants for greywater treatment and could be found as disinfects in other packaged residential greywater reuse systems (Tal, Sathasivan, & Kirshna, 2011). Disinfection can also be completed using ozone, or ultraviolet light, but chlorine is the most common disinfectant for greywater reuse as it is "effective, inexpensive, and provides a measurable residual" (Wiles, 2013).

Ozone, a gas at room temperature that is highly corrosive and toxic, can be used to effectively disinfect bacteria and harmful pathogens as well (Sharvelle et al., 2013). It has been found to be more effective at inactivation of *Cryptosporidium* and *Giardia,* relative to chlorine but uses high amount of energy to generate the gas and does not provide a disinfection residual throughout the storage and distribution of greywater (Sharvelle et al., 2013).

Ultraviolet (UV) Radiation does not require chemicals to disinfect, and effectively and quickly kills a wide variety of pathogens (Friedler & Gilboa, 2010). Similar to ozone treatment, UV treatment does not provide a residual disinfectant. Maintenance with UV radiation systems typically requires annual replacement of the UV bulb (Sharvelle et al., 2013).

A drawback to the use of chlorine is the potential for the development of disinfection by-products which are under study for their effects on human health (U.S. E.P.A, 2012).

Chemicals could be present in the treated reclaimed water including disinfection by-products (DBPs) which are developed from the disinfection process. DBPs are usually dissolved organohalogenated compounds which form when organic substances are broken down by a disinfectant, such as chlorine. However, Health Canada states that the risk of human exposure to DBPs through reclaimed greywater is minimal. Further research needs to be done to learn about the effects of pharmaceuticals, personal care products and endocrine disrupting chemicals on greywater recycling systems. No guidelines were set by Health Canada for chemicals and contaminants of emerging concern (CEC's) and they will not be tested through this project.

Appendix B: Projected Water Rates for Municipalities in Southern Ontario

As an effort to pay for infrastructure, as well as deter homeowners from consuming excess amounts of water domestically, water rates across Canada are increasing. As of 2011, the average rate for water and wastewater services in Canada was \$1.99USD/m^3, with the lowest price being \$0.42USD/m^3 and the highest was \$3.23USD/m^3. These prices are very low relative to other developed countries such as Denmark which charges \$7.65USD/m^3, or the United Kingdom which charges \$5.66USD/m^3 (Vander Ploeg, 2011). The following Table 62, compiled by the Canada West Foundation, shows prices for water and wastewater charges, for different countries.

Table 62: Global municipal rates for water supply and sanitation to households, adapted from from (Vander Ploeg, 2011).

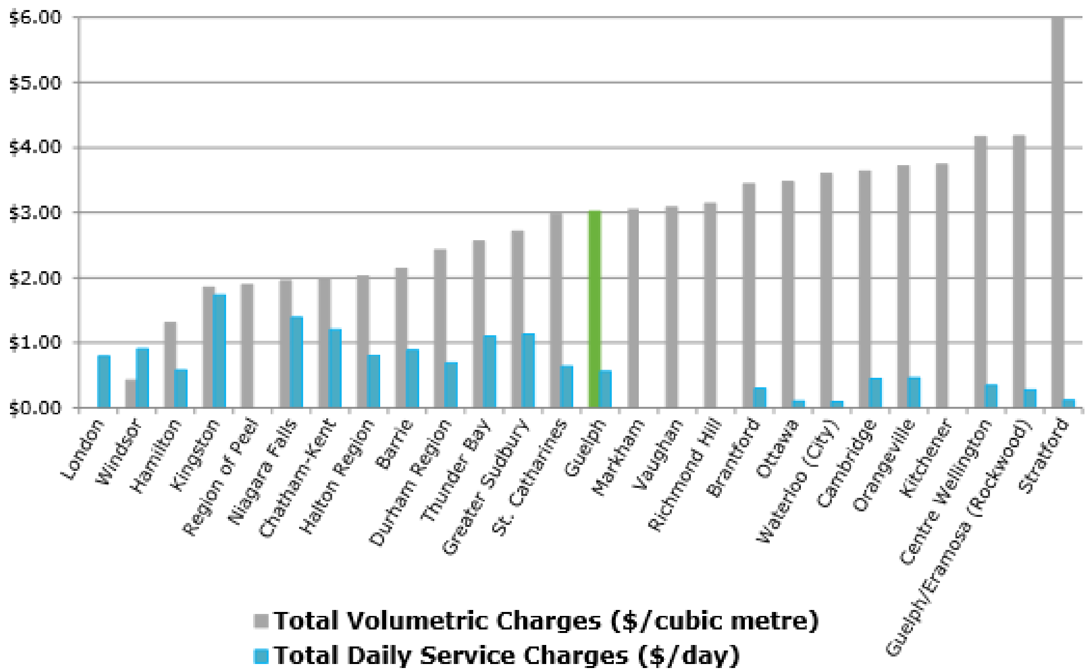
OECD Nation[1]	Date of Estimate	Lowest Cost City[2]	Highest Cost City[2]	Average of All Cities Surveyed[2]
Australia	2008	$2.61	$3.58	$3.05
Austria	2008	$3.28	$4.62	$3.93
Belgium	2008	$4.18	$5.49	$4.67
Canada	2008	$0.42	$3.23	$1.99
Czech Republic	2008	$2.22	$2.55	$2.40
Denmark	2008	$7.58	$7.71	$7.65
Finland	2008	$2.99	$4.48	$3.74
France	2008	$3.72	$4.73	$3.99
Germany	2008	$2.96	$7.49	$5.09
Greece	2008	$1.34	$1.34	$1.34
Hungary	2008	$1.71	$2.49	$2.19
Iceland	2008	$1.95	$1.95	$1.95
Ireland	2008	$0.00	$0.00	$0.00
Italy	2008	$0.75	$1.63	$1.12
Japan	2008	$1.35	$2.31	$1.81
Korea	2008	$0.75	$1.45	$0.93
Luxembourg	2008	$4.64	$4.64	$4.64
Mexico	2008	$0.15	$0.87	$0.47
Netherlands	2008	$1.67	$3.15	$2.49
New Zealand	2008	$0.98	$4.13	$2.56
Norway	2008	$2.79	$3.49	$3.14
Poland	2008	$1.86	$2.64	$2.15
Portugal	2008	$1.49	$2.14	$1.88
Slovakia	2008	$2.02	$2.36	$2.19
Spain	2008	$0.75	$2.52	$1.70
Sweden	2008	$1.54	$2.80	$2.33
Switzerland	2008	$5.16	$5.21	$5.19
Turkey	2008	$0.47	$2.10	$1.37
United Kingdom	2008	$4.31	$7.57	$5.66
United States	2008	$0.74	$4.13	$2.19

[1]Excludes Chile, Estonia, Israel and Slovenia.

[2]Prices are in $US per cubic meter of water and wastewater services provided by various cities.

Of the population in Ontario that uses municipal water, 85 percent of the municipalities have water meters and pay for their water on a volume usage basis (Watson & Associates Economists Ltd; Dillon Consulting, 2012).

The following figure (Figure 23) developed by the City of Guelph, shows the 2014 water and wastewater rates for most large municipalities in Southern Ontario.



[1]The volumetric rate shown here represents the rate charged for the first cubic metre of water used each month.

Figure 23: Residential water/wastewater total volumetric and service charges by municipality (2014 rates), from the City of Guelph Water and Wastewater Overview[1] (City of Guelph, 2015).

In 2008, the Ontario Government published O.Reg 453/07 which is a regulation under the *Safe Water Drinking Act*. This regulation states each municipality has to have a financial plan for water and wastewater services for a period of 6 years in order to be awarded their operating license (Government of Ontario, 2008).

These long range financial plans include projected total revenue values for water and wastewater services, and often include projected rate increases. The majority of the plans were published in 2009 and therefore present values until 2015. It is anticipated that this year, the plans will be renewed and further data will be presented.

Projected water and wastewater rates are available online for most municipalities and current rates from a selection of municipalities in Southern Ontario are presented in the following Table 63. In municipalities where the rate increases as water usage increases, a weighted average was calculated for rates up to $25m^3$ of usage. Base charges for meter connections were not included in the calculations.

Table 63: Current water and wastewater rates in Southern Ontario, collected from municipal websites.

	2015		
	Water Rate ($\$/m^3$)	Wastewater Rate ($\$/m^3$)	Combined Rate ($\$/m^3$)
Guelph	$1.53	$1.66	$3.19
Hamilton	$1.33	$1.33	$2.66
London	$2.34	$2.08	$4.41
St. Catharines	$1.20	$1.83	$3.03
Brantford	$1.81	$1.72	$3.53
Kitchener	$1.94	$2.17	$4.11
Waterloo	$1.66	$2.10	$3.76
Ottawa	$1.70	$1.99	$3.69
Toronto	$1.60	$1.60	$3.19
Peel	$1.15	$0.88	$2.03
Markham	$1.66	$1.65	$3.32
Vaughan	$1.48	$1.91	$3.39
Halton	$0.98	$1.15	$2.12
Durham	$0.94	$1.60	$2.55
Barrie	$0.94	$1.32	$2.26
Average	**$1.48**	**$1.67**	**$3.15**

Using the projected water rates given in some long range water financial plans, the average rates by 2022 are projected to be $2.10 and $2.37, for water and wastewater, respectively which is still less than current European water service rates. Average annual percent increase from 2015 to 2022 is 5 percent (4.95 percent) per year.

Table 64: Projected water rates for Southern Ontario from 2014 to 2022, collected from municipal websites.

Water Rates										
Year	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Avg.**
Guelph	$1.43	$1.53	$1.62	$1.73	$1.87					
Hamilton	$1.27	$1.33	$1.39	$1.44	$1.51	$1.57	$1.64	$1.71	$1.78	
London	$2.17	$2.34	$2.44							
St. Catharines	$1.23	$1.20								
Brantford	$1.75	$1.81	$1.92	$1.99	$2.07	$2.12	$2.17			
Kitchener	$1.76	$1.94								
Waterloo	$1.61	$1.66	$1.74	$1.80	$1.86	$1.92	$1.98	$2.03	$2.08	
Ottawa	$1.60	$1.70	$1.80	$1.89	$1.99	$2.08	$2.19	$2.30	$2.41	
Toronto	$1.48	$1.60	$1.73	$1.81	$1.90	$1.96	$2.02	$2.08	$2.14	
Peel	$1.07	$1.15	$1.19							
Markham	$1.34	$1.66								
Vaughan	$1.44	$1.48								
Halton	$0.97	$0.98								
Durham		$0.94								
Average	**$1.47**	**$1.52**	**$1.73**	**$1.78**	**$1.87**	**$1.93**	**$2.00**	**$2.03**	**$2.10**	
Wastewater Rates										
Year	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Avg.**
Guelph	$1.59	$1.66	$1.71	$1.82	$1.95					
Hamilton	$1.27	$1.33	$1.39	$1.44	$1.51	$1.57	$1.64	$1.71	$1.78	
London	$1.94	$2.08	$2.17							
St. Catharines	$1.76	$1.83								
Brantford	$1.69	$1.72	$1.81	$1.85	$1.90	$1.94	$1.99			
Kitchener	$1.98	$2.17								
Waterloo	$2.00	$2.10	$2.18	$2.27	$2.36	$2.45	$2.55	$2.64	$2.73	
Ottawa	$1.88	$1.99	$2.11	$2.21	$2.32	$2.44	$2.56	$2.69	$2.82	
Toronto	$1.48	$1.60	$1.73	$1.81	$1.90	$1.96	$2.02	$2.08	$2.14	
Peel	$0.82	$0.88	$0.90							
Markham	$1.20	$1.65								
Vaughan	$1.63	$1.91								
Halton	$1.10	$1.15								
Durham		$1.60								
Average	**$1.56**	**$1.69**	**$1.75**	**$1.90**	**$1.99**	**$2.07**	**$2.15**	**$2.28**	**$2.37**	
Combined Rate ($/m^3)	**$3.04**	**$3.21**	**$3.48**	**$3.68**	**$3.86**	**$4.00**	**$4.15**	**$4.31**	**$4.47**	
Percent increase (%)	-	5.59%	8.41%	5.75%	4.89%	3.63%	3.75%	3.86%	3.71%	**4.95%**

Appendix C: Field Study Testing Methodology

Table 65 : Total number of samples collected and tested at Maxxam Laboratory.

	Sample Location	House 1	House 2	House 6	House 7	House 9	House 10	House 11
Total # of Samples	**BT**[1]	5	5	3	5	7	6	4
	GS[2]	7	6	4	5	7	6	4
	TT[3]	7	6	4	5	7	6	4

[1]BT : Bath Tub (Raw Shower Water)
[2]GS : Greywater Reuse System Storage Tank (Treated Greywater)
[3]TT : Toilet Tank (Distributed Treated Greywater)

Table 66 : Samples collected and tested at Maxxam Laboratory.

Month/Year	Sample Location	House 1	House 2	House 6	House 7	House 9	House 10	House 11
08/14	BT[1]	●	●		●	●	●	●
	GS[2]	●	●	●	●	●	●	●
	TT[3]	●	●	●	●	●	●	●
10/14	BT					●		
	GS	●				●		
	TT	●				●		
11/14	BT	●	●	●	●	●	●	●
	GS	●	●	●	●	●	●	●
	TT	●	●	●	●	●	●	●
12/14	BT					●	●	●
	GS	●	●			●	●	●
	TT	●	●			●	●	●
01/15 I	BT	●	●	●	●	●	●	
	GS	●	●	●	●	●	●	
	TT	●	●	●	●	●	●	
01/15 II	BT	●	●	●	●	●	●	
	GS	●	●	●	●	●	●	
	TT	●	●	●	●	●	●	
02/15	BT	●	●		●	●	●	●
	GS	●	●		●	●	●	●
	TT	●	●		●	●	●	●

[1]BT : Bath Tub (Raw Shower Water)
[2]GS : Greywater Reuse System Storage Tank (Treated Greywater)
[3]TT : Toilet Tank (Distributed Treated Greywater)

Water Balance Program Validation

Table 67: Comparison between flow meter readings and recorded program data at House 23.

Meter 1: Greywater used to Flush				
Time Period	Dates	Flow Meter Reading (L)	Program Reading (L)	Difference (L)
1	Nov. 14 to Dec. 12	4000	2493.581	1506.419
2	Jan. 16 to Jan. 30	1700	1450.559	249.441
3	Jan. 30 to Feb. 17	2000	1536.065	463.935
Meter 2: Municipal Water Added				
Time Period	Dates	Flow Meter Reading (L)	Program Reading (L)	Difference (L)
1	Nov. 14 to Dec. 12	1110	1000.000	110.000
2	Jan. 16 to Jan. 30	320	317.217	2.783
3	Jan. 30 to Feb. 17	1040	947.750	92.250

As a second method, in order to test the recorded program volumes, the bathtub was filled with 50L and then emptied into the greywater reuse system with and without the filter in. Pouring water directly into the system resulted in too strong of a flow, where water bounced off the in-drain and flowed immediately into the overflow drain. Therefore, it was expected that when there was no filter, the recorded volume would be less than 50L. Also, when the filter was in, it was expected that some water would flow over the filter and into the overflow drain, and be less than 50L. The tank was emptied and the pressure sensor was recalibrated before Test #3 and Test #6.

Table 68: Validation of pressure sensor and water balance program accuracy.

Test #	Details	From	Volume Added (L)	Program Recorded (L)	Sensor Readout (L)	Error (L)	Notes
1	Not Calibrated No Filter	Bathtub	50	16.750		33.250	A lot of water bouncing off of bottom of greywater-in drain and flowing into overflow drain.
2	Not Calibrated Filter	Bathtub	50	33.875	67	16.125	Most water going through filter into tank, some into overflow drain. *Sensor Readout for both test 1 & 2*
3	Calibrated No Filter	Bathtub	50	16.000	25	34.000	A lot of water bouncing off of bottom of greywater-in drain and flowing into overflow drain.
4	Calibrated Filter	Bathtub	50	34.875	35	15.125	Most water going through filter into tank, some into overflow drain.
5	Calibrated Clean Filter	Bathtub	50	34.625	46	15.375	Still some water flowing into overflow drain.
6	Calibrated Direct to tank	Tank Lid	50	38.250	47	11.750	Added water directly into tank through tank lid.

Testing Equipment

Table 69: Method of water quality testing for both laboratory and field (on-site) testing.

Parameter	Method of Testing		*Standard Method of Measuring*
Biochemical Oxygen Demand (BOD_5)	Lab	Seeded Incubation	SM 5210 B
Chemical Oxygen Demand (COD)		Digestion/Titration	SM 5210 B
Total Coliforms		Membrane Filtration	SM 9221
Fecal Coliforms		Membrane Filtration	SM 9221
Total Chlorine Residual	Field	LaMotte Meter	SM 4500 Cl-B-I
Turbidity		LaMotte Meter	EPA 180.1
Colour		LaMotte Meter	SM 2120 B
Odour		Observation	SM 2150 B
Temperature		Digital Thermometer	SM 2550 B
pH		pH Pen	SM 2310 B
Hardness		Hanna Hardness Kit	EPA 200.7

Durability Testing

The following checklist is a guide of common system failures:

- Mechanical Failures
    - Pump failure
    - Filter failure
    - External water leakage
    - Flooding/Overflow
    - Corrosion
    - Irregular noise
    - Insufficient pressure
    - Insufficient water supply
    - Lack of access to chlorine
    - Lack of access to filters
- Fixture Failures
    - Film buildup in toilet tank
    - Toilet flush valve clogged
    - Deteriorated toilet flapper
- Electrical systems
    - Fragmented text on screen
    - Broken screen
- Program Failure
    - Incorrect time on the screen
    - Unnecessary flashing notifications
- Stress situations
    - Vacation mode failure
    - Power outage failure

Appendix D: Surveys

User Survey #1

User Survey #1 Questions

General User Information

1. **Name of System User:**

   ____

2. **[Greywater Reuse System] Serial Number:**

   ____

3. **Have you been involved in any previous greywater reuse system pilot studies?**

   ○ Yes

   ○ No

4. **Has the greywater reuse system been installed in your home?**
   (Some users may still be waiting for the system to be installed)

   ○ Yes

   ○ No

5. **How many residents live in the household?**

   ____

User Information
Please fill out the following information for each resident.
The order of completion for each user is not important.

Resident #1 (this was repeated for each resident)

1. **Please indicate the age of Resident #1:**

    ____

2. **How much time does Resident #1 typically spend at home during the day?**

    ○ At home all day

    ○ Away 8+ hours (work/school Full time)

    ○ Away 4+ hours (work/school Part time)

3. **How does Resident #1 typically bathe?**

    ○ Shower

    ○ Bath

4. **How *often* does Resident #1 typically bathe at this house per week? (shower or bath)**

    ○ Once per day

    ○ Every other day (3 or 4 showers per week)

    ○ 2 showers per week

    ○ 1 shower per week

<u>Personal Care Products</u>

Please answer N/A if the question is not applicable.

1. **What type/brand of *shampoo* is typically used in the shower?**

    ____

2. **What type/brand of *conditioner* is typically used in the shower?**

    ____

3. **What type/brand of *bodywash soap* is typically used in the shower?**

   ____

4. **Please indicate any other personal care products used in the shower?**

   ____

Cleaning Products

1. **What cleaning products are used to clean the shower?**

   ____

2. **How frequently do you clean the shower?**

   ○ Every day

   ○ Every other day

   ○ Once a week

   ○ Once every two weeks

   ○ Once a month

   ○ Every 2-3 months

   ○ Other:

3. **What products are used to clean the toilet(s)?**

   ____

4. **How frequently do you clean the toilet?**
   (prior to the installation of the greywater reuse system)

   ○ Every other day

   ○ Once a week

○ Once every two weeks

○ Once a month

○ Every 2-3 months

○ Other:

Greywater Reuse System Setup

1. **Where is the greywater reuse system installed in your house?**
   (i.e. basement, main floor)

   ____

2. **Does your household use a water softener?**

   ○ Yes

   ○ No

3. **Is your home equipped with a city water meter?**

   ○ Yes

   ○ No

4. **How many toilets are/will be connected to the greywater reuse system?**

   ____

Toilet Water Usage

Please estimate water usage for each toilet attached to the greywater reuse system. If you're unsure how much water a toilet uses, choose "Other" and indicate which year the toilet was installed.

Toilet #1 (repeated for all toilets connected to the greywater reuse system)

1. **How many litres of water does Toilet #1 user per flush?**

   - ◯ High Efficiency Toilet (<6 litres per flush)
   - ◯ Dual Flush Toilet (3/6 litres per flush)
   - ◯ Low Flush Toilet (6 – 12 litres per flush)
   - ◯ Conventional Toilet (13+ litres per flush)
   - ◯ Other:____

2. **Location of Toilet #1 (e.g. main floor powder room, ensuite…):**

   ____

User Survey #1 Responses (Household Characteristics)

Table 70: Classification of each house in the study as a type of greywater producer.

House #	# of Residents	Number of showers in your home that drain into the greywater reuse system:	Total number of showers in your home:	% of captured shower water	Frequency of bathing?	Method of bathing?	Type of producer	Overall House Producer Type
1	9	2	2	100	Every other day	shower	Medium	High[1]
					2 showers per week	shower	Low	
					Once per day	shower	High	
					2 showers per week	shower	Low	
					2 showers per week	shower	Low	
					2 showers per week	shower	Low	
					2 showers per week	shower	Low	
					Every other day	bath	High	
					Once per day	bath	High	
2	4	NA[2]	NA	NA	Once per day	shower	High	High
					Once per day	shower	High	
					Every other day	shower	Medium	
					Every other day	bath	High	
3	4	NA	NA	NA	Once per day	shower	High	High
					Once per day	shower	High	
					Once per day	shower	High	
					Once per day	shower	High	
4	4	3	4	75	Every other day	shower	Medium	Medium
					Every other day	shower	Medium	
					Once per day	shower	High	
					2 showers per week	bath	High	
5	3	2	2	100	Once per day	bath	High	High
					Once per day	shower	High	
					Every other day	shower	Medium	
6	4	1	1	100	Once per day	shower	High	High
					Once per day	shower	High	
					Every other day	bath	High	
					Every other day	bath	High	

7	4	NA	NA	NA	Once per day	shower	High	High
					Every other day	shower	Medium	
					Every other day	bath	High	
					Every other day	bath	High	
8	3	2	3	67	Once per day	bath	High	High
					Once per day	shower	High	
					Once per day	bath	High	
9	3	2	2	100	Every other day	shower	Medium	High
					Once per day	shower	High	
					NA	NA	NA	
10	2	1	1	100	2 showers per week	shower	Low	Low
					Every other day	shower	Medium	
11	2	2	2	100	Once per day	shower	High	High
					Once per day	shower	High	
12	2	1	1	100	Every other day	shower	Medium	Medium
					Once per day	shower	High	
13	3	1	1	100	2 showers per week	shower	Low	Medium
					Every other day	shower	Medium	
					2 showers per week	bath	High	
14	4	NA	NA	NA	Once per day	shower	High	High
					Once per day	shower	High	
					Every other day	bath	High	
					Every other day	bath	High	
15	5	1	2	50	Once per day	shower	High	High
					Once per day	shower	High	
					Every other day	shower	Medium	
					Every other day	bath	High	
					Every other day	bath	High	
16	2	1	2	50	Once per day	shower	High	High
					Once per day	shower	High	
18	4	1	1	100	Every other day	shower	Medium	Medium
					Every other day	shower	Medium	
					2 showers per week	shower	Low	
					2 showers per week	bath	High	
19	3	1	2	50	Once per day	bath	High	High
					Once per day	shower	High	

					Once per day	bath	High	
20	2	2	3	67	Once per day	shower	High	High
					Once per day	shower	High	
21	5	2	2	100	Once per day	shower	High	Medium
					Once per day	shower	High	
					2 showers per week	shower	Low	
					2 showers per week	shower	Low	
					2 showers per week	shower	Low	
22	6	2	3	67	Once per day	shower	High	High
					Once per day	shower	High	
					Once per day	shower	High	
					Once per day	shower	High	
					Once per day	shower	High	
					Once per day	shower	High	

[1]Although the overall average type of producer is low, since there are nine residents in this house, it is considered a high water producer.
[2]NA: Not available.

Table 71: Classification of each house in the study as a type of greywater consumer.

House #	# of Residents	At home during the day?	Type of consumer	Overall
1	9	Away 8+ hours - work/school Full time	Low	High[1]
		At home all day	High	
		Away 4+ hours - work/school Part time	Medium	
		Away 4+ hours - work/school Part time	Medium	
		Away 4+ hours - work/school Part time	Medium	
		Away 4+ hours - work/school Part time	Medium	
		Away 4+ hours - work/school Part time	Medium	
		At home all day	High	
		At home all day	High	
2	4	Away 8+ hours - work/school Full time	Low	Low
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
3	4	Away 8+ hours - work/school Full time	Low	Low
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
4	4	Away 8+ hours - work/school Full time	Low	Medium
		Away 8+ hours - work/school Full time	Low	
		At home all day	High	
		Away 4+ hours - work/school Part time	Medium	
5	3	Away 8+ hours - work/school Full time	Low	Low
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
6	4	Away 8+ hours - work/school Full time	Low	Low
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
7	4	At home all day	High	Medium
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
		Away 4+ hours - work/school Part time	Medium	
8	3	At home all day	High	High
		Away 8+ hours - work/school Full time	Low	
		At home all day	High	
9	3	At home all day	High	Medium
		Away 8+ hours - work/school Full time	Low	
		N/a[2]	N/a	
10	2	Away 4+ hours - work/school Part time	Medium	Medium
		Away 4+ hours - work/school Part time	Medium	
11	2	Away 8+ hours - work/school Full time	Low	Low
		Away 8+ hours - work/school Full time	Low	
12	2	Away 8+ hours - work/school Full time	Low	Low
		Away 8+ hours - work/school Full time	Low	

13	3	At home all day	High	High[3]
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
14	4	At home all day	High	Medium
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
		At home all day	High	
15	5	Away 8+ hours - work/school Full time	Low	Low
		At home all day	High	
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
16	2	Away 8+ hours - work/school Full time	Low	Medium
		At home all day	High	
18	4	Away 8+ hours - work/school Full time	Low	Medium
		Away 4+ hours - work/school Part time	Medium	
		Away 8+ hours - work/school Full time	Low	
		Away 4+ hours - work/school Part time	Medium	
19	3	Away 8+ hours - work/school Full time	Low	Low
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
20	2	Away 8+ hours - work/school Full time	Low	Low
		Away 4+ hours - work/school Part time	Medium	
21	5	Away 8+ hours - work/school Full time	Low	Low
		Away 4+ hours - work/school Part time	Medium	
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
22	6	Away 4+ hours - work/school Part time	Medium	Low
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	
		Away 8+ hours - work/school Full time	Low	

[1]House 1 is considered a high water consumer because there are 9 residents.
[2]Not available - Information was not collected during first survey.
[3]Business with additional employees works out of the home during the day.

Table 72: Hygienic and cleaning products used in the shower.

House Number	Type of Shampoo	Type of Conditioner	Type of Bodywash	Other hygienic products?	Products used to clean the shower	Advertised as "Natural Products"?	Water Softener?	Filter Issues?
1	Pantene Garnier Fructis TRESemme Naturals	Pantene Garnier Fructis	Nivea Men Dial	random soaps (Dove, Ivory, nameless brands inherited from hotels, natural soaps, ... varied)	(not sure)	●	●	
2	Johnson's shampoo Matrix biolage Nisim Joico	Loreal total repair Joining	None	Dial soap Skintimate shaving gel	Method daily shower spray Scrubbing bubbles spray		●	●
3	Trésemme Head and Shoulders Aveeno	Head and Shoulders Aveeda	Aveeno	-	Bleach and water	●	●	
4	Johnson baby shampoo Dandruff shampoo	Shoppers name brand	Shoppers	-	Shoppers named brand daily shower spray		●	●
5	Kirkland Pantene	Pantene	Dove soap	Gillette shave cream	vinegar / baking soda Peroxide Vim Lysol		●	●
6	Jason Naturals	Jason Naturals	Dove	-	George Forman Bathroom cleaner	●	●	
7	Head and Shoulders	See above	Axe	-	Scrubbing bubbles automated shower cleaner		NO	
8	Nioxin	Nioxin	Zest	-	Scrubbing Bubbles		●	
9	Jason and Live Clean	Jason and Live Clean	Jason and Live Clean	Spectro face wash	Tried various including natural. Latest	●	●	●

					using Scrubfree Extreme.			
10	Sauve naturals	Live clean exotic shine -bali oil	Nature Clean - unscented	-	Vinegar	●	NO	●
11	L'Oreal & Vichy	L'Oreal & Vichy	Dove for Men & Ivory	N/A	Scrubbing bubbles, CLR		●	
12	This varies by what's on sale. Currently Dove & Tressame	This varies by what's on sale. Currently Dove & Tressame	I think my son currently has Axe, but it varies. I mostly bar soap but a visitor left St Ives bodywash which I use occasionally. When I take a bath I use a variety of products including bath oils.	St Ives apricot facial scrub	baking soda & water		●	
13	Eufora	Eufora	N/A	glycerin based bar soap	Mostly just water and elbow grease.		NO	
14	Down Under Natural's Tresemme naturals Avalon Organics Peppermint Shampoo Bumble & Bumble Thickening Kiss my Face - obsessively natural kids shampoo & conditioner	Bumble & Bumble Thickening Avalon Organics Lavender	Dial Healthy Moisture - soy & almond Arbonne FC5 Bodyshop honeymania kiss my face - obsessively natural bubble wash	Gillette satin care shaving cream Arbonne awaken sea salt scrub (aroma essentials)	none	●	●	n/a
15	Baby or head and shoulders	Clairol	None	Dove soap Irish spring soap Shaving cream	Scrubbing bubbles		NO	●

16	Head and Shoulders Dove	Dove	Axe Shower Gel	Skintimate Shave Cream	M/r Clean shower and tub foam		●	●
18	Dove for Men, Herbal Essences, Johnson's Baby	Herbal Essences	Dove for Men, Dove for Her, Olay, Bath & Body Works	Gillette Shave Cream	Scrubbing Bubbles, Clorox		NO	
19	Herbal Essences	Head and shoulders Herbal Essences	Old Spice AXE	Bubble bath/Avon/dollar store brands	Scrubbing Bubbles		NO	
20	ABBA (Natural) John Masters (Organic)	ABBA (Natural) John Masters (Organic)	Weleda Bodywash Soap Dove for Sensitive Skin Bar Soap John Masters Organics Bar Soap	John Masters Shave Lotion Kiss My Face Shave Lotion Eminence Face Wash Dermalogica exfoliate	Meyers all-purpose bathroom cleaner Homemade (Water, vinegar, baking soda, essential oils) Nature clean	●	NO	●
21	Natures Gate	Natures Gate	Jason’s		Ecomax	●	NO	●
22	Giovanni	Giovanni	Not Applicable	Irish Spring Cerave Hydrating Cleanser	Vinegar & Vim	●	●	●

User Survey #2

Development of User Satisfaction Survey Questions

In order to develop questions for the user satisfaction survey, the following points from the Handbook of Survey Research (2010) should be followed (Marsden & Wright, 2010):

- There is no standard number of points on a response rating scale. Survey responses have historically had 2, 5, 7, 11, or even 101-point scale responses.
- Dichotomous responses (yes or no), or even three-point scales are not optimal, as it makes the respondent choose a response even if they do not have a firm position.
- Alternatively, it is found that with a larger number of response categories, respondents have trouble differentiating between the different intervals and yields inaccurate results.
- Therefore, a rating scale between 4 and 10 is recommended, with enough points so that respondents can show moderate positions (e.g. more than just "like" and "dislike"), but not too many that clarity is compromised.
- A combination of verbal labels and numerical labels (e.g. 1 – Very Satisfied) adds clarity.
- Questions of the same topics should be grouped together.

User Survey #2 Questions

General User Information

1. Name
2. Street Address
3. Region
    a. Guelph
    b. Kitchener
    c. Barrie
    d. Toronto
4. Estimated installation date of the greywater reuse system
5. Number of showers in your home that drain into the greywater reuse system
6. Total number of showers in your home (including showers that aren't connected to the greywater reuse system)

Environmental Awareness

7. What methods of water conservation (apart from greywater reuse) do you practice in your home? (Select all that apply)
    a. High-efficiency dishwasher
    b. High-efficiency washing machine
    c. Low-flow faucets
    d. Low-flow showerheads
    e. Low-flow or High Efficiency Toilets
    f. Rainwater collection for indoor use
    g. Rainwater collection for outdoor use
    h. Water conserving behaviours (e.g. monitoring shower duration)
    i. Other:

8. How did you end up with a greywater reuse system in your house?
    a. Knew about the concept, and searched for a system.
    b. Built a new home, and the builder recommended a system.
    c. Moved in to an existing home with an existing system.
    d. Approached by Canplas
    e. Other:

9. What is your primary reason to reuse greywater in your home?
    a. To save money on water bills
    b. To use less fresh water
    c. To adopt innovative technology
    d. Other:

10. Rate how much of the waste produced in your home you recycle:
    a. 1 – Everything
    b. 2 – Mostly everything
    c. 3 – Unsure
    d. 4 – Some things
    e. 5 - Nothing

Maintenance

Toilets

11. After installing the greywater reuse system, what products are now used to clean the toilet bowls?
    (recorded during first survey, so can see if they changed products)

12. After installing the greywater reuse system, how frequently do you now clean the toilet bowl?
    a. Every other day
    b. Once a week
    c. Once every two weeks
    d. Once a month
    e. Every 2-3 months
    f. Other:

13. After installing the greywater reuse system, how frequently do you now clean the toilet tank(s)?
    a. Every other day
    b. Once a week
    c. Once every two weeks
    d. Once a month
    e. Every 2-3 months
    f. Never
    g. Other:

If they selected anything BUT Never, ask next question:

14. What prompted you to clean the toilet tanks? (select all that apply)
    a. Unpleasant odour in toilet bowl
    b. Excessive buildup in toilet bowl
    c. Toilet wasn't flushing properly
    d. Regular maintenance
    e. Other:

15. Rate the impact this greywater reuse system has had on your toilets and their components (e.g. flush valves)?
    a. 1 - No impact on toilets
    b. 2 - Minor impact on toilets
    c. 3 - Neutral
    d. 4 - Major impact on toilets
    e. 5 – Severe – (caused damage to toilets)

If they select "5 – caused damage to fixtures"

16. Please explain the damage that was caused to the fixtures due to this greywater reuse system:
    a.

17. Any additional comments about toilet maintenance for this greywater system?

Chlorine

18. How frequently did you add chlorine pucks?
    a. Every 2 weeks
    b. Once a month
    c. Every 2-3 months
    d. Every 5-6 months
    e. Once a year
    f. Other:

19. What size of chlorine pucks do you use?
    a. Large (“Super pucks” – 200g)
    b. Small (“Mini-pucks” – 50g
    c. Unsure

20. Rate your level of satisfaction with the procedure to add chlorine to this greywater reuse system.
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 - Neutral
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

21. Any additional comments about chlorine maintenance for this greywater system?

Filter

22. How frequently did you have to clean the filter?
    a. Every 2 weeks
    b. Once a month
    c. Every 2-3 months
    d. Every 5-6 months
    e. Once a year
    f. Never
    g. Other:

If they selected anything BUT Never, ask next question:

23. What prompted you to clean the filter?
    a. Screen notification
    b. Unusual water levels in greywater reuse system tank
    c. Poor water quality at toilet bowl
    d. Routine maintenance
    e. Other

24. How did you clean the filter?
    a. Water and light scrubbing
    b. Vinegar and scrubbing
    c. CLR and scrubbing
    d. Other:

25. Any additional comments about filter maintenance for this greywater system?

26. Rate your level of satisfaction with all maintenance required for this greywater reuse system.
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 - Neutral
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

27. Any additional comments about required maintenance for this greywater reuse system?

<u>Technical Performance</u>

General Technical Performance

28. Did you experience any of the following technical issues or difficulties with your greywater reuse system? (Please check all that apply)
    a. Chlorine odour at toilets
    b. Unpleasant "greywater" odour at toilets
    c. Film buildup in toilet bowl
    d. Film buildup in toilet tank
    e. Unable to flush toilets (no water in greywater reuse system tank)
    f. Unable to flush toilets (pump issues)
    g. Flooding
    h. Screen malfunctions
    i. Improper installation
    j. Pump issues
    k. Noise nuisance
    l. None
    m. Other:

29. Rate your satisfaction with the water aesthetics at the toilet (colour/ cloudiness)
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 - Neutral
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

30. Rate your level of satisfaction with water savings of the system
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 - Neutral
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

31. Rate your level of satisfaction with the process to by-pass greywater reuse and access municipal water to flush your toilets?
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 - Neutral
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied
    f. N/A – Did not use this function

32. Rate your level of satisfaction with any noise produced by the greywater reuse system.
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 - Neutral
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

33. Rate your level of satisfaction regarding energy use of the system
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 - Neutral
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

34. Rate your level of satisfaction with the system aesthetics (does it take up too much space in your home/is it ugly)?
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 - Neutral
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

35. Rate your level of satisfaction with how long it took to install this greywater reuse system.
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 – Neutral / unsure
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

36. Any additional comments on any aspect of the technical performance of this system?

Vacation Mode

37. How well would you rate the system performance when you went on vacation?
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 – Neutral, did not go on vacation
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

If they selected anything BUT 3 – did not go on vacation, ask next question:

38. Please comment on the water quality in the toilet bowl when you returned from your vacation (Select all that apply):
    a. Unusually cloudy
    b. Unusually clear
    c. Unpleasant "greywater" odour
    d. Strong chlorine odour
    e. Excessive buildup in toilet bowl
    f. Excessive buildup in toilet tank
    g. Other:
39. Any additional comments on vacation mode?

Purge Setting

The system was initially set to empty the greywater in the system storage tank every 48 hours (unless the stored water in the tank had been used up by flushing and then the 48 hour countdown would reset).

40. Was your system set up to NOT purge the greywater in the system storage tank, at any point?
    a. Yes
    b. No
    c. Unsure

If yes, continue to 14. If No, continue to next section

41. Rate your level of satisfaction with the water quality at your toilets when the system did not purge the stored greywater every 48 hours.
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 – Neutral / unsure
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

42. Rate your level of satisfaction with water savings of the system when the system did not purge the stored greywater every 48 hours.
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 - Neutral
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

43. Any additional comments on the purge or no-purge settings?

Use of "State of the Art" Technology

This system incorporates a control board, which allows the user to change chlorine levels, purge time, dye levels as well as has a screen readout of how much water the system has saved.

44. Rate your level of satisfaction with the display screen user interface.
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 – Neutral / unsure
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

45. Please comment on how the system performed if the power went out. (Did it restart automatically without issue)?

46. Any additional comments on the user interface of this greywater reuse system?

<u>Economics</u>

The retail capital cost for this greywater system is $2499.00.
Annual maintenance and operating costs were found to be minimal (less than $15/year).
Additionally, every year, the homeowner will have to pay for a backflow prevention test ($23-$150 depending on region).

47. How likely are you to pay the capital cost to have this system in your home?
    a. 1 – Very likely
    b. 2 – Somewhat Likely
    c. 3 – Neutral
    d. 4 – Somewhat Unlikely
    e. 5 – Very unlikely

48. How likely are you to pay the annual expenses to have this system in your home?
    a. 1 – Very likely
    b. 2 – Somewhat Likely
    c. 3 – Neutral
    d. 4 – Somewhat Unlikely
    e. 5 – Very unlikely

49. How likely are you to pay for a system in your home, if the capital cost was subsidized by a government incentive of $1000?
    a. 1 – Very likely
    b. 2 – Somewhat Likely
    c. 3 – Neutral
    d. 4 – Somewhat Unlikely
    e. 5 – Very unlikely

50. What is an acceptable payback period for you to consider a greywater reuse system in your home? (in years)

51. Any additional comments on the expenses associated with this greywater reuse system?

<u>Overall Satisfaction</u>

52. Rate your level of satisfaction with the overall performance of this greywater reuse system.
    a. 1 - Very satisfied
    b. 2 - Somewhat Satisfied
    c. 3 - Neutral
    d. 4 - Somewhat Unsatisfied
    e. 5 - Very Unsatisfied

53. Have you noticed a change in your water bill since installing this greywater reuse system?
    a. 1 - Major water savings
    b. 2 - Minor water savings
    c. 3 - No change
    d. 4 - Minor Increase in water usage
    e. 5 - Major increase in water usage
    f. Unsure

54. Do you believe that this greywater reuse system provides a reliable water supply to flush your toilets?
    a. 1 - Strongly agree
    b. 2 – Somewhat Agree
    c. 3 - Neutral
    d. 4 – Somewhat Disagree
    e. 5 - Strongly disagree

55. Would you continue to have this system in your house?
    a. 1 - Yes, definitely.
    b. 2 – Possibly
    c. 3 - Unsure
    d. 4 – Not unless some improvements are made.
    e. 5 - No, never again.

If they choose No…

56. What changes would have to happen in order to keep this greywater reuse system in your house?
    a. explain

57. Rate how much you agree with the following statement: "I would recommend this greywater system to someone else"
    a. 1 - Strongly agree
    b. 2 – Somewhat Agree
    c. 3 - Neutral
    d. 4 - Somewhat Disagree

        5 - Strongly disagree

User Survey #2 Responses

Summary of additional general maintenance comments:

- One user wrote that the system was advertised as less maintenance than previous generations, but in reality was not,
- difficult to justify (environmentally) the amount of chlorine pucks used in toilet tanks,
- a lot of ongoing alerts and beeping,
- if user doesn't routinely maintain the filter, system will still run but they won't be saving water,
- have to get used to cleaning filter but is ok with it

Toilet Maintenance

Summary of additional toilet maintenance comments:

- Too much effort, maintenance needs are excessive
- Not a good experience
- Quick buildup in the toilet tank and toilet bowl when chlorine levels are low
- need to empty toilet tank and apply bleach to fixture to reduce odor,
- have to place chlorine pucks in toilet tank,
- tank mould can't be removed with scrubbing and chlorine pucks,
- need a higher chlorine setting,
- need to fill with fresh water before vacationing,
- buildup is greater in toilet tanks with styrofoam liner
- Water in toilet tank doesn't empty completely,
- premature failure of rubber parts in toilets
- flush valves had to be replaced

Table 73: User survey responses regarding toilet maintenance.

After installing the greywater reuse system, what products are now used to clean the toilet bowls?		
Stronger Products	No Change in Product Strength	Most common response
3	**14**	Regular strength toilet bowl cleaner (e.g. Lysol, Toilet Duck)

After installing the greywater reuse system, how frequently do you now clean the toilet bowl(s)?			
More Frequently	No Change	Less Frequently	Most common response
4	**9**	4[1]	Once a week

After installing the greywater reuse system, how frequently do you now clean the toilet tank(s)?					
Every Week	Every Month	Every 2-3 Months	Every 6-12 Months	Only when chlorine runs out	Never
1	3	4	2	2	**5**

[1]Users completed the initial survey when they had already been using a greywater reuse system for more than a year. Their estimation on how much they cleaned prior to a greywater reuse system could be underestimated

Chlorine Maintenance

Summary of additional chlorine maintenance comments:

- Chlorine lid needs a handle so that it can be opened easily after sealed for an extended period of time,
- System is using too much chlorine with having to add chlorine pucks to the toilet tanks (worried about health effects of chlorine gas in home from excessive chlorine addition & still fouling in the tank - would rather use municipal water),
- need low chlorine level alarm (note the discussion of the chlorine alarm above)
- Frequent test visits affected chlorine maintenance,
- want higher chlorine setting

Table 74: User survey responses regarding chlorine maintenance.

How frequently did you add chlorine pucks?					
Every 2 weeks	Once a month	Every 2 - 3 months	Every 5-6 months	Once a year	Other
0[1]	1	**11**	3	0	2
Other:	2 users were unsure because chlorine pucks had been replaced during test visits.				
What size of chlorine pucks do you use?					
Small "Mini-pucks" - 50g		Large - "Super pucks" - 200g		Unsure	
7		9		1	

[1]This question intended to ask about adding chlorine pucks to the specified chlorine location in the greywater reuse system. However, one user indicated they had to add chlorine pucks to their toilet tanks every 2 weeks.

Table 75: Final performance comments from the User Survey.

House #	Any final comments on the performance of this greywater reuse system?
1	"I strongly support the concept of greywater reuse, but cannot recommend greywater solutions in good conscience unless the performance is stronger and the maintenance is reasonable. We experienced far too much toilet tank fouling. Morally, environmentally, right now I'm inclined to believe that it would be better to treat water municipally than to be dumping more chlorine into the air in my home (for the health of my family), and into the sewer (for the health of the water system)."
6	"This system is much better than the [Previous] system that we started with. The nearly maintenance-free system is great (no more cleaning the yucky filter or worrying about the hair trap at the shower drain)."
8	"I am very satisfied with the product and the people behind it, and will recommend the product. I would like to see integration into the web so that data collected can be exported and reviewed by the customer. It would also be nice if settings could be adjusted via a network api. It would also be helpful if a care package could be dropped off with dye pucks etc. on a quarterly basis via some kind of customer subscription. It's nice not to have to make that extra trip."
9	"Because it has been here since we built this home we do not have a clear picture exactly how much this is saving us since we have no comparison."
10	"I am extremely pleased with the customer follow-up from [the manufacturer]. Problems with system after initial install were quickly resolved and modifications have made the system more reliable and trouble free .The water quality testing also was excellent and done in a courteous manner."
12	"It doesn't seem to get along marvellously with pressure assisted toilets."
19	"I wish it chlorinated more and the filter was more easily accessible for cleaning instead of removing a bunch of screws, just because I need to do it once a month it seems."

Appendix E: Water Balance Results

Raw Program Code

An excerpt from the raw data is shown below:

```
“const unsigned int V_Table[20][2] = // first column pressure A2D reading, 2nd column volume
in liters * 8
{ {468,1632 },//(overflow)35.06"  1.508Volts
  {452,1536},//33.22  1.457
  {435,1440},//31.37  1.402
  {419,1344},//29.53  1.350
  {402,1256},//27.68  1.296
  {386,1160},//25.84  1.244
  {369,1064},//23.99  1.189
  {353,968},//22.15   1.138
  {336,872},//20.30   1.083
  {320,776}, //18.45  1.031
  {303,680}, //16.61  0.976
  {287,584},//14.76   0.925
  {270,496},//12.92   0.870
  {254,400},//11.07   0.818
  {237,304},//9.23    0.764
  {221,208},//7.38    0.712
  {204,112},//5.54    0.657
  {188,40},//3.69     0.606
  {172, 8},//1.18     0.554
  {155,4},//0         0.5
  };
```

The first column represents the “10 bit processor’s analog to digital value from the pressure sensor”. The second column is the current volume. After the “//”, the value is the depth of the water in inches, and the sensor voltage.

Table 76: Raw results from water balance program.

Depth	Volume	Sensor pressure	Sensor voltage	Bits 2^8	Bits 2^9	Bits 2^10
35.06	204	1.26216	1.509728	117	234	468
33.22	192	1.19592	1.456736	113	226	452
31.37	180	1.12932	1.403456	108	217	435
29.525	168	1.0629	1.35032	104	209	419
27.68	156	0.99648	1.297184	100	201	402
25.835	145	0.93006	1.244048	96	193	386
23.99	133	0.86364	1.190912	92	184	369
22.145	121	0.79722	1.137776	88	176	353
20.3	109	0.7308	1.08464	84	168	336
18.455	97	0.66438	1.031504	80	160	320
16.61	85	0.59796	0.978368	76	151	303
14.765	73	0.53154	0.925232	71	143	287
12.92	62	0.46512	0.872096	67	135	270
11.075	50	0.3987	0.81896	63	127	254
9.23	38	0.33228	0.765824	59	119	237
7.385	26	0.26586	0.712688	55	110	221
5.54	14	0.19944	0.659552	51	102	204
3.695	5	0.13302	0.606416	47	94	188
1.85	1	0.0666	0.55328	43	86	172
0.005	0.5	0.00018	0.500144	39	77	155

Table 77: Example of edited recorded water balance data.

Event	Relative Day	Hour	am or pm	Minute	Quantity (L)
Flush	0	10	pm	9	-11.875
Chlorination	1	6	am	45	0
Flush	1	6	am	49	-9.5
Chlorination	1	3	pm	0	0
Flush	1	5	pm	46	-13.625
Full Purge	2	3	am	5	-54.375
Gray Added	2	6	am	33	36.5
Filter Clean	2	6	am	34	0
Mini Purge	2	7	am	33	0

Greywater Production

Table 78: Average daily greywater production, sorted by household with the highest greywater production volumes to least.

House #	# of Res.	Estimated type of producer	Avg. Daily GW Production (Lhhd)	Avg. Daily GW Production (Lcd)
1	9	High	122.233	13.581
3	4	High	120.767	30.192
20	3	High	101.896	33.965
21	5	Medium	93.067	18.613
19	3	High	84.003	28.001
8	3	High	82.501	27.500
14	4	High	79.266	19.816
23	4	-	76.010	19.003
9	2	High	71.130	35.565
15	5	High	71.124	14.225
2	4	High	61.301	15.325
18	4	Medium	60.919	15.230
6	4	High	53.727	13.432
5	3	High	49.142	16.381
16	2	High	45.038	22.519
7	4	High	34.276	8.569
12	2	Medium	31.325	15.663
4	4	Medium	29.619	7.405
13	3	Medium	24.782	8.261
10	2	Low	23.840	11.920
	Average		65.798	18.758

Table 79: Summary of average shower frequency (per household and per resident) and average shower volumes.

		Oct - Nov			Nov - Dec			Dec - Jan I			Jan I - Jan II			Jan II - Feb			Overall Averages		
House #	# of Res.	# of showers/HH/day	# showers/capita/day	Avg. shower volume (L)	# of showers/HH/day	# showers/capita/day	Avg. shower volume (L)	# of showers/HH/day	# showers/capita/day	Avg. shower volume (L)	# of showers/HH/day	# showers/capita/day	Avg. shower volume (L)	# of showers/HH/day	# showers/capita/day	Avg. shower volume (L)	# of showers/HH/day	# showers/capita/day	Avg. shower volume (L)
1	9	3.90	0.43	33.337	3.30	0.37	34.712	2.67	0.30	35.743	2.87	0.32	33.227	3.48	0.39	43.341	3.24	0.36	36.072
2	4	-	-	-	3.75	0.94	24.538	2.61	0.65	21.925	0.80	0.20	32.708	2.47	0.62	20.534	2.41	0.60	24.926
3	4	2.95	0.74	38.396	3.24	0.81	34.733	2.59	0.65	41.202	3.20	0.80	36.219	3.42	0.85	38.041	3.08	0.77	37.718
4	4	-	-	-	1.41	0.35	13.354	1.63	0.41	23.889	1.40	0.35	20.613	1.67	0.42	14.020	1.53	0.38	17.969
5	3	1.14	0.38	12.215	1.79	0.60	20.757	-	-	-	1.93	0.64	39.095	1.84	0.61	32.457	1.68	0.56	26.131
6	4	-	-	-	-	-	-	2.29	0.57	24.58	2.07	0.52	21.246	2.33	0.58	23.014	2.23	0.56	22.947
7	4	-	-	-	-	-	-	0.67	0.17	49.512	0.80	0.20	47.531	0.53	0.13	52.250	0.67	0.17	49.764
8	3	2.14	0.71	37.949	2.66	0.89	32.114	2.18	0.73	31.448	3.29	1.10	24.935	-	-	-	2.56	0.85	31.611
9	2	1.91	0.95	31.226	1.74	0.87	36.934	1.79	0.90	41.587	1.80	0.90	42.218	2.13	1.07	32.605	1.87	0.94	36.914
10	2	0.82	0.41	45.590	0.62	0.31	37.149	0.50	0.25	41.063	0.80	0.40	21.198	0.73	0.37	21.989	0.69	0.35	33.398
12	2	0.82	0.41	32.694	0.73	0.37	33.426	0.86	0.43	33.766	1.07	0.53	31.180	1.47	0.73	25.966	0.99	0.49	31.406
13	3	0.36	0.12	30.234	1.29	0.43	22.792	1.14	0.38	25.927	1.13	0.38	19.485	1.47	0.49	17.670	1.08	0.36	23.222
14	4	1.50	0.38	50.504	1.59	0.40	54.908	1.58	0.39	45.976	1.93	0.48	38.996	1.73	0.43	42.548	1.67	0.42	46.586
15	5	1.86	0.37	18.107	1.60	0.32	31.745	2.77	0.55	31.145	3.20	0.64	29.716	2.40	0.48	29.618	2.37	0.47	28.066
16	2	-	-	-	1.43	0.71	35.156	1.08	0.54	36.897	1.13	0.57	30.449	1.26	0.63	39.534	1.23	0.61	35.509
17	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	4	1.41	0.35	36.565	1.62	0.41	46.880	1.44	0.36	46.346	1.40	0.35	53.304	0.93	0.23	27.163	1.36	0.34	42.052
19	3	-	-	-	-	-	-	-	-	-	0.87	0.29	55.865	2.07	0.69	56.315	1.47	0.49	56.090
20	3	-	-	-	-	-	-	2.86	0.95	36.879	-	-	-	2.93	0.98	31.345	2.89	0.96	34.112
21	5	-	-	-	1.84	0.37	45.608	1.94	0.39	46.377	2.40	0.48	45.868	1.27	0.25	57.645	1.86	0.37	48.875
23	4	3.80	0.95	33.211	2.24	0.56	40.585	2.64	0.66	27.426	2.40	0.60	39.191	1.71	0.43	27.284	2.56	0.64	33.539
Average		1.88	0.52	33.34	1.93	0.54	34.09	1.85	0.52	35.65	1.82	0.51	34.90	1.89	0.55	33.33	1.87	0.535	34.845

Table 80: Average number of showers daily (per house hold and per resident) and average shower volume.

		Overall Averages		
House #	# of Res.	# of showers/HH/day	# showers/capita/day	Avg. shower volume (L)
1	9	3.24	0.36	36.072
2	4	2.41	0.60	24.926
3	4	3.08	0.77	37.718
4	4	1.53	0.38	17.969
5	3	1.68	0.56	26.131
6	4	2.23	0.56	22.947
7	4	0.67	0.17	49.764
8	3	2.56	0.85	31.611
9	2	1.87	0.94	36.914
10	2	0.69	0.35	33.398
12	2	0.99	0.49	31.406
13	3	1.08	0.36	23.222
14	4	1.67	0.42	46.586
15	5	2.37	0.47	28.066
16	2	1.23	0.61	35.509
17	2	-	-	-
18	4	1.36	0.34	42.052
19	3	1.47	0.49	56.090
20	3	2.89	0.96	34.112
21	5	1.86	0.37	48.875
23	4	2.56	0.64	33.539
Average		1.87	0.535	34.845

Greywater Consumption

Table 81: Average daily greywater consumption, sorted by household with the highest greywater consumption volumes to least.

					Overall Consumption		Flush Details		
House #	**# of Res**	**# toilets**	**Type of Toilet (Lpf)**	**Estimated Type of Consumer**	**Avg. Daily (Lhhd)**	**Avg. Daily (Lcd)**	**# of flushes/ HH/day**	**# of flushes/ capita/day**	**Avg. flush volume (L)**
1	9	3	Dual Flush (3/6)	High	-123.618	-13.735	24.87	2.76	4.513
13	3	2	HET (<4.8)	High	-117.762	-39.254	30.71	10.24	4.846
21	5	3	2 HET (<4.8) & 1 Dual (3/6)	Low	-115.617	-23.123	16.42	3.28	6.556
19	3	2	Low Flush Toilet (6-12)	Low	-104.665	-34.888	7.80	2.60	12.935
14	4	3	2 HET (<4.8) & 1 Press. Assist	Medium	-103.000	-25.750	9.98	2.49	9.820
9	2	3	13+ L	Medium	-102.116	-51.058	14.27	7.13	6.661
23	4	3	Dual Flush (3/6)	-	-91.116	-22.779	19.02	4.75	5.048
4	4	5	HET (<4.8)	Medium	-87.779	-21.945	16.73	4.18	4.743
2	4	3	Dual Flush (3/6)	Low	-80.769	-20.192	17.64	4.41	4.108
16	2	2[2]	Low (6 - 12) & Dual (3/6)	Medium	-71.085	-35.543	6.86	3.43	9.817
20	3	2	Dual Flush (3/6)	Low	-64.319	-21.440	11.73	3.91	4.997
3	4	3	Dual Flush (3/6)	Low	-63.249	-15.812	14.32	3.58	3.921
5	3	3	Low Flush Toilet (6 - 12)	Low	-60.544	-20.181	8.26	2.75	6.661
8	3	4	3 Dual (3/6), 1 Low (6-12)	High	-52.056	-17.352	10.71	3.57	4.399
7	4	2	Dual Flush (3/6)	Medium	-45.394	-11.349	6.83	1.71	6.170
15	5	3[1]	HET (<4.8)	Low	-42.899	-8.580	13.44	2.69	2.746
6	4	2	HET (<4.8)	Low	-36.625	-9.156	7.32	1.83	4.511
12	2	2	Dual Flush (3/6) & Press. Assist	Low	-28.438	-14.219	6.00	3.00	4.264
18	4	2	Dual Flush (3/6)	Medium	-28.235	-7.059	5.98	1.50	4.221
10	2	1	HET (<4.8)	Medium	-27.587	-13.794	5.06	2.53	4.920
	Overall Average				-72.344	-21.360	12.70	3.62	5.79

[1] Total of 4 toilets in House 15, but the fourth was under renovation and not in use during testing.

[2] Total of 3 toilets in House 16, but the third toilet is not connected to the greywater system and is used only by the children in the home (not included in resident count).

Table 82: Summary of greywater consumption sorted by toilet type and average flush volume.

				Overall Averages		
House #	# of Res.	# of toilets	**Type of Toilet (Lpf)**	# of flushes/HH/day	# flushes/capita/day	Avg. flush volume (L)
9	2	3	13+ L	6.06	7.53	8.135
19	3	2	Low Flush Toilet (6 - 12)	7.80	2.60	12.935
5	3	3	Low Flush Toilet (6 - 12)	2.88	8.37	5.011
16	2	2[2]	Low Flush Toilet (6 - 12) & Dual (3/6)	3.28	11.69	4.430
8	3	4	3 Dual (3/6) & 1 Low (6-12)	3.78	6.20	6.855
1	9	3	Dual Flush (3/6)	2.86	6.32	12.605
23	4	3	Dual Flush (3/6)	3.99	10.98	11.509
2	4	3	Dual Flush (3/6)	3.59	6.86	8.872
20	3	2	Dual Flush (3/6)	3.07	10.03	7.364
3	4	3	Dual Flush (3/6)	3.40	6.03	7.283
7	4	2	Dual Flush (3/6)	1.80	6.40	5.417
18	4	2	Dual Flush (3/6)	1.65	8.89	4.992
12	2	2	Dual Flush (3/6) & Press. Assist	3.07	6.83	3.999
21	5	3	2 HET (<4.8) & 1 Dual (3/6)	3.29	11.23	10.709
13	3	2	HET (<4.8)	4.86	8.27	16.856[3]
15	5	3[1]	HET (<4.8)	3.67	6.75	9.222
4	4	5	HET (<4.8)	4.41	6.67	8.050
6	4	2	HET (<4.8)	1.89	7.45	5.084
10	2	1	HET (<4.8)	1.94	6.58	3.532
14	4	3	2 HET (<4.8) & 1 Press. Assist	2.74	11.30	6.990

[1] Total of 4 toilets in House 15, but the fourth was under renovation and not in use during testing.
[2] Total of 3 toilets in House 16, but the third toilet is not connected to the greywater system and is used only by the children in the home (not included in resident count).
[3] Potentially had a leaking toilet.

Freshwater Added

Table 83: Summary of fresh water added to greywater system used for flushing.

	Total volumes over testing period					
	With Purge			No Purge		
House	Municipal Added (L)	Water used to Flush (L)	% Fresh Water	Municipal Added (L)	Water used to Flush (L)	% Fresh Water
1	2411.750	8720.968	27.655	925.691	4493.418	20.601
2	1478.375	4723.704	31.297	748.918	2315.585	32.342
3	1398.973	7087.398	19.739			
4	5598.625	8168.478	68.539			
5	2096.500	4997.915	41.947			
6	1060.625	1753.130	60.499	148.739	1132.478	13.134
7	1957.625	3025.700	64.700	245.500	1333.587	18.409
8	833.625	4185.906	19.915			
9	3282.750	7957.061	41.256	545.750	3169.000	17.222
10	1338.500	2346.479	57.043	159.500	716.250	22.269
12	623.500	3182.999	19.588			
13	8066.375	8392.400	96.115			
14	4583.125	11546.397	39.693			
15	3757.375	4336.257	86.650			
16	3559.250	7026.625	50.654			
18	1181.625	2959.133	39.931	90.875	400.700	22.679
19	950.625	3007.000	31.614			
20	645.375	3409.549	18.928			
21	3992.875	11689.774	34.157			
23	2906.967	8061.711	36.059			
Average			44.299%			20.951%

Table 84: Average daily municipal added volumes per household and per capita.

		With Purge		No Purge	
House	**# Residents**	L/HH/day	L/capita/day	L/HH/day	L/capita/day
1	9	33.185	3.687	26.100	2.900
2	4	26.400	6.600	24.964	6.241
3	4	12.462	3.116		
4	4	59.040	14.760		
5	3	24.742	8.247		
6	4	20.797	5.199	4.958	1.239
7	4	30.588	7.647	8.183	2.046
8	3	8.384	2.795		
9	2	42.045	21.023	18.192	9.096
10	2	17.034	8.517	5.317	2.658
12	2	5.010	2.505		
13	3	117.623	39.208		
14	4	39.924	9.981		
15	5	32.634	6.527		
16	2	36.794	18.397		
17	2	-	-		
18	4	11.531	2.883	6.491	1.623
19	3	32.678	10.893		
20	2	12.442	6.221		
21	5	40.961	8.192		
23	4	30.279	7.570		
Overall Average		31.728	9.698	13.458	3.686

Purged Water

Table 85: Average daily purge volumes for each house, by month and as averages.

	Average volume purged (L/HH/day)					Overall Average	
House #	Oct - Nov	Nov – Dec	Dec - Jan I	Jan I - Jan II	Jan II - Feb	With Purge (L/HH/day)	No Purge (L/HH/day)
1	-48.167	-63.277	-40.630	-57.350	-75.077	-50.691	-66.214
2	-	-55.089	-26.813	-2.642	-5.858	-40.951	-4.250
3	-90.057	-70.302	-58.188	-90.358	-98.073	-81.395	
4		-3.099	-8.102	-3.200	-3.867	-4.567	
5	-11.051	-14.569	-	-42.800	-29.493	-24.478	
6	-	-	-20.850	-3.242	-5.317	-20.850	-4.279
7	-	-	-25.459	-1.325	-1.617	-25.459	-1.471
8	-76.057	-94.776	-78.813	-13.714		-65.840	
9	-18.176	-15.757	-30.411	-3.100	-3.908	-21.448	-3.504
10	-26.739	-14.515	-12.984	-1.733	-1.417	-18.079	-1.575
12	-4.869	-30.388	-60.941	-16.642	-59.892	-34.546	
13	-0.733	-2.536	-14.389	-8.033	-14.958	-8.130	
14	-12.551	-30.690	-29.178	-36.292	-32.025	-28.147	
15	-6.455	-24.296	-31.827	-31.408	-38.633	-26.524	
16	-	-5.853	-11.677	-5.475	-23.495	-11.625	
18	-32.864	-30.289	-28.191	-13.167	-3.795	-26.128	-3.795
19	-	-	-	-20.475	-48.839	-34.657	
20	-	-	-75.333	-	-87.518	-81.426	
21	-	-24.213	-16.198	-39.558	-18.100	-24.517	
23	-1.850	-35.392	-26.960	-29.083	-16.338	-21.925	
Overall Average						-32.569	-12.155

[1]Values with black boxes represent systems that were operating without the purge function.

Water Savings

Table 86: Summary of daily average water savings

House #	# Res.	Age?	# toilets	Type of Toilet (Lpf)	Oct - Nov	Nov - Dec	Dec - Jan I	Jan I - Jan II	Jan II - Feb	Average (Purge)	Average (No Purge)
1	9	35,34,23,11,9, 7,4,2,1	3	Dual Flush (3/6)	117.169	86.469	68.885	83.721	110.091	90.841	96.906
2	4	40,41,9,7	3	Dual Flush (3/6)	-	67.422	48.483	45.928	58.517	57.952	52.222
3	4	42,43,15,13	3	Dual Flush (3/6)	43.527	54.070	48.718	54.640	52.976	50.786	
4	4	43,40,39,5	5	HET (<6)	-	15.869	36.666	34.756	27.667	28.739	
5	3	44,37,10	3	Low Flush Toilet (6 - 12)	31.288	32.409	-	49.776	42.534	39.002	
6	4	40,38,4,2	2	HET (<6)	-	-	13.579	28.416	37.167	13.579	32.791
7	4	41,38,5,3,	2	Dual Flush (3/6)	-	-	16.689	40.592	31.947	16.689	36.270
8	3	32,32,3	4	3 Dual (3/6), 1 Low (6-12)	29.511	42.986	49.406	52.786	-	43.672	
9	3	46,37	3	13+ L	51.737	62.157	59.281	83.233	91.650	57.725	87.442
10	2	62,59	1	HET (<6)	18.464	10.688	9.933	18.275	18.842	13.028	18.558
12	2	55,17	2	Dual Flush (3/6)	26.244	19.983	15.663	22.117	33.800	23.561	
13	3	40,40,1	2	HET (<6)	-10.584	-26.399	6.253	5.675	19.017	-1.208	
14	4	35,32,4,1	3	2 HET (<6) & 1 Press. Assist	60.686	58.978	54.564	73.532	67.617	63.075	
15	5	40,38,11,9,5	4	HET (<6)	-35.196	-13.151	15.789	39.425	44.460	10.265	
16	2	35,37	2	Low (6 - 12) & Dual (3/6)	-	43.415	28.517	34.408	30.826	34.292	
17	2	58,59	2	Dual Flush (3/6)	-	-	-	-	-	-	
18	4	32,32,5,3	2	Dual Flush (3/6)	6.237	20.266	21.601	18.329	22.130	16.608	22.130
19	3	38,38,8	2	Low Flush Toilet (6-12)	-	-	-	40.750	103.223	71.987	
20	3	34,31,0	2	Dual Flush (3/6)	-	-	59.618	-	44.137	51.878	
21	5	32,31,8,6,5	3	2 HET (<6) & 1 Dual (3/6)	-	69.896	79.991	88.468	60.269	74.656	
23	4				89.175	51.503	53.344	75.556	34.607	60.837	

Table 87: Average daily water balance results, with and without the purge function, sorted from highest household water savings to lowest.

		Avg. Daily Water Balance			
House #	**# Res.**	**With Purge (L/day)**	**With Purge (L/day/capita)**	**No Purge (L/day)**	**No Purge (L/day/capita)**
1	9	90.841	10.093	96.906	10.767
21	5	74.656	14.931	-	-
19	3	71.987	23.996	-	-
14	4	63.075	15.769	-	-
23	4	60.837	15.209	-	-
2	4	57.952	14.488	52.222	13.056
9	3[1]	57.725	19.242	87.442	29.147
20	3[1]	51.878	17.293	-	-
3	4	50.786	12.697	-	-
8	3	43.672	14.557	-	-
5	3	39.002	13.001	-	-
16	2[2]	34.292	17.146	-	-
4	4	28.739	7.185	-	-
12	2	23.561	11.781	-	-
7	4	16.689	4.172	36.270	9.067
18	4	16.608	4.152	22.130	5.533
6	4	13.579	3.395	32.791	8.198
10	2	13.028	6.514	18.558	9.279
15	5	10.265	2.053	-	-
13	3	-1.208	-0.403	-	-
17	2	-	-	-	-
AVG	**-**	40.898	11.364	49.474	12.150

[1]One resident is a newborn, and is considered in greywater production values but not in toilet flushing values.

[2]Occasionally, one child would use the toilets connected to the greywater system, increasing the number of residents at House 16 to three.

Appendix F: Water Quality

BOD_5

Table 88: Complete BOD_5 results from Maxxam laboratories.

BOD_5 (mg/L)								
Month/Year	**Sample Location**	**House 1**	**House 2**	**House 6**	**House 7**	**House 9**	**House 10**	**House 11**
08/14	**BT**	60	160	-	8	170	93	95
	GS	35	ND	31	2	110	29	60
	TT	79	ND	38	5	69	27	51
10/14	**BT**	-	-	-	-	92	-	-
	GS	60	-	-	-	ND	-	-
	TT	25	-	-	-	14	-	-
11/14	**BT**	85	150	68	ND	170	110	36
	GS	39	66	38	9	ND	38	ND
	TT	44	52	41	7	86	30	26
12/14	**BT**	-	-	-	-	130	21	ND
	GS	ND[1]	66	-	-	89	16	100
	TT	4	96	-	-	83	15	ND
01/15 I	**BT**	58	150	41	ND	140	>58	-
	GS	17	13	27	160	100	ND	-
	TT	30	70	29	140	83	ND	-
01/15 II *"No-Purge"*	**BT**	**93**[2]	**130**	**23**	**4**	**110**	**22**	-
	GS	**4**	**ND**	**6**	**37**	**83**	**ND**	-
	TT	**81**	**4**	**6**	**41**	**91**	**14**	-
02/15 *"No-Purge"*	**BT**	**85**	**19**	**-**	**4**	**140**	**84**	44
	GS	**84**	**83**	**ND**	**12**	**100**	**47**	ND
	TT	**62**	**67**	**ND**	**16**	**47**	**66**	ND

[1]ND: Not detected

[2]Values with double lined border, and filled with light grey were taken when the system was operating without the purge function.

COD

Table 89: Complete COD results from Maxxam laboratories.

COD (mg/L)								
Month/Year	**Sample Location**	**House 1**	**House 2**	**House 6**	**House 7**	**House 9**	**House 10**	**House 11**
08/14	**BT**	150	200	-	22	210	160	220
	GS	170	10	68	14	190	71	120
	TT	170	29	70	30	140	67	120
10/14	**BT**	-	-	-	-	180	-	-
	GS	100	-	-	-	8.6	-	-
	TT	64	-	-	-	28	-	-
11/14	**BT**	120	150	100	6.2	250	180	55
	GS	80	110	72	24	230	86	49
	TT	72	67	68	35	190	86	47
12/14	**BT**	-	-	-	-	190	50	ND
	GS	ND[1]	120	-	-	91	38	200
	TT	9.8	170	-	-	130	41	ND
01/15 I	**BT**	110	210	77	ND	180	100	-
	GS	66	20	65	220	150	6.5	-
	TT	78	220	48	240	130	13	-
01/15 II *"No-Purge"*	**BT**	150[2]	210	50	7.9	190	65	-
	GS	59	6.4	15	78	130	72	-
	TT	150	19	2	120	160	77	-
02/15 *"No-Purge"*	**BT**	160	36	-	4.7	190	110	87
	GS	250	76	42	60	170	100	ND
	TT	140	130	40	44	170	100	ND

[1]ND: Not detected
[2]Values with double lined border, and filled with light grey were taken when the system was operating without the purge function.

Colour

Table 90: Average colour results for municipal, bathtub, greywater reuse system and toilet tank samples at each house.

	With Purge				No Purge	
Sample Location	**M**	**BT**	**GS**	**TT**	**GS**	**TT**
H1	18	373	252	282	199	537
H2	36	521	239	270	173	210
H3	42	411	294	183	-	-
H4	50	644	295	151	-	-
H5	33	849	344	298	-	-
H6	26	234	113	186	88	57
H7	40	49	413	484	141	200
H8	42	583	296	384	-	-
H9	32	510	270	262	210	297
H10	32	459	199	215	280	298
H11	12	345	140	165	-	-
H13	26	693	124	140	-	-
H15	37	950	569	526	-	-
H16	37	424	296	184	-	-
H18	39	670	225	270	225	219
H19	45	207	174	271	-	-
H20	63	1037	215	180	-	-
H21	37	1654	298	256	-	-
H22	46	443	280	296	-	-

Hardness

Table 91: Hardness measurements and results.

	House Number	Water Softener?	# of Samples taken	Average Hardness (mg/L CaCO3)
Guelph	1	Yes	0	-
	2	Yes	0	-
	3	Yes	1	0
	4	Yes	2	6
	5	Yes	1	0
	6	Yes	0	-
	7	**No**	2	377.5
	8	Yes	0	-
	9	Yes	1	-
	10	**No**	2	405
	11	Yes	0	-
	12	Yes	2	-
	13	**No**	2	310
Barrie	14	Yes	0	-
	15	**No**	0	-
	16	Yes	1	0
	18	**No**	2	107.5
	19	**No**	2	162.5
	20	**No**	2	110
	21	**No**	0	-
Well	22	Yes	1	0

Odour

Table 92: Summary of odour measurements.

			Total	Greywater	Soap	Chlorine	None
With Purge	Municipal	# of Samples	106	0	0	0	106
		%	-	0%	0%	0%	100%
	Bathtub	# of Samples	88	0	65	0	23
		%	-	0%	74%	0%	26%
	Greywater Reuse System	# of Samples	93	6	17	56	14
		%	-	6%	18%	60%	15%
	Toilet Tank	# of Samples	87	19	1	43	24
		%	-	22%	1%	49%	28%
No Purge	Greywater Reuse System	# of Samples	13	1	0	12	0
		%	-	8%	0%	92%	0%
	Toilet Tank	# of Samples	13	4	0	6	3
		%	-	31%	0%	46%	23%

Appendix G: Energy Results

The Kill-a-Watt energy meters logged energy usage for the entirety of the testing process. When a house was not able to be visited to clear the memory of the water balance data, the energy meter continued. Therefore, water consumption events continued to take place, but were not being tracked, while energy consumption continued to record. In order to calculate the energy intensity (kWh/m^3 of water used to flush), it was ensured that the total kWh consumed value aligned with the total volume of treated water presented. For example, only 77 days of water consumption data were collected at House 11, while the energy meter recorded 163 days of energy consumption.

In Ontario, most electricity consumers pay for energy at "time-of-use" prices, where electricity rates are higher at peak times, which are between 7am and 7pm, with highest rates from 11am to 5pm (Ontario Energy Board, 2015). These energy rates can affect the total energy cost associated with greywater reuse systems, especially since water consumption peak times seem to correlate with energy peak times.

Table 93: Weighted average energy cost for Ontario, as of April 30, 2015.

Electricity Rates ($/kWh)	7am - 11am	11am - 5pm	5pm - 7pm	7pm - 7am
Weekdays ($)	0.14	0.114	0.14	0.077
Weekends ($)	0.077	0.077	0.077	0.077
Weekdays (hours)	20	30	10	60
Weekends (hours)	8	12	4	24
Weighted Cost for electricity ($)	0.09485			

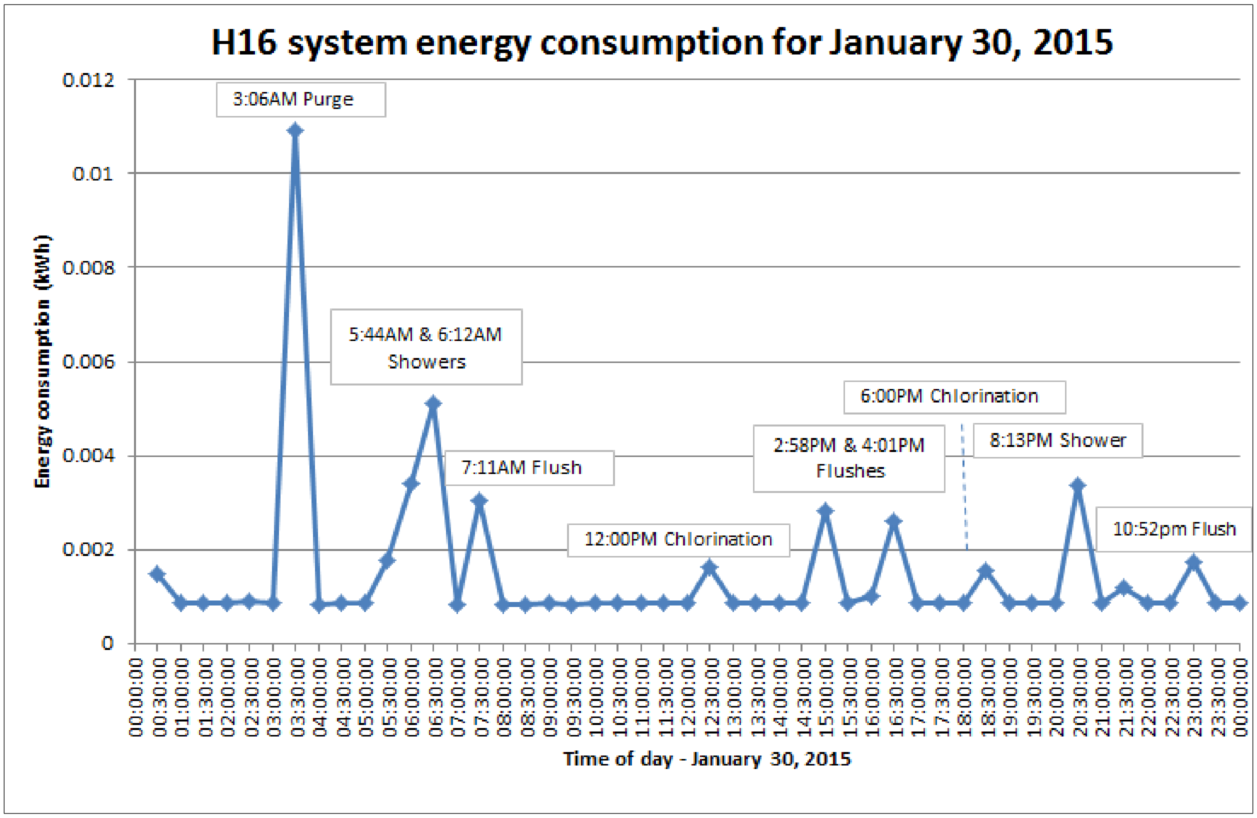


Figure 24: Example of detailed energy consumption at House 16 for January 30, 2015.

Appendix H: Durability Assessment

Table 94: Durability results for the greywater reuse system, at each house in the pilot study.

	House																						
Failure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	Total
Pump issues		●[1]			●					●					●						●	●	4 of 23
Clogged greywater filter		●		●	●				●	●				n/a[2]	●	●			●	●	●	●	11 of 22
Clogged pump filter					●																●		2 of 23
External Water Leakage		●	●	●		●			●			●	●				●				●		9 of 23
Flooding / Overflow																							0 of 23
Corrosion	●	●	●	●	●	●	●	●	●		●	●	●									●	13 of 23
Insufficient Pressure						●		●					●		●						●		5 of 23
Insufficient water supply									●														1 of 23
Limited access to filter																							0 of 23
Limited access to chlorine	●		●																				2 of 23
Film Buildup in toilet tank	●	●	●	●	●		●	●	●	●		n/a	●	n/a	●		●	●	●	●	●	n/a	16 of 20
Toilet Flush Valve issues	●		●										●								●	●	4 of 23
Deteriorated toilet flush valve							●																1 of 23
Broken Screen								●	●		●				●				●		●		6 of 23
Incorrect time on screen	●		●	●		●		●	●			●		●	●			●	●			●	12 of 23
Flashing notifications	●	●	●	●	●	●	●	●	●			●	●		●		●	●	●		●	●	17 of 23
Fragmented text on screen		●																			●		1 of 23

[1]A black point indicates this failure occurred at least once at this house.
[2] n/a means this measurement was not recorded at this house.

Table 95: Durability assessment of the greywater reuse system.

Failure	Failure Frequency		Description
Film Buildup in toilet tank	16 of 20	80%	Film (grey, green, or black) would build up at the water level in the toilet tank as well as in the flush valve components.
Flashing notifications	17 of 23	74%	An early version of the program installed on the greywater reuse system prompted unnecessary "check filter", "toilet leak detected" or "pump overrun" flashing screen notifications.
Corrosion	13 of 23	57%	Screws and solenoids surrounding the tank lid became corroded, due to leakage or the strong chlorine environment.
Incorrect time on screen	12 of 23	52%	The recorded time on the screen was not correct.
Clogged greywater filter	11 of 22	50%	The filter mesh would clog with a thin, semi-transparent undetermined film that would force greywater to bypass the system and not be reused.
External Water Leakage	9 of 23	39%	Water would pool on top of tank lid.
Broken Screen	6 of 23	26%	The screen would be blank and none of the buttons would work for the user to operate the system. Treatment events continued.
Insufficient Pressure	5 of 23	22%	The system supplied pressure to the toilet tanks through an external pressure accumulator tank, which would deflate.
Toilet Flush Valve issues	5 of 23	22%	Toilets were leaking because their toilet flush valves were not closing completely either due to deterioration of valves or blockage from greywater film.
Pump issues	4 of 23	17%	The pump often would pulse every couple of minutes at some houses, rather than filling the toilet after a flush, consistently.
Clogged pump filter	2 of 23	9%	The filter at the base of the tank prior to the pump would get clogged and not be able to draw water in to flush.
Limited access to chlorine	2 of 23	9%	The gasket on the lid to the chlorine store was faulty and would not open without an additional grip or tool.
Insufficient water supply	1 of 23	4%	Municipal water was not automatically refilling the greywater reuse tank when it was empty. Users had to run bathtub for water supply.
Deteriorated toilet flush valve	1 of 23	4%	Potentially due to excess of chlorine in the water, due to previous greywater reuse system that was attached or typical aging.
Fragmented text on screen	1 of 23	4%	The screen did not read out clearly and the user was not able to follow screen instructions.
Flooding / Overflow	0 of 23	0%	Did not occur with this system.
Limited access to filter	0 of 23	0%	Did not occur with this system.

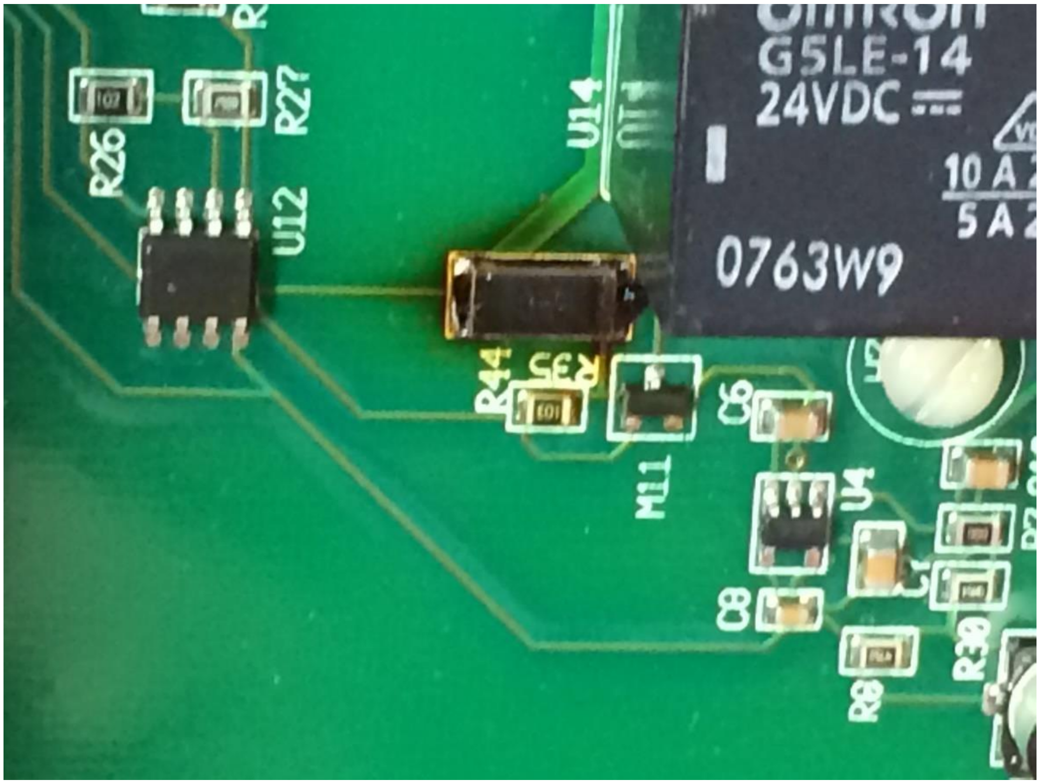


Figure 25: Visibly burned control circuit board.


Figure 26: Clogged pump filter from House 22.

Table 96: Comparison between presence of natural hygienic products and water softeners, with filter issues.

House Number	Use products advertised as "Natural Products"?	Water Softener?	Filter Buildup Issues?
1	●	●	
2		●	●
3	●	●	
4		●	●
5		●	●
6	●	●	
7		No	
8		●	
9	●	●	●
10	●	No	●
11		●	
12		●	
13		No	
14	●	●	n/a
15		No	●
16		●	●
18		No	
19		No	
20	●	No	●
21	●	No	●
22	●	●	●

Appendix I: Maintenance

Figure 27: Toilet tank at House 9, with severe black mould buildup in the toilet tank.

Appendix J: Economics

Summary of additional user comments on the expenses associated with this greywater reuse system:

- chlorine use excessive in some homes (by adding to toilet tanks), therefore operating costs are higher,
- not feasible without incentives and pilot study subsidizing,
- capital cost is too high for wide acceptance,
- more likely to install a system if water rates increase, decreasing payback period,
- not willing to pay $150 for annual backflow prevention test.

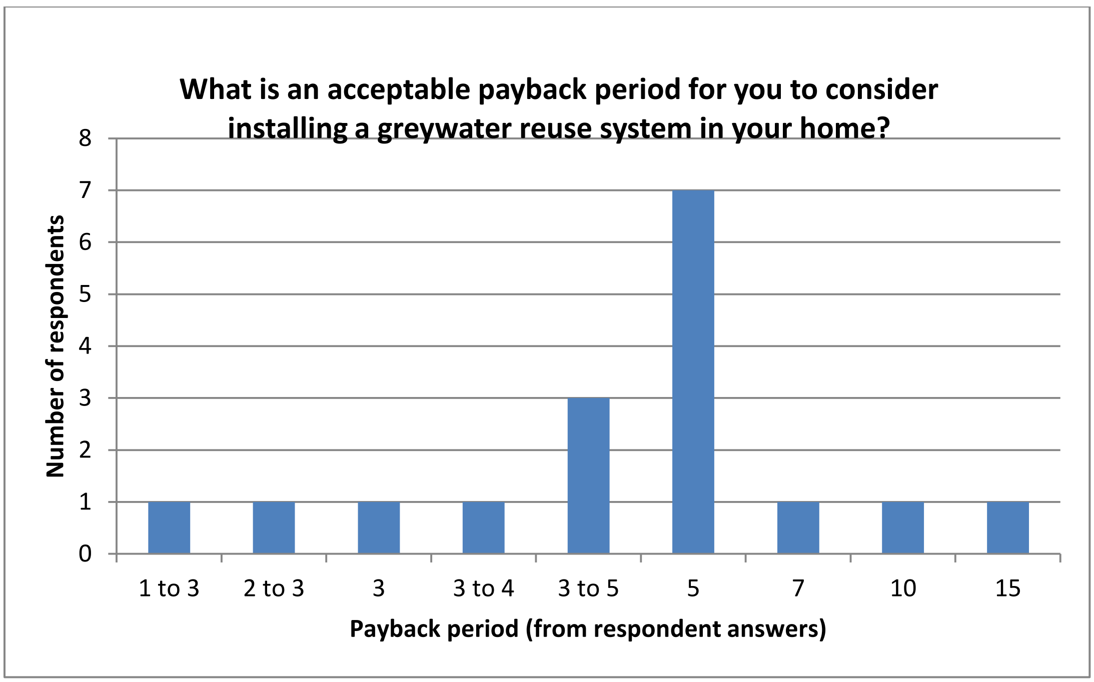


Figure 28: Range of acceptable payback periods, as identified by survey respondents.

Table 97 below shows details from installation and repairing invoices. Invoices were available for houses beyond the houses which were chosen for the field study, and these houses were labelled Houses A through F.

Table 97: Installation details for Houses 1 through 23, and Houses A through F.

House	Roughed-in, replacement or new install?	House type	Plumber	Cost ($)	Installation ($)	Repairs ($)	Total ($)
1	Replacement		1	14661.51			862.44
2	Replacement		1				862.44
3	Replacement		1				862.44
4	Replacement		1				862.44
5	Replacement		1				862.44
6	Replacement		1				862.44
7	Replacement		1				862.44
8	Replacement		1				862.44
9	Replacement		1				862.44
10	Replacement		1				862.44
11	Replacement		1				862.44
12	Replacement		1				862.44
13	Replacement		1				862.44
A	Replacement		1				862.44
B	Replacement		1				862.44
C	Replacement		1				862.44
D	Replacement		1				862.44
E	New install	Single story bungalow	2				2012.88
F	New install	Single story bungalow	2		2063.45	1025.00	3088.45
14	New install	Two story home	2				2912.26
15	New install	Two story home	2				2269.24
16	New install	Two story home	2				2756.40
17	New install	Two story home	2		2179.76	2214.80	4394.56
18	New install	Two story home	2		1740.10	2621.60	4361.70
19	New install	Single story bungalow	2				1123.38
20	New install	Single story bungalow	2		1818.86	1260.00	3078.86
21	New install	Two story home	2		2393.89	2245.00	4638.89
22	Replacement	Single story bungalow	3				296.63
23	Roughed-in	Three story home	4				

Best Economic Case Analysis

Table 98: Best case economic scenario for the tested greywater reuse system.

BEST CASE									
Capital Cost ($)	-$1,499.00								
Installation Cost ($)	-$862.44								
Total Immediate Costs ($)	**-$2,361.44**								
Year	1	2	3	4	5	...	10	11	12
Costs									
Annual Maintenance	-$8.04	-$8.04	-$8.04	-$8.04	-$8.04	...	-$8.04	-$8.04	-$8.04
Annual Operation	-$1.55	-$1.55	-$1.55	-$1.55	-$1.55	...	-$1.55	-$1.55	-$1.55
Total Annual Maintenance & Operation Costs	-$9.59	-$9.59	-$9.59	-$9.59	-$9.59	...	-$9.59	-$9.59	-$9.59
Benefits									
Annual Water Savings (m^3)	35.371	35.371	35.371	35.371	35.371	...	35.371	35.371	35.371
Combined Water Rates (with 5% annual increase) ($/$m^3$)	$4.44	$4.66	$4.90	$5.14	$5.40	...	$6.89	$7.23	$7.59
Annual Water Savings ($)	$157.05	$164.90	$173.14	$181.80	$190.89	...	$243.63	$255.81	$268.60
Balance (Annual Benefits - Annual Costs)	$147.46	$155.31	$163.55	$172.21	$181.30	...	$234.04	$246.22	$259.01
Net Cash Flow	-$2,213.98	-$2,058.68	-$1,895.12	-$1,722.91	-$1,541.61	...	-$482.03	-$235.81	$23.20

Table 99: 5 Year Payback Analysis - Best case economic scenario for the tested greywater reuse system.

5 year Payback - Best Case							
Capital Cost ($)	-$2,499.00						
Installation Cost ($)	-$862.44						
Total Immediate Costs ($)	**-$2,361.44**						
Government Incentive ($)	**$1,351.00**						
Subsidized Immediate Costs($)	**-$1,010.44**						
Year	1	2	3	4	5	6	7
Costs							
Annual Maintenance	-$8.04	-$8.04	-$8.04	-$8.04	-$8.04	-$8.04	-$8.04
Annual Operation	-$1.55	-$1.55	-$1.55	-$1.55	-$1.55	-$1.55	-$1.55
Total Annual Maintenance & Operation Costs	-$9.59	-$9.59	-$9.59	-$9.59	-$9.59	-$9.59	-$9.59
Benefits							
Annual Water Savings (m^3)	35.371	35.371	35.371	35.371	35.371	35.371	35.371
Combined Water Rates (with 5% annual increase) ($/$m^3$)	$4.44	$4.66	$4.90	$5.14	$5.40	$5.67	$5.95
Annual Water Savings ($)	$157.05	$164.90	$173.14	$181.80	$190.89	$200.43	$210.46
Balance (Annual Benefits - Annual Costs)	$147.46	$155.31	$163.55	$172.21	$181.30	$190.84	$200.87
Net Cash Flow	-$862.98	-$707.68	-$544.12	-$371.91	-$190.61	$0.23	$201.10

Table 100: 10 Year Payback Analysis - Best case economic scenario for the tested greywater reuse system.

10 year Payback - Best Case									
Capital Cost ($)	-$2,499.00								
Installation Cost ($)	-$862.44								
Total Immediate Costs ($)	**-$2,361.44**								
Government Incentive ($)	**$236.00**								
Subsidized Immediate Costs($)	**-$2,125.44**								
Year	1	2	3	4	5	...	9	10	11
Costs									
Annual Maintenance	-$8.04	-$8.04	-$8.04	-$8.04	-$8.04	...	-$8.04	-$8.04	-$8.04
Annual Operation	-$1.55	-$1.55	-$1.55	-$1.55	-$1.55	...	-$1.55	-$1.55	-$1.55
Total Annual Maintenance & Operation Costs	-$9.59	-$9.59	-$9.59	-$9.59	-$9.59	...	-$9.59	-$9.59	-$9.59
Benefits									
Annual Water Savings (m^3)	35.371	35.371	35.371	35.371	35.371	...	35.371	35.371	35.371
Combined Water Rates (with 5% annual increase) ($\$/m^3$)	$4.44	$4.66	$4.90	$5.14	$5.40	...	$6.56	$6.89	$7.23
Annual Water Savings ($)	$157.05	$164.90	$173.14	$181.80	$190.89	...	$232.03	$243.63	$255.81
Balance (Annual Benefits - Annual Costs)	$147.46	$155.31	$163.55	$172.21	$181.30	...	$222.44	$234.04	$246.22
Net Cash Flow	-$1,977.98	-$1,822.68	-$1,659.12	-$1,486.91	-$1,305.61	...	-$480.07	-$246.03	$0.19

Average Economic Case Analysis

Table 101: Average case economic scenario for the tested greywater reuse system.

AVERAGE CASE									
Capital Cost ($)	-$2,000.00								
Installation Cost ($)	-$1,677.71								
Total Immediate Costs ($)	-$3,677.71								
Year	1	2	3	4	5	...	42	43	44
Costs									
Annual Maintenance	-$52.69	-$52.69	-$52.69	-$52.69	-$52.69	...	-$52.69	-$52.69	-$52.69
Annual Operation	-$2.68	-$2.68	-$2.68	-$2.68	-$2.68	...	-$2.68	-$2.68	-$2.68
Total Annual Maintenance & Operation Costs	-$55.37	-$55.37	-$55.37	-$55.37	-$55.37	...	-$55.37	-$55.37	-$55.37
Benefits									
Annual Water Savings (m^3)	9.506	9.506	9.506	9.506	9.506	...	9.506	9.506	9.506
Combined Water Rates (with 5% annual increase) ($\$/m^3$)	$4.44	$4.66	$4.90	$5.14	$5.40	...	$32.82	$34.46	$36.18
Annual Water Savings ($)	$42.21	$44.32	$46.53	$48.86	$51.30	...	$311.99	$327.59	$343.97
Balance (Annual Benefits - Annual Costs)	-$13.16	-$11.05	-$8.84	-$6.51	-$4.07	...	$256.62	$272.22	$288.60
Net Cash Flow	-$3,690.87	-$3,701.93	-$3,710.76	-$3,717.27	-$3,721.34	...	-$295.57	-$23.35	$265.25

Table 102: 5 Year Payback Analysis - Average case economic scenario for the tested greywater reuse system.

5 year Payback - Average Case									
Capital Cost ($)	-$2,499.00								
Installation Cost ($)	-$1,677.71								
Total Immediate Costs ($)	-$4,176.71								
Government Incentive ($)	$4,176.71	NF							
Subsidized Immediate Costs($)	$0.00								
Year	1	2	3	4	5	...	10	11	12
Costs									
Annual Maintenance	-$52.69	-$52.69	-$52.69	-$52.69	-$52.69	...	-$52.69	-$52.69	-$52.69
Annual Operation	-$2.68	-$2.68	-$2.68	-$2.68	-$2.68	...	-$2.68	-$2.68	-$2.68
Total Annual Maintenance & Operation Costs	-$55.37	-$55.37	-$55.37	-$55.37	-$55.37	...	-$55.37	-$55.37	-$55.37
Benefits									
Annual Water Savings (m^3)	9.506	9.506	9.506	9.506	9.506	...	9.506	9.506	9.506
Combined Water Rates (with 5% annual increase) ($/$m^3$)	$4.44	$4.66	$4.90	$5.14	$5.40	...	$6.89	$7.23	$7.59
Annual Water Savings ($)	$42.21	$44.32	$46.53	$48.86	$51.30	...	$65.48	$68.75	$72.19
Balance (Annual Benefits - Annual Costs)	-$13.16	-$11.05	-$8.84	-$6.51	-$4.07	...	$10.11	$13.38	$16.82
Net Cash Flow	-$13.16	-$24.22	-$33.05	-$39.56	-$43.63	...	-$22.83	-$9.45	$7.37

Table 103: 10 Year Payback Analysis - Average case economic scenario for the tested greywater reuse system.

10 year Payback - Average Case									
Capital Cost ($)	-$2,499.00								
Installation Cost ($)	-$1,677.71								
Total Immediate Costs ($)	-$4,176.71								
Government Incentive ($)	$4,176.71	NF							
Subsidized Immediate Costs($)	$0.00								
Year	1	2	3	4	5	...	10	11	12
Costs									
Annual Maintenance	-$52.69	-$52.69	-$52.69	-$52.69	-$52.69	...	-$52.69	-$52.69	-$52.69
Annual Operation	-$2.68	-$2.68	-$2.68	-$2.68	-$2.68	...	-$2.68	-$2.68	-$2.68
Total Annual Maintenance & Operation Costs	-$55.37	-$55.37	-$55.37	-$55.37	-$55.37	...	-$55.37	-$55.37	-$55.37
Benefits									
Annual Water Savings (m^3)	9.506	9.506	9.506	9.506	9.506	...	9.506	9.506	9.506
Combined Water Rates (with 5% annual increase) ($/$m^3$)	$4.44	$4.66	$4.90	$5.14	$5.40	...	$6.89	$7.23	$7.59
Annual Water Savings ($)	$42.21	$44.32	$46.53	$48.86	$51.30	...	$65.48	$68.75	$72.19
Balance (Annual Benefits - Annual Costs)	-$13.16	-$11.05	-$8.84	-$6.51	-$4.07	...	$10.11	$13.38	$16.82
Net Cash Flow	-$13.16	-$24.22	-$33.05	-$39.56	-$43.63	...	-$22.83	-$9.45	$7.37

Table 104: 20 Year Payback Analysis - Average case economic scenario for the tested greywater reuse system.

20 Year Payback - Average Case									
Capital Cost ($)	-$2,499.00								
Installation Cost ($)	-$1,677.71								
Total Immediate Costs ($)	-$4,176.71								
Government Incentive ($)	$3,832.00								
Subsidized Immediate Costs($)	-$344.71								
Year	1	2	3	4	5	...	19	20	21
Costs									
Annual Maintenance	-$52.69	-$52.69	-$52.69	-$52.69	-$52.69	...	-$52.69	-$52.69	-$52.69
Annual Operation	-$2.68	-$2.68	-$2.68	-$2.68	-$2.68	...	-$2.68	-$2.68	-$2.68
Total Annual Maintenance & Operation Costs	-$55.37	-$55.37	-$55.37	-$55.37	-$55.37	...	-$55.37	-$55.37	-$55.37
Benefits									
Annual Water Savings (m^3)	9.506	9.506	9.506	9.506	9.506	...	9.506	9.506	9.506
Combined Water Rates (with 5% annual increase) ($/$m^3$)	$4.44	$4.66	$4.90	$5.14	$5.40	...	$10.69	$11.22	$11.78
Annual Water Savings ($)	$42.21	$44.32	$46.53	$48.86	$51.30	...	$101.58	$106.65	$111.99
Balance (Annual Benefits - Annual Costs)	-$13.16	-$11.05	-$8.84	-$6.51	-$4.07	...	$46.21	$51.28	$56.62
Net Cash Flow	-$357.87	-$368.93	-$377.76	-$384.27	-$388.34	...	-$107.79	-$56.51	$0.11

Worst Economic Case Analysis

Table 105: Worst case economic scenario for the tested greywater reuse system.

WORST CASE									
Capital Cost ($)	-$2,499.00								
Installation Cost ($)	-$4,638.39								
Total Immediate Costs ($)	-$7,137.39								
Year	1	2	3	4	5	...	51	**52**	53
Costs									
Annual Maintenance	-$194.23	-$194.23	-$194.23	-$194.23	-$194.23	...	-$194.23	-$194.23	-$194.23
Annual Operation	-$6.30	-$6.30	-$6.30	-$6.30	-$6.30	...	-$6.30	-$6.30	-$6.30
Total Annual Maintenance & Operation Costs	**-$200.53**	**-$200.53**	**-$200.53**	**-$200.53**	**-$200.53**	...	**-$200.53**	**-$200.53**	**-$200.53**
Benefits									
Annual Water Savings (m^3)	3.747	3.747	3.747	3.747	3.747	...	3.747	3.747	3.747
Combined Water Rates (with 5% annual increase) ($/$m^3$)	$4.44	$4.66	$4.90	$5.14	$5.40	...	$50.92	$53.46	$56.13
Annual Water Savings ($)	$16.64	$17.47	$18.34	$19.26	$20.22	...	$190.78	$200.32	$210.33
Balance (Annual Benefits - Annual Costs)	-$183.89	-$183.06	-$182.19	-$181.27	-$180.31	...	-$9.75	-$0.21	$9.80
Net Cash Flow	-$7,321.28	-$7,504.34	-$7,686.53	-$7,867.80	-$8,048.11	...	-$630.89	-$631.10	$9.80

Table 106: 5 Year Payback Analysis - Worst case economic scenario for the tested greywater reuse system.

5 Year Payback - Worst Case									
Capital Cost ($)	-$2,499.00								
Installation Cost ($)	-$4,638.39								
Total Immediate Costs ($)	-$7,137.39								
Government Incentive ($)	$7,137.39	NF							
Subsidized Immediate Costs($)	$0.00								
Year	1	2	3	4	5	...	51	**52**	53
Costs									
Annual Maintenance	-$194.23	-$194.23	-$194.23	-$194.23	-$194.23	...	-$194.23	-$194.23	-$194.23
Annual Operation	-$6.30	-$6.30	-$6.30	-$6.30	-$6.30	...	-$6.30	-$6.30	-$6.30
Total Annual Maintenance & Operation Costs	**-$200.53**	**-$200.53**	**-$200.53**	**-$200.53**	**-$200.53**	...	**-$200.53**	**-$200.53**	**-$200.53**
Benefits									
Annual Water Savings (m^3)	3.747	3.747	3.747	3.747	3.747	...	3.747	3.747	3.747
Combined Water Rates (with 5% annual increase) ($/$m^3$)	$4.44	$4.66	$4.90	$5.14	$5.40	...	$50.92	$53.46	$56.13
Annual Water Savings ($)	$16.64	$17.47	$18.34	$19.26	$20.22	...	$190.78	$200.32	$210.33
Balance (Annual Benefits - Annual Costs)	-$183.89	-$183.06	-$182.19	-$181.27	-$180.31	...	-$9.75	-$0.21	$9.80
Net Cash Flow	-$183.89	-$366.95	-$549.14	-$730.41	-$910.72	...	-$630.89	-$631.10	$9.80

Table 107: 10 Year Payback Analysis - Worst case economic scenario for the tested greywater reuse system.

10 Year Payback - Worst Case									
Capital Cost ($)	-$2,499.00								
Installation Cost ($)	-$4,638.39								
Total Immediate Costs ($)	-$7,137.39								
Government Incentive ($)	$7,137.39	NF							
Subsidized Immediate Costs($)	$0.00								
Year	1	2	3	4	5	...	51	**52**	53
Costs									
Annual Maintenance	-$194.23	-$194.23	-$194.23	-$194.23	-$194.23	...	-$194.23	-$194.23	-$194.23
Annual Operation	-$6.30	-$6.30	-$6.30	-$6.30	-$6.30	...	-$6.30	-$6.30	-$6.30
Total Annual Maintenance & Operation Costs	**-$200.53**	**-$200.53**	**-$200.53**	**-$200.53**	**-$200.53**	...	**-$200.53**	**-$200.53**	**-$200.53**
Benefits									
Annual Water Savings (m^3)	3.747	3.747	3.747	3.747	3.747	...	3.747	3.747	3.747
Combined Water Rates (with 5% annual increase) ($\$/m^3$)	$4.44	$4.66	$4.90	$5.14	$5.40	...	$50.92	$53.46	$56.13
Annual Water Savings ($)	$16.64	$17.47	$18.34	$19.26	$20.22	...	$190.78	$200.32	$210.33
Balance (Annual Benefits - Annual Costs)	-$183.89	-$183.06	-$182.19	-$181.27	-$180.31	...	-$9.75	-$0.21	$9.80
Net Cash Flow	-$183.89	-$366.95	-$549.14	-$730.41	-$910.72	...	-$630.89	-$631.10	$9.80

Table 108: 20 Year Payback Analysis - Worst case economic scenario for the tested greywater reuse system.

20 Year Payback - Worst Case									
Capital Cost ($)	-$2,499.00								
Installation Cost ($)	-$4,638.39								
Total Immediate Costs ($)	-$7,137.39								
Government Incentive ($)	$7,137.39	NF							
Subsidized Immediate Costs($)	$0.00								
Year	1	2	3	4	5	...	51	**52**	53
Costs									
Annual Maintenance	-$194.23	-$194.23	-$194.23	-$194.23	-$194.23	...	-$194.23	-$194.23	-$194.23
Annual Operation	-$6.30	-$6.30	-$6.30	-$6.30	-$6.30	...	-$6.30	-$6.30	-$6.30
Total Annual Maintenance & Operation Costs	**-$200.53**	**-$200.53**	**-$200.53**	**-$200.53**	**-$200.53**	...	**-$200.53**	**-$200.53**	**-$200.53**
Benefits									
Annual Water Savings (m^3)	3.747	3.747	3.747	3.747	3.747	...	3.747	3.747	3.747
Combined Water Rates (with 5% annual increase) ($/$m^3$)	$4.44	$4.66	$4.90	$5.14	$5.40	...	$50.92	$53.46	$56.13
Annual Water Savings ($)	$16.64	$17.47	$18.34	$19.26	$20.22	...	$190.78	$200.32	$210.33
Balance (Annual Benefits - Annual Costs)	-$183.89	-$183.06	-$182.19	-$181.27	-$180.31	...	-$9.75	-$0.21	$9.80
Net Cash Flow	-$183.89	-$366.95	-$549.14	-$730.41	-$910.72	...	-$630.89	-$631.10	$9.80