# Greywater Recycling

## An Overview of its use in British Columbia

Abstract:

The adoption of home Greywater recycling systems have been found to effectively reduce household water usage by up over 50%. Different treatment methods are chosen based on specific household needs and source water qualities. Policies regarding greywater recycling are few and often hinder increased system adoption. A review of case studies has identified long payback periods to be the largest barrier to widespread adoption. Government rebates, larger scale systems, and top-down social change are among the recommendations to advance widespread adoption.

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# I. INTRODUCTION

Greywater is all the wastewater that drains from a residential unit or complex, and excludes toilet water (blackwater). Greywater includes water from showers, bathtubs, sinks, kitchen, dishwashers, laundry tubs, and washing machines, containing soap, shampoo, toothpaste, food scraps cooking oils, detergents and hair. Greywater is largest proportion of the total volume of wastewater from a residence. Typically, 50-80% of the household wastewater is greywater. Reasons for wanting to use a greywater recycling system would be to reduce water consumption and reduce wastewater disposal (ARHWU, n.d.). There are benefits to substitute high quality potable water for a purpose that does not be to of drinking water quality. Examples of non-potable reuse include industrial, irrigation, toilet flushing and laundry washing. All examples are dependent on the available and appropriate technologies for the treatment process.

New designs and technologies around water conservation are emerging, likely responding to more conservative building and plumbing codes that push for advancements in technology. As more efficient energy appliances are available, more homeowners are switching to water smart appliances. By recycling greywater, wastewater from households' it helps to reduce volumes by repurposing the same water before final disposal. Although greywater recycling may appear simple in its application, the practice has numerous challenges (Anderson, 2003). These challenges must be overcome before it greywater reuse will be scaled up and become more mainstream. Implementation of household greywater recycling systems is common throughout many European countries; however, the practice has struggled to become mainstream in British Columbia (Pidou et al., 2007).

This research paper will investigate the factors of design and installation of greywater recycling systems in residential buildings to determine their water conservation value and overall efficiencies. In addition, the four primary treatment methods for greywater recycling are discussed. The paper will also investigate two case studies as well the barriers for using greywater recycling systems water from a policy and social context. Also discussed briefly is the importance of recognizing systems thinking from an urban water setting and conservation. Finally, based on the literature research and analysis several recommendations are discussed in support of the encouragement for increased greywater acceptance is presented.

# II. GREYWATER FUNDAMENTALS

## A. GREYWATER SYSTEM DESIGN

To determine a greywater treatment system design it is important to understand the water quality characteristics and volume of the greywater generated. Characterizing the wastewater constituents into their physical, chemical, and microbial elements, as seen in Figure 1, wastewater from the kitchen sink and washing machine consistently have higher organic and physical contents than other waste sources. The highest microorganism content is concentrated in kitchen wastewater, which also contain higher loads of nitrogen, phosphorous and turbidity; compared to all other greywater sources (Gross, Maimon, Alfiya & Friedler, 2015).

| |
|---|
| pH ( |
| TSS |
| Turb |
| COD |
| BOD |
| TN ( |
| TP ( |
| Tota (C |
| Faec (C |

**Figure 1:** Breakdown of household greywater (Gross et al., 2015).

Further improvements to overall treatment efficiencies and acceptability for greywater re-use can occur by using domestic cleaning products that contain less nutrients, i.e., phosphate free, In Figure 2, the constituents of total water demand in a typical UK residential unit are shown. When all potential greywater sources are combined (wash basin, shower, bath, laundry, dishwasher and kitchen sink), it is noted that 59% of wastewater can potentially be recycled. This ratio can range from between 50 to 80% depending on the region and individual water use practices (Pidou, Memon, Stephenson, Jefferson, & Jeffrey, 2007).

| Use | Fraction of total water demand: % |
|---|---|
| Toilet flushing | 35 |
| Wash basin | 8 |
| Shower | 5 |
| Bath | 15 |
| Laundry | 12 |
| Dishwasher | 4 |
| Outside use | 6 |
| Kitchen sink | 15 |

**Figure 2:** Household water use breakdown (Pidou et al., 2007).

An ideal target would be to recycle 100% of the wastewater that enters the system, possibly multiple times; at an affordable initial cost with full payback within the lifetime of the system through water cost savings. However, this goal is difficult to achieve because of the rigorous process of converting blackwater back into a safe reusable source. Regardless of the level of recycling planned, any water conservation effort within a domestic dwelling is beneficial as every effort to increase water reuse is beneficial for independently combating water scarcity.

Deciding which type of treatment system to implement varies based on the size of the house, the volume of wastewater generated, regional climate, personal habits, and desired use of the finished recycled water. For example, a greywater system designed for a rural farmhouse may have different components and recycling options than a small two-unit townhouse in a city. As stated by Li, Wichmann and Otterpohl (2009), “One shall also keep in mind that different reuse applications require different water quality specifications and thus demand different treatments varying from simple processes to more advanced ones”.

Differentiation of greywater into ‘light’ and ‘dark’ components as seen in Figure 3, allows treatment technologies to target smaller volumes of water, reducing the complexity and size on the treatment system, reducing cost.

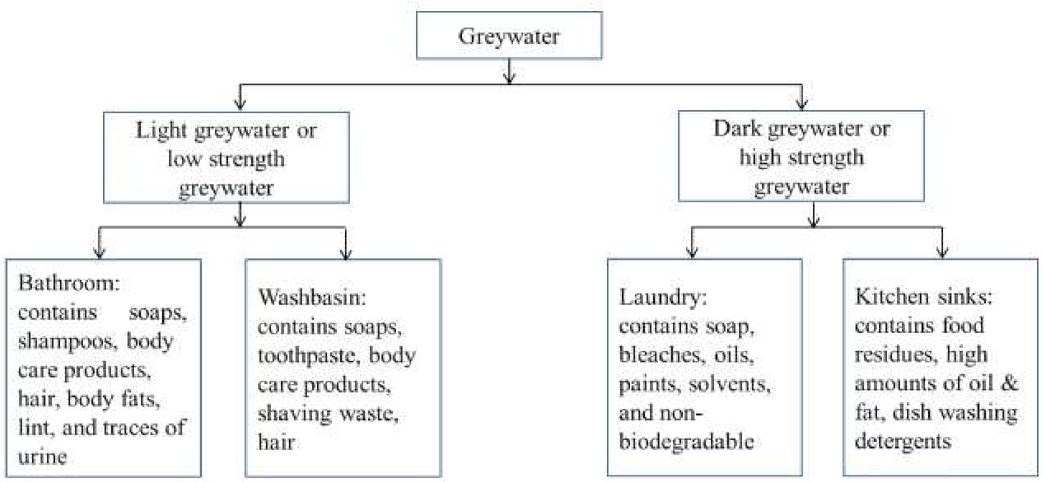


**Figure 3:** Breakdown of Greywater into Light and Dark (Albalawneh & Chang, 2015).

The two primary greywater recycling systems are i) diversion systems and ii) a treatment and storage system. The first and simpler of the two systems is the diversion method, which enables direct recycling of greywater into another water source. These diversion options have limitations in the quality of the wastewater leaving the first system, as it must meet the requirements of its secondary use without the need for any intermediate treatment. This system is typically the least expensive and most direct form of recycling, in addition, it does not require any treatment, resulting in easier implementation and lower costs (Caroma, 2015). The most commonly accepted use of greywater produced by the diversion method is to supply water to flush toilets. An example is the Caroma low flush toilet, as seen in Image 1. This efficient fixture has a washbasin built into the top of the toilet reservoir to allow for the direct recycling from the washbasin into the toilet without requiring any filtration. Designed as a low-flow toilet with a 3.0 Litre per flush usage, this toilet has reduced toilet water use by up to 74% compared to standard methods (Caroma, 2015). Direct diversion approaches for greywater recycling systems are not restricted by additional treatment systems. Another example, found in Image 2, is an innovative method of direct recycling, where the laundry wastewater was directed into a toilet bowl. Both designs are physically connected to the toilet; however, as long as the design allows for direct reuse of the wastewater without filtration then any configuration of the system would work. Another common method of the diversion system is to direct wastewater directly outside for use recycling and then for irrigation of agriculture or landscaping.

**Image 1:** Coroma Low Flush all in one toilet. (Caroma, 2015).

**Image 2:** Washing machine direct (Knapp, 2009)

The second standard form of greywater reuse includes a hub design and implementation of an interconnected plumbing system that leads to a catchment hub. From this hub, water is treated and stored to be available for later use. This design style allows for a wide range of reuse options and treatment effectiveness is based on the end use greywater recycling needs; however, there is also increased legal scrutiny as the storage of treated greywater has associated health risks (WaterSMART, 2011). The decision on appropriate storage capacity needs to consider the volumes associated with daily fluxes of water use, with common spikes occurring in the morning and in the evening with little use in between for the average home. This results in large storage requirements if greywater is to meet the 100% of reuse needs; however, often greywater stored for reuse is combined with new water to meet the peak demands of the household (Albalawneh & Chang, 2015). The more elaborate greywater treatment process' designs are most effective when implemented during the construction of the building, allowing plumbing configuration to maximize efficiency while keeping costs to a minimum. An effective design involves storing the treated greywater on the roof to be readily available when needed without the need for a water pump.

A component of greywater recycling not commonly discussed is the ability to convert the heat retained in the greywater into electricity savings. Since the majority of greywater is heated to 40–50 °C prior to disposal, a large amount of heat energy can be saved through a heat exchange system. An effective method involves modifying the hot water tank by replacing a piece of the cold water intake line with a copper coil, this wraps around a copper line containing the heated greywater. Through conduction, heat is transferred from the greywater to the clean-water before entering the hot water tank and the load of the hot water tank is reduced. This process can reduce energy use of the tank by up to 21.5%, similar methods from other studies have been shown to reduce energy requirements by as high as 51% (Eslami-nejad & Bernier, 2009).

Concerns that the greywater contains traces of fecal coliform from wash basins, bathtubs and showers has been identified as a deterrent to the practice (Finley, Barrington & Lyew, 2009). A study funded by the Natural Science and Engineering Research Council of Canada at the Macdonald campus of McGill, directly compared the presence and quantity of coliform bacteria between tap water and greywater treated by slow sand filtration from a single family home. The test was conducted on a lettuce, carrots and peppers grown in a greenhouse with the water being used for irrigation. Vegetables exposure to potential contamination was reduced by irrigating using non-direct methods, i.e. as surface drip, avoiding contact with foliage. Although the test was on a small scale, it confirmed a common finding that using treated greywater is generally equivalent to using tap water directly. The results of the study are shown in Figure 4.

| | Lettuce-tap water | Lettuce-greywater | Carrot-tap water | Carrot-greywater | Pepper-tap water | Pepper-greywater |
|---|---|---|---|---|---|---|
| Bacteria (CFU/gram of crop) | 5.21 | 2.76 | 10.52 | 2.93 | 0 | 0 |
| Mass ingested (g/day) | 40 | 40 | 40 | 40 | 40 | 40 |
| Ingestion frequency (days/year) | 45 | 45 | 45 | 45 | 45 | 45 |
| Probability of infection[a] | 0.00001 | 0.00001 | 0.00001 | 0.00001 | 0.00001 | 0.00001 |
| Probability of illness[a] | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 |
| Estimated annual risk of illness | 0.046 | 0.024 | 0.093 | 0.026 | 0 | 0 |
| Comparative risk | | 47% lower than tap water | | 72% lower than tap water | | N/A |

**Figure 4:** Risk assessment of different greywater uses in Agriculture (Finley et al, 2009).

## B. TYPES OF GREYWATER TREATMENT PROCESSES

### 1. PHYSICAL TREATMENT METHODS:

Physical treatment techniques remove sediments, particles and oils from greywater and provide pretreatment. Sand filters are common methods of physical treatment and use specific grain sized sand as the media for filtration. Sand is layered up to 1 meter in height and placed in containers made of concrete, plastic, or other impermeable material. Conventional slow sand filter, as shown in Figure 5 in which grey water enters the filter compartment above the media and flows down through the sand and, in time, will form a thin biological layer called a "schmutzdecke". This biological layer is very important and will help to remove bacteria if maintained properly (Amit Gross, 2015). The Pidou et al, (2007) case study experimented on simple system of direct feed coarse filtration/sedimentation with disinfection. There was a short hydraulic residence time; however, there was also a potential health risk from exposed untreated greywater and possible vector control considerations to make. The Pidou results were not good and showed a limited capacity for treatment of suspended solids and organics. As mentioned, physical systems are good for pre-treatment. These systems on their own tend to not be economically viable over long term, as water volume savings not enough to cover capital and O&M cost.

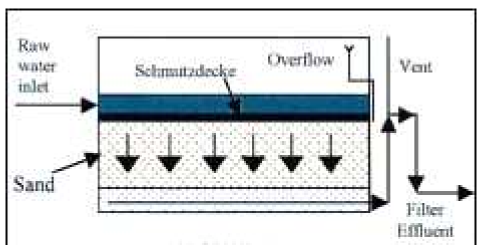


**Figure 5:** Schematic representation of a conventional sand filter **(**Mays, 1996).

## 2. CHEMICAL TREATMENT METHODS:

Chemical systems rely on the addition of reagents called coagulants, that function to weaken suspended solids into smaller (colloidal) particles. Trivalent ions such as aluminum and iron are used for the coagulation processes in the form of salts or polymers. Adding a coagulant such as alum (aluminum sulfate) to water causes particle adhesion, which result in formation of a flocculent mass, that or floc, which traps suspended microorganisms (Amit Gross, 2015). The Pidou et al, (2007) case study experimented with three chemical systems: coagulation, electrocoagulation with disinfection, and a photo catalytic-oxidation with titanium oxide, followed by UV disinfection. The results all had good treatment of greywater with good removal of solids and organics, but limited removal for bacteria. All of the chemical systems had short hydraulic residence time. Unfortunately, there was not enough data on water use savings or energy demands, so it was not possible to determine sustainability.

## 3. BIOLOGICAL TREATMENT METHODS:

There is a variety of biological treatment processes for greywater recycling. All of the methods use microorganisms to convert suspended contaminants into settleable solids, carbon dioxide and water. These greywater treatment processes usually require primary treatment to remove larger solid particles and sediments. During the treatment process microorganisms grow and consume the contaminants in the wastewater, resulting in more microorganisms (sludge) that needs to be removed in subsequent steps of secondary settling, to destroy any pathogens contained in the sludge (Amit Gross, 2015). The Pidou et al, (2007) case study experimented with various biological treatments systems, examples included: fixed-film reactors, rotating biological reactors, anaerobic filters, sequencing batch reactors, biological aerated filters and membrane bio-reactors. These systems were not used on their own, instead they were reported to be ideal for larger flow volumes, i.e., housing complex. The hydraulic residence time for these systems was short. All of the biological treatment systems, combined with disinfection, resulted in excellent removal of organics and TSS and able to meet stringent standards for reuse. The membrane bio-reactor resulted in "superior" removal of all contaminants, without disinfection. The membrane bio-reactor was also the most resilient for dealing with intentional shocks to the treatment process, namely loss of air feed and inflow below 1 hour. Large data volumes of water savings, costs on capital and operation and maintenance (O&M), energy, on all the biological systems made it difficult to determine sustainability of these types (Pidou et al, 2007).

## 4. MEMBRANE FILTRATION SYSTEMS

The main advantages of a membrane technology are that it works without the addition of chemicals and with relatively low energy use. A membrane process separates raw influent flow into two streams, either gaseous or liquid. Movement through the membrane occurs by a pressure and concentration difference as the driving force. Examples of pressure driven membrane processes (high and low) are: microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. The four types differ primarily based on the size of the particles required to be separated. The smaller the pore size of the membranes, the greater pressure needed to reach separation, resulting in higher costs (M. Pidou, 2007).

## 5. EXTENSIVE TREATMENT METHODS:

An extensive treatment system is essentially a constructed biofiltration wetland that filters water. A wetland function to break down wastewater constituents through both mechanical and biological processes within an impervious container with selected aquatic plants. The treatment occurs within the microbes that live in the soil around the plant roots. Extensive treatment systems consist of a base layer of sand topped by a thicker layer of medium sized gravel, and topped with a thin layer of mulch (Yocum, 2010). Ideal vegetation types for extensive systems are: cattails (*Typha spp*), bulrushes (*Schoenoplectus spp*), and reed grasses (*Glyceria maxima*). The size of a constructed wetland depends on the regional precipitation trends, the volume of greywater flow and the amount of nutrient reduction desired in the wastewater, i.e., biochemical oxygen demand. As a rule, one cubic meter of a wetland can process about 135 liters of greywater. Potential limitations to extensive systems include clogging, introduction of invasive species and overflow from storms (Sookbiringh, n.d.). The Pidou et al, (2007) case study on various constructed wetlands, with reed beds and ponds, and with a variety of vegetation species, showed good removal efficiencies of organics and TSS, but was less effective at micro-organism reduction. The experiments had greywater pretreatment with sedimentation and sand filtration. The hydraulic residence time was up to 5 days. Advantages of extensive systems are that they are relatively inexpensive and ecologically accepted, but typically have a large footprint, limiting where they can be used. The Pidou et al, (2007) case study summarized that other than the membrane bioreactor, there was no one treatment method that better performed over the other. Different treatment methods and combinations will show different results in their performance efficiencies. A combination of treatment systems proved to be best, but depended on treatment goals and costs. The footprints of the treatment facility can be a limiting factor in certain locations. In the reviewed literature there was a lack of data for life cycle costs, total energy requirements and their social acceptability.

## C. CURRENT GREYWATER RECYCLING POLICIES

The policies supporting greywater recycling and reuse differ from region to region, and are typically adapted for provincial and municipal purposes. In Canada, each province has a different emphasis surrounding regulations of greywater recycling. In Alberta, for example, recycled water cannot be used within any buildings, but it can be used for irrigation purposes. However, irrigation water use is prohibited in urban residential areas due to regulations that require a minimum of 60-meters clearance between inhabited buildings and the reclaimed water. Concerns that are not covered by legislation include the ponding or runoff from the property, having a minimum separation distance from a watercourse and being below a certain volume. The introduction of recycled greywater use into all residential communities will require a broader approach and new legislation, various building and plumbing codes, guidelines and standards. (Alberta Environment, 2000)

The Government of Alberta established the Alberta Reclaimed Water Working Group, which included participants from five sectors of government: Alberta Environment; Alberta Health and Wellness; Alberta Health Services Board; Alberta Municipal Affairs; and Alberta Transportation. This group was tasked with developing the framework to facilitate safe use of reclaimed water, monitoring water quality, ensuring technical standards and guidelines, and a management system for approvals, reporting and overall monitoring. Further development of this reclamation framework will be important in order to introduce greywater use throughout the province, and establishing a market for greywater technology in Alberta. (Alberta Water SMART, 2011) Therefore, in Alberta, regulations, standards and guidelines will only be viable if they integrate into existing Alberta policies and actions committed to protecting the environment, enhancing economic prosperity, and improving the health and lifestyle of communities.

## III. CHALLENGES OF IMPLEMENTATION.

### A. REGULATORY BARRIERS OF GREYWATER RECYCLING

In British Columbia, greywater recycling applications are regulated under the *Waste Management Act-Municipal Sewage Regulation* (MSR, 1999). Reclaimed water may be used in residential and commercial buildings where permitted by applicable building codes and health legislation. The use of reclaimed water within single family dwellings may be permitted with specific measures in place, developed in consultation with the Ministry of Environment regional director and local officer.

There are some general requirements under the Municipal Sewage Regulation (MSR) that are to be followed for greywater recycling. Among them, the capability to chlorinate reclaimed water should be available and a residual level of chlorine should be maintained. In cases where potable water is also supplied to the property, a backup connection to the potable water system is recommended. Where commercial applications are practiced, adequate signage must be provided to inform the public that reclaimed water is used. Signage should be easily visible and located near fixtures (Metcalf & Eddy Inc., 2007). Toilet and urinal flushing should use greater exposure potential category of reclaimed water quality. Reclaimed water used in toilets must be clear, odorless and sufficient residual chlorine must be provided for continuous disinfection. Furthermore, Health Canada Guidelines should be followed carefully to avoid any other potential negative health effects related to reusing water (Health Canada, 2010).

Internal building plumbing for reclaimed water must meet the requirements of the BC Building Code and any applicable municipal requirements. During installation, a dedicated piping system must be available when reclaimed water is supplied and all reclaimed water piping inside buildings must be properly labeled and color-coded, including plumbing to toilets and urinals. Purple is commonly used to identify reclaimed water piping. Toilet and urinal flushing uses can only be approved with installed and tested backflow prevention devices and must under no circumstances connected the reclaimed water supply to the potable water supply. Further detailed plumbing requirements can be found in the BC Building Code (Metcalf & Eddy Inc., 2007).

As expected, Provincial health authorities would have concerns with any wastewater reuse project. Their concerns vary depending upon the final use and the treatment process, examples being: any disposal of wastewater into the subsurface of soils would be of little concerns, whereas the reuse of wastewater entering into a plumbing system would present immediate health concerns. In British Columbia, two regulations directly deal with residential wastewater issues but not specifically for 'greywater recycling'. The two regulations are the *Sewerage System Regulations* (SSR) under the BC Health Act and the *Municipal Wastewater Regulations* (MWR), under the BC Waste Management Act. Although the SSR are silent on the topic of greywater systems or water reuse, it does define "the discharge of domestic sewage or effluent onto land" as a "health hazard" unless "authorized under another enactment" The SSR also defines "sewage" as being both greywater and blackwater combined but does not define them separately. Only the MWR has reference about water quality standards for reclaimed water; however, not specifically in reference to application of reclaimed water but rather to more conventional wastewater ground disposal systems. Still, the MSR does set out the conditions to allow reclaimed water to be used for a range of applications (British Columbia Government, July 2013).

In 2013, the BC Government issued the "Reclaimed Water Guideline", a companion document for the *Municipal Wastewater Regulations.* The Guide outlines all the steps and requirements needed to obtain approvals from the BC government Health Branch for use a greywater recycling systems, although not called as such within the Guide. The entire approval process for a grey water recycling system in BC is left up to the authorized person within the Ministry of Health and project is done on a case-by-case basis. As expected, these authorities would impose these conditions on any project, to include a minimum standard of effluent quality for the parameters of pH, BOD, TSS, turbidity and fecal coliform. Other conditions are the completion of an environmental impact assessment and a Liquid Waste Management Plan, a permit, a back-up system and the deposit of financial security (British Columbia Government, 2013).

## V. CASE STUDIES

### A. BRAC WATER TREATMENT SYSTEM

To understand the economics behind the residential installation of a standard greywater recycling system in British Columbia, a case study involving the use of a common Brac owned

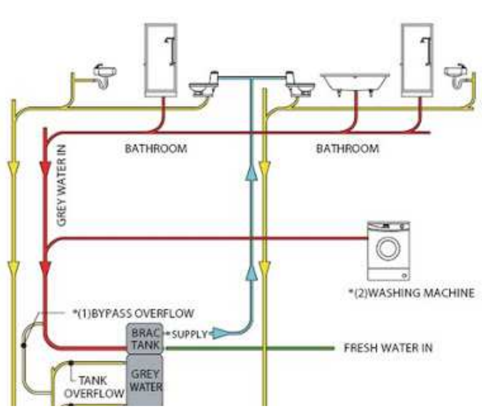


**Figure 7:** BRAC System (Econnics, 2010).

Residential Greywater Recycling (RGW) System has been analyzed. The RGW system was designed as an all-in-one greywater recycling unit that processes light grey wastewater, specifically water from sinks (excluding the kitchen), laundry, and bath/showers that would to be reused specifically for flushing toilets. These water sources are specifically chosen as they tend to be the cleanest of the greywater sources and require the least amount of treatment (Gross, Maimon, Alfiya & Friedler, 2015). To install the RGW system, a plumbing system was installed beside the existing conventional piping to direct wastewater from its source, into the RGW treatment reservoir. The reservoir came in a number of different sizes specific to the volume of water needed. The standard treatment system is the same throughout all model sizes and consists of: a cleanable pre-filter intended to capture large particles such as hair or large sediments before it enters the containment unit; a pleated micro-filter to separate out finer particles and reduce turbidity; and an automatically distributing chlorination system with built in chlorine sensor to disinfect water and provide residual protection for microbiological contamination (Econnics, 2010).

As seen in Figure 7, water enters the system whenever water was released from one of the greywater source locations and undergoes treatment before it is held in the reservoir until a toilet requires water to flush or be filled. To achieve the lift necessary to carry the greywater to the required destination, often to the second story of a house, a water pump contained within the unit was used. If not enough water was contained in the reservoir, clean water supplemented the greywater to prevent the system from going dry.

An important function of the RGW system is that it is not intended to treat all forms of greywater, instead, by focusing on light-greywater it maintains a simple design that can be easily maintained by the average user. By avoiding the dark-greywater sources, the system is capable of keeping its costs relatively low by using simple filtration and disinfection technologies that provide adequate treatment for the specific use of toilet flushing. The total cost of any water treatment function is typically composed of three main factors: i) system hardware, ii) installation, and iii) annual O&M costs. The cost of the Brac RGW-250 system in 2010 was $2350 plus taxes and shipping which was a standard cost in comparison to other similar systems (Econnics, 2010). The installation costs range based on the size of the house, number of occupants, the extent of the plumbing, and local pricing; however, these costs were typically around $1500 per installation. Annual O&M costs was composed of three components: $19 plus taxes for the annually replaced filter unit; $15 for energy costs for running the water pumps; $45 for calcium hypochlorite tablets used during disinfection; totaling at $79 per year for O&M costs. With careful maintenance of the system, the lifetime is expected to be 10-20 years of functional use (Econnics, 2010). To assess the value of the RGW greywater system versus the cost in water savings over a 20-year period, the calculated total cost of installation, plus the combined total of the annual fees over its lifetime was be $5430. The cost of water is a considerable factor in determining the effectiveness of a system. As water price increases, the greater the potential savings. In British Columbia, water is priced around $2 per $m^3$ which allows for inefficient consumption practices without noticeable economic hardship (Econnics, 2010). The water use in the standard four-person household can be reduced by 35 $m^3$ per year, which results in an annual saving of $70. Unfortunately, this saving does not cover the cost of operating the RGW system, nor cover the cost of the system implementation. If the adoption of the system was to be based on a financial decision alone, the price of water would need to be $6.50 per $m^3$ to pay off the system over its 20-year lifetime (Econnics, 2010). Unfortunately, this does not provide much incentive for common adoption resulting in limited system adoption. As a result of poor sales on their units the Brac Systems Inc. went out of business before being purchased by a large company, Greyter Water Systems, also specializing in all-in-one greywater treatment systems. The results of this case study would be similar across Canada as the price of water is relatively low compared to the pricing required for a lifetime payback. For the system to be cost effective, the initial cost combined with the annual operating costs would have to be paid off within the life of the system.

## B. CENTER FOR INTERACTIVE RESEARCH ON SUSTAINABILITY

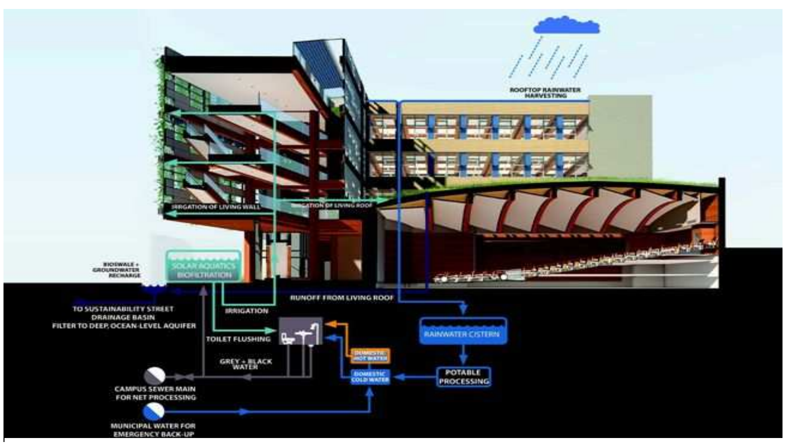


**Figure 8:** CIRS Building, UBC Vancouver Campus-Source: (UBC, 2016)

In 2011, the Center for Interactive Research on Sustainability (CIRS) was created by the University of British Columbia (UBC) to display and develop advanced methods involving sustainability. The Solar Aquatic System (SAC) at UBC was designed to remove water and nutrients from their building and the campus sewer to supply the needs of the building and surrounding units if needed. The SAC, seen in figure 8, reuses 100% of the buildings blackwater and greywater through a series of treatment processes before reusing the water in toilets, and irrigating the buildings living components and landscaping.

The building itself produces two cubic meter of wastewater per day, while its treatment capacity is 10 cubic meters per day. The additional eight cubic meters of reclaimed water was collected from sewer discharge of other buildings and was treated and exported for reuse such as in the greenhouse at the horticulture research faculty (UBC, 2016).

The treatment system used conventional activated sludge processes for bacterial retention, but also had floating plants over the bioreactors and treated effluent through a constructed wetland. The CIRS system was very evident to visitors entering the building, with a large greenhouse located right in front of the main entrance. While the plants do very little to treat the wastewater, they do serve as a highly visible reminder to the occupants and visitors. The internal wetland treatment reminds residence that what is flushed down sinks and urinals will directly affect the plants in the treatment process, inherently making the occupants of the building part of the overall treatment process, helping to prevent contaminants from being released to the environment through source control (UBC, 2016).

Wastewater is collected in the collection tank. From the tank it's directed to the blending aeration tanks where bacterial digestion breaks down the waste. Nutrients in the water are converted into readily available forms for plant uptake, such as ammonia to nitrate and creating solvable phosphorous. Nutrients stimulate root growth leading to increased bacterial habitat, increasing bacterial processes key to biological treatment. A gravity clarifier unit then allows the bacteria to be separated from the clarified water and is recycled. The clarified water moves through a sand filter and constructed wetlands where particles, fecal coliform and some metals get removed from the water. Ultra-filtration acts as the final barrier to remove suspended particles and bacteria. Finally, water is disinfected through a two-step process: exposure to ultraviolet light and the addition of residual chlorine. The reclaimed water is then directed to the storage tanks for reuse purposes (UBC, 2016).

The solar aquatic system incorporates components from all five treatment processes to allow for safe, reusable water to be generated for reuse on location. The system was designed in two parallel sections, allowing experimentation and testing to be conducted after changes are implemented to a single side of the system. Monitoring and testing at each process step enables modifications to be made by students, supporting ongoing improvement and education. Although the cost of the system was not available, it is expected the true value of the systems is weighted more on its ability to present cutting edge innovation to students rather then by creating a cost effective model to be simulated in other buildings. By implementing sustainable practices throughout the building, solutions to combat energy consumption and water waste are displayed, raising the awareness of the community around it while creating a healthy learning environment for students.

## VI. DISCUSSIONS:

## A. WATER SYSTEMS THINKING:

To be innovative in conserving urban water, such as wanting to implement a greywater recycling system, usually implies that one has made an intentional mental (mindset) shift from the more conventional thinking and practice around the status quo. In order to be successful in shifting to new and innovative approaches around increased water sustainability, one needs to think in terms of ‘systems’ and understand all the different relationships between each component of the other systems all within a hierarchy of local, regional and global systems (Homewood, 2009). Urban water systems themselves can be defined as the water systems that supply a city or a town, and this project will mainly look at the water supplied to the residents within them rather than looking at the industrial sector. The three main parts of an urban water system are the water supply, wastewater treatment and stormwater collection and treatment. Water supply is the provision of potable water, wastewater treatment is the collection of wastewater, the removal of pollutants, and the disposition back into the environment. Stormwater services will deal with the drainage of water in urban areas so to avoid flooding and health issues. Sustainable urban water systems are included within many other systems, such as a sustainable project of a local community, which itself is a subsystems of city planning, which can be part of a system of sustainable development of society in general (Grigg, 1999).

Because urban water systems are open systems, there will be many interactions between their components and the environment. Concepts of systems thinking goes back many years, when Emery (1969) stated, “to really understand a certain system, knowledge needs to be gained from many various studies in many different disciplines, which then need to be all brought together and integrated to really see the larger picture”. So, systems thinking means synthesizing all the relevant components independently, then look at key relationships, influences and trends between all of them, to get a sense of the larger complete system. Homewood (2009) claimed that in urban water systems, different stakeholders are going to have many differing opinions about different components of a water system and are often usually viewed independently just as the water supply, water treatment and stormwater management strategies and infrastructures. It is often through different departments, organizations and companies that each of these components are operated, so if they do not interact with one another, they may miss out on possible important opportunities to become more integrated and sustainable. A sustainable urban water system needs to be able to cope with the changing demand, have a long life cycle, and improve the quality of the surrounding system environment, both for natural and human systems. Also the system-users, the general public, are a key component within the overall system, because if they do not use the system properly or efficiently, achieving sustainability will not occur (Emlahdi, 2008).

The boundary of an urban water systems may vary from an individual scale to a community scale (Homewood, 2009). Some people may see a boundary of an individual property, rather than looking at the whole area that the system is supplying. There are many different components and systems of an urban water system, with examples seen in Table 1. Each of these factors may be viewed as separate systems; however, the challenge arises when trying to conceptualize them all as integrated component of a whole system then properly manage all components.

| Components of an Urban Water System (Homewood, 2009). | |
|---|---|
| • Water catchment area<br>• Natural water systems<br>• Water infrastructure<br>• Water treatment plants<br>• Water suppliers<br>• Stormwater management | • Wastewater treatment plants<br>• Built water systems<br>• Social systems<br>• Water and wastewater companies<br>• Policy makers<br>• Users of the water systems |

**Table 1:** Components of an urban water system.

In terms of sustainability, urban water infrastructures are best understood as being the system which provides the services to the system-users, which in this case are the consumers. Therefore, users, policy makers and social systems will all be part of the system environment. This project should concentrate on looking at supplying, treating and the removal of water and storm water sustainably. The natural environment and ecosystems within it are also importantly included within the urban water system in terms of sustainability.

## VII. RECOMMENDATIONS

### A. ECONOMIES OF SCALE

The implementation of greywater recycling systems in the home can be an effective practice to conserve water; however, it is often uneconomical due to high capital startup costs and the recurring O&M costs, negatively affecting the likelihood homes of homes willing to adopt its implementation. If greywater

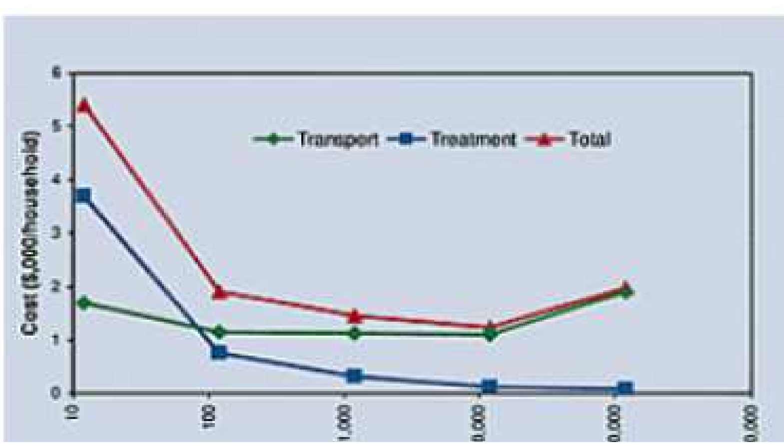


**Figure 9:** Economies of Scale (Capital Regional District, 2004).

recycling is to be effective in helping reduce the amount of water waste, the first problem that needs to overcome is the high capital system cost. The case study discussing the economics of the BRAC system highlighted how the installation of a basic system could be inhibited by its cost at the household level. To lower individual costs, implementation of systems at a larger scale, ideally at the community level need to be initiated. Legislation requiring housing complexes, apartments and buildings to implement greywater recycling would lower the volume of water ending up in wastewater treatment facilities. Apartments, subdivisions and hotels are good locations to install larger scale greywater recycling systems as treatments costs would incrementally be reduced for each per person. As seen in Figure 9 through economies of scale, the individual cost for water treatment is drastically reduced by distributing costs to large groups of people. By distributing, the construction and operation costs between a number of different people the economics of the system begin to show their value and become more enticing to homeowners, especially for those that want to reduce their water consumption but cannot afford a system of their own.

In addition to the benefits of economies of scale, the decision to construct a greywater recycling system in a larger unit can help the building complex advertise as “sustainable” or “green” of which a growing number of people want to be associated. Further it has proven to help with sales and allow the construction of the treatment system to be offset by proportionally small increased unit costs (Capital Regional District, 2004). When numerous residences are connected to a single treatment unit, as in an apartment building, the responsibility of maintaining the unit can be transferred from the individual use to the building owner which can extend the life of the system and enabling a wider range of people to use it that were otherwise turned off by the efforts required to maintain the system.

## B. CHANGE REGULATIONS AND POLICY

A significant detriment to installing greywater systems in homes is the lack of financial incentives (Li, Wichmann & Otterpohl, 2009). With low water pricing in BC and the perception of water availability as nearly infinite, the majority of people do not worry about actively conserving water. If there is no financial incentive to conserve water, then the adoption of greywater reuse systems will continue to wane except to the few that value environmental sustainability over costs. Currently, the majority of homes in BC do not have water meters installed, regulations to implement their use are directed at new homes or homes that are to be renovated, while leaving the rest of the population unmetered. Without meters in place, monitoring of residential water volume usage is not possible. Awareness of water-use volumes gained through a meter can be directly linked to the amount of water conserved. Studies comparing people who actively monitored their water consumption versus people without access to meters have shown that the latter were less conservative (Kappel & Grechenig, 2009).

Populations in cities are expected to continue to grow, forcing local water treatment facilities to continually be expanded to keep up to the growing water demand. If household water use was reduced by 59% through basic greywater recycling systems or community systems, the installation of new water treatment facilities needed to cope with increased volume demand, could be delayed. By creating a policy that incentivizes the adoption of greywater recycling, such as through tax incentives that pay for a portion of the installation fee or provide a rebate based on water use reduction, household adoption would be increased. Currently, British Columbia does not have incentive programs for the adoption of greywater recycling systems. If BC were to look to other provinces in Canada, they would see that water incentive programs are successfully implemented elsewhere, contributing to increased household adoption of greywater systems (City of Guelph, 2012). Ontario is leading the way in water conservation initiatives with efforts starting in 2007 (Water Tap Ontario, 2013). Ontario's Water Opportunities and Water Conservation Act began the process of requiring cities to create their own municipal water sustainability plans to better manage and conserve their water use. A number of municipalities offer incentives for the implementation of greywater systems. The city of Guelph conducted a systematic study of greywater reuse systems and determined that the largest inhibiting factor to their implementation was the high cost of the system and the subsequent payback period. To reduce this payback-period the City began offering a $1500 incentive for the installation of a greywater reuse system in new homes. This greatly reduced the payback period of the system and greatly increased public acceptance and adoption. If British Columbia was to take such an approach, the incentive to install such systems could greatly improve its use.

## C. HOUSEHOLD ALTERNATIVES

In many scenarios where the cost of water is low enough that greywater implementation is not viable, many alternative water saving methods provide a better return on their investment compared to greywater recycling. Low-flow toilets are very efficient requiring only 6.05 Litres of water per flush compared to more than 18.9 Litres required by conventional toilets. Low-flow toilets save the average U.S. household (2.64 people) about 94 Litres of water per day, or more than 34,000 Litres per year (Steve Maxwell, 2006). Some cities in Canada that offer toilets rebate programs for promoting low flow toilets. For example, the City of Richmond, BC Toilet Rebate Program provides a utility tax rebate to homeowners who install a low-flush toilet. Single and multi-family homeowners are eligible to apply for a lifetime maximum of two rebates per household. Industrial, commercial and other non-residential properties are not eligible at this time. The purpose of the toilet rebate program is to encourage homeowners to replace high volume toilets with low-flush toilets in order to conserve water and to reduce costs. Homeowners noticed a reduction in their utility bill while contributing to the sustainable water conservation initiative (City of Richmond, 2016). Similarly, in Halton, Ontario, they also use a rebate program of $75 per household on approved model of toilet (Halton, 2010).

Rainwater collection systems can be constructed inexpensively and may help to alleviate the supply of water needed for irrigation of vegetable gardens and landscaping. The simplest designs consist of the capturing rain water on the the roof, via gutters that flow into a series of downspouts to a filter to remove debris. The rainwater collects in a tank where it is stored for later use. Rainwater collection systems can include pressurization pumps to convey the water to the point of use. For non-potable purposes such as irrigation, livestock or commercial processing, the water may need little (if any) filtration. For potable use, the filtration and sterilization requirements are more defined which causes similar cost problems linked to greywater recycling (Autodesk Community Education, 2013). A third method of water conservation involves the use of low-flow showerheads. An amendment to the BC Plumbing Code now requires all newly installed showerheads to be low-flow, defined as having a flow rate of 9.5 Litres per minute or less (POA, 2015). However, since no regulations require older homes to replace their existing showerheads, voluntarily replacing them will further reduce water waste. Through implementation of cheap alternatives to greywater recycling, widespread water conservation is possible for homeowners who can not afford the more expensive greywater treatment systems.

## D. SOCIAL AND ECONOMIC RECOMMENDATIONS

The concept of wastewater is relatively new and naturally, there will be reluctance and resistance by people with different perceptions. People are easily conditioned to think linearly and most have become accustomed to accepted norms. As Garvin (2011) wrote, the process of change is difficult for people, organizations and municipal governments. Stepping away from conventional thinking is challenging. People are generally resistance to change, especially if they are not impacted by something, or conversely they are profoundly impacted by something. Thus, despite its perceived importance to the authors, greywater recycling is not of interest for most of the public. Tap water on demand and flush toilets are just another public service taken for granted.

When citizens observe proactive leadership, change is more acceptable and is conducive to persuade people to get people on board. If Mayor and Council do not embrace a vision around sustainability, it can be difficult for municipal leadership to re-think their “business as usual” approach, in water conservation and innovation. There ultimately needs to be a mindset shift towards sustainable principles, followed by actions that aim to consider the ecological and social aspects about their decisions. Mayor and Council can publically state their values and vision for a municipal process that works towards more sustainable systems. These words then need to be put into action, and hopefully with the support of an informed public. Working towards sustainability requires leadership and a willingness to take risks is required to push the boundaries on accepted norms.

## VIII. CONCLUSION

This research paper attempted to explore several aspects around the implementation of water conservation strategies through the approach of greywater recycling. Examined within were the considerations and implications around designing a greywater system in residential units and the importance to consider the objectives of the end use of the water. The research indicated that there were substantial benefits in water conservation by using energy efficient home appliances with low flow characteristics: toilets, showerhead, rather than in greywater recycling. The paper described the two primary system types of greywater recycling: direct diversion method and the treat and store method, each type having different application and benefits. Presented were the five primary treatment processes of physical, chemical, biological, membrane and extensive methods, while revealing how each of them had their own limitations, but when combined some the methods proved more effective in reductions in various contaminants. Further, the paper also revealed that each Province has their own regulations, codes and policies around greywater recycling. There were very few examples of a regulatory regime for greywater recycling; instead, existing wastewater regulations and plumbing codes are in fact more of a deterrent to its use. However, there was one example from the BC government, where they developed specific policy to guide greywater projects, which was encouraging to discover. Subsequently, two case studies of greywater recycling projects were examined. The Brac 'Residential Greywater Recycling System' proved to be too expensive for single residential units with certain fixed water costs. Because of its poor economies of scale, the Brac Systems Inc. eventually went out of business and its technology bought by another business. The second case study from the University of BC, used an innovative Solar Aquatic System, which relied on conventional activated sludge processes, bioreactors, and extensive constructed wetland and membrane filtration for its treatment of greywater. This approach proved beneficial as it incorporated the components from all five-treatment processes to allow safe, reusable water to be generated for reuse on location. A system-thinking approach around urban water components was discussed, to essentially expand on the integration required when new and innovative water conservation approaches, such as greywater recycling, are planned. Also discussed was how to achieve improved economies of scale using a greywater system through larger treatment system (community level) units to overcome the initial high capital costs. The paper then presented several recommendations for developing incentives, overcoming high capital costs, changes required in regulations, codes and policies to support safe greywater recycling, collecting data on water demand and usage through metering, the importance of efficient appliances and low-flow plumbing fixtures, providing incentives and the importance of leadership for change.

The authors learned that in British Columbia (BC), where the cost of water is still low, the primary reasoning behind domestic water conservation appears to be more on personal environmental values, than on any monetary savings. However, water conservation and greywater reuse should not be assessed only in terms of economic performance but also in terms of its more significant social and environmental benefits in contributing towards sustainable development and resource use.

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