GREYWATER REUSE IN AGRITOURISM DESTINATIONS

by

Sarah Bonnie Partanen

B.A.Sc., Queen's University, 2012

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Civil Engineering)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

April 2015

Abstract

Though Canada has a perceived abundance of fresh water resources, they can be affected by localized drought, changing weather patterns and aging infrastructure. Greywater collected from sinks, baths, showers and washing machines can provide an alternate source of non-potable water, improving the security of fresh water resources in Canada.

The agriculture sector is one area where greywater could be put to beneficial use. Farming at the rural-urban interface has been growing in popularity within North America, and provides farmers with new opportunities as they attract more visitors to the farm. Greywater reuse is one way farmers can address the challenge of how to manage the associated increased influx of wastewater. However, there is a lack of integrated research that explores the feasibility of using greywater as a water resource on farms at the rural-urban interface. There is also a lack of knowledge regarding farmers' perceptions and opinions of greywater reuse. Without this information, the barriers to greywater reuse on farms are unknown.

This research undertook a feasibility study into the reuse of greywater at the UBC Farm in British Columbia, Canada. It explored feasibility from a technical, regulatory, and economic standpoint. A questionnaire was also developed and administered to farmers across BC as a way to discover the barriers to greywater reuse.

It was found that the UBC Farm could generate enough greywater through produce washing operations to flush all the toilets in the proposed new farm centre throughout the summer months. The farm centre's roof provides the opportunity to capture enough

rainwater to flush the toilets throughout the remainder of the year. The greywater treatment and distribution system becomes more economically feasible as the price of potable water increases. The questionnaire responses also highlighted that cost is a significant barrier to farmers' adoption of greywater reuse on their own farms. While most farmers saw the benefit of reusing water, they couldn't predict their customers' view of the practice. Farmers are unlikely to adopt a practice having the potential to hurt their business, so an awareness of customer perceptions will be required prior to their consideration of greywater reuse.

Preface

The design of the research question and program was completed by Sarah Partanen with consultation from Jim Atwater, thesis supervisor. All research and analysis of research data was completed by Sarah Partanen. The qualitative study design was reviewed by the UBC Behavioural Research Ethics Board, BREB number H13-02982.

Table of Contents

List of Tables

List of Figures

Acknowledgements

This research would not have been possible without the support of many individuals. I'd first like to thank my supervisor, Jim Atwater. Apart from doing all the things a good supervisor does – guide, encourage, discuss, correct – Jim also allowed me to dream up my own research topic. This was something I had a passion for, but no one in the department was doing similar research at the time. Jim gave me the freedom to pursue my own research interests, and this remains one of the things I am most grateful for.

I'd like to thank my colleagues in PCWM – having a group of people going through the same experiences you are certainly helps to keep the spirits up. A special thanks goes to Sam Stime for sharing his knowledge on Arduino systems as well as his extra parts. Thanks also to Paula and Tim in the lab. Although I wasn't in there much, when I needed to do lab tests they generously gave their time to help me figure it all out.

Thanks to Alf and Peter for their time and their insights into the minds of their fellow farmers. A big thanks is deserved by the staff at the UBC Farm, especially Tim and Véronik for always answering my questions, and for letting me use the Farm as a place to test out my ideas.

I'm so grateful to my parents for their enduring support, and their encouragement to pursue whatever made me happy. Thanks for steering me towards engineering. I think it was the right choice.

And finally, I couldn't have gotten through without Jordan. He saw all my day-to-day stresses and accomplishments, and his steadfast nature smoothed out all the bumps.

Chapter 1: Introduction

Many counties worldwide suffer from freshwater shortages. While Canada has a perceived abundance of freshwater, it is affected by variance in geographic availability, aging infrastructure, and periodic drought. Greywater - defined here as used water from domestic sinks, baths, showers, and washing machines - can provide an alternate source of non-potable water, improving the security of Canada's freshwater supply.

Farming at the rural-urban interface has been increasing in popularity within North America as the boundaries between city and country blur. This provides farmers with interesting new business opportunities as they begin to not only grow their products on the land, but also attract visitors and customers to the land. This could be to simply sell products at farmgate sales, but can incorporate other attractions such as farm stores, souvenir shops, cafes, hedge mazes, and petting zoos. These activities are classified as "agritourism", and the farms are referred to as "agritourism destinations". The British Columbia Agritourism Alliance (BCATA) is an organization whose members represent the wide variety of farms that are considered agritourism destinations within BC.

One of the challenges faced by these farmers is how to effectively manage the wastewater that goes hand in hand with encouraging people to visit their farms. The specific challenges will vary from farm to farm, but could range from increased load on a septic system or lagoon in a rural area, to higher water bills from metered irrigation water at a farm closer to an urban center. City water resources can also become stressed if agritourism destinations operate on a city grid. Research into the reuse of greywater from sources such

as sinks, showers and washing machines has been completed for many locations and uses. Uses for this recycled water depend on the level of contamination of the water and the regulatory requirements of the region. However, there is a lack of integrated research that explores the feasibility of using greywater as a water resource in an agricultural setting at the rural-urban interface.

Another specific research gap is a lack of information about farmers' perceptions of greywater and nutrient reuse. Public perception and acceptance of water reuse programs have been widely studied, and it is well understood that public buy-in is a requirement for the success of any water reuse project. However, this implies that a municipality or company is invested in the project, and is trying to garner public support. In the case of water reuse in an agritourism setting, the owner of the farm is the first person that needs to buy into the idea. If he or she believes that water reuse isn't worth the trouble, whether that's due to capital cost, perceived public resistance, or difficulty with regulations, then a water reuse system will never be implemented.

A study on the feasibility of reusing greywater on a farm in British Columbia was carried out in partnership with the UBC Farm in Vancouver, British Columbia. This feasibility study examined greywater reuse from a technical, regulatory, and economic standpoint. Greywater reuse is not common on farms in British Columbia, and without a sound business case and visible proof of a system's long term operation, greywater reuse is unlikely to catch on. Case studies on farms are important, because they become test systems that can be analyzed by farmers who are interested in implementing their own

greywater reuse system. This feasibility study will allow both the UBC Farm and similar farms to gauge whether they can undertake greywater reuse.

A qualitative study was also carried out in order to assess farmers' existing perceptions, pre-existing knowledge, and opinions regarding greywater reuse. This study took the form of a questionnaire, distributed to members of the BC Agritourism Alliance. The responses from farmers who took the questionnaire helped to identify barriers to greywater reuse at the rural-urban interface. The data collected from the survey will be of use mainly to researchers, policy makers, and government agencies. Having information on institutional and economic barriers to adoption of greywater reuse is important for the success of any type of regulation or incentive program that encourages the behaviour. The data obtained from this study can also be used to guide future research by highlighting the concerns that are currently foremost in the minds of farmers who work at the rural-urban interface.

This thesis will begin with an in-depth review of the literature pertaining to greywater, a rationale for its reuse, especially in agritourism destinations, and the importance of public perception in the acceptance of greywater reuse projects. The methods used to answer the research questions will then be explained. The results from the application of these methods will be presented, along with a discussion as to their significance. Finally, the results will be summarized along with any limitations of the research, and some suggestions for further exploration of the topic.

The goal of this research has been to begin a discussion as to the feasibility of greywater reuse on farms in British Columbia, with a focus on social feasibility alongside the more commonly assessed metrics of technical and economic feasibility.

1.1 Greywater definition and rationale for reuse

"Greywater" is a general term that has been used to describe domestic wastewater from a variety of different sources. No matter the particulars of how it is defined, most people agree that greywater excludes inputs from toilets (Boyjoo, Pareek, & Ang, 2013; Eriksson, Auffarth, Henze, & Ledin, 2002; World Health Organization, 2006, etc.). By separating out feces and urine, the bulk of the pathogen load in typical domestic wastewater is avoided. This means that that greywater is generally considered to be less polluted than domestic wastewater (Friedler, 2004). Typically, greywater sources include water outputs from bathroom sinks, showers, bathtubs and washing machines (Boyjoo et al., 2013; Rose, Sun, Gerba, & Sinclair, 1991). Wastewater from kitchen sinks and dishwashers is considered more polluted than other sources of domestic wastewater due to higher loads of microorganisms and organic matter from food particles. Therefore, it is often excluded as a component of greywater (Casanova, Little, Frye, & Gerba, 2001; Friedler, 2004).

Depending on the definition of greywater being used, 50-75% of domestic water consumption produces greywater (Eriksson et al., 2002; Friedler, 2004), so its reuse could significantly offset domestic water usage.

1.1.1 The perception of abundance

Canada is typically perceived as having an abundance of fresh water resources. This perception is reinforced by the news media, politicians, and most Canadians, however it is not an accurate perception (Bakker & Sprague, 2006). The misconception seems to persist due to the large number of lakes and rivers that Canada possesses, but this ignores the distinction between the volume of water in these lakes, and Canada's renewable supply of water. While the volume of water in the Great Lakes may seem to be large, it can only be used once; the total volume is not renewable. Canada's renewable fresh water consists of the water that falls from the sky as precipitation, replenishing groundwater and augmenting streams and rivers as it runs towards the oceans (Bakker & Sprague, 2006). Using this more accurate definition of water abundance, Canada has a relatively modest share of the world's renewable water supply. Canada possesses 6.5% of the world's renewable fresh water (Environment Canada, 2013b), a similar amount to Indonesia (6.5%), the United States (6.4%), and the People's Republic of China (6.4%) (Bakker & Sprague, 2006). By contrast, Brazil possesses 12.4% of the world's renewable fresh water supply, and Russia possesses 10.0%. The volumes corresponding to these percentages can be seen in Table 1.1.

Table 1.1: Internal renewable water resources by country (Bakker & Sprague, 2006). This table is reprinted with permission of the Publisher from *Eau Canada: The Future of Canada's Water* by Karen Bakker © University of British Columbia Press 2006. All rights reserved by the Publisher. Original data from WRI, 2005.

	Supply (km^3 per year)	Percentage of world supply
Brazil	5,418	12.4
Russian Federation	4,313	10.0
Canada	2,850	6.5
Indonesia	2,838	6.5
United States	2,818	6.4
People's Republic of China	2,812	6.4
Columbia	2,112	4.8
Peru	1,616	3.7
India	1,261	2.9
Democratic Republic of Congo	900	2.1
World total	43,773	

The numbers in Table 1.1 enumerate the precipitation occurring within a country's borders, and do not account for water flowing into or out of the country.

Another nuance to Canada's water supply is geographical. Of the 6.5% of renewable fresh water that Canada possesses, 60% of that water drains into the Arctic Ocean and Hudson's Bay while 85% of Canada's population lives near the southern border (Environment Canada, 2013b). The supply in southern Canada is closer to 2.6% of the world's fresh water resources. Across Canada, pollution and periodic drought can make fresh water resources unusable or unavailable (Environment Canada, 2013b). Large municipalities can also experience limits on their fresh water supply due to problems with infrastructure, both as demand exceeds the capacity of the system, and due to aging sewer and water systems that are in need of repair (Environment Canada, 2006). The myth of freshwater abundance in Canada is perpetuated within the news media, despite the availability of accurate statistics.

This has perhaps led to a more cavalier attitude towards water use by Canadians than people in countries where this myth does not exist.

Of all the fresh water withdrawn from the environment in Canada, domestic water is the third largest use, representing 9% of the total (Minister of Industry, 2010). Despite household water conservation efforts such as low flow faucets and toilets, water metering, and leak detection, Canada remains one of the world's largest per capita users of fresh water (274 L person^{-1} day^{-1-} for a metered water user in 2009) (Environment Canada, 2013a).

Greywater reuse is uncommon in Canada, partially due to the commonly held perception that Canada holds an abundance of fresh water. This perception is reinforced by the perennially low cost of water in Canada. Canada, and North America in general, tend to charge some of the lowest prices for water compared to other Organization for Economic Cooperation and Development (OECD) nations. In Canada, the average municipal water and wastewater price is $2.31 per cubic metre[1]. This is contrasted to Denmark ($9.22/m^3), the United Kingdom ($6.57/m^3) and Germany ($5.90/m^3) (Vander Ploeg, 2011). By sector, Canadians also pay less than other OECD nations to use freshwater. In general water costs for industry and agriculture are lower than for domestic water across OECD nations, but for irrigation and agriculture, Canada pays $0.01 per m^3 for its water use. This is contrasted to the Netherlands ($1.67/m^3) and Austria ($1.17/m^3) (Vander Ploeg, 2011). In general, it can

[1] Water prices in Canadian dollars

be said that Canada is relatively water rich compared to other OECD nations. These trends help to explain why greywater reuse in Canada is uncommon.

In areas of the world that experience stress on their fresh water resources such as Australia, the Middle East, and parts of the United States, greywater reuse is an accepted practice (Glenn, 2012; Sinclair, O'Toole, Malawaraarachchi, & Leder, 2013). Greywater can be reused for a variety of purposes, including for irrigation or for household reuse. The mechanisms for reuse can vary widely as well, from a dedicated greywater reuse treatment and distribution system, to individuals collecting and reusing their own greywater using buckets. However, in Canada the lack of immediate need in many regions of the country punctuated by inexpensive municipal water means that greywater reuse projects are few and far between. Be that as it may, greywater constitutes an alternative source of non-potable water, which improves the reliability of a fresh water supply and provides resistance to drought (National Research Council, 2012a). By reducing the amount of water entering the sewers, it also reduces the discharge of treated effluent from wastewater treatment plants into receiving waters, and in some cases provides an economic benefit by reducing wastewater treatment infrastructure costs (Exall, Marsalek, & Schaefer, 2004).

1.2 Greywater composition

Greywater has similar characteristics as low- to medium-strength wastewater, but with biodegradability characteristics of a tertiary effluent (Jefferson, Palmer, Jeffrey, Stuetz, & Judd, 2004). It also tends toward nutrient deficiency, as urine contains a high fraction of the nutrients present in a typical domestic wastewater, and is excluded from greywater.

Greywater tends to have a higher COD:BOD ratio than domestic wastewater, indicating that it contains a higher non-biodegradable fraction (Jefferson et al., 2004). Greywater commonly contains detergents and personal care products which themselves contain non-biodegradable surfactants and salts (Rodda, Salukazana, Jackson, & Smith, 2011).

The composition of greywater can vary widely depending on its source and the practices that generate it (Maimon, Friedler, & Gross, 2014; Meinzinger & Oldenburg, 2009). Despite being less polluted than domestic wastewater due to the source separation of toilet water, greywater can still contain organic, inorganic, and biological contaminants that can be harmful to human health and the environment (Gross, Kaplan, & Baker, 2007; O'Toole et al., 2012). Organics in greywater can consist of a wide range of chemicals including low concentrations of pharmaceuticals, hormones, and detergents (Buxton & Kolpin, 2002), as well as oil and grease. Biological material consists of bacteria and viruses (O'Toole et al., 2012), while inorganic material such as grit or metals could also be present (Eriksson & Donner, 2009). Despite being excluded in this research, some researchers include wastewater generated in the kitchen as a source of greywater. This inclusion means that factors such as diet and use of a kitchen food waste grinder can affect the levels of organic matter present in that greywater. Depending on which specific household detergents and cleaning products are used, the types of chemical constituents present in greywater will also vary. Some research has shown that greywater from households with young children has higher levels of fecal coliforms (Casanova, Gerba, & Karpiscak, 2001).

Though there is no such thing as a "typical" greywater, a range of values for water quality parameters can be seen in Table 1.2.

Table 1.2: Composition of greywater. Reprinted from "Model guidelines for domestic greywater reuse for Australia" by Jepperson & Solly (1996). http://www.wri.org/our-work/project/earthtrends-environmental-information.

Parameter (Unit)	Range of Values
Suspended solids (mg/L)	45 - 330
Turbidity (NTU)	22 - 200
BOD_5 (mg/L)	90 - 290
Nitrite (mg/L)	0.1 - 0.8
Ammonia (mg/L)	0.1 - 25.4
Total Kjeldahl nitrogen (mg/L)	2.1 - 31.5
Total phosphorus (mg/L)	0.6 - 27.3
Sulphate (mg/L)	7.9 - 110
pH (--)	6.6 - 8.7
Conductivity (mS/cm)	325 - 1140
Sodium (mg/L)	29 - 230

1.3 Uses for greywater

Greywater can be reused for many applications that do not require potable water. These can be broken down into three main categories:

1. Domestic reuse
2. Industrial reuse
3. Agricultural reuse

1.3.1 Domestic reuse

Applications for greywater within or around the home, such as toilet flushing and garden or lawn irrigation constitutes domestic greywater reuse (Christova-Boal, Eden, & McFarlane, 1996; Friedler, 2004). The reuse of greywater in a domestic setting can be achieved in a variety of ways, from manual bucketing, to individual greywater treatment

and distribution systems for a single-family home, to more centralized systems that service entire apartment buildings.

Domestic greywater reuse is practiced worldwide, but it is most common in places that are affected by water shortages such as Australia, the Middle East, and parts of the United States. In one study, the use of greywater was observed by researchers in Melbourne, Australia over a five year period that included three years of severe drought and accompanying water use restrictions (Sinclair et al., 2013). They found that in the majority of households simple mechanisms for reusing greywater were most frequently employed. Greywater was collected by hand from washing machines, and used for garden watering without any type of treatment. When water restrictions eased, over 40% of the households discontinued their use of greywater (Sinclair et al., 2013). During the drought period, 71% of Melbourne residents reported reusing greywater, while greywater use fell to 42% three years later. Even with the 30% drop in households reusing greywater, these numbers show that in places like Australia, the reuse of greywater is normalized, and seen as an acceptable activity. It is difficult to know the percentages of Canadians who use greywater in a similar manner, as there is little research on this topic.

1.3.2 Industrial reuse

Water used in industrial processes can be recycled in many industries, including the plastics, pulp and paper, rubber, and petroleum and coal industries (Schaefer, Exall, & Marsalek, 2004). The use of recycled water in industry is split almost equally between process water, and cooling, condensing and steam generation. In 2009, 2003 m^3 of water

was reported by industries in Canada as having been recirculated, that is, used more than once by the facility. For the manufacturing industry in Canada, recirculated water as a percentage of intake was 52.6%. In the primary metals industry a recirculation rate of 97.9% was reported (Minister of Industry, 2009). Canadian industry accounts for approximately 80% of total freshwater use (Minister of Industry, 2010), so further water recirculation in this sector could lead to large gains in water conservation (Schaefer et al., 2004). However, further discussion on industrial water reuse is outside the scope of this document.

1.3.3 Agricultural reuse

Greywater is reused in agriculture for the purpose of irrigation, and has been used worldwide for irrigation of food crops (Finley, Barrington, & Lyew, 2009; Rodda et al., 2011), fodder crops and flowers (Grieve, 2011). When greywater is reused without treatment, there are concerns about the safety of human health and the environment (See Sections 1.8 and 1.9). In Canada, there are restrictions on how and when greywater can be used in irrigation (See Section 1.7).

Sometimes there are opportunities for multiple types of greywater reuse to be incorporated into a single system. This is the case for farms that have sufficient volumes of greywater to reuse it both for irrigation and for toilet flushing.

1.4 Agritourism

Agritourism can refer to a wide range of activities whereby a visitor to a farm or other agricultural setting participates in an agricultural process for recreation or leisure (Tew &

Barbieri, 2012). There are inconsistencies within the range of research on agritourism as to what specifically counts as agritourism. Some research does not include activities that make use of an agricultural setting without any further involvement on the part of the visitor (such as a wedding or meal hosted on a farm) (Gil Arroyo, Barbieri, & Rozier Rich, 2013). One broad definition of agritourism that was developed by Phillip et al. (2010) classifies agritourism into five non-hierarchical classes.

1. Non-working farm agritourism (i.e. a bed and breakfast on a former farm)
2. Working farm, passive contact agritourism (i.e. a bed and breakfast on a current farm)
3. Working farm, indirect contact agritourism (i.e. serving a meal on the farm that contains products from the farm)
4. Working farm, direct contact, staged agritourism (i.e. viewing farming demonstrations)
5. Working farm, direct contact, authentic agritourism (i.e. helping with farm chores)

From an academic perspective, it is important to have a consistent definition of agritourism to help develop a uniform field of study, leading to more specialized contributions to the field in the future (Phillip et al., 2010). However, for the purposes of this research, agritourism was considered to be any visit to an agricultural setting for leisure, entertainment, education, or retail.

1.4.1 Importance of agritourism

Agritourism is a way for agricultural enterprises to diversify. By providing educational or recreational opportunities to the public, farmers can increase their revenue as well as adjust aspects of their business according to market needs (Barbieri & Mahoney, 2009; Gao, Barbieri, & Valdivia, 2013). However, this model of agriculture may have unforeseen consequences when it comes to the management of water. While there are no requirements regarding the location of agritourism destinations in order for them to meet the above definitions, many agritourism destinations are peri-urban – that is, they are located on the boundary between city and country (Brinkley, 2012). Farms located within a short distance from a city are in a unique position to attract visitors and customers to the land, in part because tourists are generally only willing to travel a certain distance to visit these locations (Brinkley, 2012). When a farm becomes an agritourism destination, waste production tends to increase due to an increase in the number of visitors. In general, this correlates to more activities that require water, such as cooking for a farm cafe, washing produce for a farm market, and wash water in public restrooms. This in turn generates larger amounts of greywater, such as from hand washing and produce washing. There is also more waste generation from public toilet use by the increased numbers of visitors.

The potentially large volumes of greywater generated at agritourism destinations, coupled with agriculture typically being a large user of fresh water, highlights a unique opportunity to research greywater reuse at these locations.

1.5 Greywater treatment

In developing countries that are water stressed, greywater is often reused without treatment. Much emphasis has been placed on developing treatment technologies that are simple, efficient, and inexpensive for the safe reuse of greywater or wastewater by subsistence farmers (where most of the produce grown is consumed by the farmer and his family, leaving little to be sold) (World Health Organization, 2006a). In Canada, greywater must meet stringent quality regulations prior to reuse (See Section 1.7.1) in order to remain protective of human health and the environment.

The removal or inactivation of enteric pathogens is usually the primary objective of greywater treatment (Exall et al., 2004; Maimon, Tal, Friedler, & Gross, 2010). Many treatment technologies can be employed to deliver greywater effluent that can be safely used in a variety of applications. The type of treatment depends heavily on the characterization of the greywater (Boyjoo et al., 2013), as both the sources of greywater and the constituents within greywater can vary widely depending on location and household habits (See Section 1.2) (Maimon et al., 2014; Meinzinger & Oldenburg, 2009). Similar to municipal wastewater treatment, greywater can be treated using a combination of biological, chemical and physical processes, and treatment systems can be either mechanical, or passive.

For greywater applications that do not require a high quality of water (for example lower exposure potential water, see Section 1.7.2), basic filtration and disinfection may be sufficient to meet regulatory limits for using reclaimed water. This can be the case for the

use of rainwater, which can be a high quality water source to begin with (Regional District of Nanaimo, 2012). Typically rainwater is considered to be a category of water separate from greywater due to its source and apparent quality. Reuse of rainwater is much more common than the reuse of greywater, with municipalities across Canada and around the world subsidizing rain barrels for rainwater collection (e.g. City of Guelph, 2014; City of San Diego, 2015; Selkirk, 2012). For the purposes of this research, rainwater was considered alongside greywater as a potential alternate source of non-potable water, but is not itself considered to be greywater.

For greywater which requires more extensive treatment to meet the applicable standards, biological treatment is often employed. Examples of biological treatment includes membrane bioreactors (MBRs) (Friedler, Shwartzman, & Ostfeld, 2008; Paris & Schlapp, 2010) and rotating biological contactors (RBCs) (Friedler, Kovalio, & Galil, 2005; Gilboa & Friedler, 2008). MBR technology is a combination of biological and physical processes, as following biological treatment, the membrane acts as a physical barrier against microorganisms (Boyjoo et al., 2013). The ability of MBRs to treat a variety of influent qualities and quantities makes them especially applicable for the treatment of greywater. An RBC consists of an attached growth biological treatment unit which rotates through a flowing greywater stream, allowing for contact between the greywater and the bacteria which consume organic material, providing treatment (Friedler et al., 2005). RBCs have been found to remove parabens in greywater that come from household chemicals and pharmaceuticals (Eriksson, Andersen, Madsen, & Ledin, 2009). Since the presence of micropollutants in greywater is a concern to both human health and the environment, this

is an attractive quality in a treatment technology. Biological systems are typically preceded and followed by a filtration stage used to remove solid material and sludge. (Boyjoo et al., 2013; Gilboa & Friedler, 2008). These are just two examples of biological treatment trains which could be applied to the treatment of greywater. Depending on the characteristics and quantities of the greywater, other types of treatment might be more applicable. Biological treatment systems are often better suited to treating greywater from multiple households, as they have more intensive maintenance and operational requirements than passive treatment systems.

A passive system for greywater treatment refers to a constructed wetland or pond which uses natural biological, physical, and chemical processes to treat greywater (Maimon et al., 2010; Masi et al., 2010). The physical filtration medium in a passive system is typically a natural material such as sand or gravel. Physical treatment is combined with biological degradation from aerobic or anaerobic microorganisms including biofilms, rhizoshpere microorganisms, and earthworms (Boyjoo et al., 2013). This type of system would likely be a suitable option for an agritourism destination, because natural systems are generally inexpensive to implement, and can be maintained by unskilled operators (Gross, Shmueli, Ronen, & Raveh, 2007). Their large land requirements make them unsuitable for urban environments (Boyjoo et al., 2013), but a farm is more likely to have land that could be used for a treatment pond or wetland.

In British Columbia, disinfection of reclaimed water is required, regardless of the intended use. The most common method of disinfection worldwide is chlorination by sodium hypochlorite. For certain applications, such as in irrigation, a chorine residual is not desired

as it can be toxic to plants. UV disinfection is another alternative, and is preferred in some cases as a way to avoid storage of chlorine based disinfectants, and for its inactivation of a wide variety of pathogens (Boyjoo et al., 2013).

1.6 Economics of greywater reuse

There is a cost associated with all of the treatment technologies mentioned in Section 1.5. For farmers in British Columbia to incorporate greywater reuse into their business, the practice must make economic sense.

The economic challenges associated with implementing a greywater reuse project are varied. They can be grouped into the following categories (Listowski, Ngo, & Guo, 2013):

- High capital and operating costs
- Inadequate incentives associated with the conservation of water resources or the reduction of pollutants
- Long investment return period
- Limited revenue from recycled water

The Food and Agriculture Organization of the United Nations released a report in 2010 about the economics of wastewater use in agriculture (Winpenny, Heinz, & Koo-Oshima, 2010). The report is written on the basis of evaluating the use of reclaimed water as one option to mitigate water scarcity. In order for a system for reusing reclaimed water to be feasible, for agriculture or other opportunities, the proposals must be economically justified, cost effective, and financially feasible.

The first of these criteria, economical justification, is assessed through a cost-benefit analysis. The reuse of greywater means that it must be treated as though it has some economic value. The value of greywater is most apparent when freshwater is scarce. Greywater also has a cost, including the capital costs to treat and distribute the reclaimed water, the ongoing operational costs to provide water of a certain quality, long term environmental costs such as increased soil salinity, costs of the measures to protect human health from any negative effects of reclaimed water use, and the cost associated with regulatory restrictions on the types of produce that can be grown with reclaimed water. In places affected by water scarcity, a major benefit to water reuse is the savings of an equivalent amount of freshwater that can be used for an alternate purpose (Winpenny et al., 2010). Other benefits may include a savings in the cost of fertilizer, depending on the source of the reclaimed water, greater reliability of the water supply, and environmental benefits from reduced water abstraction from surface or groundwater sources. The difference between the value and cost of greywater is the basis of an economic justification for greywater reuse (Winpenny et al., 2010). Once the costs and benefits of a project are quantified, a net sum, either positive or negative can be arrived at for each year of the project. The annual amounts can be discounted to arrive at a net present value for each year. The length of time it takes to reach a positive net present value can be used to assess whether the project is economically feasible.

One of the main concepts of a cost-benefit analysis is that for a given proposal, a variety of alternatives exist, one of which is to do nothing, and another of which is to implement the greywater reuse system. The use of this approach is that it allows a quantitative evaluation

of all project alternatives on the basis of effectiveness, feasibility, and cost effectiveness (Winpenny et al., 2010). Many of the first studies to evaluate the cost of reclaimed water used a general cost-benefit methodology. The downside to this approach is that only the internal costs (investment costs, financial costs, and operating and maintenance costs) are taken into account, while external costs (including environmental and social impacts) are ignored (Hernández, Urkiaga, Fuentes, Bis, & Chiru, 2006; Molinos-Senante, Hernandez-Sancho, & Sala-Garrido, 2011). The result is that the true costs and benefits of a water reuse project are inaccurately evaluated, leading to a decision based on incomplete information. The reason that water reuse projects were originally evaluated on this simplified basis is because there isn't a lot of consensus on how to place a monetary value on the external costs and benefits.

Cost effectiveness, meaning that a proposed project achieves its objectives at the minimum cost, is measured through a cost-effectiveness analysis (CEA). It is used as an alternative decision making tool to the CBA, and is especially useful when the benefits of a project are difficult to quantify, as with externalities such as environmental or public health considerations. In general, a CEA consists of defining the project objective and identifying options for achieving it, comparing the costs of the various options, and choosing the one with the lowest total cost (Winpenny et al., 2010). Complications arise because in many cases, externalities do not have a market value. Researchers have accounted for this by using economic valuation methods (Hernández et al., 2006; Molinos-Senante et al., 2011). In other cases, external costs are assumed to be negligible, by stating that there are no significant environmental impacts (Verlicchi et al., 2012). One example of an economic

valuation method is the Contingent Valuation Method (CVM), used in one case to determine the value of the recreational benefit arising from a water reclamation project (Verlicchi et al., 2012). The CVM was carried out using a questionnaire to determine participants willingness to pay (WTP) for a perceived benefit. The value of the benefit is then calculated as the average WTP of a family that will benefit multiplied by the number of families (Verlicchi et al., 2012). Another researcher used the concept of "shadow pricing" to quantify the undesirable outputs (pollutants) generated from water regeneration (Molinos-Senante et al., 2011). For further information on calculating shadow pricing to estimate external costs and benefits, the reader is referred to the work of Molinos-Senante et al. (Molinos-Senante et al., 2011).

The last of Winpenny et al's criteria, financial feasibility, takes into consideration the interests of the various stakeholders of a proposed project (Winpenny et al., 2010). Assessing financial feasibility includes determining the financial impact of the project on the stakeholders, including which stakeholders have the most to gain and lose. In the case of farmers, a key factor is how much of the project's cost the farmers themselves have to bear. Benefits to farmers include a reliable source of irrigation water, assuming that this is a current issue for the farm. Depending on the source of the reclaimed water, there may also be cost savings from reduced fertilizer requirements, whereas the cost of restrictions on what produce can be grown using reclaimed water is one that is borne by farmers. Assessing financial feasibility also incorporates a discussion of which incentives are suitable to make the project acceptable to all stakeholders.

These methods of evaluating economic feasibility pertain most directly to a water utility or government that is considering implementation of a water reuse project. For an individual farm or household, some of the costs and benefits are not applicable. For example there would be no income generated from selling the reclaimed water, but instead a potential savings from not having to purchase water. One benefit to decentralized greywater treatment, such as would be found on a farm, is that the majority of the cost of a greywater reuse project comes from the conveyance and distribution of the water (Asano, 1991). If the distance between the generation of the greywater, the treatment of the water, and the proposed location of reuse are minimized, the cost of the system will be lower.

1.7 Regulatory framework

In Canada, water reuse is practiced on a relatively small scale. British Columbia is the only province with provincial legislation that contains provisions for greywater reuse. In 2012, the Alberta Chamber of Commerce published a document recommending that the Government of Alberta adopt the Health Canada guidelines (See Section 1.7.1) as a way to begin reusing greywater within Alberta, and to encourage the reuse of greywater in toilet flushing, irrigation and industry (Alberta Chamber of Commerce, 2012). The Saskatchewan plumbing regulations reference the use of reclaimed water, and mandate that the CSA standards (See Section 1.7.1) must be followed (Government of Saskatchewan, 2011). however, no provinces other than BC have their own regulations, or provisions that allow for reuse other than in toilet flushing. Other provinces and municipalities evaluate water reuse on a case-by-case basis. For example, in Ontario the city of Guelph provides a $1000 incentive to households that install a greywater reuse system to use shower and bath water

for toilet flushing. They are a municipal leader for greywater reuse in Canada, and operate by maintaining compliance with the Ontario building code which supports greywater reuse for toilet flushing (City of Guelph, 2013).

1.7.1 National guidelines

Nationally, Health Canada's "Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing" provide some guidance regarding the reuse of water (Health Canada, 2010). The reclaimed water referenced by this document includes both domestic wastewater and greywater. As implied by the title of the document, these regulations do not discuss uses for reclaimed water in addition to toilet flushing, although it is indicated that the long term goal is to develop guidelines for many beneficial uses. Given the nature of the organization, there is naturally a focus on the health impacts of reusing water, and on mitigating any risk to those who reuse water. The Health Canada guidelines, published in 2010, address the lack of standards pertaining to the quality of reclaimed water. They also advocate for a preventative risk management strategy to be developed for each reclaimed water system.

The water quality parameters for reclaimed water stipulated by the Health Canada guidelines are shown in Table 1.3.

Table 1.3: Guideline values for domestic reclaimed water used in toilet and urinal flushing (Health Canada, 2010)

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

These guidelines are designed to protect the public from microbiological contaminants. Although there are also chemical constituents found within reclaimed water, compared to bacteria, protozoa, and viruses, the health impacts associated with the chemical constituents are thought to be minimal (Health Canada, 2010).

The Health Canada Guidelines reference a multi-barrier approach to risk management, which was adapted from the report "From source to tap: The multi-barrier approach to safe drinking water" (Federal-Provincial-Territorial Committee on Drinking Water & Water Quality Task Group, 2002). The following principles constitute the various barriers to risk in this approach (Health Canada, 2010):

- **policy frameworks,** which should provide a commitment to the responsible use of reclaimed water and which should include the responsibilities of the authorities, owners, and operators of a greywater reuse system
- **public awareness,** to maintain partnerships and communication between the various stakeholders of a reclaimed water system
- **guidelines and standards,** which provide authorities and operators with applicable water quality targets to ensure that the quality of the reclaimed water is acceptable for its end use

- **treatment and distribution,** which ensure that the reclaimed water is safely delivered to its end use, and at the target quality for the intended application
- **management,** including owner/operator training, public consultation, research and development, system validation, and systems for documentation and reporting
- **monitoring** to ensure that the treatment and distribution systems are working correctly, and that the water is at an acceptable quality for its end use.

While the Health Canada guidelines emphasize that monitoring is an important aspect of reclaimed water system risk management, they also acknowledge the fact that ongoing monitoring is often too expensive and time consuming to be practical. The guidelines recommend that once the system has been proven to meet the water quality parameters required for the intended application under specific operating conditions, that verification of those specific operating conditions should be enough to verify water quality. They recommend periodically confirming this assumption through more intensive testing. The exception to this methodology is the disinfection system, which as a critical control point of the reclaimed water system should be tested daily or weekly (Health Canada, 2010).

The Health Canada guidelines reference the CSA Standards B128.1-06/B128.2-06, "Design and installation of non-potable water systems/Maintenance and field testing of non-potable water systems" (Murra, 2007) for plumbing requirements. These are the only other national standards pertaining to the reuse of water. CSA Standard B128.1-06 is more inclusive than the Health Canada guidelines, as it acknowledges uses for reclaimed water in addition to toilet flushing, such as irrigation of lawns and gardens, car washing, showering, bathing, washing clothes, and heating and cooling. However, its scope is limited to the

design and installation of non-potable water systems, and does not cover the quality of the water. The CSA standard indicates that the water used in a non-potable water system shall meet the water quality requirements of the intended application. Since in Canada the only water quality requirements for non-potable water are exclusively for toilet flushing (the Health Canada Guidelines), even though the CSA standard includes provision for other uses, it is for all intents and purposes also restricted to systems used for toilet flushing.

An important feature of the CSA standards are the requirements for backflow prevention and cross-contamination. Specific measures to protect against backflow are listed, as well as requirements for testing for potential cross-connections. The CSA standards also include requirements for storage tanks designed to hold non-potable water, and labeling and identification of pipes used to transport non-potable water.

CSA Standard B128.2-06 addresses maintenance and field testing of non-potable water systems. It provides a recommended maintenance schedule, including checking backflow preventers, pressure and storage tanks, pumps, and warning labels annually, filter systems quarterly, and roof gutters, drains, and treatment systems every 6 months. The required action for most of these items is a simple inspection and verification of operation.

The Wastewater Systems Effluent Regulations (Government of Canada, 2013), are Canada's current standards for wastewater treatment. They include mandatory minimum effluent quality requirements, but have no provisions for non-potable water reuse. This means that at the national level, the reuse of greywater is most fully regulated for use in toilet and urinal flushing, making it difficult to reuse greywater for other applications.

1.7.2 Guidelines in British Columbia

The regulations governing the use of reclaimed water in BC are more specific than the Health Canada guidelines. While the Health Canada guidelines still apply, it is the provincial regulations that must be closely followed in order to reuse water in BC.

British Columbia addresses the use of reclaimed water in Part 7 of the Municipal Wastewater Regulations (BC Ministry of the Environment, 2012). This section of the regulations begins by defining a set of categories of reclaimed water. These are as follows:

- Indirect potable reuse, for any use of reclaimed water to replenish a potential potable water supply
- Greater exposure potential, for any use for which public contact is likely, or that presents a threat to the receiving environment
- Moderate exposure potential, for uses for which public contact is likely minimal, or public access is restricted and users are educated as to the risks posed by the reclaimed water
- Lower exposure potential, for uses for which public access is restricted and users are not likely to have contact with the water. Commercial and industrial reuse falls under this category so long as the users are educated as to the risks.

Under the BC regulations, authorization from a health official must be obtained prior to providing reclaimed water. The BC regulations also include parameters for water quality, but unlike the Health Canada guidelines, the limits are tiered according to the exposure potential category. These parameters can be seen in Table 1.4.

Table 1.4: MWR quality requirements for reclaimed water (BC Ministry of the Environment, 2012)

Parameters (Unit)	Category			
	Indirect potable reuse	**Greater exposure potential**	**Moderate exposure potential**	**Lower exposure potential**
pH	Site specific	6.5 - 9	6.5 - 9	6.5 - 9
BOD_5, TSS (mg/L)	BOD_5 5 mg/L TSS < 5 mg/L	10 mg/L	25 mg/L	45 mg/L
Turbidity (NTU)	Maximum 1 NTU	Average 2 NTU Maximum 5 NTU	n/a	n/a
Fecal coliform (CFU/100 mL)	Median < 1 Or < 2.2 MPN	Median < 1 Or < 2.2 MPN; maximum 14	Median 100 Maximum 400	Median 200 Maximum 1000

The regulations also state that no reclaimed water can be provided unless it has been disinfected. A minimum total chlorine residual of 0.5 mg/L is to be maintained unless the chorine will negatively impact aquatic flora or fauna.

The BC regulations do not limit the reuse of water to toilet and urinal flushing, but they do place limits on how reclaimed water can be used in other applications, including restrictions on grazing animals after irrigating livestock fields, and processing crops to destroy pathogens.

Similar to the CSA Standards, the regulations address storage, alternate disposal and distribution of reclaimed water, and provide a schedule for monitoring of water quality that is dependent on the category of water.

Water quality and discharge quantity reports must be submitted weekly for indirect potable reuse, monthly for greater exposure potential water, and quarterly for moderate

and lower exposure potential water. The monitoring requirements for the different categories of reclaimed water are shown in Table 1.5.

Table 1.5: Monitoring requirements for different categories of reclaimed water (BC Ministry of the Environment, 2012)

		Exposure potential		
Parameters	**Indirect potable reuse**	**Greater**	**Moderate**	**Lower**
pH	Site specific	Weekly	Weekly	Weekly
BOD_5, TSS, flow volume	Weekly	Weekly	Weekly	Weekly
Turbidity	Continuous monitoring	Continuous monitoring	n/a	n/a
Fecal coliform	Daily	Daily	Weekly	Weekly

The MWR has the authority to administer fines up to a total of $200,000 if false monitoring data, or a false report is submitted.

British Columbia also has a companion document to the MWR, the Reclaimed Water Guideline, released in July 2013 (BC Ministry of Environment, 2013). One of the document's underlying characteristics is that no reclaimed water may be reused without the oversight of a qualified professional to ensure that the requirements of the MWR are met, and that the public's health is protected.

The companion document adds value to the topic of reclaimed water use in BC by providing practical advice as to how to apply for a reclaimed water permit, as well as specific information pertaining to the regulatory agencies that one must comply with. The BC guideline also provides some potential applications for each category of reclaimed water (i.e. indirect potable reuse, and greater, moderate or lower exposure potential). Potential applications for the reclaimed water are not explicitly addressed in the MWR,

making the guideline an important source of information. However, even if the guideline outlines specific uses for certain qualities of water, there are many caveats to its use. To take irrigation as an example, the guideline requires the consultation of a health officer when assessing new irrigation areas, and the assessment of a qualified professional when considering a new use of reclaimed water. The assessment must be submitted to the regional director prior to any new use of reclaimed water. The implication of these requirements is that regulations notwithstanding, any one of these individuals could veto the use of the reclaimed water for its intended purpose.

In general, the BC guidelines provide more detail as to the practical aspects of reusing reclaimed water. They provide lists of reference documents, and enumerate the officials who must be engaged at the various stages of the reclaimed water use project. The goal of the BC guideline, and by extension the MWR, is to remain protective of public health and the environment.

The BC guideline also references the most recent version of the BC Plumbing Code, which includes a section on plumbing requirements for reclaimed water systems. Section 2.7 of the 2012 BC Plumbing Code is the first version of the Code to include provisions for the use of reclaimed water (BC Government, 2012). General limitations are outlined in the Code, including that non-potable water systems must not be connected to a potable water system, and that non-potable water pipes must not be located where food is prepared, or above potable water tanks. The BC Code references the CSA Standard B128.1-06 for the design of non-potable water systems. For water quality requirements, the BC Code acknowledges that good engineering practice dictates that the non-potable water be of

appropriate quality for its intended end use, and defers to the appropriate authority (BC Government, 2012), such as Health Canada. Because the BC Plumbing Code deals with residential plumbing, the most likely use for plumbed non-potable water would be for toilet flushing. The BC Code references the Health Canada Guidelines for this reason.

1.8 Greywater reuse and health

Although greywater is commonly held to be less polluted than domestic wastewater, the risk of microbial and chemical contamination mean that greywater does have the potential to transmit disease. However, there have been no recorded incidents of serious negative effects on human health resulting from the reuse of greywater (World Health Organization, 2006b).

Exposure to contaminants in greywater can occur through multiple routes, the most prevalent of which is fecal-oral contact, whereby fecal pathogens pass from one host and are introduced orally to another host (Crook & Rimer, 2009). Exposure routes include direct ingestion, ingestion via contaminated hands, or indirect exposure through contact with a contaminated object (Crook & Rimer, 2009). Exposure to contaminated greywater can also occur through inhalation of aerosols in the form of irrigation spray or toilet flushing spray (Health Canada, 2010), or transmission through broken skin. The constituents present in greywater that are of concern can be organic, inorganic, or biological. Organics in greywater can consist of a wide range of chemicals including low concentrations of pharmaceuticals, hormones, and detergents (Buxton & Kolpin, 2002), as well as oil and grease. Biological material consists of bacteria, viruses and protozoa

(O'Toole et al., 2012), while inorganic material such as grit or metals could also be present (Eriksson & Donner, 2009).

The greatest health concern associated with the reuse of greywater is the presence of enteric pathogens. A wide range of enteric microorganisms colonize the human digestive tract, and many are harmless. However, some bacteria, viruses and protozoa are pathogenic when they enter the intestines, causing a range of gastrointestinal illnesses (Imperial College London School of Public Health, 2013). Bacterial species such as *E. coli* or *Shigella* spp. cause diarrhoea, which is a common symptom of waterborne illness (Arizona Department of Health Services, 2014). On the far end of the spectrum, the bacteria *Vibrio cholerae* causes cholera, a waterborne illness that can be rapidly fatal. Waterborne viruses can also cause diarrhoea. Viruses that can be excreted by humans, and thereby enter water, include adenovirus, enterovirus and rotavirus (Westcot, 1997). The parasites *Giardia* spp. and *Cryprosporidium* are found in the feces of animals and humans, and can also cause gastrointestinal illness (Arizona Department of Health Services, 2014).

Despite the exclusion of toilet water from greywater streams, fecal contamination can occur through some laundry activities such as diaper washing, and sometimes from bathing and showering (Ottoson & Stenström, 2003). Greywater containing high levels of easily-degradable organic matter can lead to the growth of fecal indicator bacteria. Reliance on the presence of fecal indicator bacteria in the case of greywater reuse can lead to an overestimation of the fecal contamination of the water source, and therefore an overestimation of the risk associated with its reuse (Ottoson & Stenström, 2003). Differentiation between actual fecal contamination, and the presence of indicator

organisms must be made in order for regulatory limits to be set that remain protective of human health while also not stifling the reuse of greywater.

Quantitative microbial risk assessment (QMRA) has been employed to establish health-based targets for greywater reuse around the world (Godfrey et al., 2010; Seidu et al., 2008; World Health Organization, 2006c). QMRA is a method of applying risk assessment principles to the estimation of the consequences of exposure to a microorganism. Information such as dose-response relationships and exposure magnitudes are often used to understand the potential effects from an exposure (Haas, Rose, & Gerba, 2014). It is challenging to develop a robust and accurate risk assessment model. As an example, one study used three different models of risk estimation: (1) measuring fecal contamination using coprostanol concentrations (formed by the hydrogenation of cholesterol in the intestine by gut bacteria and often used as a biomarker for fecal contamination) and epidemiological data; (2) using a dose-response model of fecal enterococci occurrence in marine waters; and (3) using fecal enterococci as an indicator for *Salmonella* occurrence in greywater (Ottoson & Stenström, 2003). The researchers found a potential underestimation of fecal load when coprostanol was used as an indicator, as children and infants often lack the gut microorganisms that convert cholesterol to coprostanol. Since the fecal load in greywater is heavily influenced by activities such as diaper washing, an underestimation of fecal load could occur. They also found that while indicator organisms can overestimate the fecal load, their susceptibility to treatment may compensate for this overestimation (Ottoson & Stenström, 2003). In general, developing an accurate model for greywater risk assessment is a challenge.

The presence of metals, surfactants, detergents, personal care products, and other chemical contaminants in greywater is another concern as they can pollute groundwater and alter soil characteristics (Eriksson & Donner, 2009; Gross et al., 2005; Travis, Weisbrod, & Gross, 2008). However, these contaminants are considered to pose a minor risk to human health compared to pathogenic organisms (Maimon et al., 2014). The risks to human health can vary widely depending on concentration, duration of exposure (National Research Council, 2012b), and the application. For example, the presence of contaminants that affect human health is less concerning if the potential for human exposure is low, as it would be in landscape or fodder crop irrigation.

Many studies have assessed the health risk of greywater reuse globally, but these results are difficult to generalize as the risk of greywater reuse depends on the characterization of the greywater, what treatment technology is used, and the people that are exposed to the greywater (World Health Organization, 2006c). Certain populations such as the elderly or those with compromised immune systems have a higher risk associated with their reuse of greywater (Dixon, Butler, & Fewkes, 1999).

1.9 Greywater reuse and the environment

The impacts of greywater on human health are quite widely studied, and it is on the basis of protecting human health that the reuse of reclaimed water is regulated in Canada and British Columbia. However, there are also environmental consequences to reusing greywater. There is a relative lack of research into the environmental impacts of

wastewater and greywater irrigation, as most studies are devoted to the health impacts of pathogens and chemicals present in the water (Muñoz et al., 2009).

Environmental concerns with using greywater for irrigation usually stem from the use of untreated greywater, a more common practice outside of North America. Irrigation with untreated greywater can be beneficial in some regards, as any nutrients within greywater can benefit plant growth (Rodda et al., 2011), essentially providing a low-grade fertilizer along with irrigation water. The beneficial nutrient content of reclaimed water is more of a factor when it is wastewater instead of greywater being reused, as the toilet inputs provide most of the nutrients. This is especially important in developing countries, where a potential decrease in fertilizer costs benefits low income gardeners and farmers. In Canada, no reuse of reclaimed water, (wastewater or greywater) is permitted without at least disinfection, and for most uses further treatment is required. In this case, the risks to human health are seen to outweigh the benefits of the intrinsic nutrient content of the water. In addition, researchers have observed a range of impacts, including that irrigation with untreated reclaimed water has no effect on overall plant biomass, indicating that the nutrient benefit of the water can be minimal in some cases (Pinto, Maheshwari, & Grewal, 2010). It has also been found that although beneficial nutrients may be found within reclaimed water, they are not necessarily present in the correct ratios required by the crops (Pereira et al., 2011). This becomes an even larger challenge given that the quality of reclaimed water is rarely stable. Whether or not reclaimed water has a beneficial impact on plant growth, it is important to consider the nutrient requirements of the specific plant, as well as the existing soil concentrations of plant nutrients in order to avoid accumulation of

nutrients in the soil, or potential leaching of nutrients to groundwater (Mohamed, Kassim, Anda, & Dallas, 2013).

Some studies have shown increased soil salinity and SAR (soil absorption ratio) increasing over periods of greywater irrigation (Mohamed et al., 2013; Rodda et al., 2011). Excess sodium is toxic to plants, and the salinization of soils can lead to a deterioration of soil structure, and the eventual inability of the soil to support plant growth (Rodda et al., 2011). One potential recommendation for counteracting the accumulation of sodium in soils is to alternate irrigation with greywater and freshwater (Al-Hamaiedeh & Bino, 2010; Rodda et al., 2011).

Because greywater is typically alkaline due to the presence of laundry water which contains surfactants and builders (used to soften water and provide alkalinity (ACCORD, n.d.)), greywater irrigation can cause a increase in soil pH over time (Mohamed et al., 2013). A pH range of 6 to 7.5 is often considered optimal for the growth of many types of plants due to the specific phytoavailability of micro-nutrients such as Cu, Pb,Mn, Mb and Zn. An increase in soil pH can affect the phytoavailability of these micronutrients, having adverse effects on plant growth (Pinto et al., 2010). Alternating freshwater-greywater irrigation is also thought to reduce the increase in soil pH observed from irrigation with greywater (Pinto et al., 2010).

Surfactants and synthetic fragrances, both of which are found in detergents, belong to the broad category of emerging pollutants (Muñoz et al., 2009). Surfactants and oils and grease in particular have been shown to cause water repellency within soils, and decrease the soil

hydraulic conductivity. Oils and grease arise predominantly from kitchen activity, though they are present in all greywater streams. Their accumulation within soils can lead to varying degrees of water repellency, causing runoff, ponding, and transport of other contaminants within greywater (Travis et al., 2008). While some research has shown that oils and grease are readily degraded in soils, this reflects a single application of greywater to soil. Since greywater is typically applied to soil in ongoing applications over a period of time, this suggests that long term irrigation may be required to observe detectable accumulation of oils and grease (Travis et al., 2008). Surfactants can also cause phytotoxicity by affecting the microbial community associated with the rhizosphere (Pinto et al., 2010). This observation is dependent on the type of plant, as in some cases, the microbial community appears to degrade the surfactants, thus reducing any toxic effect (Pinto et al., 2010).

Heavy metals are also candidates for accumulation within soils, as they do not biodegrade (Muñoz et al., 2009). Their persistence in the environment and ability to be taken up by plants contributes to their negative impact on soil quality and biodiversity (Katanda, Mushonga, Banganayi, & Nyamangara, 2007). While small amounts of some heavy metals such as Cu and Zn are essential to organism growth, others such as Cd and Pb have no known benefits. The toxicity of Cd occurs due to its chemical similarity to Zn, which causes it to replace zinc in metalo-enzyme complexes, thereby causing zinc deficiencies within organisms (Katanda et al., 2007). Two studies examined the effects of 30 years of irrigation with sewage sludge and effluent in a similar area in Zimbabwe, and found accumulation of Zn and Cu in lettuce and mustard rape beyond toxic limits without any impact to plant

growth. This poses risks for the transportation of toxic quantities of these metals up the food chain (Katanda et al., 2007; Tandi, Nyamangara, & Bangira, 2005). It is important to note that different plants uptake heavy metals differently, with some excluding metals entirely, some accumulating metals, and some "hyperaccumulating" metals to concentrations higher than the surrounding soil concentration. Katanda et al. (2007) also found toxicity to soil microorganisms when they added low concentrations of cadmium serially to soil samples, as evidenced by decreasing biomass C and N with increasing concentrations of Cd. Heavy metal contamination can have adverse affects on soil microorganisms, especially *Rhizobium* strains. Because these bacteria are essential for biological nitrogen fixation in legume crops, the presence of heavy metals in the soil could cause a suppression of N fixation, and therefore lower biomass N. Conversely, a different study performed in 2005 found that while 20 years of sewage irrigation led to metals buildup in soils, the tissue metal concentrations within crops was below phytotoxicity levels (Rattan, Datta, Chhonkar, Suribabu, & Singh, 2005). These seemingly disparate results highlight that a wide range of factors contribute to the phytoavailability of metals, including climate, physical and biological processes within the soil, organic matter content, soil pH, plant species, and land management practices (Katanda et al., 2007; Rattan et al., 2005).

Fewer studies have researched the environmental impacts of treated greywater versus untreated greywater, but with treatment, many of the environmental risks associated with greywater reuse can be mitigated. One study used artificial greywater, both raw and treated using a recirculating vertical-flow constructed wetland system, to assess the effects

on soil properties (Travis, Wiel-Shafran, Weisbrod, Adar, & Gross, 2010). They found that hydrophobicity resulting from irrigation with raw greywater containing surfactants and oil & grease could be prevented with sufficient greywater treatment. They also found significantly less coliform bacteria in the soils irrigated with treated greywater, indicating that health risks as well as environmental risks can be mitigated with treatment (Travis et al., 2010).

1.10 Public perception of greywater reuse

All projects, be they construction, energy, or environmental, require some degree of public acceptance to be successfully implemented. Greywater reuse projects are no exception. In fact, public perceptions and acceptance are now seen as key factors in whether a reuse project will succeed or fail (Friedler & Lahav, 2006; Po, Kaercher, & Nancarrow, 2003). The first projects to use recycled water viewed gaining the public's acceptance as an obstacle to overcome. It is now generally accepted that this type of persuasion cannot convince people to use recycled water or accept water reuse projects. Instead, it is important to understand what factors influence public perception, and how they can lead to acceptance of water reuse (Po et al., 2003).

Public perception remains important to a greywater reuse project at an agritourism destination. The influence the public holds in this case comes with their buying power. Gaining public acceptance for such a project would likely be a priority to farmers due to the consequence of losing customers.

1.10.1 Past approaches to public involvement

Public involvement at the earliest stages of project conception is important, because the public has the power to prevent projects from being implemented through political action (Hartley, 2006). Slogans such as "toilet to tap" that are employed by a concerned public can be persuasive, even if the slogans are not accurate. Proposed projects in San Diego, the San Gabriel Valley, and in Dublin County, California have all been halted after the "toilet to tap" slogan mobilized worried residents (Po et al., 2003). A public awareness campaign centered around factual information is not likely to be as persuasive as a catchy slogan. In many cases a logical need for water reuse is not enough to result in public acceptance, because there are many other societal factors that influence a person's decision making process.

In the past, water reuse projects took place without a lot of community involvement, possibly due to the public's trust in the decision makers who were implementing these projects (Po et al., 2003). However, there has been a noted decline in public trust of government authorities, which can lead to greater opposition of water reuse projects (Hartley, 2006; Recycled water task force, 2003). An approach where the implementation of a recycled water project is seen as a foregone conclusion, and public outreach is used to persuade the public to accept the project is unlikely to be successful. Persuasion works by providing information in an attempt to encourage someone to make a rational decision, which may be why it has been unsuccessful in increasing acceptance of greywater reuse (Nancarrow, Leviston, Po, Porter, & Tucker, 2008). Using public outreach as a way to make project decisions that reflect the communities concerns and values is an approach that is

more likely to succeed, especially if there are multiple project alternatives to solve one problem (eg. water shortages) (Recycled water task force, 2003).

In the past, public acceptance for water reuse projects was typically sought after the project had already been planned out by public utilities and government. Current approaches have shifted to engagement of stakeholders from the beginning of project conception. This shifts the focus from water reuse as the only solution to water reuse as one of multiple project options to solve a given problem.

1.10.2 Current behavioural models

There have been attempts to model the factors that impact the public's decision making, but it is difficult to capture the complexity of how each identified factor interacts and overlaps with the others (Hartley, 2006). Despite the understanding that public acceptance is a significant challenge in the implementation of successful water reuse projects, there is little systematic research on the factors that affect the public's decision making process (Nancarrow et al., 2008).

Behavioral models are important, because positive public perception does not neatly translate into public acceptance. Even when communities support the principle of reusing greywater, when the time comes to actually use the recycled water, people's reactions can be quite different. This response is seen more and more the closer the personal contact with the recycled water (for example landscape irrigation versus indoor toilet flushing) (Nancarrow et al., 2008; Po et al., 2003).

Current behavioural models developed by Nancarrow et al. (Nancarrow et al., 2008; Nancarrow, Leviston, & Tucker, 2009) are based on the theory of planned behavior originally developed by Icek Ajzen (Ajzen, 1985). This theory holds that whether a person successfully performs a given behaviour will depend on the level of control they hold over a variety of internal and external factors that may influence the execution of the intended behaviour. For further information on the theory of planned behavior, please see "From intentions to actions: A theory of planned behavior" by Icek Ajzen (1985).

Nancarrow et al. (Nancarrow et al., 2008) took Ajzen's theory of planned behaviour, and adapted it to model the factors that affect decision making with regards to using reclaimed water. Ajzen's model has been used successfully to provide predictive evidence in relation to environmental behaviours and was seen as providing a reliable base to build a water reuse model on (Po et al., 2005). The model developed by Nancarrow et al. also incorporated factors from related literature in food technology and risk management. Nancarrow et al.'s initial hypothesized model is shown in Figure 1.1.

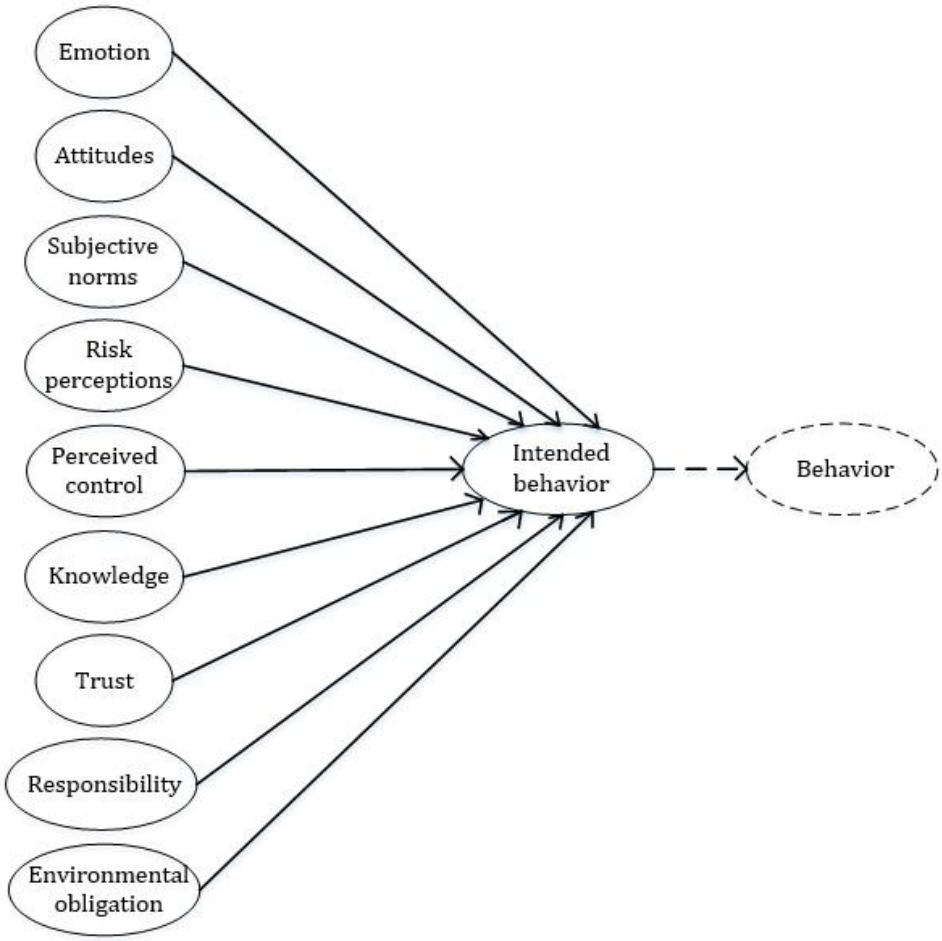


Figure 1.1: Hypothetical model showing the factors that affect the acceptance of water reuse proposed by Nancarrow et al. (Nancarrow et al., 2008)

Familiar from Ajzen's model is the concept that a variety of factors affect people's behavioural intentions, which are directly related to the prediction of that person's behaviour. The hypothesized model in Figure 1.1 was further tested and refined by Nancarrow et al. (2008, 2009). The variables hypothesized to have an effect on intended behaviour were found to vary in degree, and are described in detail below.

The factors that can influence people's acceptance of greywater reuse despite its logical benefits include (Nancarrow et al., 2009; Po et al., 2003):

- Emotion: Also known as the "yuck" factor, or the extent to which someone feels positive or negative emotions towards water reuse
- Attitudes: Whether a person believes that supporting water reuse will lead to positive outcomes
- Subjective norms: The amount of pressure a person feels from others to support the issue
- Risk perceptions: The level of risk a person feels is associated with the plan to reuse water. This can be further split into health risk, environmental risk, and systems risk
- Perceived control: The amount of control a person feels they have over the specific uses and sources of the recycled water
- Knowledge: The level of knowledge a person feels they have on the subject of water reuse
- Trust: The amount a person trusts the authorities involved in the water reuse plan
- Responsibility: The amount a person feels the individual, the community and the authorities are responsible for assuring future water supplies
- Environmental obligation: The extent to which a person feels personally responsible to protect the environment
- Environmental justice: The perceived fairness in the decision making process and whether the water reuse project is seen to be unfairly directed at a specific group
- Cost of recycled water: The perceived value of the recycled water and whether that value should be reflected in the cost to the consumer

As indicated above, not all of the above factors are of equal importance in predicting someone's intended behaviour. Through the use of questionnaires and interviews, it has been shown that a person's knowledge on the subject of water reuse is not a significant predictor of that person's intended behaviour (Nancarrow et al., 2008). Policy making traditionally relies on the notion that scientific fact will have a significant effect on people's

behaviours. In the case of environmental issues, people can become disenfranchised with the scientific information that is disseminated, and develop opinions based on other information such as anecdotal evidence. The practical use of such behaviour models comes from understanding how people make decisions. Knowing that appealing to logic does not significantly impact somebody's decision making process, one might be less likely to distribute informational pamphlets.

On the other hand, emotion, trust, subjective norms, and fairness have been shown to have a significant effect on intended behavior, i.e. intent to use recycled water (Nancarrow et al., 2009). Adapting this model to a water reuse project at an agritourism destination, the intended behavior becomes purchasing produce that may have been grown using treated greywater, or visiting a location where treated greywater is used to flush public toilets. However a reasonable hypothesis is that similar factors would affect this intended behavior.

Chapter 2: Methodology

2.1 Feasibility study

Many traditional feasibility studies for greywater reuse implementation are performed from the perspective of a wastewater utility (Latino, 2007), and evaluate environmental, technical, and economic constraints associated with the reuse of greywater.

In the case of an individual considering greywater reuse on their property, the breakdown of costs and benefits is quite different, as some large scale benefits do not apply, but neither do some costs. Specific to a water reuse project, economic issues are not the only, or even the largest consideration as to whether a project will be feasible. Public acceptance and environmental and health concerns have a large impact on the final success of the project (Urkiaga, A., Bis, B., Hernandez, F., Koksis, T., Balasz, B., Chiru, 2006). In many cases, the difference between success and failure of a reuse project will be the implementation of financial or regulatory incentives.

A study was undertaken to determine the feasibility of incorporating greywater and rainwater reuse into the design of the new Farm Centre at the UBC Farm in Vancouver, British Columbia. A description of the data collected to inform the feasibility study is discussed in the following sections.

2.1.1 Study location

The feasibility study was carried out at the UBC Farm, a 24-ha production farm that grows over 200 varieties of fruits, vegetables, and herbs. An annotated map showing some of the prominent features of the farm can be seen in Figure 2.1.

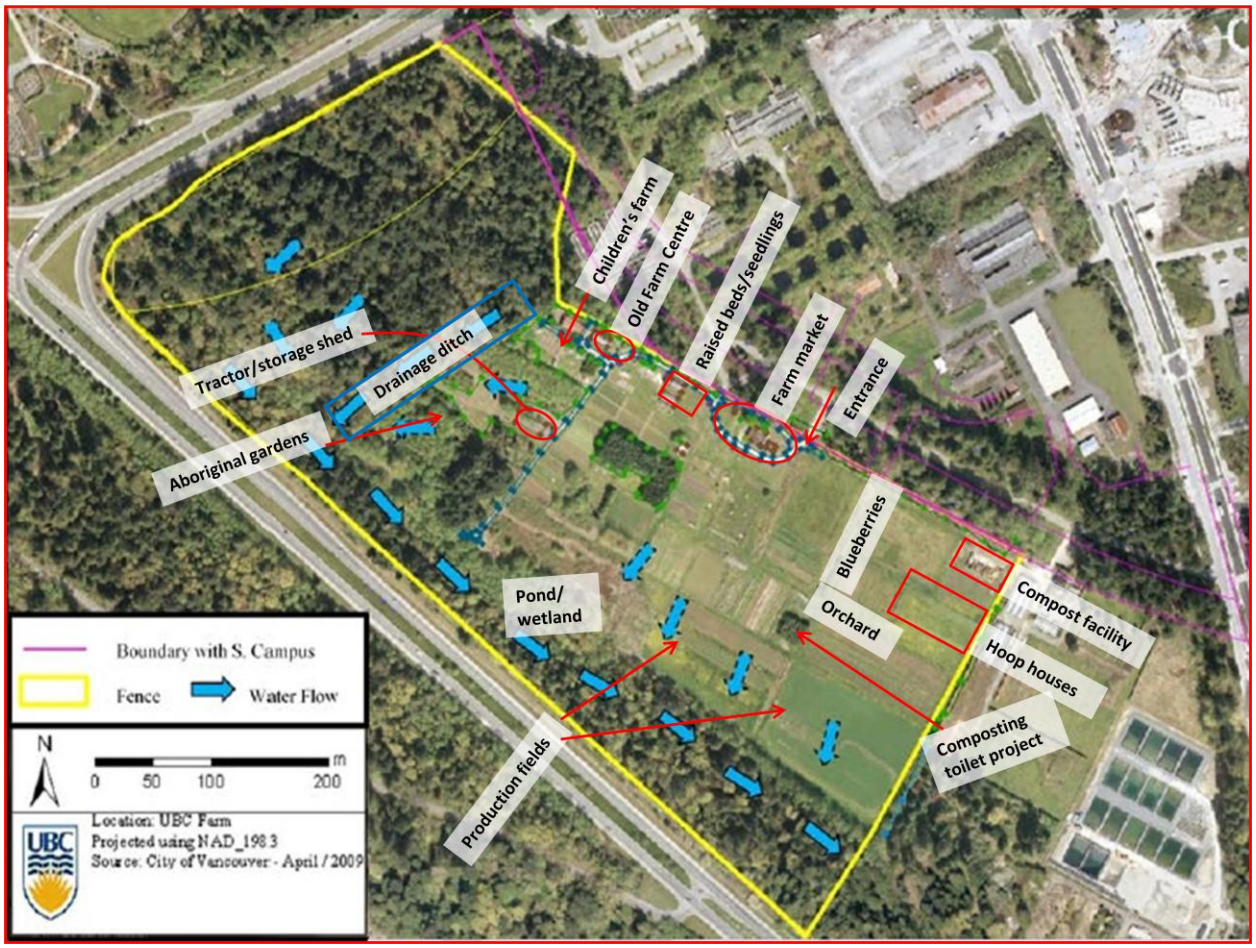


Figure 2.1: Map of the UBC Farm showing some prominent features (Mitchell, Roehr, & Laquian, 2012)

The farm contains annual crop fields, perennial hedgerows, orchards, pasture, teaching gardens and forest stands (UBC Farm, 2014b). The UBC Farm houses the Centre for Sustainable Food Systems, a research centre who's focus is on transforming local and global food systems toward a more sustainable, food secure future (UBC Farm, 2014a). The

Centre transforms the UBC Farm into a "living laboratory" by providing researchers with a living food system where social, economic, and environmental initiatives can be designed, tested and monitored (UBC Farm, 2014c). The multidisciplinary nature of a food system means that there are opportunities for a wide range of research. The characteristic of the UBC Farm as a living laboratory made it an ideal location for a feasibility study on greywater reuse. The farm directors have a stake in the outcomes of the research, as they are interested in implementing greywater reuse into their plans for future farm upgrades. Furthermore, the location of the UBC Farm on UBC's South Campus simplified data and sample collection.

2.1.2 UBC Farm data collection

A water balance enumerating the supplies and demands for water at the UBC Farm was undertaken in order to quantify the water that might be available for reuse. In this research both rainwater and greywater were included as sources of water. While most of the research completed was focused on greywater reuse, the feasibility study took into account the whole water balance of the farm. Rainwater is an integral part of this balance, and should not be ignored. The following sections outline the methods used to collect data for each water source or use.

2.1.2.1 Rainwater collection

Rainfall at UBC Farm was approximated from 22 years of UBC precipitation data, compiled from the UBC climate station (Black & Christen, 2011). The rainwater catchment area was estimated from the current Farm Centre Building Program (UBC Farm, 2012). The

catchment area refers to the horizontal footprint of a roof, and is not affected by the slope (Regional District of Nanaimo, 2012). In all rainwater calculations, the catchment area used is from the new farm centre buildings (not yet constructed). Rainwater capture using the current farm infrastructure is unlikely, as the roofs of the existing farm centre and harvest hut are either flat or have many overhanging trees. While roof slope does not affect the catchment area, it does impact the amount of water that runs into gutters where it can be easily captured. Overhanging trees can drop needles, leaves and pollen onto the roof, which can clog gutters and impact rainwater quality. It is expected that the design of the new farm centre will include provisions for rainwater capture.

Rainwater collection efficiencies at the UBC Farm were estimated using guidelines from the Nanaimo rainwater harvesting best practices guidebook (Regional District of Nanaimo, 2012). The guidebook was also referenced for rainwater storage considerations, and for efficient piping layouts. The Nanaimo guidebook was used as a reference document for rainwater capture and reuse as Nanaimo has a similar climate, and similar seasonal variability as Vancouver.

2.1.2.2 Produce wash water

At the UBC Farm, some of the produce that is grown is washed prior to being sold in weekly farm markets. There are five ways that produce can be washed:

1. Spray wash: leafy crops such as kale, collards, arugula and spinach are sprayed down with a hose inside rubber totes. Standard unit = 10 lb tote

2. Spray table: bunches of beets, carrots, radishes and turnips are washed on a table with overhead sprayers. Standard unit = 1 bunch
3. Root washer: bulk amounts of beets, carrots, and potatoes are washed within a 120 gallon tank. Standard unit = 400 lb
4. Root washer spray off: after exiting the root washer the beets, carrots and potatoes are given a final spray off. Standard unit = 40 lb
5. Dunk tank: escarole and lettuce heads, and mixed greens are washed in a 60 gallon tank. Standard unit = 24 heads or 50 bags

The standard unit refers to the amount of produce washed at a time. In the case of the root washer and dunk tank, the standard unit refers to the amount of produce washed before the water in the tank is changed.

All of the produce washing operations are serviced by one potable water connection. A DLJ single jet water meter (Daniel L. Jerman Co., n.d.) was attached to this water line in June, 2014. A 5% error on flow meter data was taken into account throughout this research.

In order to have more than one year's worth of produce wash water data, an estimate of produce washing water use for 2013 was developed based on sales data for 2013, and simulations of produce washing.

Produce washing was simulated by having a knowledgeable farm employee run a hose for the time it would take to wash a standard unit of produce using a given produce washing method. These simulations were done using the same hose that produce is typically washed with, and flow was measured using the same DLJ single jet water meter later used to measure produce wash water in real time. These hose washing simulations were done in

triplicate for spray washing, spray table and root washer spray off. For the root washer and dunk tank, the volume of the vessel was measured and the standard unit of produce washed in a tank before the water is changed was taken into account. The units of produce sold in 2013 were obtained from the 2013 sales data. Knowing the operation of each type of produce washing (e.g. 10 lb of produce is spray washed in a tote, and 40 lb of produce is sprayed off after exiting the root washer), it was possible to estimate the amount of water used in produce washing in 2013. This method does not take into account any produce that was harvested and washed in anticipation of selling, but not sold. It also assumes that the farm employee was able to accurately estimate the time it takes to wash a given type of produce.

Weekly amounts of produce sold were used to estimate the weekly volume of produce wash water generated in 2013. These values were then compared to the actual volume of water generated from produce washing in 2014. Note that these numbers aren't expected to be the same, as different amounts and types of produce are washed each year.

Quality of the produce wash water at the UBC Farm was assessed using the parameters regulated by the Code of Practice for the Use of Reclaimed Water (Ministry of Environment Lands and Parks, 2001): BOD_5, TSS, turbidity, fecal coliform, and pH.

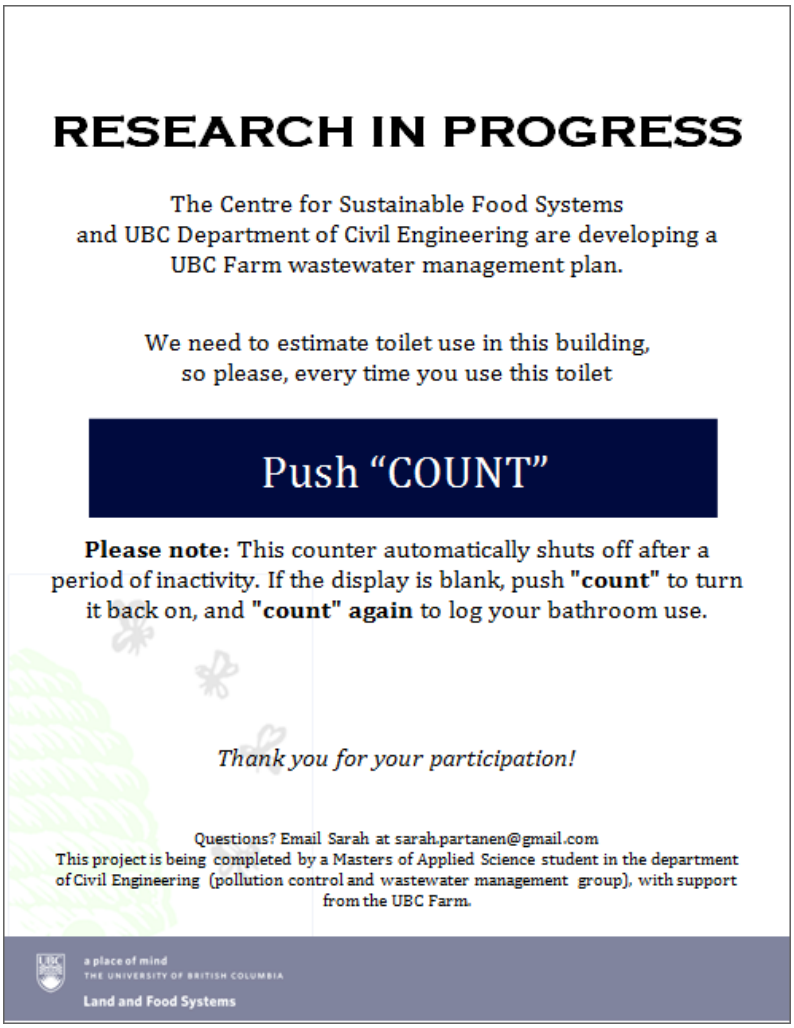
Produce wash water was collected from the farm as it was being generated from vegetable washing. Water was collected from a dunk tank being used to soak leeks, from an overhead spray table used to wash radishes, and a table and hose used to wash carrots.

Procedures for water quality testing were adapted from Standard Methods for the Examination of Water and Wastewater (Water Environment Federation, American Public Health Association, & American Water Works Association, 2006). Full procedures can be seen in Appendix A

2.1.2.3 Toilet water

There are two public toilets in the current farm centre. These toilets are used by farm staff year round, and by seasonal staff, community members, and farm program participants during the spring, summer and fall. When the new farm centre is built there will be many more toilets, eleven in total according to the current UBC Farm building program (UBC Farm, 2012). Because the farm's capacity is projected to increase, multiplying current usage numbers by the new number of toilets will not give an accurate estimate of future use. However, the water balance depends on future toilet use, as future rainwater capture potential is based on the new farm centre's roof area. Therefore rough estimates of future toilet use are used in some calculations, with the acknowledgement that the numbers could be improved by incorporating farm use projections.

Toilet flush water was measured in two ways. The first was through a self-reporting system using an informational sign and a digital counter. A picture of the sign can be seen in Figure 2.2.



RESEARCH IN PROGRESS

The Centre for Sustainable Food Systems
and UBC Department of Civil Engineering are developing a
UBC Farm wastewater management plan.

We need to estimate toilet use in this building,
so please, every time you use this toilet

Push "COUNT"

Please note: This counter automatically shuts off after a period of inactivity. If the display is blank, push **"count"** to turn it back on, and **"count" again** to log your bathroom use.

Thank you for your participation!

Questions? Email Sarah at sarah.partanen@gmail.com
This project is being completed by a Masters of Applied Science student in the department of Civil Engineering (pollution control and wastewater management group), with support from the UBC Farm.

a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA
Land and Food Systems

Figure 2.2: Sign used in the bathrooms at the UBC Farm to get toilet users to report their use

The sign shown in Figure 2.2 was put in each of the two bathrooms by the mirror along with a small digital counter. Water volume per toilet flush was estimated to be 27.4 L, from measurements of the toilet tanks.

Some challenges with the self-reporting system were noted. After the counters were first put into the bathrooms, it was observed that they were reset to zero quite frequently. This issue was circumvented by placing a piece of black electrical tape over the small reset button on the counter to discourage it from being pressed. A second challenge was the

propensity of the counters to shut their display off after a period of inactivity. When the "count" button is pressed with the display off, the first button press will only turn the display back on, not register one additional count. This issue was prevented by adding a note to the sign advising users to press the button twice if the counter display is off - the first time to turn it back on, and the second to register their toilet flush. The final challenge associated with self-reporting is the inherent lack of accuracy. Sometimes people forget to press the button, or don't want to press it. Once, when there was a children's camp taking place at the farm, the count jumped by hundreds in a day indicating that the button had been pressed multiple times when the toilet was not being flushed. These limitations of the self-report system were what led to the development of an alternative way to measure toilet flushes.

The alternative method of measuring toilet flushes was using an IR sensor connected to an Adafruit Trinket microcontroller board (Adafruit, 2014). The unit was placed in a waterproof container and suspended in the back of the toilet tank (See Figure 2.3).

.

Figure 2.3: Toilet counters in the back of the toilets at the UBC Farm

The IR sensor registered the presence of the water in the toilet tank. When the toilet was flushed, the IR sensor would stop sensing the water. Once the tank refilled with water, the sensor sensed the water again, and added one to a running count. By flipping a toggle switch on the unit, the mode could be switched from recording data to playing back data in order to relay the count. The count was relayed through flashing LED lights, one in each of the one's, ten's and hundred's place values.

The Adafruit Trinket unit eliminated the issues that come from people self-reporting on an activity, as there was no need for human intervention in order to accurately report the toilet flush count. However, there were issues with the power supply of the unit. Originally, the unit was powered from a single 9 V battery, but the battery did not have sufficient capacity to last between weekly checks on the unit. The power supply was changed to 4 AA batteries in order to increase the capacity of the unit, but this was only able to last marginally longer than the 9 V.

2.1.2.4 Kitchen sink water

There is currently one kitchen sink in use at the UBC farm centre. Similar to the toilets, when the new farm centre is built there will be many more sinks that greywater could be collected from. Without having a clear picture of the projected increases in population at the farm, it is difficult to scale kitchen sink use. The current sink is used by farm centre staff, as well as by numerous farm programs. It is mainly used for cooking activities, though much of the kitchen's dishes are washed in an adjacent dishwasher. This sink was metered with a DLJ single jet water meter (Daniel L. Jerman Co., n.d.). The meter was only hooked up to the cold water line, as it is not rated for use with hot water. Through conversations with users of the sink, it was determined the hot water tap is used less frequently than the cold water tap due to the presence of the dishwasher. Therefore, although metering only the cold water line caused an underestimation of the amount of water used, it was assumed to be an insignificant fraction of the total.

2.1.2.5 Irrigation water

The UCB Farm irrigates its fields using potable water purchased from the City of Vancouver. Irrigation water at the UBC Farm is metered in three separate locations, shown in Figure 2.4.

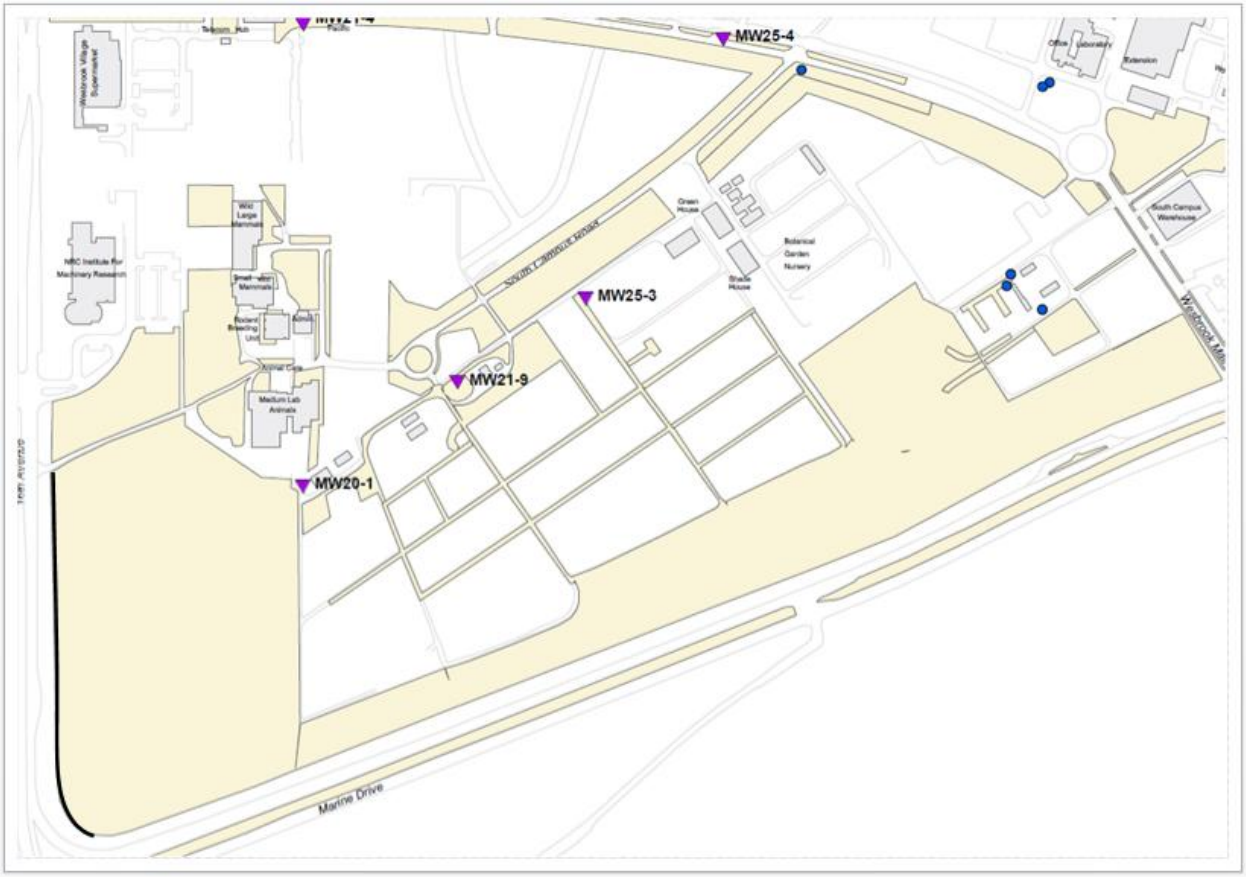


Figure 2.4: Purple triangles MW20-1, MW21-9 and MW25-3 show the locations of the water meters for irrigation water use at the UBC Farm

Data on irrigation water use at the UBC Farm is available through UBC Building Operations. The UBC Farm West (MW21-9) and UBC Farm East (MW25-3) meters have been operational since January 2011, and the UBC Farm #3 (MW20-1) meter has been in use since June 2011. The meters are read on average once a month during the growing season, though in some cases monthly readings are missed. For the purposes of this research, for months without a meter reading, water use was interpolated from the surrounding months. In the absence of further information, it was assumed that water use was equally split between the months with no readings.

2.2 Questionnaire

Questionnaires are a widely used research tool used to gather data about a specific population's knowledge, attitudes, beliefs, behaviours, and opinions on a topic (Radhakrishna, 2007). The benefits to employing a questionnaire include its practicality and efficiency. Large amounts of data can be collected from a wide range of people in a short amount of time and in a cost effective manner. People are generally familiar with questionnaires, and they can be completed on a respondent's own time. The data obtained from a questionnaire is also simple to objectively analyze.

2.2.1 Study population

The study population for this research was farmers in British Columbia who self-identify as being involved in agritourism. The definition of agritourism introduced in Section 1.4 was not used to cross reference research participants. This means that if they believe that they are involved in agritourism, that was considered sufficient for the purposes of this research. Participants were sourced from the members listing of the BC Agritourism Alliance (BCATA). This is an organization in BC, founded in 2002 to facilitate the development of a provincial agritourism sector. Their goals include facilitating and supporting strategic partnerships, the development of quality standards in agritourism, and the development of education and awareness initiatives (Collins & Thompson, 2004). Members of the BCATA include farms, homesteads, dude-ranches, wineries and orchards, and range geographically from Vancouver Island to Northern British Columbia.

The BCATA was used to source participants for this research because BCATA members already self-identify as being involved in agritourism. It removed a layer of complication from the research methods by not requiring any pre-screening of participants. This way, every person that was contacted was a potential participant. However, the BCATA website is not necessarily updated regularly. One BCATA member contacted the researchers saying that her farm had not been involved in agritourism for many years. It is unknown whether BCATA advertises or actively recruits members, or whether inactive members are removed from the members listings.

The members listing on the BCATA website contained only 70 organizations. There were 19,759 farms in British Columbia in 2011, as assessed by the 2011 Census of Agriculture (Statistics Canada, 2011). While many of these farms are considered conventional and do not incorporate agritourism into their business, it is likely that many more participate in some form of agritourism. These farms were not included as participants in this research. Future research could send out a more broad call for participants to ensure that valid participants are not excluded. This could be done by exploring other for-profit or non-profit farming organizations such as BC Cattleman's Association and BC Fruit Growers' Association, and contacting their members. This would result in the creation of an extra step, but would provide an opportunity to produce a study population that conforms to a given definition of agritourism.

This research also excludes potential non-English speaking participants. In British Columbia, Punjabi is the second most common mother tongue, spoken by 8.8% of the farm

population according to the 2011 Census of Agriculture (Statistics Canada, 2011). Future research should ensure that no segment of the population is excluded based on language.

2.2.2 Preliminary interview

Prior to developing a questionnaire to be distributed to BCATA members, a preliminary interview was completed with Peter, the farm manager at Bakerview Eco-Dairy in Abbotsford, BC. Bakerview Eco-Dairy is also a member of BCATA. The goal of the preliminary interview was to inform the development of the questionnaire through speaking with an expert in the field. To this end, webpages of BCATA members were studied in order to find people who were already invested in environmentally friendly initiatives in their businesses. This could range from an environmental farm management plan, to greywater reuse, to having an anaerobic digestor. Three farms were contacted to participate in the preliminary interview, but the Bakerview Eco-Dairy was the only response. The Bakerview Eco-Dairy is a 50 acre demonstration dairy in Abbotsford, BC, that has been operating since 2006. The dairy has 50 cows, and places an emphasis on environmentally friendly and transparent practices. A large part of their operation focuses on tourism, and they try to highlight the latest in dairy technology.

2.2.3 Questionnaire development and validation

The questionnaire used in this research was created with Vovicci EFM Continuum (UBC IT, 2014), a survey software provided free to employees of the University of British Columbia. The questionnaire was divided into five sections: self characterization, water use and opinions on greywater reuse, fertilizer use and opinions on nutrient reuse, how farmers

perceive their customers, and basic data about their operation. A sampling of these questions follows:

Self characterization

- Which of the following apply to the ways your farm generates income or attracts customers? (Please select all that apply)
    - Farmers market
    - Farmgate sales
    - Farm store
    - Cafe/restaurant
    - Farm tours
    - U-pick operations
    - Petting zoo
    - Wedding venue
    - Camping/farm holiday
    - Seasonal events (hay rides, corn maze, harvest celebration etc.)
    - Other

- What types of challenges do you face on your farm? (Response options include big challenge, somewhat of a challenge, or not at all a challenge)
    - Cost of running the farm
    - Maintaining health of livestock/animals
    - Attracting customers
    - Poor soil quality
    - Lack of potable water resources
    - Treatment/storage of waste products
    - Other

- Would you say that one of your farm's goals is to attract more visitors/customers to the farm? (Response options include yes, no, or not sure)

- Attracting more people to your farm means that there will also be an increase in the amount of wastewater generated. Do you foresee any issues in dealing with a larger amount of wastewater in the future? (Response options include yes or no)

Water use and opinions on greywater reuse

- What is your source of potable water for irrigation?
    - Municipal water supply
    - A well
    - A creek, lake or river
    - Other

- What is your source of potable water for other outdoor uses (lawn watering, equipment washing, animal husbandry, etc.)?
    - Municipal water supply
    - A well
    - A creek, lake or river
    - Other

- How concerned are you about having enough freshwater now, and five years from now? (Response options include not at all concerned, slightly concerned, moderately concerned, fairly concerned, and very concerned)

- How is wastewater dealt with on your farm?
    - Municipal sewer
    - Septic tank
    - Lagoon
    - Composting toilet
    - Other

- Water can be reused in multiple ways. This includes capturing and using rainwater, and reusing greywater from sinks, baths, showers and washing machines. Do you currently reuse greywater? (Response options include yes or no, and an opportunity to explain how greywater is reused)

- If you don't currently reuse water, have you ever considered it? (Response options include yes, no, and not sure)

- There are many different obstacles to greywater reuse in Canada. What are the obstacles you would face if you chose to reuse greywater on your farm? (Response options include big obstacle, somewhat of an obstacle, and not at all an obstacle)
    - Cost of installing a greywater reuse system
    - Reliability of the greywater reuse system
    - Complying with greywater reuse regulations
    - Public/customer perception of greywater reuse
    - Personal concerns about the safety of treated greywater
    - Collecting sufficient water for reuse
    - Having a use for the treated greywater
    - Other

- Do you think there would be benefits associated with reusing greywater on your farm? (Response options include yes or no)

- If you were to ever reuse greywater on your farm, what would you most likely use it for?
    - Irrigation of food crops
    - Irrigation of fodder crops or pasture
    - Flower garden or lawn irrigation
    - Orchard or vineyard irrigation
    - Equipment washing

    - Toilet flushing
    - Other

Fertilizer use and opinions on nutrient reuse

- Do you use fertilizer on your farm? (Response options include yes or no)

- Do you use compost or animal manure as a source of fertilizer for your farm? (Response options include yes or no)

- How many public toilets do you have on your farm? (Response can be entered as a number)

- Animal manure contains nutrients that are valuable to plants such as nitrogen, phosphorus and potassium. Do you believe that human waste also contains beneficial nutrients? (Response options include yes, no, or not sure)

- Have you ever considered using treated wastewater or composted human waste as a source of nutrients for the crops you grow on your farm? (Response options include yes, no, or not sure)

- If you answered "No" to question 20, what are your reasons for not considering using treated wastewater or composted human waste as a source of nutrients for the crops you grow on your farm?
    - Never thought about it before
    - Health concerns
    - Public perception
    - Cost of a treatment system
    - Risk of treatment system failure
    - Compliance with regulations
    - Other

- Do you think there would be any benefit associated with using treated wastewater as a source of nutrients? (Response options include yes, no, or not sure)

How do farmers perceive their customers

- In your opinion, do your customers value environmental initiatives such as reduced pesticide use, reduced nutrient leaching, groundwater quality monitoring, or water conservation? (Response options include yes, no, or not sure)

- Reusing greywater on a farm might put this practice into the public's eye. In your opinion, would this help or hurt the farm's business? (Response options include help or hurt)

- Reusing wastewater as a source of nutrients on a farm might put these practices into the public's eye. In your opinion, would this help or hurt the farm's business? (Response options include help or hurt)

- In your opinion, would your customers purchase produce grown using recycled water? (Response options include yes, no, or not sure

- In your opinion, would your customers purchase produce grown using animal manure? (Response options include yes, no, or not sure)

- In your opinion, would your customers purchase produce grown using treated wastewater? (Response options include yes, no, or not sure)

Prior to beginning the questionnaire, respondents were presented with some introductory information about the topics that they were being asked about. The information provided can be seen in Figure 2.5 below.

Purpose

This questionnaire was developed in order to get a better sense of how farmers across British Columbia feel about greywater reuse. We are especially interested in the answers of farmers who participate in "agritourism", or who otherwise are interested in attracting customers to their land.

Definitions

For the purposes of this questionnaire, "greywater" is defined as the domestic wastewater that does not come from toilets. It can include water that comes from sinks, baths, showers and washing machines. In this questionnaire, "wastewater" refers to all domestic wastewater, including from toilets. When "nutrients" are referred to in this questionnaire, that means nitrogen, phosphorus, and potassium.

Motivation for greywater reuse

Greywater reuse is currently most common in places that are affected by water scarcity, such as California and Australia. It is used as a way to conserve freshwater resources for the applications that truly need water of a potable quality. Greywater reuse is not as common in Canada, though some places do use it for toilet flushing and irrigation. This may be because there is a perception in Canada that we have plenty of water resources. This can vary greatly, however, even across BC. (Consider the water resources of the Okanagan versus Vancouver, or the decreasing groundwater resources in the Fraser Valley). Canadians are also one of the highest per-capita water users in the world.

Background on regulations

Because greywater does not contain toilet water, it is thought to be less polluted. It can still contain things that may be harmful to human health or the environment, which is why there are requirements for greywater to be treated before it is reused. The regulations that govern the reuse of water in British Columbia are the Municipal Wastewater Regulation and the Code of Practice for the Use of Reclaimed Water. Both these documents are available for free online. The purpose of these regulations is to ensure that water be reused in a way that protects human health and the environment, and is beneficial to British Columbians. They outline the different levels of treatment the water must receive to be safely used in a variety of applications, as well as storage and monitoring requirements.

There are also regulations that govern the quality and application of biosolids (stabilized municipal sewage sludge resulting from a municipal wastewater treatment process or septage treatment process which has been sufficiently treated to reduce pathogen loads in order for the sludge to be beneficially recycled on agricultural land). The primary regulation is the Organic Matter Recycling Regulation, which categorizes compost and biosolids into different classes for use based on the pathogen reduction process,quality of the material, sampling protocol and record keeping, among others.

Figure 2.5: Introductory information provided to questionnaire respondents prior to completing the questionnaire

The questionnaire's efficiency and clarity was reviewed by the same farm manager at Bakerview Eco-Dairy who participated in the preliminary interview. He made recommendations regarding word choice, question type, and background information

provided to questionnaire participants. Background information was provided to questionnaire participants to ensure that all those completing the questionnaire had the same basic knowledge. This included information such as a definition for greywater, rationale for greywater reuse, and summaries of pertinent regulations.

2.2.3.1 Recruitment

Potential participants were recruited via email using the Vovicci software. Email addresses were obtained from the BCATA online members listing. An introductory email was sent with an invitation to participate in the questionnaire. Two additional emails were sent to participants to remind them to participate, and to thank them for their participation. A total of 16 participants were obtained by the end of the questionnaire rollout period. Out of 67 potential participants, this corresponds to a 24% response rate.

Chapter 3: Results and Discussion

3.1 Feasibility study

Water supply and demand at the UBC Farm is very seasonal. On the supply side, produce wash water is only generated in the summer, between June and October, whereas precipitation mainly occurs during the winter, from November to April. Kitchen wash water is generated year-round, and was metered during this research. However, lots of the water taken from the kitchen sink is used in cooking, and therefore not available for reuse. The dish wash water that is generated is likely to be high in organics, and therefore less suitable for reuse. For these reasons, kitchen wash water was not further included in the water balance at the Farm.

On the demand side, toilet use occurs year round, though with an increase in the spring and summer months that coincides with community and children's programs. Irrigation of produce occurs mainly in the spring and throughout the summer. Figure 3.1 shows a conceptual model of the temporal supply and demand of water at the UBC Farm.

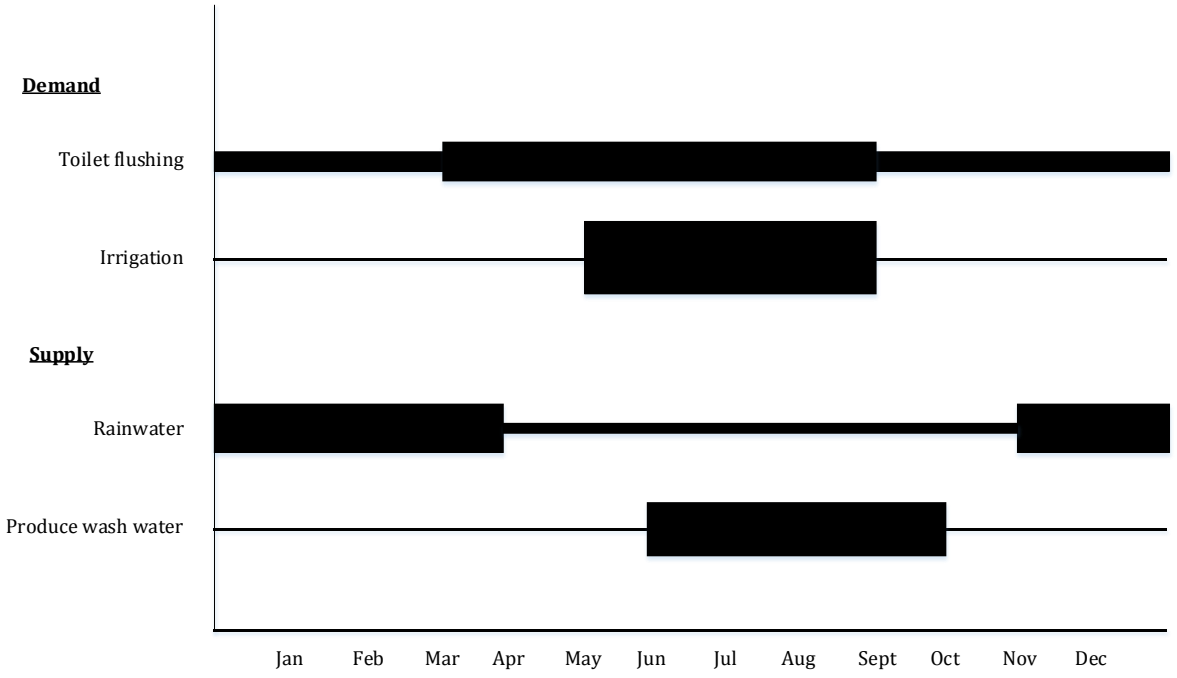


Figure 3.1: A conceptual model of temporal water supply and demand at the UBC Farm. The thickness of the bars corresponds to the relative volumes of water

Figure 3.1 explains when water is available for use, or required for use at the UBC Farm, and the relative volumes of water. It does not show the scale, or the absolute volumes of water that are available or required. The following sections answer this question through data collected for each use or source of water at the UBC Farm.

3.1.1 Rainwater

As explained in Section 2.1.2.1, the current farm centre roof is not suited to rainwater capture. For this reason, rainwater collection was estimated using the roof area of the proposed new farm centre. From the current UBC Farm Centre Building Program (UBC Farm, 2012), the total roof catchment area was determined to be 2580 m^2.

Potential rainwater collection was calculated on the basis that one millimetre of rainwater falling on one square meter of roof area results in one liter of rainwater that can be collected (Eq 1).

$$1m^2 of\ catchment\ area \times 1mm\ of\ rainfall = 1L\ of\ rainwater\ capture \qquad \textbf{Eq 1}$$

However, a 100% collection efficiency of rainwater is not possible due to seasonal quality issues such as pollen on roofs in spring, and other losses due to wind, gutter leaks, etc. Monthly collection efficiencies from the Nanaimo rainwater harvesting best practices guidebook (Regional District of Nanaimo, 2012) were used in rainwater capture calculations.

Precipitation data for UBC was collected from the UBC climate station (Black & Christen, 2011). Daily data was aggregated into weekly and monthly data. Weekly data can be seen in Appendix B This data was analyzed on the basis of quartiles. A box plot of monthly precipitation data can be seen in Figure 3.2. In Figure 3.2, the left edge of the purple box represents the lower quartile (the 25th percentile) of each monthly data set, the right edge of the blue box represents the upper quartile (the 75th percentile), the boundary between the purple and blue boxes represents the median of each data set, and the green dots represent the mean of the data sets. The "whiskers" in the plot show the data point within the lower quartile minus 1.5 times the interquartile range, and the upper quartile plus 1.5 times the interquartile range, and the red dots represent outlying data points. This methods of data representation is intended to show the spread of a data set.

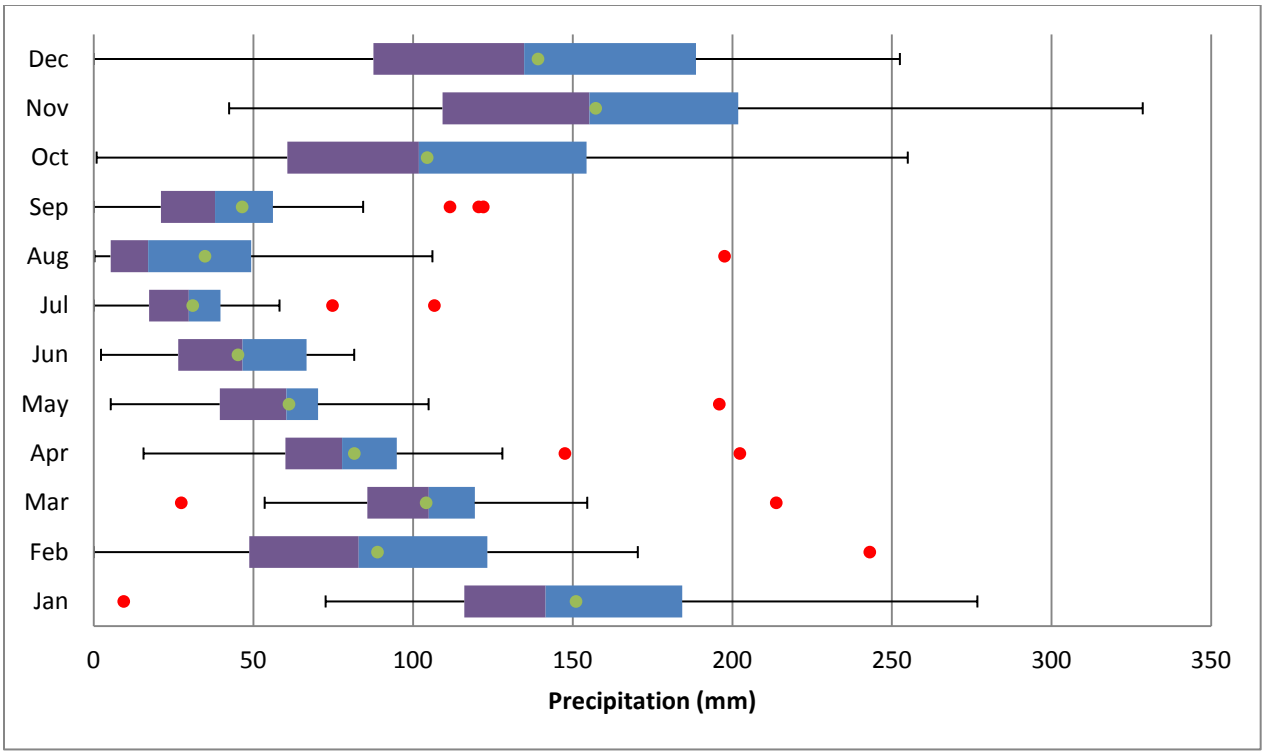


Figure 3.2: Box plot showing monthly precipitation data at UBC

Daily precipitation data was aggregated into weeks for the water balance analysis. Using the precipitation data, monthly rainwater collection efficiencies, and the total rainwater catchment area of the Farm Centre, weekly rainwater collection volumes were calculated. This data can be seen in Appendix B , and a plot of potential rainwater collection volumes each week over the course of a year can be seen in Figure 3.3.

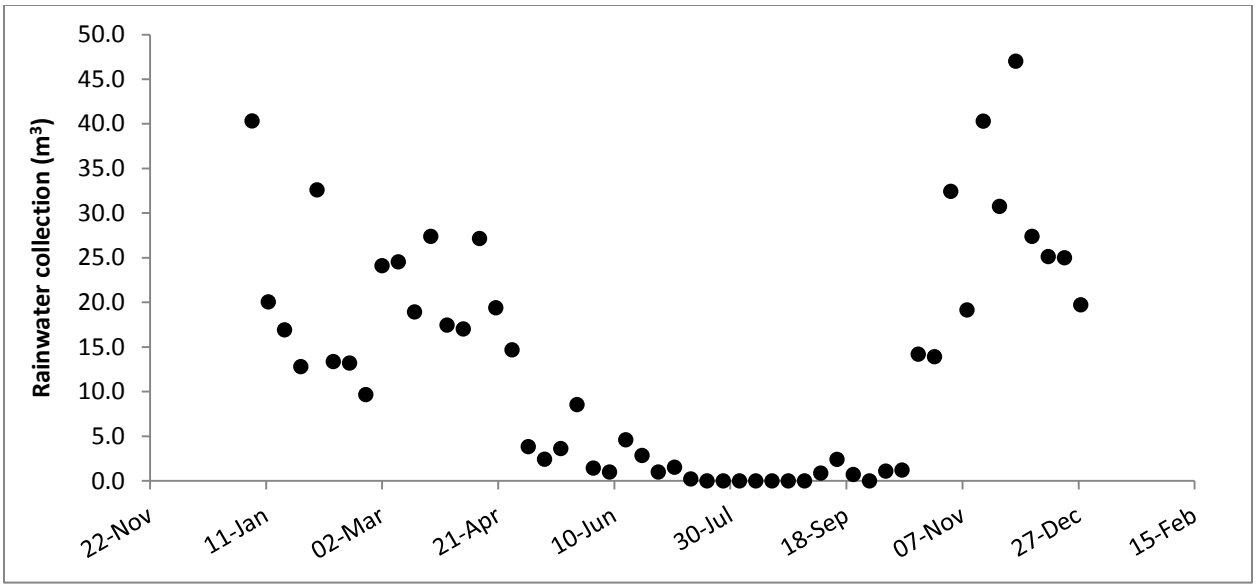


Figure 3.3: Weekly potential rainwater collection volumes from the new UBC Farm Centre

The values shown in Figure 3.3 were calculated using the 25th percentile of UBC precipitation data. The 25th percentile data was used in this analysis to represent the "worst case scenario" of having below average rainfall. This level of rainwater capture was found to provide sufficient volume to use in toilet flushing for the months of January to April, and October to December. In this scenario, excess rainwater would bypass the collection system and be discharged as appropriate, likely to the onsite wetland (Figure 2.1).

3.1.2 2013 produce wash water

The 2013 produce sales data from the UBC Farm was broken down by the number pounds of each type of produce sold each week. Knowing the amount of water required to wash a standard unit of each type of produce from the produce washing simulations (described in

Section 2.1.2.2), the amount of water used for washing produce each week was estimated. This data can be seen in Figure 3.4.

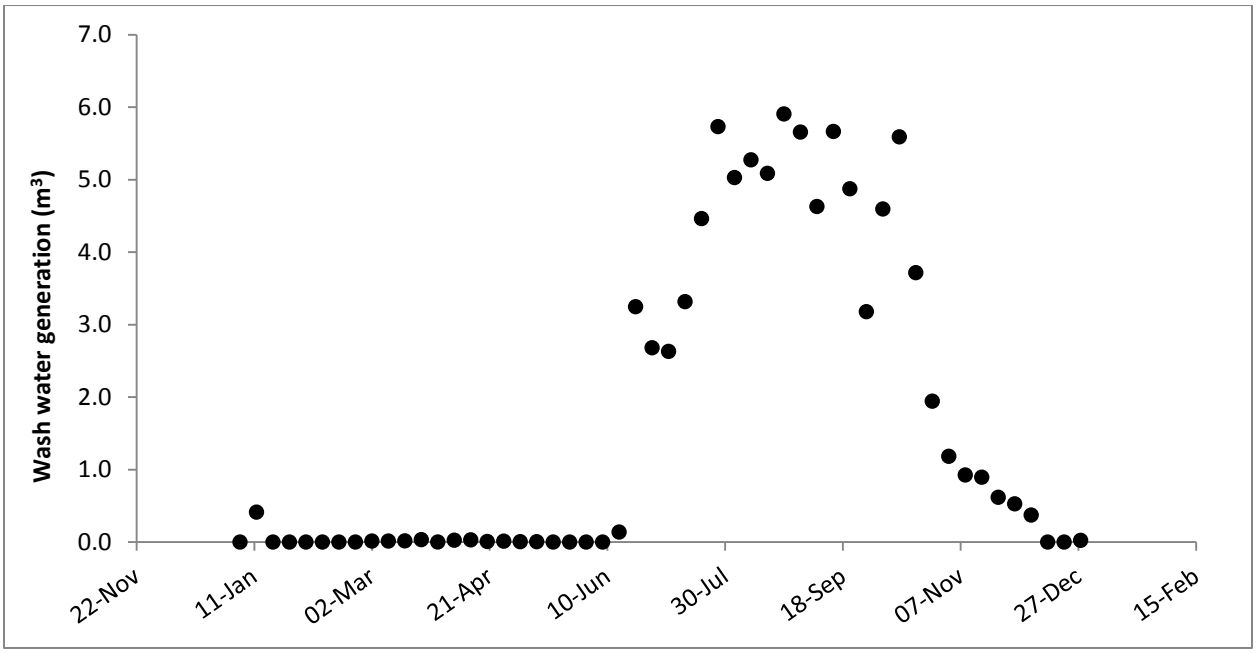


Figure 3.4: Weekly wash water generation at the UBC Farm in 2013

3.1.3 2014 produce wash water

Data from the meter on the potable water connection used to wash produce at the UBC Farm is shown in Figure 3.5. This meter was put into service in June, 2014.

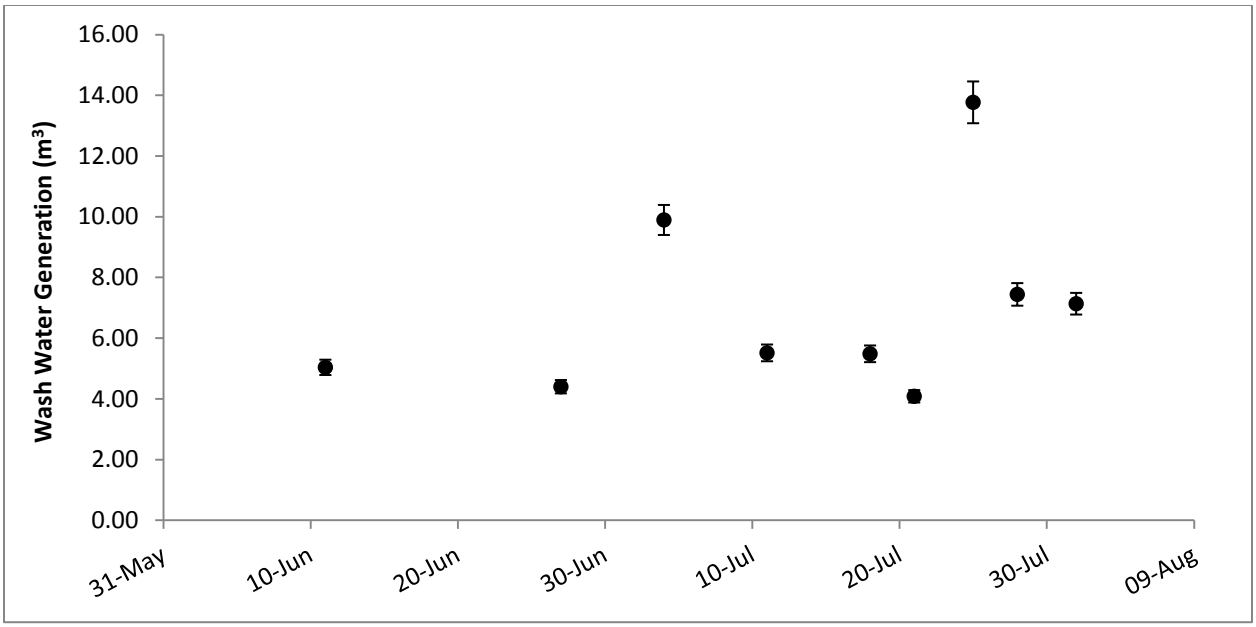


Figure 3.5: Wash water generation at the UBC Farm in 2014

Comparing the 2013 produce wash water estimates over the months that the produce wash water was metered in 2014, it was found that the 2013 data underestimated the amount of wash water that would be generated. The extra water being generated in practice can likely be attributed to other activities such as rinsing outdoor surfaces, or the hose being left running. Different volunteers and employees likely also have different washing techniques, leading variety in the amount of wash water being generated. It is recommended that the farm continue to monitor produce wash water over multiple seasons in order to get a clear picture of how much water they can rely on being generated.

3.1.4 Toilet water use

Toilet use at the current UBC farm centre was monitored from January to August, 2014. The data was obtained through a self reporting method described in Section 2.1.2.3. Water use was estimated to be 27.4 L per flush, based on measurements of the toilet tanks. Dual flush,

or high efficiency single-flush toilets are required for all new homes under the Green Homes Program in Vancouver, so the new Farm Centre toilets will likely only use 6 L per flush (City of Vancouver, 2013). Current toilet water use data can be seen in Figure 3.6.

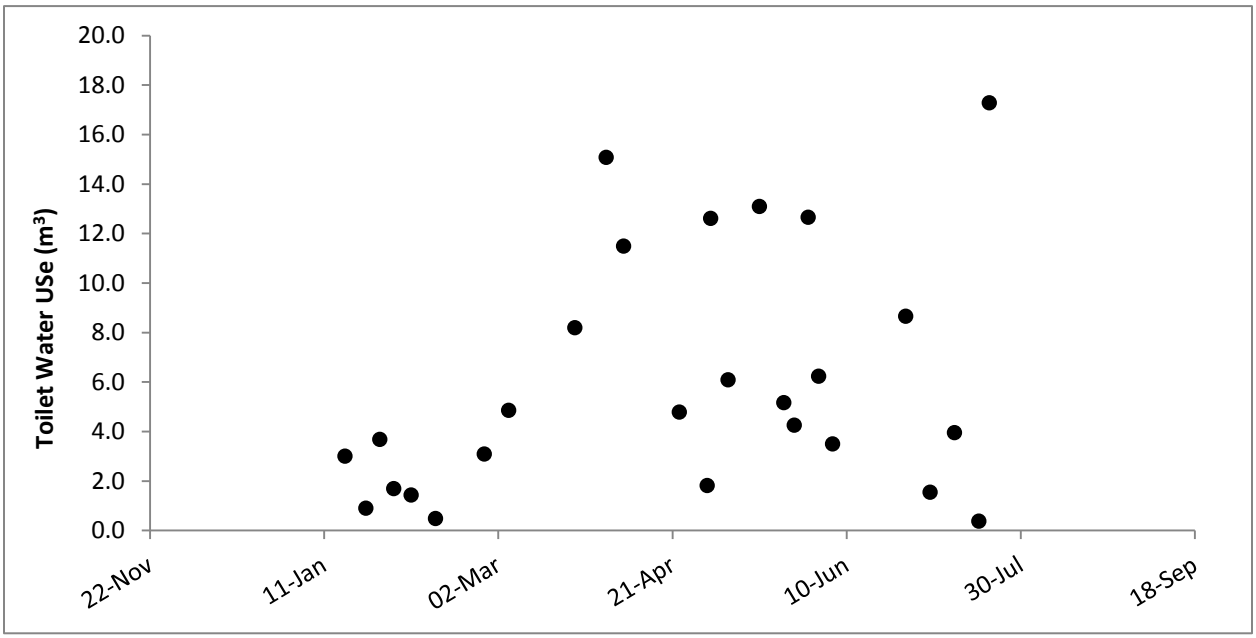


Figure 3.6: Toilet water use at the current UBC Farm Centre

3.1.5 Irrigation water use

A summary of monthly irrigation water use from 2011 to present at the UBC Farm can be seen in Table 3.1.

Table 3.1: Monthly irrigation water use at the UBC Farm

Month	Water Consumption (m^3)
Jan	127
Feb	128
Mar	128
Apr	141
May	1322
Jun	3569
Jul	4544
Aug	5161
Sep	4284
Oct	533
Nov	527
Dec	169

Irrigation water use at the UBC Farm is not monitored on the basis of individual crops. There are three separate water meters (See Figure 2.4), but it is unclear how much water the distinct areas of the farm require. This information would be beneficial to an overall water use plan at the Farm. Certain types of produce, such as tree fruits and vines, are able to be irrigated with greywater requiring a lower standard of treatment. This is because the water can be applied directly to the roots of the trees and vines, resulting in little to no contact of the edible fruits with the water. Excess greywater that is not required for use in toilet flushing at the farm centre could be used for certain irrigation purposes.

3.1.6 Water balance

Weekly water use and generation data was compiled into a single figure to compare water requirements throughout the year with water availability. Irrigation requirements are not included in Figure 3.7. The total irrigation requirements for the farm during the summer

far eclipse the water that is available from produce washing and precipitation. It is possible that there would be sufficient greywater generated for specific irrigation areas. However, a finer granularity of data is required to determine the feasibility of using greywater for irrigation at the UBC Farm.

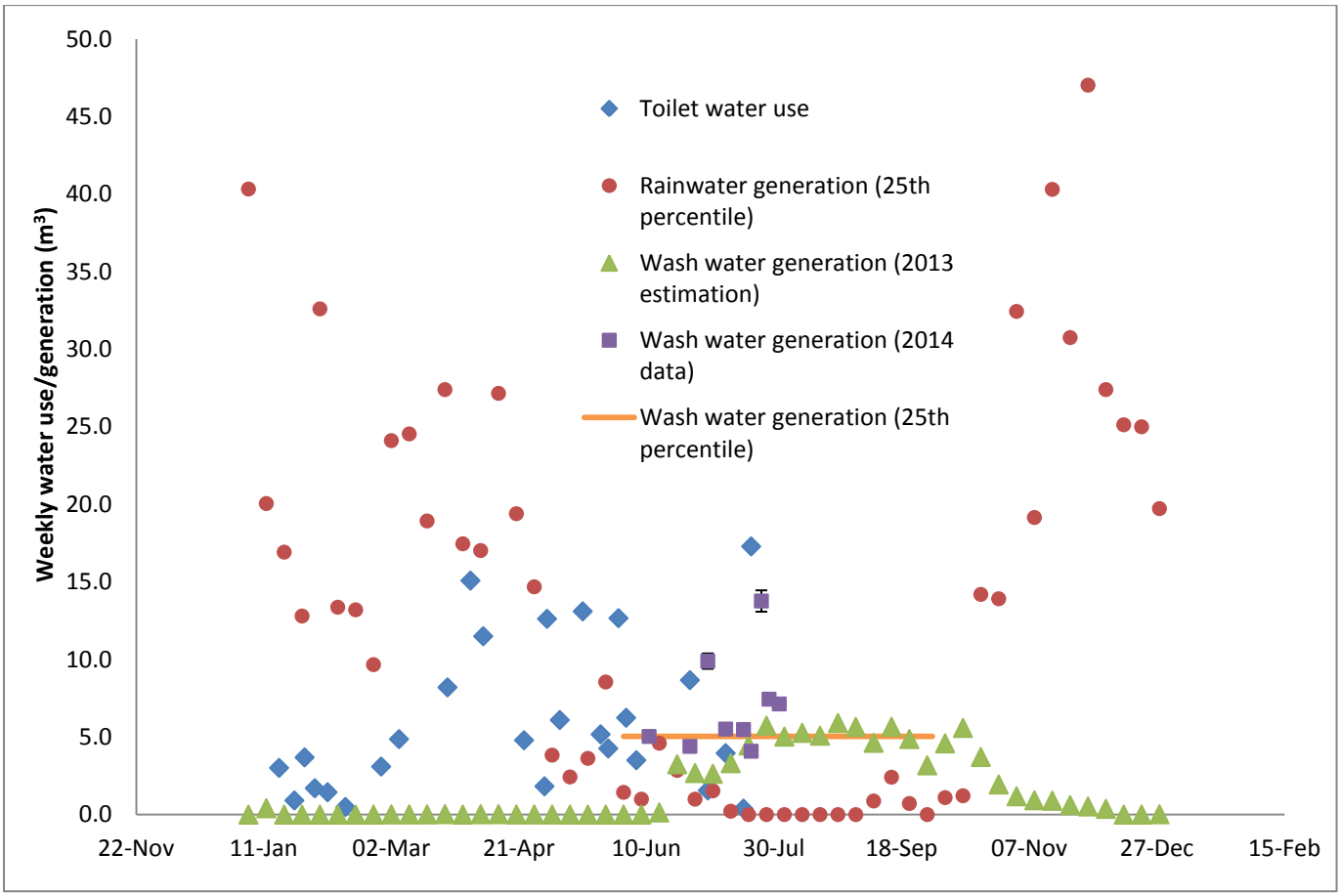


Figure 3.7: Weekly water use and water generation at the UBC Farm over a year

In Figure 3.7 it can be seen that precipitation provides adequate water for toilet flushing until May. After May, the supply of water from precipitation is not consistently sufficient for toilet flushing. However, recall that the precipitation volumes shown represent the lower quartile of weekly precipitation over the past 20 years, or a "worst case scenario" of below

average rainfall. By the second or third week of June, produce washing operations have begun, again providing sufficient toilet flushing water. Water use and generation over the spring shoulder season can be seen in Figure 3.8.

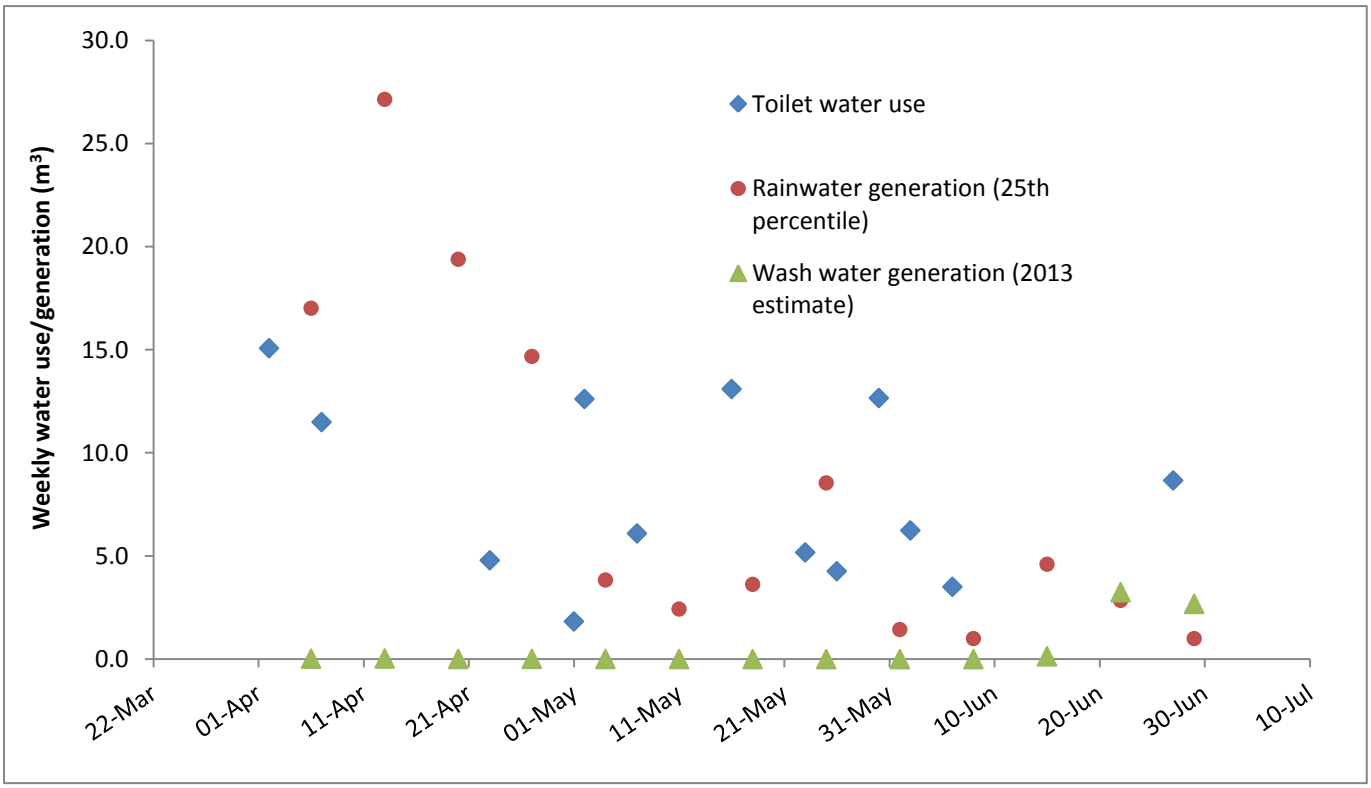


Figure 3.8: Weekly water use and water generation at the UBC Farm over the spring shoulder season (April-June)

3.1.7 Greywater storage

Storage capacity for greywater was determined based on capturing sufficient water to flush the toilets in the farm centre 100% of the time throughout the year. This goal is reasonable during the winter and the summer given the large amounts of precipitation and produce wash water generated in those seasons. The shoulder seasons are more of a challenge to

accommodate. However, if the system is ever to fail (i.e. run dry), the extra water required for toilet flushing can be made up with potable water.

As can be seen in Figure 3.7, capturing the 25th percentile of rainwater, and all of the produce wash water (2014 data) would provide enough greywater to flush toilets at the current UBC Farm Centre throughout the summer months. This is equivalent to a storage capacity of 1500 gallons. Once produce wash water generation tapers off (in October, see Figure 3.1), the frequency of precipitation begins to increase. Since after November even the 25th percentile of rainwater generation far surpasses 1500 gallons per week, there should be sufficient rainwater to flush toilets until May.

However, the roof area used to calculate rainwater capture potential is based on the new farm centre building program. The new farm centre has a much larger roof that can be designed with the intention of rainwater capture, but it will also have more toilets than the current farm centre. Because building use projections are not available, the current use patterns were applied to the number of toilets estimated in the UBC Farm Centre Building Program in order to estimate future water requirements for toilet flushing.

The new farm centre will have eleven toilets (UBC Farm, 2012). An updated version of Figure 3.7 taking into account the increase in toilets at the new farm centre can be seen in Figure 3.9.

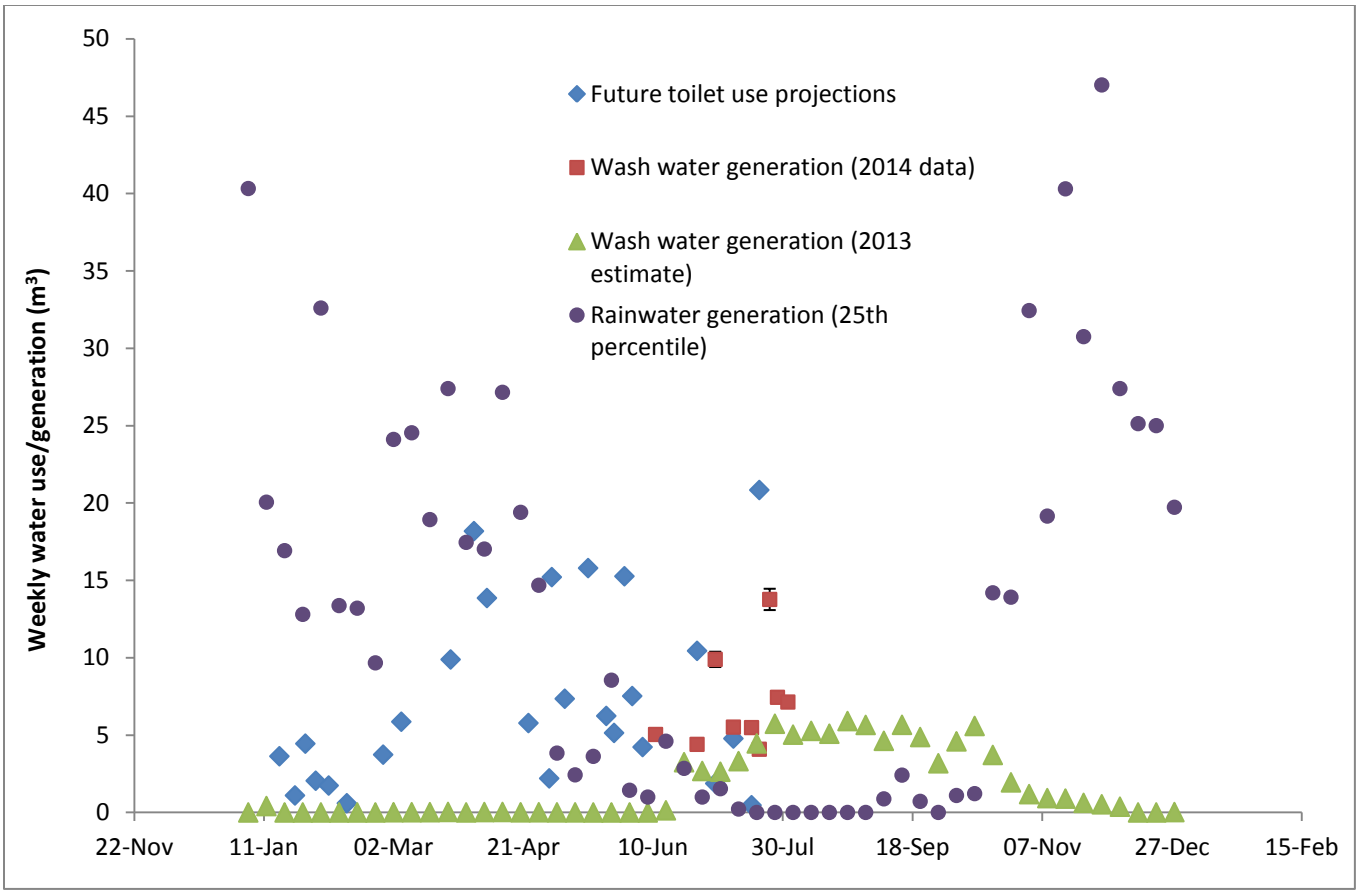


Figure 3.9: Projected weekly water use and water generation at the UBC Farm over a year, taking into account the number of toilets used at the new farm centre.

Toilet use at the current UBC farm centre increases in the spring, summer and fall, and decreases during the winter. This is because there are many community programs that take place at the farm that are seasonal. When the new farm centre is built, more programs may make use of the additional space, and take place throughout the year. This would result in higher winter toilet use than implied in the data shown in Figure 3.9.

As can be seen in Figure 3.9, much more storage volume will be required to capture enough greywater for toilet flushing once the new farm centre is built. In the context of the new farm centre, the amount of wash water generated from produce washing does not go as far

as it would if currently used at the farm. This is because while the amount of buildings on the farm and the amount of visitors and customers attracted to the farm can increase, the area used for growing produce will not significantly increase, and therefore the amount of produce wash water will not increase.

Future storage should capture 100% of the produce wash water, but there will likely be days near the end of the week where the stored water from the previous week runs out. Due to the cyclical nature of wash water generation (one large influx of water on a single day), topping up the greywater with potable water is likely unavoidable in the future, unless there are some opportunely timed summer rain showers.

The data shown in Figure 3.9 is weekly. Therefore even if future storage was sized with the intention of capturing enough water to flush all the farm centre toilets 100% of the time, there may be periods where rainwater generation does not coincide with toilet use (i.e. a few dry days where the storage volume in the tank is drawn down because toilet use is fairly consistent). Again, this is why having potable water top up connections are important to the steady functioning of the system. Conversely, there will be many occasions when there is more rainwater available than can be stored in the storage tank. Recall that the rainwater capture data presented above represents the 25th percentile of rainwater. As a visual aid, mean rainwater generation data is shown in context in Figure 3.10.

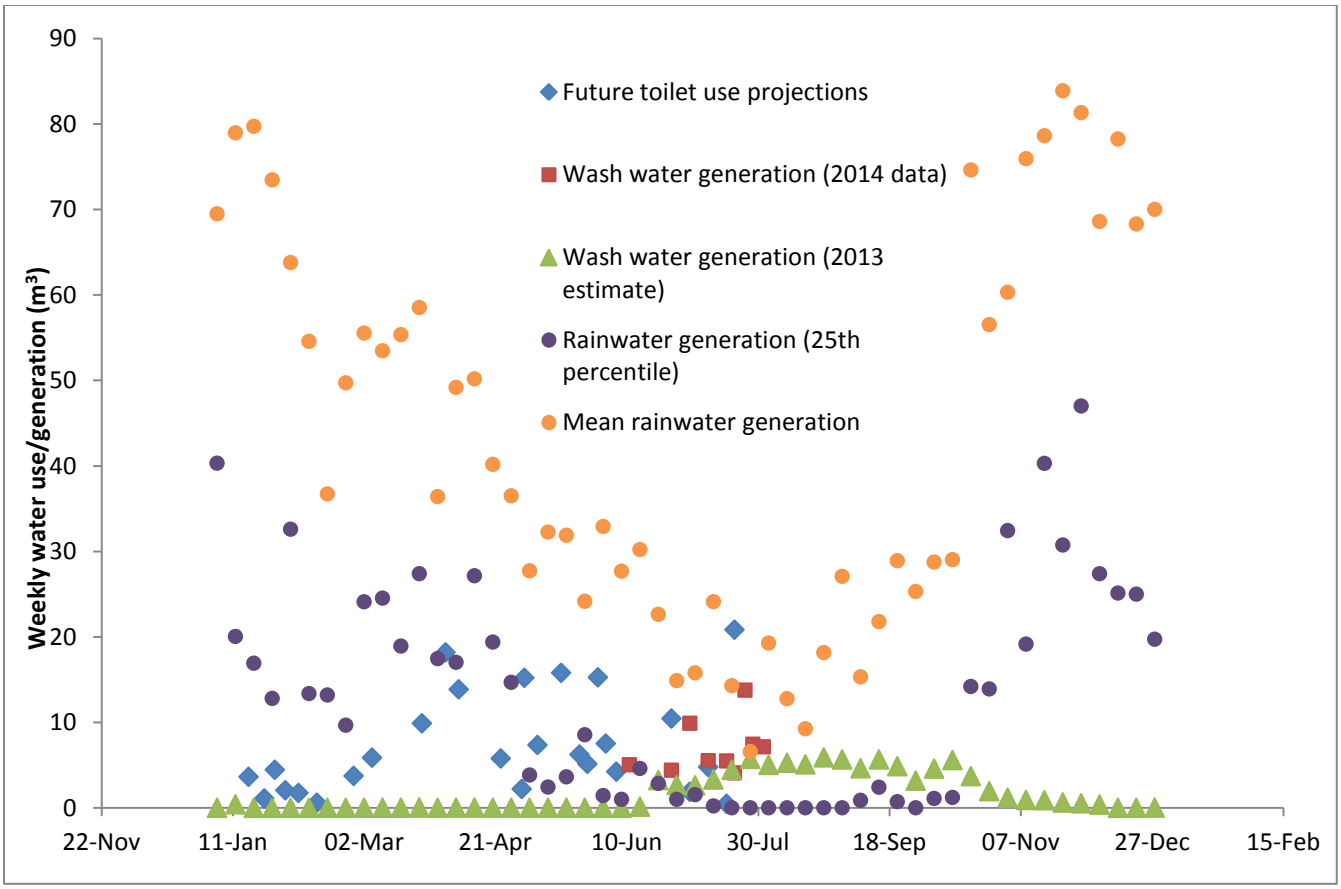


Figure 3.10: Weekly water use and water generation at the UBC Farm over a year showing mean rainwater generation for context only

As can be seen in Figure 3.10, rainwater generation will often be higher than the "worst case scenario" of the 25th percentile rainwater generation. In many cases more rainwater could potentially be captured than there is room to store it. However, this doesn't imply that there is insufficient storage volume. In the winter months when the majority of rainwater is generated, there are not as many beneficial uses for the water outside of toilet flushing. If, in the spring, summer, or fall, there is additional water that has been stored and is not required for toilet flushing, it will likely find a use somewhere else on the farm. One might wonder why one couldn't store the excess rainwater generated throughout the winter for use in the summer. Apart from requiring very large storage volumes, there are

issues with the growth of bacteria if greywater or rainwater is left to sit (Friedler & Gilboa, 2010). It is not recommended that greywater be left to sit for months.

In order to retain sufficient water for use in toilet flushing at the new farm centre at the UBC Farm, a 5000 gal storage volume is recommended.

3.1.8 Water quality

The water from produce washing at the UBC Farm is widely varied. A complete picture of water quality would require an extensive monitoring program to ensure that the range of water being generated was sampled. Wash water from each vegetable will generate a different composition of greywater, and the overall greywater composition will likewise vary depending on the vegetables washed in a given day. However, the snapshot generated by a single day of testing is still useful, as it gives benchmark values that can be used to make educated decisions regarding the type and extent of treatment that would be required to reuse the water.

Wash water from the UBC Farm was collected on September 5th, 2014 from three separate vegetable washing operations. This included dunk tanks used for soaking leeks, overhead spray tables for washing radishes, and a hose and table used for washing carrots. Collecting water from these three different vegetables showed the variation in water quality over just a single day of produce washing at the farm. This will have implications for how produce wash water is collected and treated in the future.

Table 3.2 summarizes the quality of water produced from washing leeks, radishes and carrots at the UBC Farm.

Table 3.2: Water quality profile from produce wash water generated by the UBC Farm. Two water samples were taken from each of three vegetable washing process.

	Vegetable		
Parameter (Units)	**Leeks**	**Radishes**	**Carrots**
pH	6.11	6.18	6.21
BOD5 (mg/L)	1.42 - 4.00	2.63 - 6.60	7.99 - 246
TSS (mg/L)	7.0 - 9.2	42.0 - 63.0	234.0 - 374.0
Turbidity (NTU)	3.53 - 4.07	20.8 - 34.6	27.8 - 40.8
Fecal coliforms (CFU/100 mL)	0	0	0

3.1.9 Treatment and distribution

Produce wash water from the farm will require treatment before it can be reused indoors for the purpose of toilet flushing. One proposed treatment train is shown below, but it is important to keep in mind that each farm will have a different greywater composition, and different desired end uses for the treated greywater. Therefore this treatment train may not be applicable to another location, and there are likely multiple treatment processes that could deliver greywater of a sufficient quality.

The first treatment step for the produce wash water after it is generated could be a lamella clarifier. Lamella clarifiers use a series of inclined steel plates whose high effective settling area removes solid particulate matter from the water using a small total footprint (Cheremisinoff, 2002). These clarifiers can handle variable solids loading (Hydro Flo Technologies, 2002), making them ideal for treating produce wash water, whose solids content varies depending on the types of produce being washed. These clarifiers are an

especially good technology for a small scale treatment operation like the UBC Farm because they do not require energy inputs besides the requisite pumps, and do not have any mechanical parts that could be prone to failure (Cheremisinoff, 2002). Maintenance requirements are also minimal, limited to cleaning the lamella plates every 6 months (Cheremisinoff, 2002).

The lamella clarifier would provide temporary detention of the greywater prior to treatment. The greywater generated at the UBC Farm can be treated using pressure filtration. Vertical pressure filtration units are applicable in small operations, and can easily be placed in parallel to allow for system redundancy. Since the produce wash water has fairly low turbidity, a dual media system of anthracite and sand would provide sufficient treatment (WesTech, 2014). Filtration systems require backwashing as part of regular maintenance. Backwash water from this system will be generated in small enough volumes that it can be directed on the onsite wetland for disposal (Figure 2.1).

Greywater must be disinfected prior to use in toilet flushing. Because organic particulates can cause formation of disinfection by-products when combined with chlorine, and can shield water from contact with UV rays, filtration prior to disinfection is very important (Winward, Avery, Stephenson, & Jefferson, 2008). For greywater reuse on the farm, a product such as calcium hypochlorite is easy to handle in the form of compressed pellets. Free chlorine also requires a shorter contact time to produce the same levels of inactivation as chloramines, making it suitable for this application (Winward, 2007). A chemical disinfectant in a pelletized format would negate the need for a dosing system, contributing to keeping capital costs low. Conversely, the high capital cost of physical system such as UV

disinfection would likely make it infeasible, especially for a small scale system (Winward, 2007).

After treatment and disinfection, the treated greywater would be stored in an above ground holding tank where it would be pumped to toilets on demand. The 5000 gallon polyethylene resin tank is coloured black or dark green to inhibit algae growth, and meets FDA and NSF specifications, allowing for the safe storage of the water (Barr Plastics, 2014). A schematic for this potential treatment train can be seen in Figure 3.11.

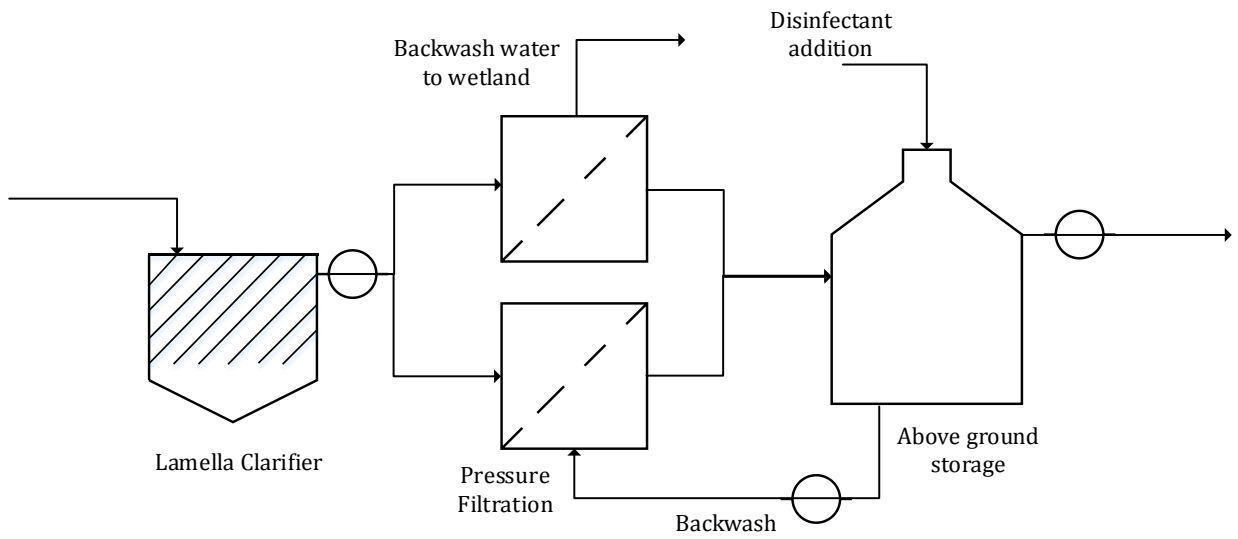


Figure 3.11: Schematic for potential greywater treatment train

3.1.9.1 Treatment system cost

The capital cost for the greywater reuse system shown in Figure 3.11, including engineering design, materials, and construction was estimated to be $95,000[2]. A cost estimate breakdown can be found in Appendix C . Operation costs for the greywater reuse

[2] Costs and water prices in this section are in Canadian dollars

system will including water quality testing to remain in compliance with the regulations, periodic cleaning and maintenance, and chlorine disinfectant costs. These costs could range from $200-$1000 per year (Waterwise Systems, 2009; Yu, Deshazo, Stenstrom, & Cohen, 2011).

The UBC Farm currently pays $0.897 per m^3 for water during June through September, and $0.7176 per m^3 during the off-season (October to May). Assuming that the farm makes use of all 5000 gallons of water they have stored each week, this corresponds to a yearly water savings of $709.

The payback period of this system was calculated, assuming the full capital cost of the system would be paid in the first year, that operation costs remain low at $200/year, and that the farm's water price does not increase. Given these constraints, the payback period for the farm is 185 years. This is an entirely unreasonable payback period, and results from the seemingly low price the farm currently pays for its water. This payback period was compared with the payback period that would arise from a higher water price. A recent news report from California stated that due to the current drought, farmers were paying anywhere from double up to ten times more for water than usual. Their increased water price is between $1,261 and $2,292 per acre-ft, or $1.022 to $1.859 per m^3 (Vekshin, 2014). Using $1.859 per m^3 and keeping all other variables the same, the payback period for the system drops to 52 years. In Australia in 2012 and 2013, farmers paid $0.074/1000 L, or $73.5 per m^3 (Australian Bureau of Statistics, 2014). With this very high cost of water, the payback period becomes just two years.

It is evident that the cost of water to farmers directly impacts the feasibility of implementing a greywater reuse system. It is unlikely in British Columbia that the price of water would increase to prices seen in Australia. To realize a reasonable payback period of 10 years, the water price for the UBC Farm would need to increase to around $10.00 per m^3. However, the mandate of the UBC Farm is to be a living laboratory, testing and monitoring environmental interventions within their food system (UBC Farm, 2014c). Therefore, the value of a greywater reuse project for the UBC Farm might lie more in its demonstrative function of a method for conserving freshwater. In this case, a long payback period might not affect the decision to proceed with such a project.

All payback period calculations can be found in Appendix C

3.1.9.2 Regulatory implications for UBC Farm

The proposed greywater treatment and distribution system (Figure 3.11) will need to be designed and developed in consultation with the appropriate authorities, in this case the regional Ministry of the Environment (MoE) office, and the local health authority (Vancouver Costal Health in the case of the UBC Farm). A full list of the information that must be provided to the health officer by a qualified professional can be found in the Reclaimed Water Guideline, a companion document to the Municipal Wastewater Regulation (MWR) (BC Ministry of Environment, 2013). Any aspect of the design and construction of a greywater reuse project that qualifies as "practice of professional engineering" as defined in the *Engineers and Geoscientists Act* (BC Government, 2014) must be carried out by a professional engineer, who is referred to as a "Qualified Professional" in the guideline. The farm must authorize the system through either an approved liquid waste

management plan (LWMP), or registration under the MWR prior to providing reclaimed water. For use in toilet flushing, the water to be reused must comply with the "greater exposure potential" category of reclaimed water as defined in the MWR. Refer to Section 1.7.2 for the water quality parameters of greater exposure potential reclaimed water.

Section 3.1.9 represents three different aspects of feasibility - technical, economic, and regulatory. Implementing a greywater reuse program at the UBC Farm is likely technically feasible. Technologies are available and tested for greywater reuse, and the system itself is fairly simple. Economically, the system is not currently feasible due to the price of irrigation water. However, due to the mandate of the UBC Farm, cost might not be a crucial factor in determining whether to pursue greywater reuse. Regulatory feasibility is a larger hurdle to overcome. Since there are not many greywater reuse projects to look to for guidance, there is not a clear method for regulatory compliance. Open communication with Vancouver Coastal Health and the MoE is likely the best way to move forward with development of a greywater reuse program. A qualified professional must be consulted throughout the project, and would have to ensure that the designed system is fully compliant with all relevant regulations.

3.2 Qualitative study

The qualitative study on the potential to reuse greywater on farms was divided into two parts. The first was an interview with a farm manager at a local farm. The purpose of this interview was to gain a snapshot of the sustainable practices being pursued on a local farm. This farm was chosen in particular because of its emphasis on sustainability. The interview

was used to trial potential questionnaire questions to ensure that they were clear and concise. Feedback was requested from the interviewee regarding what types of questions were relevant to the topic, and whether any additional questions needed to be included. Using results from the interview, a questionnaire was developed and distributed to farmers across British Columbia. This second phase of the qualitative study was used as a way to pick out general trends in the opinions of farmers regarding greywater reuse. Respondents to the questionnaire could choose not to answer any questions they didn't want to, and all responses were collected anonymously. The number of respondents who answered each question can be seen in Appendix D Due to the small sample size, a respondents answers to the questionnaire could not be correlated to the type of farm or operation they have.

3.2.1 Preliminary interview

The Bakerview Eco-Dairy is a unique business that places high importance on environmentally friendly initiatives. They embody agritourism through an onsite "learning centre" where people can learn about the dairy and its operation. They attempt to highlight the latest in dairy technology through their anaerobic digestor and manure scrapers. The property's products are also diversified. There is a small self-harvest (U-Pick) berry patch, a vegetable garden, a research flock of 1000 laying hens, as well as some leased land. In addition to the products that are grown, the Eco-Dairy has a small farm market, and a laboratory with a focus on feed and forage analysis.

The challenges faced by the dairy are similar to others in the industry. First and foremost, the cost of running the business is the largest challenge they face. Other challenges include

animal health and manure storage and handling. Concerns about potable water aren't a current priority. Water for the livestock is obtained from a shallow well that requires treatment in order to meet regulations. Potable water for human consumption is obtained from a municipal water connection. Wash water from the dairy process is pre-treated prior to being discharged to a city drain. The well is an important feature of the dairy because of the cost of potable water in Abbotsford. The high water table in the area results in many farms having wells, but the cost to install a well is high, around $10,000. However, because it could cost a farm $8000 per year to purchase all their water, the high capital cost of the well is seen as a worthwhile investment. In addition, the more water that is used, the higher the premiums.

Bakerview Eco-Dairy currently captures rainwater in order to water a green roof on an out-building. They have a 5000 gallon cistern, which when full can last two months. No greywater reuse from sinks, showers, baths or produce washing is practiced, and a fee of a few hundred dollars is collected annually by the City of Abbotsford for greywater discharge. The largest obstacle to further greywater reuse in the eyes of the farm manager is the treatment requirements. Any technology used for greywater treatment must be cost effective and reliable. For many farmers, having a proven technology is an important factor when considering whether to adopt a new practice. Because the Bakerview Eco-Dairy is a demonstration farm, they would be more likely than a typical farm to attempt greywater reuse.

Public perception is seen as another important factor when considering adopting a new practice. The farm manager believes that transparency, and demonstrating

environmentally friendly initiatives on their farm has helped their business. People who visit the dairy have a sense that resources are limited. However, using recycled water to grow food is something that is perceived as a "tough sell" to customers. The farm manager said that if he were to use recycled water to grow food, he would think carefully about telling customers it was being done. He believes that people's perceptions would be difficult to influence, and that it would be a challenge to convince customers that such a practice was safe.

This interview was used to gain a snapshot of the sustainable farming practices one farm is pursuing. The interview helped to inform the questionnaire by revealing which questions about greywater reuse were relevant, and by bringing to light other questions that needed to be asked.

3.2.2 Questionnaire

3.2.2.1 Farm characterization

The first section of questions helped to characterize the types of farms that participated in the questionnaire. Figure 3.12 shows how the respondents generate income from their farms. The top three ways that farms generate income are through farmgate sales (75%), sales at a farm store (69%) and through seasonal events such as corn mazes and hay rides (63%). Interestingly, a relatively small percentage of farmers generate any income from farmers markets (25%), which is the one category included that would generate income off the farm property. The rest of the income generating activities hinge on customers visiting the farm. This means that their impact might be felt through an increase in water usage and

greywater generation from sinks, toilets, kitchens, and produce washing operations, among others.

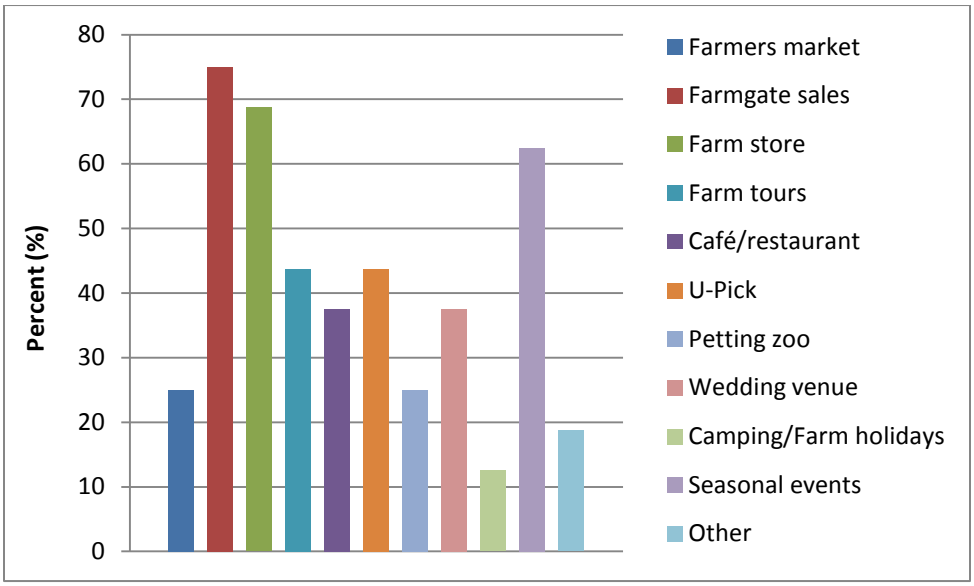


Figure 3.12: The popularity of different ways farms generate income

Confirming the trend towards income generating activities on farms, 81% of farmers said that one of their goals is to encourage visitors to their farm. (Figure 3.13)

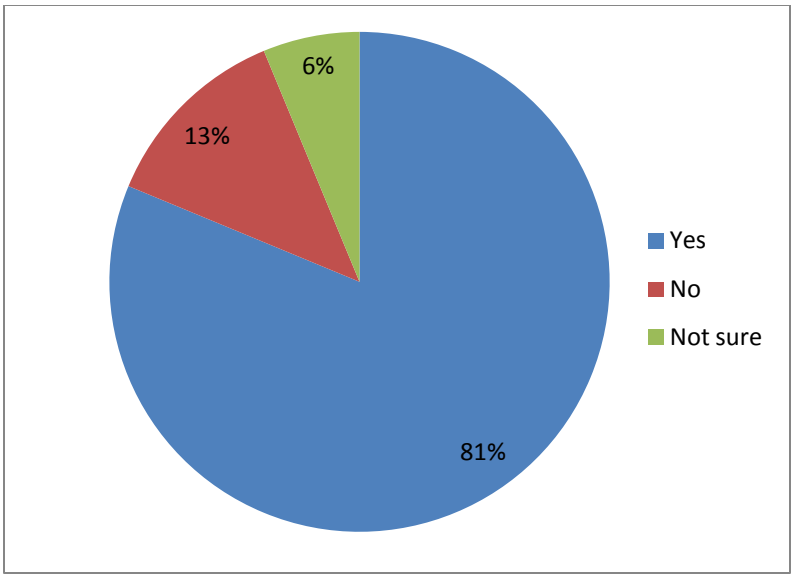


Figure 3.13: Responses to a question asking whether one of the farmer's goals is to attract more visitors/customers to the farm

To see whether encouraging visitors to the farm has farmers worried about potable water or waste generation, farmers were asked about the challenges they face on their farms (Figure 3.14).

By far the biggest challenge faced by farmers in BC is the cost of running their farms (56%). No respondents found that a lack of potable water resources or the treatment and storage of waste products is a big challenge. In fact 81% and 63% of respondents didn't find potable water resources and treatment and storage of waste products, respectively, to be a challenge at all.

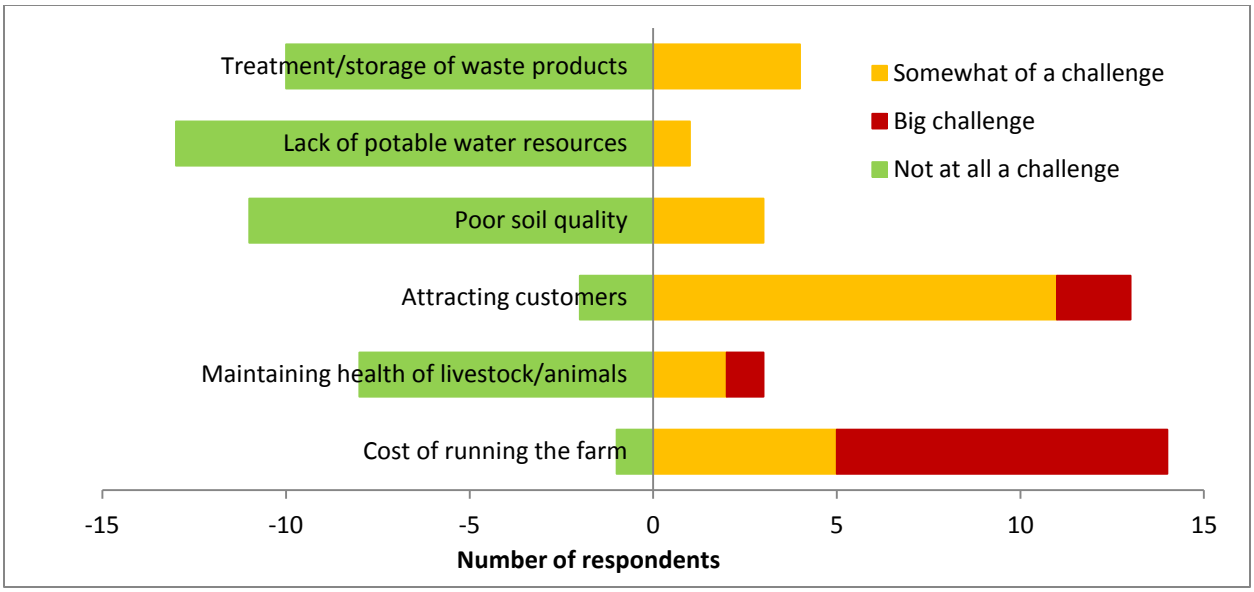


Figure 3.14: The challenges faced by farmers in BC

Explicitly connecting an increase in visitors to the farm with an increase in wastewater generation, respondents were asked if they foresaw any difficulties in dealing with increased amounts of wastewater. Only 15% said that they foresaw any difficulties. Of those who did not foresee any difficulties, reasons why included having sufficient methods of treatment (such as gravel pits and septic fields) to accommodate any increase in wastewater generation, and being connected to a municipal sewer system.

3.2.2.2 Water use patterns

To understand current patterns of water use on farms, respondents were asked about their sources of potable water for irrigation, other outdoor uses (such as lawn watering, equipment washing, and animal husbandry), and indoor use. Responses are shown in Figure 3.15, Figure 3.16, and Figure 3.17.

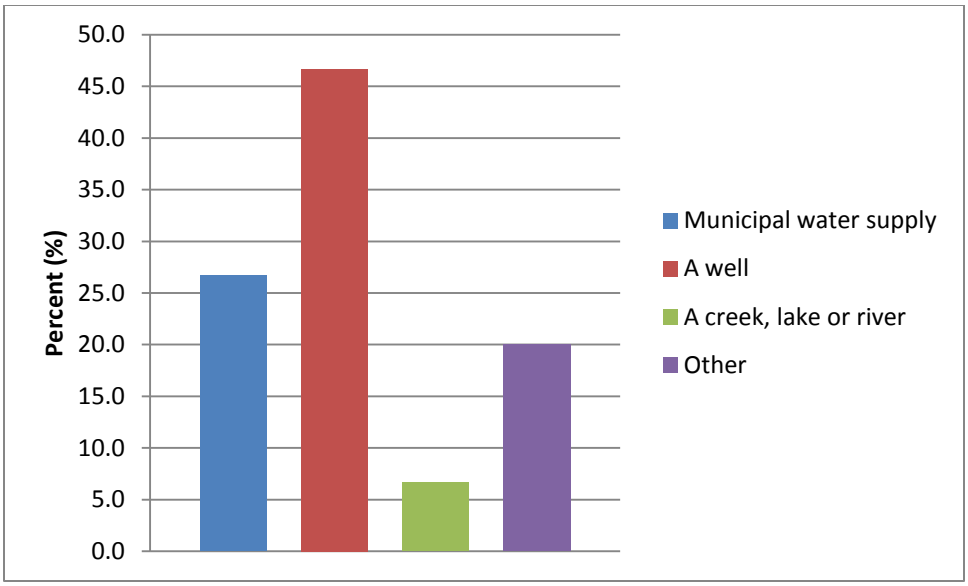


Figure 3.15: Respondent's sources of potable water for irrigation on their farms. (Respondents who answered "other" either had a pond, or did not irrigate)

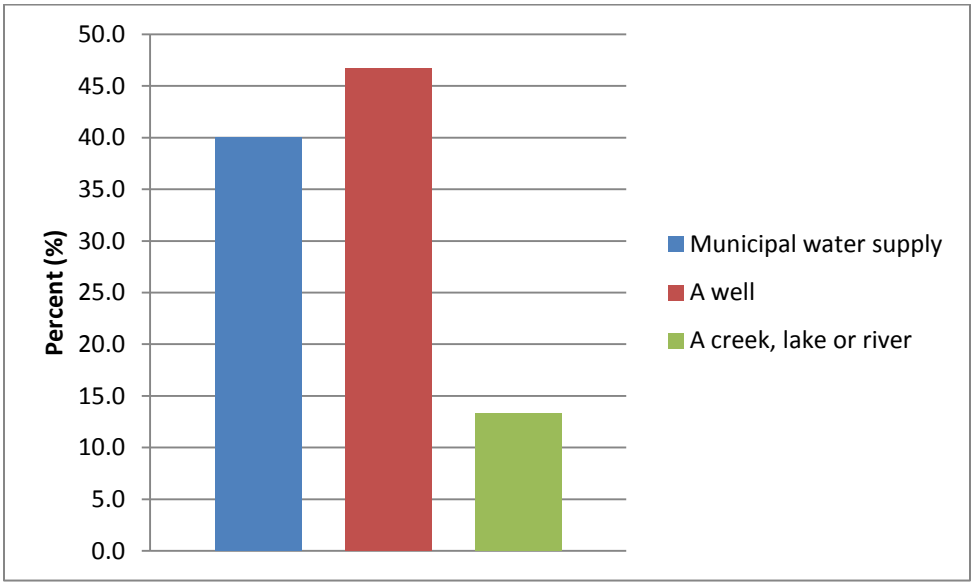


Figure 3.16: Respondent's sources of potable water for other outdoor uses

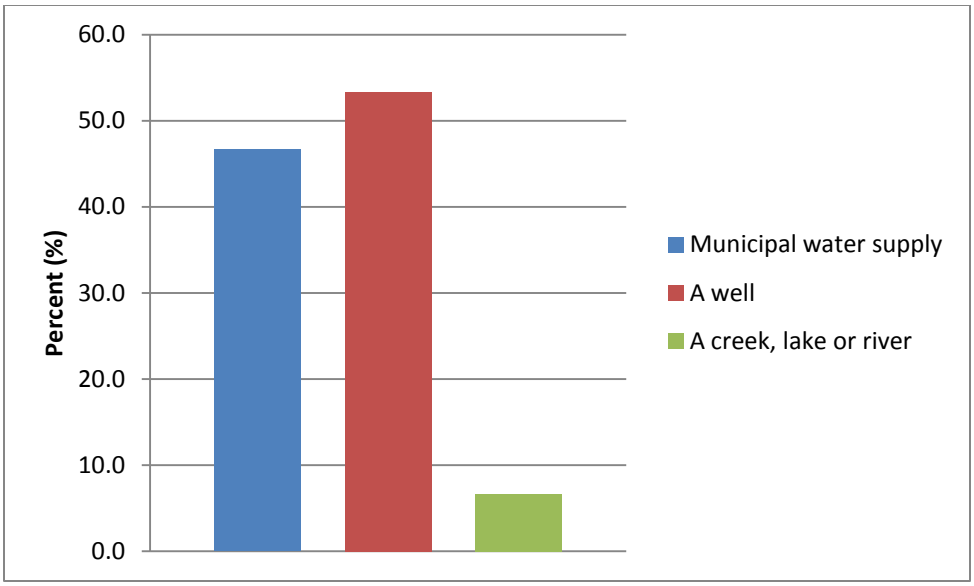


Figure 3.17: Respondent's sources of potable water for indoor uses

One observation from Figure 3.15 to Figure 3.17 is that as the potential for human contact with the water increases from irrigation, to outdoor uses, to indoor uses, the percentage of users who rely on a municipal water supply also increases. This may have implications for acceptance of greywater reuse, as it has been observed that the closer recycled water is to human contact, the more reluctant people are to use it. It is possible that a perception already exists that a municipal water supply is cleaner, or safer than a well or surface water supply, and therefore is more often used as the degree of human contact with the water increases. This may mean that there are pre-existing barriers to the use of alternative water sources for indoor uses such as toilet flushing. However, future research should delve into this question deeper in order to understand farmer's motivations for using a variety of sources of water for different uses.

Respondents were then asked about their level of concern regarding having enough fresh water right now, and five years from now. This data can be seen in Figure 3.18.

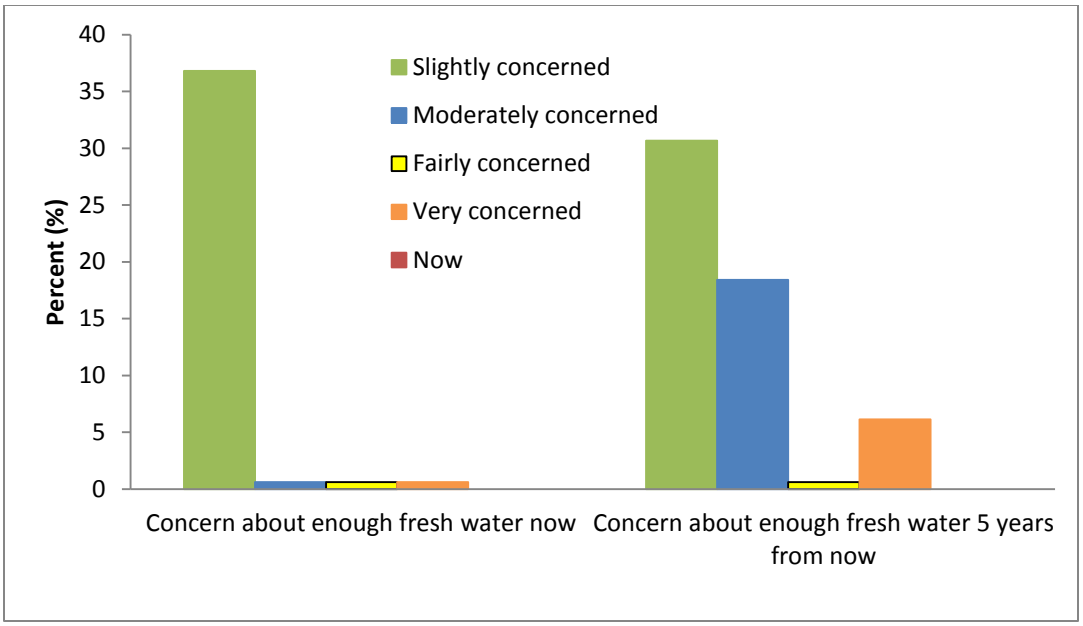


Figure 3.18: Respondent's concern about having enough fresh water now, and five years from now

As can be seen in Figure 3.18, zero percent of respondents are currently even moderately concerned about having enough fresh water right now. However, thinking to the future, the percentage of farmers not at all concerned about having enough fresh water drops 25%, and the percentage moderately concerned increases by 18%. Five years is not the distant future, it is the near future. Data such as this may suggest that farmers will be looking into alternative sources of water to maintain water security before too long.

Next, respondents were asked about how wastewater is dealt with on their farms. Answers can be seen in Figure 3.19.

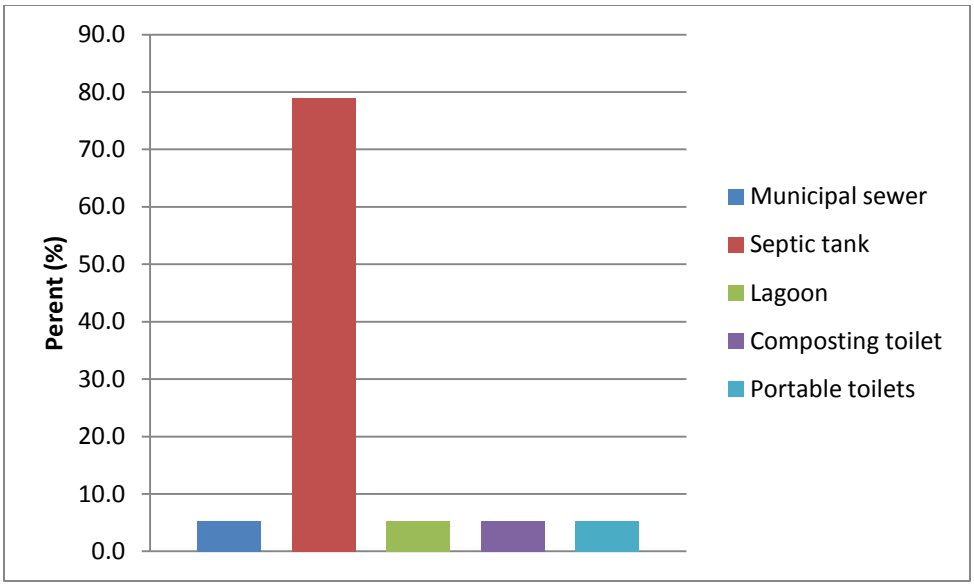


Figure 3.19: Methods for dealing with wastewater on respondent's farms

Close to 95% of respondents do not rely on municipal services for wastewater treatment. The majority of respondents have a septic tank, and under 10 percent use lagoons, composting toilets and portable toilets, respectively. The discrepancy between reliance on city services for waste disposal and for water provision is interesting. Whether this difference is due to a belief that municipalities should be relied on to provide such an important service as potable water provision, or because rural areas often have access to municipal water but not sewer systems, this is an interesting question for further research.

3.2.2.3 Opinions of greywater reuse

Respondents were asked whether they currently reuse water on their farms, explaining that it can be reused in a multitude of ways, including capturing and reusing rainwater, or reusing greywater from sinks, baths and showers. They were then asked - if they don't currently reuse water - whether they have ever considered it. Responses can be seen in Figure 3.20 and Figure 3.21.

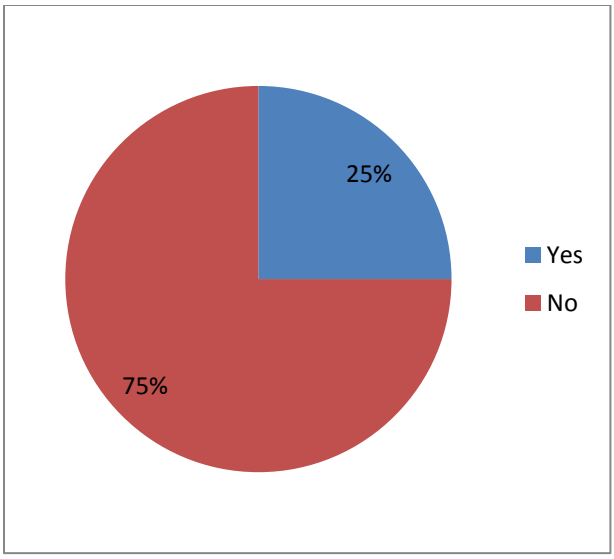


Figure 3.20: Whether respondents currently reuse water on their farms

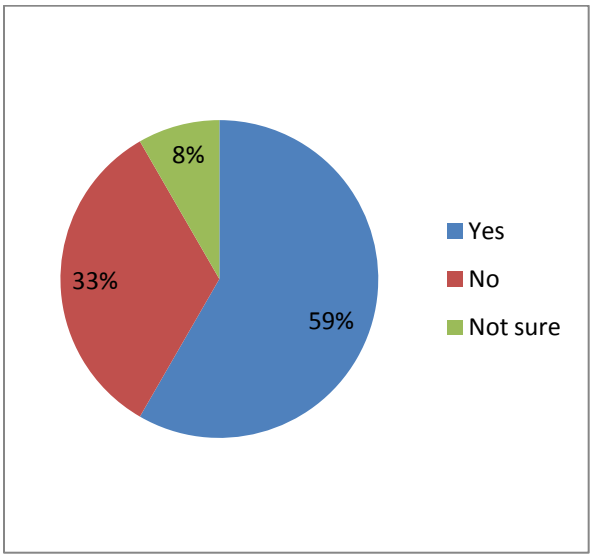


Figure 3.21: Whether respondents have ever considered reusing water on their farms

While only 25% of farmers currently reuse water, close to 60% have considered it before. This points to the existence of barriers towards water reuse on farms. What are those barriers? Respondents were asked what they see as the biggest barriers to greywater reuse on their farms (Figure 3.22).

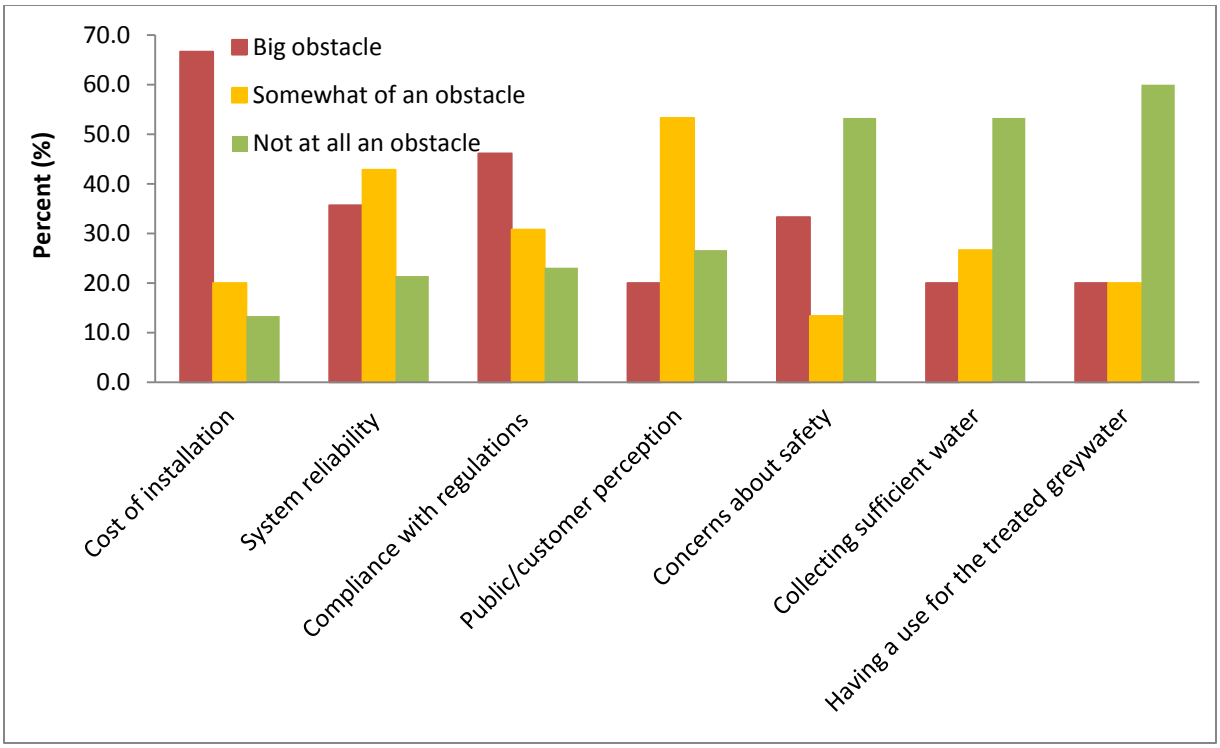


Figure 3.22: Respondent`s perceived barriers to greywater reuse

As can be seen in Figure 3.22, an agreed-upon barrier to greywater reuse is the cost of system installation, with two thirds of respondents finding it a big obstacle. While the majority of respondents do not think that either collecting enough water to use or finding a use for the greywater is an obstacle, 20% do think that these issues are a big obstacle. This points to two separate viewpoints on reusing water. The first being that one must collect enough water for all uses, for example all the irrigation, or all other outdoor uses. However for all farmers in British Columbia, there is always going to be an alternative source of water, from either the municipal supply or from a well or surface water body. Since generation of greywater can be seasonal, or otherwise not consistent, it is likely that the system will have been designed with the option for potable water top up when necessary. The opposite frame of mind arises from believing that there is no use for greywater, were it

to be collected. This often stems from unfamiliarity of the treatment process, and unfamiliarity with reclaimed water use regulations. Having clear guidance regarding what qualities of water can be safely used in what applications may be sufficient for people to develop some ideas of how to use greywater in their specific situation.

This viewpoint was reinforced when respondents were asked whether there would be benefits associated with reusing greywater on their farms. While the majority (70%) said yes, there would be benefits, that still leaves 30% who said that there wouldn't be any benefit. Feedback suggests that compliance with regulations, as well as the increase coordination for farmers selling products outside of the country would make the endeavor not worthwhile. A common sentiment was that while the reuse of greywater would represent a better use of resources, obstacles such as cost, compliance with regulations, and providing sufficient treatment might be prohibitive. Some farmers said that while reusing greywater might be beneficial, they didn't feel like they had sufficient information to give an informed viewpoint.

Finally, farmers were asked if they were to reuse greywater, what uses they would consider. This data is shown in Figure 3.23.

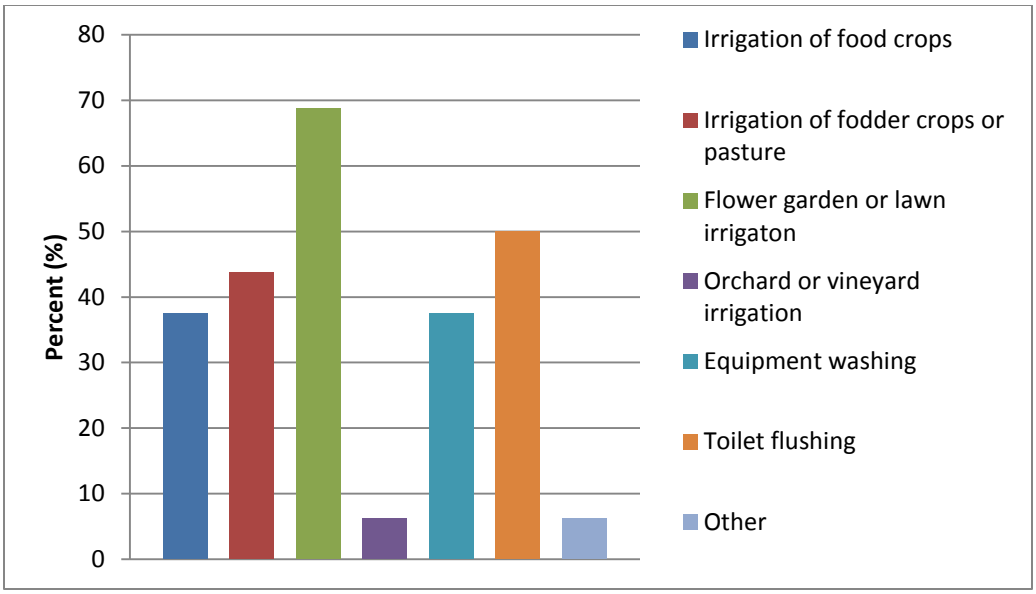


Figure 3.23: Respondent's potential uses of greywater

One interesting result from Figure 3.23 is the low percentage of respondents who said they would be likely to reuse greywater for orchard or vineyard irrigation. This is because fruit trees and vines are well suited to greywater drip irrigation, as the recycled water does not directly touch the fruit. This result could have appeared simply because most of the questionnaire respondents do not farm orchards or vineyards, but it would be interesting to explore this result further.

3.2.2.4 Perception of the public's views

In a definitive statement of consumer values, one hundred percent of respondents reported that their customers value environmentally friendly initiatives on the respondent's farms. Examples of environmentally friendly initiatives included reduced pesticide use, steps taken to reduce nutrient leaching, groundwater quality monitoring, and water conservation. Asking this question after a suite of questions about greywater reuse was

designed for respondents to place greywater reuse among this list as an environmentally friendly initiative.

An interesting observation is that over 70% of respondents feel that customer perceptions of greywater reuse would be either somewhat of an obstacle or a significant obstacle (Figure 3.22). This is a significant number because farmers are unlikely to pursue a technology that they feel would interfere with their customer's perceptions of themselves. While it is clear that both farmers and their customers value environmentally friendly initiatives, it may point to a disconnect in the way that farmers and customers understand "environmentally friendly".

Respondents were then asked if they thought that their customers would purchase produce grown using recycled water. These results are shown in Figure 3.24.

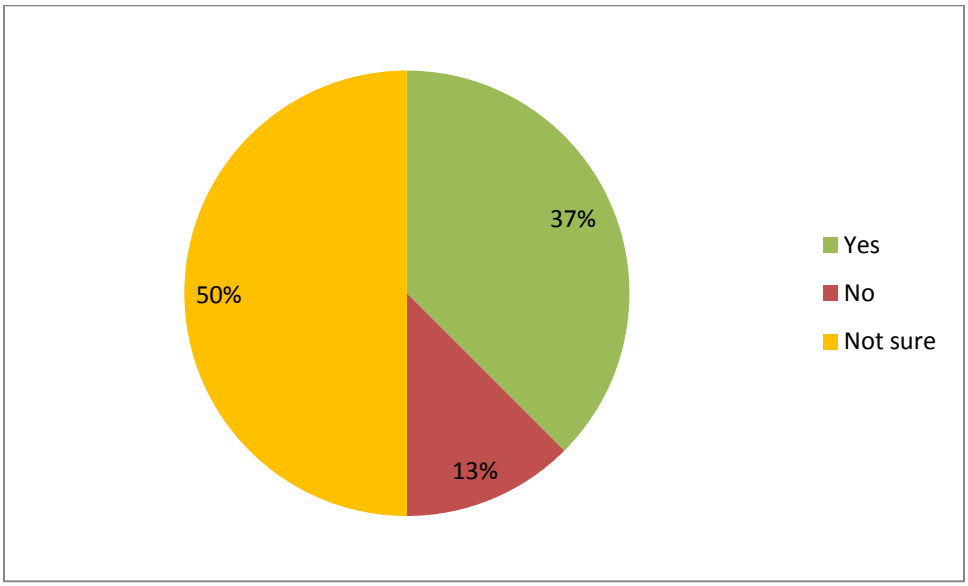


Figure 3.24: Respondent's thoughts on whether their customers would purchase produce grown using recycled water

Compared to when respondents were asked whether their customers would purchase produce grown using treated wastewater (Figure 3.25), Figure 3.24 shows somewhat of a lack of awareness regarding how recycled water is seen in the public eye. This may point to an opportunity to promote greywater reuse as an environmentally friendly initiative that farms can employ.

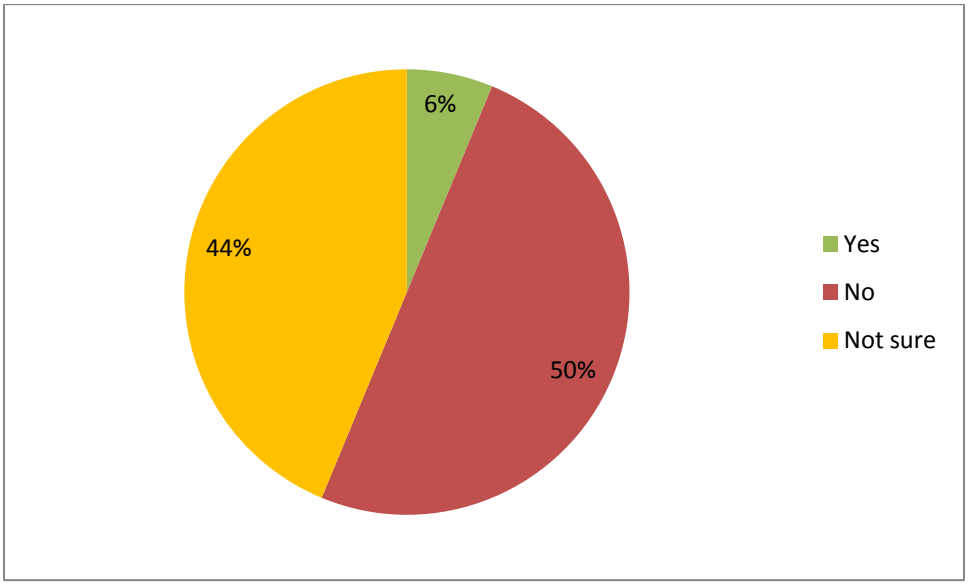


Figure 3.25: Respondent's thoughts on whether their customers would purchase produce grown using treated wastewater.

As can be seen in Figure 3.25, there is much less positivity when considering whether respondent's customers would purchase produce grown with treated wastewater.

Finally, respondents were told that reusing greywater on a farm could put that practice into the public eye, and asked for their opinion on whether that would help or hurt the farm's business. This data is shown in Figure 3.26.

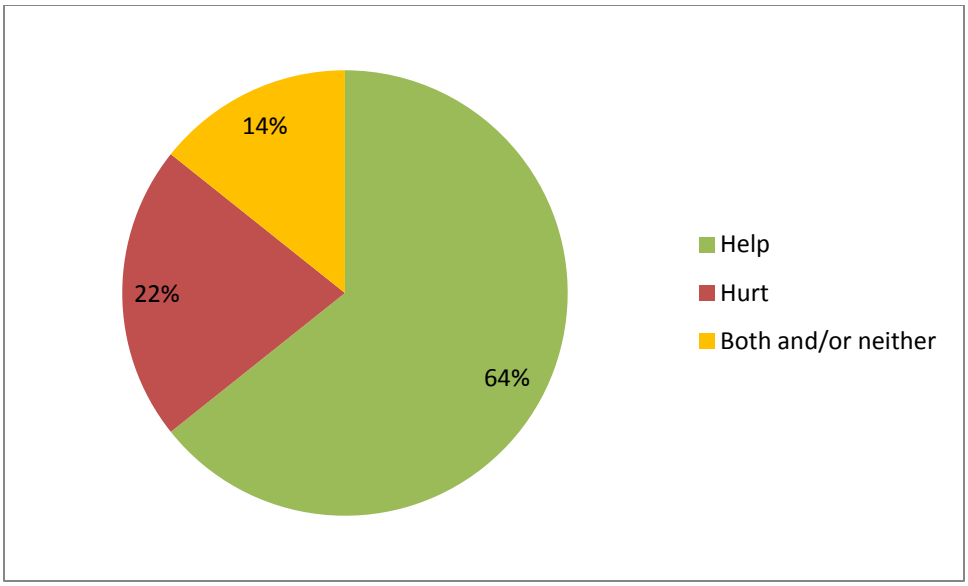


Figure 3.26: Respondent's thoughts on whether greywater reuse would help or hurt a farm's business

The majority of respondents felt that depending on the application for the greywater, their customers would appreciate their attention to sustainability. A few felt that it would be a tough sell to their customers, stating that people are uncomfortable with that which they are not familiar with or don't understand. It would be interesting to see if the farmers who thought it would hurt their business would consider incorporating education into the greywater reuse system in order to help their customers understand the reasoning behind greywater reuse.

Chapter 4: Conclusion

Greywater is an abundant and consistent source of non-potable water that can be reused for beneficial purposes using an appropriate treatment and distribution system.

A greywater reuse feasibility study was undertaken at the UBC Farm in Vancouver, British Columbia. The feasibility study revealed that the farm could generate enough water from produce washing in the summer months and rainwater capture in the winter months to use for toilet flushing in the proposed new farm centre. The potential also exists to use excess greywater and rainwater for irrigation of certain types of produce, including fruit trees and vines. Preliminary water quality testing was done on produce wash water generated from washing leeks, radishes, and carrots. While a complete water quality profile of produce wash water will need to be generated prior to a greywater system installation at the farm, it was determined that a simple treatment system consisting of preliminary settling, pressure filtration and chlorine disinfection would be sufficient to produce reclaimed water of high enough quality to use in toilet flushing within the UBC farm centre. The price of water that the farm must pay was found to be a deciding factor into the greywater reuse system's economic feasibility.

The qualitative study of farmers' perceptions and opinions on greywater reuse also highlighted that cost is a significant barrier to farmers' adoption of greywater reuse on their own farms. Farmers do not currently have problems with disposing of their wastewater, or having sufficient potable water. This lack of urgency may also be a factor influencing adoption of greywater reuse. While farmers in general see the benefit of

reusing water, and many have considered it before, they were unsure of their customers' view of the practice. Since it is unlikely that farmers would adopt a practice which had the potential to hurt their business, it will be important for them to know their customers' opinions before considering greywater reuse.

The feasibility study carried out at the UBC Farm provides important data that can be used in the detailed design stage of installing a greywater reuse system. The information gathered through this research provides evidence that the amount of water generated from produce washing and rainwater collection is sufficient for beneficial uses. This research echoes reports and other research that show the cost and availability of potable water strongly influence whether greywater reuse is economically feasible. Responses to the questionnaire have highlighted some of the biggest barriers to greywater use by farmers. In the future, if programs are designed to incentivize greywater reuse, it will be important to target the biggest barriers to reuse, as shown by data such as this.

Because the research into greywater reuse at the UBC Farm was started from scratch, the findings are preliminary. This research topic would benefit from an in-depth study into water requirements for irrigation. The metered irrigation data available from the UBC Farm is not separated based on type of produce. Some crops are more amenable to greywater reuse than others, for example fruit trees and grape vines. Whether a crop is typically eaten raw, whether the reclaimed water contacts the part of the plant that is to be eaten, and whether the crop grows above or below ground are all criteria that affect how appropriate a crop is for irrigation by reclaimed water. Installing a suite of water meters directly upstream of irrigation for a single field would allow for a more detailed analysis of

water requirements at the farm, and might present further opportunities for greywater and rainwater reuse.

A comprehensive water quality profile of produce wash water at the UBC Farm would also provide the farm with important data for the design of a greywater reuse system. Each crop produces a different quality of greywater due to a variety of factors including how it is grown, harvested, and washed. Over the length of the growing season at the farm, the quality of greywater will change depending on what is being harvested. By monitoring water quality of the produce wash water at the farm over a season, a range of values can be calculated. This will allow for the development of a water treatment system based on the "worst case scenario" water that is generated. This data is also important for developing a retention time profile in the lamella plate separators, and a backwashing schedule for the pressure filters.

Repeating the qualitative study with a broader range of participants would provide a clearer picture of farmers' opinions on greywater reuse. This study focused on members of the BC Agritourism Alliance, but many farmers in BC likely meet the definition of being an agritourism destination who do not belong to the BCATA. Being able to correlate participants' responses to the type of farm or facility they run would help to break down the data in more complex ways. It may be that certain types of farms or farmers have different acceptances of greywater reuse, but there is currently not enough data to develop any conclusions.

Due to a perceived high availability and a low cost of fresh water in Canada, greywater reuse is not currently an urgent priority in British Columbia. However changing weather patterns, declining infrastructure, and a greater societal understanding of the importance of preserving our water resources mean that greywater reuse may find its way into the public and political consciousness. Undertaking research into this topic now is one way to ensure we will not be caught by surprise when the day comes that greywater reuse is no longer discretionary.

Bibliography

ACCORD. (n.d.). *Laundry detergent ingredients: Information sheet*.

Adafruit. (2014). Introducing Trinket. Retrieved July 11, 2014, from https://learn.adafruit.com/introducing-trinket/introduction

Ajzen, I. (1985). From Intentions to Actions : A Theory of Planned Behavior. In J. Kuhl & J. Beckmann (Eds.), *Action Control*. Berlin: Springer Berlin Heidelberg.

Alberta Chamber of Commerce. (2012). *Domestic Reclaimed Water Use* (pp. 1–2).

Al-Hamaiedeh, H., & Bino, M. (2010). Effect of treated grey water reuse in irrigation on soil and plants. *Desalination*, *256*(1-3), 115–119. doi:10.1016/j.desal.2010.02.004

Arizona Department of Health Services. (2014). Waterborne Diseases. Retrieved October 05, 2014, from http://www.azdhs.gov/phs/oids/epi/waterborne/list.htm

Asano, T. (1991). Planning and implementation of water reuse projects. *Water Science & Technology*, *24*(9), 1–10.

Australian Bureau of Statistics. (2014). *Australia's water use highest in years*. Canberra. Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/latestProducts/4610.0Media Release12012-13

Bakker, K., & Sprague, J. B. (2006). Great Wet North? Canada's Myth of Water Abundance. In *Eau Canada: The Future of Canada's Water*. Vancouver: UBC Press.

Barbieri, C., & Mahoney, E. (2009). Why is diversification an attractive farm adjustment strategy? Insights from Texas farmers and ranchers. *Journal of Rural Studies*, *25*(1), 58–66. doi:10.1016/j.jrurstud.2008.06.001

Barr Plastics. (2014). Large Outdoor Rainwater Storage Tanks. Retrieved December 01, 2014, from http://www.barrplastics.com/large-outdoor-rainwater-storage-tanks.html#.VHy1fMmOc9Q

BC Government. (2012). *BC Plumbing Code*. Victoria.

BC Government. (2014). *Engineers and Geoscientists Act*. Victoria. Retrieved from http://www.bclaws.ca/civix/document/id/complete/statreg/96116_01

BC Ministry of Environment. (2013). *Reclaimed Water Guideline*.

BC Ministry of the Environment. (2012). *Municipal Wastewater Regulation*. Victoria. Retrieved from http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/87_2012#section104

Black, A., & Christen, A. (2011). UBC Climate Station. Vancouver. Retrieved from http://137.82.254.122/PlotTraces.aspx

Boyjoo, Y., Pareek, V. K., & Ang, M. (2013). A review of greywater characteristics and treatment processes. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *67*(7), 1403–24. doi:10.2166/wst.2013.675

Brinkley, C. (2012). Evaluating the Benefits of Peri-Urban Agriculture. *Journal of Planning Literature*, *27*(3), 259–269. doi:10.1177/0885412211435172

Buxton, H. T., & Kolpin, D. W. (2002). *Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams*. Reston.

Casanova, L. M., Gerba, C. P., & Karpiscak, M. (2001). Chemical and microbial characterization of household graywater. *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering*, *36*(4), 395–401.

Casanova, L. M., Little, V., Frye, R. J., & Gerba, C. P. (2001). A survey of the microbial quality of recycled household graywater. *Journal of the American Water Resources Association*, *37*(5), 1313–1319.

Cheremisinoff, N. P. (2002). *Handbook of water and wastewater treatment processes*. Woburn: Butterworth-Heinemann.

Christova-Boal, D., Eden, R. E., & McFarlane, S. (1996). An investigation into greywater reuse for urban residential properties. *Desalination*, *106*(March 1993), 391–397.

City of Guelph. (2013). Greywater reuse pilot. Retrieved December 21, 2014, from http://guelph.ca/living/environment/rebates/greywater-reuse-pilot/

City of Guelph. (2014). Rainwater Harvesting System Rebate. Retrieved March 21, 2015, from http://guelph.ca/living/environment/rebates/rainwater-harvesting-system-rebate/

City of San Diego. (2015). Rain Barrel Rebates. Retrieved March 21, 2015, from http://www.sandiego.gov/water/conservation/rebates/rainbarrel.shtml

City of Vancouver. (2013). Green home building policies. Retrieved November 17, 2014, from http://vancouver.ca/home-property-development/green-home-building-policies.aspx

Collins, A., & Thompson, R. (2004). *British Columbia Agritourism Alliance*. Quesnel.

Crook, J., & Rimer, A. E. (2009). *Technical Memorandum on Graywater*. Nevada.

Daniel L. Jerman Co. (n.d.). *DLJ Single Jet Water Meters*. Hackensack.

Dixon, A. M., Butler, D., & Fewkes, A. (1999). Guidelines for Greywater Re-Use: Health Issues. *Water and Environment Journal*, *13*(5), 322–326. doi:10.1111/j.1747-6593.1999.tb01056.x

Environment Canada. (2006). *A Primer on Fresh Water: Questions and Answers*. Ministry of the Environment.

Environment Canada. (2013a). Residential water use indicator. Retrieved November 29, 2013, from https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=7E808512-1

Environment Canada. (2013b). *The Importance of Surface Water Data*. Retrieved from http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=1CC21B07-1

Eriksson, E., Andersen, H. R., Madsen, T. S., & Ledin, A. (2009). Greywater pollution variability and loadings. *Ecological Engineering*, *35*(5), 661–669. doi:10.1016/j.ecoleng.2008.10.015

Eriksson, E., Auffarth, K., Henze, M., & Ledin, A. (2002). Characteristics of grey wastewater. *Urban Water*, *4*(1), 85–104. doi:10.1016/S1462-0758(01)00064-4

Eriksson, E., & Donner, E. (2009). Metals in greywater: Sources, presence and removal efficiencies. *Desalination*, *248*(1-3), 271–278.

Exall, K., Marsalek, J., & Schaefer, K. (2004). A Review of Water Reuse and Recycling , with Reference to Canadian Practice and Potential : 1 . Incentives and Implementation. *Water Quality Research Journal of Canada*, *39*(1), 1–12.

Federal-Provincial-Territorial Committee on Drinking Water, & Water Quality Task Group. (2002). *From source to tap: The multi-barrier approach to safe drinking water*.

Finley, S., Barrington, S., & Lyew, D. (2009). Reuse of Domestic Greywater for the Irrigation of Food Crops. *Water, Air, and Soil Pollution*, *199*(August), 235–245. doi:10.1007/s11270-008-9874-x

Friedler. (2004). Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities. *Environmental Technology*, *25*(9), 997–1008. doi:10.1080/09593330.2004.9619393

Friedler, E., Kovalio, R., & Galil, N. I. (2005). On-site greywater treatment and reuse in multi-storey buildings. *Water Science and Technology*, *51*(10), 187–94.

Friedler, E., & Lahav, O. (2006). Centralised urban wastewater reuse: what is the public attitude? *Water Science & Technology*, *54*(6-7), 423. doi:10.2166/wst.2006.605

Friedler, & Gilboa, Y. (2010). Performance of UV disinfection and the microbial quality of greywater effluent along a reuse system for toilet flushing. *The Science of the Total Environment*, *408*(9), 2109–17. doi:10.1016/j.scitotenv.2010.01.051

Friedler, Shwartzman, Z., & Ostfeld, A. (2008). Assessment of the reliability of an on-site MBR system for greywater treatment and the associated aesthetic and health risks. *Water Science and Technology*, *57*(7), 1103–10. doi:10.2166/wst.2008.248

Gao, J., Barbieri, C., & Valdivia, C. (2013). Agricultural Landscape Preferences: Implications for Agritourism Development. *Journal of Travel Research*, *53*(3), 366–379. doi:10.1177/0047287513496471

Gil Arroyo, C., Barbieri, C., & Rozier Rich, S. (2013). Defining agritourism: A comparative study of stakeholders' perceptions in Missouri and North Carolina. *Tourism Management*, *37*, 39–47. doi:10.1016/j.tourman.2012.12.007

Gilboa, Y., & Friedler, E. (2008). UV disinfection of RBC-treated light greywater effluent: kinetics, survival and regrowth of selected microorganisms. *Water Research*, *42*(4-5), 1043–50. doi:10.1016/j.watres.2007.09.027

Glenn, R. T. (2012). *Regulatory issues associated with greywater reuse*. Colorado State University.

Godfrey, S., Singh, S., Labhasetwar, P., Dwivedi, H. B., Parihar, G., & Wate, S. R. (2010). Health-based targets for greywater reuse in residential schools in Madhya Pradesh, India. *Water and Environment Journal*, *24*(3), 215–222. doi:10.1111/j.1747-6593.2009.00180.x

Government of Canada. (2013). *Wastewater Systems Effluent Regulations*.

Government of Saskatchewan. (2011). *The plumbing regulations*. *2011 Ieee Autotestcon*. Regina: Ieee. doi:10.1109/AUTEST.2011.6058799

Grieve, C. M. (2011). Review: Irrigation of floricultural and nursery crops with saline wastewaters. *Israel Journal of Plant Sciences*, *59*(2), 187–196. doi:10.1560/IJPS.59.2-4.187

Gross, A., Azulai, N., Oron, G., Ronen, Z., Arnold, M., & Nejidat, A. (2005). Environmental impact and health risks associated with greywater irrigation: a case study. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *52*(8), 161–9.

Gross, Kaplan, D., & Baker, K. (2007). Removal of chemical and microbiological contaminants from domestic greywater using a recycled vertical flow bioreactor (RVFB). *Ecological Engineering*, *31*(2), 107–114. doi:10.1016/j.ecoleng.2007.06.006

Gross, Shmueli, O., Ronen, Z., & Raveh, E. (2007). Recycled vertical flow constructed wetland (RVFCW)--a novel method of recycling greywater for irrigation in small communities and households. *Chemosphere*, *66*(5), 916–23. doi:10.1016/j.chemosphere.2006.06.006

Haas, C. N., Rose, J. B., & Gerba, C. P. (2014). *Quantitative Microbial Risk Assessment* (2nd ed.). Hoboken: John Wiley & Sons Inc. Retrieved from http://reader.eblib.com.ezproxy.library.ubc.ca/(S(cq4hdr2mv0zsgthd4cncoy54))/Reader.aspx?p=1706900&o=1267&u=98KmL5kz6Uw=&t=1412534446&h=ABC17C12892DAA9BE8A8D3D7548470D7FBB0F548&s=26581278&ut=4226&pg=1&r=img&c=-1&pat=n&cms=-1&sd=2#

Hartley, T. W. (2006). Public perception and participation in water reuse. *Desalination*, *187*(1-3), 115–126. doi:10.1016/j.desal.2005.04.072

Health Canada. (2010). *Canadian guidelines for domestic reclaimed water for use in toilet and urinal flushing*. Ottawa.

Hernández, F., Urkiaga, A., Fuentes, L. De, Bis, B., & Chiru, E. (2006). Feasibility studies for water reuse projects : an economical approach. *Desalination*, *187*(February 2005), 253–261.

Hydro Flo Technologies. (2002). Inclined Plate (Lamella) Clarifiers. Retrieved December 01, 2014, from http://www.clarifier.hydroflotech.com/

Imperial College London School of Public Health. (2013). Enteric bacterial pathogens. Retrieved October 04, 2014, from http://www1.imperial.ac.uk/publichealth/departments/ide/outbreaks/research/ebp/

Jefferson, B., Palmer, a, Jeffrey, P., Stuetz, R., & Judd, S. (2004). Grey water characterisation and its impact on the selection and operation of technologies for urban reuse. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *50*(2), 157–64. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15344786

Jepperson, & Solly. (1996). *Model guidelines for domestic greywater reuse for Australia*.

Katanda, Y., Mushonga, C., Banganayi, F., & Nyamangara, J. (2007). Effects of heavy metals contained in soil irrigated with a mixture of sewage sludge and effluent for thirty years on soil microbial biomass and plant growth. *Physics and Chemistry of the Earth, Parts A/B/C*, *32*(15-18), 1185–1194. doi:10.1016/j.pce.2007.07.016

Latino, B. R. (2007). *More than purple pipe - Conducting water reuse feasibility studies*. North Carolina.

Listowski, a., Ngo, H. H., & Guo, W. S. (2013). Establishment of an economic evaluation model for urban recycled water. *Resources, Conservation and Recycling*, *72*, 67–75. doi:10.1016/j.resconrec.2012.12.011

Maimon, A., Friedler, E., & Gross, A. (2014). Parameters affecting greywater quality and its safety for reuse. *The Science of the Total Environment*, *487*, 20–5. doi:10.1016/j.scitotenv.2014.03.133

Maimon, A., Tal, A., Friedler, E., & Gross, A. (2010). Safe on-site reuse of greywater for irrigation - a critical review of current guidelines. *Environmental Science & Technology*, *44*(9), 3213–3220.

Masi, F., El Hamouri, B., Abdel Shafi, H., Baban, A., Ghrabi, A., & Regelsberger, M. (2010). Treatment of segregated black/grey domestic wastewater using constructed wetlands in the Mediterranean basin: the zer0-m experience. *Water Science and Technology*, *61*(1), 97–105. doi:10.2166/wst.2010.780

Meinzinger, F., & Oldenburg, M. (2009). Characteristics of source-separated household wastewater flows: a statistical assessment. *Water Science and Technology*, *59*(9), 1785–91. doi:10.2166/wst.2009.185

Minister of Industry. (2009). *Industrial Water Use*. Ottawa.

Minister of Industry. (2010). *Freshwater supply and demand in Canada*. Ottawa.

Ministry of Environment Lands and Parks. (2001). *Code of Practice for the Use of Reclaimed Water: A Companion Document to the Municipal Sewage Regulation*.

Mitchell, S., Roehr, D., & Laquian, P. (2012). *Land Use Plan for UBC South Campus Farm* (pp. 1–30). Vancouver.

Mohamed, R. M. S. R., Kassim, A. H. M., Anda, M., & Dallas, S. (2013). A monitoring of environmental effects from household greywater reuse for garden irrigation. *Environmental Monitoring and Assessment*, *185*(10), 8473–88. doi:10.1007/s10661-013-3189-0

Molinos-Senante, M., Hernandez-Sancho, F., & Sala-Garrido, R. (2011). Feasibility studies for water reuse projects: Economic valuation of environmental benefits. In P. Hlavinek, I. Winkler, J. Marsalek, & I. Mahrikova (Eds.), *Advanced Water Supply and Wastewater Treatment: A Road to Safer Society and Environment*. Dordrecht: Springer Netherlands. doi:10.1007/978-94-007-0280-6

Muñoz, I., Gómez-Ramos, M. J., Agüera, A., Fernández-Alba, A. R., García-Reyes, J. F., & Molina-Díaz, A. (2009). Chemical evaluation of contaminants in wastewater effluents and the environmental risk of reusing effluents in agriculture. *TrAC Trends in Analytical Chemistry*, *28*(6), 676–694. doi:10.1016/j.trac.2009.03.007

Murra, A. E. (2007). *Design and installation of non-potable water systems/Maintenance and field testing of non-potable water systems*.

Nancarrow, B. E., Leviston, Z., Po, M., Porter, N. B., & Tucker, D. I. (2008). What drives communities' decisions and behaviours in the reuse of wastewater. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *57*(4), 485–91. doi:10.2166/wst.2008.160

Nancarrow, B. E., Leviston, Z., & Tucker, D. I. (2009). Measuring the predictors of communities' behavioural decisions for potable reuse of wastewater. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *60*(12), 3199–209. doi:10.2166/wst.2009.759

National Research Council. (2012a). Summary. In *Water reuse - Potential for expanding the Nation's water supply through reuse of municipal wastewater* (pp. 15–22). Washington: The National Academies Press.

National Research Council. (2012b). Water Quality. In *Water reuse - Potential for expanding the Nation's water supply through reuse of municipal wastewater* (pp. 69–80). Washington: The National Academies Press.

O'Toole, J., Sinclair, M., Malawaraarachchi, M., Hamilton, A., Barker, S. F., & Leder, K. (2012). Microbial quality assessment of household greywater. *Water Research*, *46*(13), 4301–13. doi:10.1016/j.watres.2012.05.001

Ottoson, J., & Stenström, T. A. (2003). Faecal contamination of greywater and associated microbial risks. *Water Research*, *37*(3), 645–55. doi:10.1016/S0043-1354(02)00352-4

Paris, S., & Schlapp, C. (2010). Greywater recycling in Vietnam — Application of the HUBER MBR process. *Desalination*, *250*(3), 1027–1030. doi:10.1016/j.desal.2009.09.099

Pereira, B. F. F., He, Z. L., Silva, M. S., Herpin, U., Nogueira, S. F., Montes, C. R., & Melfi, a J. (2011). Reclaimed wastewater: impact on soil-plant system under tropical conditions. *Journal of Hazardous Materials*, *192*(1), 54–61. doi:10.1016/j.jhazmat.2011.04.095

Phillip, S., Hunter, C., & Blackstock, K. (2010). A typology for defining agritourism. *Tourism Management*, *31*(6), 754–758. doi:10.1016/j.tourman.2009.08.001

Pinto, U., Maheshwari, B. L., & Grewal, H. S. (2010). Effects of greywater irrigation on plant growth, water use and soil properties. *Resources, Conservation and Recycling*, *54*(7), 429–435. doi:10.1016/j.resconrec.2009.09.007

Po, M., Kaercher, J. D., & Nancarrow, B. E. (2003). *Literature review of factors influencing public perceptions of water reuse*.

Po, M., Nancarrow, B. E., Leviston, Z., Porter, N. B., Syme, G. J., & Kaercher, J. D. (2005). *Predicting community behaviour in relation to wastewater reuse: What drives decisions to accept or reject?* Perth.

Radhakrishna, R. B. (2007). Tips for developing and testing questionnaires/instruments. *Journal of Extension*, *45*(1). Retrieved from http://www.joe.org/joe/2007february/tt2.php

Rattan, R. K., Datta, S. P., Chhonkar, P. K., Suribabu, K., & Singh, a. K. (2005). Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. *Agriculture, Ecosystems & Environment*, *109*(3-4), 310–322. doi:10.1016/j.agee.2005.02.025

Recycled water task force. (2003). *Water recycling 2030 - Recomendations by California's recycled water task force*. Sacramento.

Regional District of Nanaimo. (2012). *Rainwater Harvesting Best Practices Guidebook* (Vol. 4). Nanaimo.

Rodda, N., Salukazana, L., Jackson, S. a. F., & Smith, M. T. (2011). Use of domestic greywater for small-scale irrigation of food crops: Effects on plants and soil. *Physics and Chemistry of the Earth*, *36*(14-15), 1051–1062. doi:10.1016/j.pce.2011.08.002

Rose, J. B., Sun, G.-S., Gerba, C. P., & Sinclair, N. A. (1991). Microbial quality and persistence of enteric pathogens in graywater from various household sources. *Water Research*, *25*(1), 37–42.

Schaefer, K., Exall, K., & Marsalek, J. (2004). Water Reuse and Recycling in Canada : A Status and Needs Assessment. *Canadian Water Resources Journal*, *29*(August), 195–208.

Seidu, R., Heistad, A., Amoah, P., Drechsel, P., Jenssen, P. D., & Stenström, T.-A. (2008). Quantification of the health risk associated with wastewater reuse in Accra, Ghana: a contribution toward local guidelines. *Journal of Water and Health*, *6*(4), 461–71. doi:10.2166/wh.2008.118

Selkirk, D. (2012). Conserve Rainwater with a Rain Barrel. *BC Living*. Retrieved March 21, 2015, from http://www.bcliving.ca/garden/rain-barrel-conserve water

Sinclair, M., O'Toole, J., Malawaraarachchi, M., & Leder, K. (2013). Household greywater use practices in Melbourne, Australia. *Water Science & Technology*, *13*(2), 294. doi:10.2166/ws.2013.022

Statistics Canada. (2011). *2011 Census of Agriculture*. Retrieved from http://www.statcan.gc.ca/pub/95-640-x/2012002/prov/59-eng.htm

Tandi, N. K., Nyamangara, J., & Bangira, C. (2005). Environmental and Potential Health Effects of Growing Leafy Vegetables on Soil Irrigated Using Sewage Sludge and Effluent: A Case of Zn and Cu. *Journal of Environmental Science and Health, Part B*, *39*(3), 461–471. doi:10.1081/PFC-120035930

Tew, C., & Barbieri, C. (2012). The perceived benefits of agritourism: The provider's perspective. *Tourism Management*, *33*(1), 215–224. doi:10.1016/j.tourman.2011.02.005

Travis, M. J., Weisbrod, N., & Gross, A. (2008). Accumulation of oil and grease in soils irrigated with greywater and their potential role in soil water repellency. *The Science of the Total Environment*, *394*(1), 68–74. doi:10.1016/j.scitotenv.2008.01.004

Travis, M. J., Wiel-Shafran, A., Weisbrod, N., Adar, E., & Gross, A. (2010). Greywater reuse for irrigation: effect on soil properties. *The Science of the Total Environment*, *408*(12), 2501–8. doi:10.1016/j.scitotenv.2010.03.005

UBC Farm. (2012). *UBC Farm Centre preliminary area estimate* (pp. 1–5). Vancouver.

UBC Farm. (2014a). Centre for Sustainable Food Systems at UBC Farm. Retrieved August 29, 2014, from http://ubcfarm.ubc.ca/about/

UBC Farm. (2014b). Food Production. Retrieved August 29, 2014, from http://ubcfarm.ubc.ca/food-production/

UBC Farm. (2014c). Research and Teaching. Retrieved August 29, 2014, from http://ubcfarm.ubc.ca/research-teaching/

UBC IT. (2014). Survey Tool. Retrieved September 08, 2014, from http://it.ubc.ca/services/teaching-learning-tools/survey-tool

Urkiaga, A., Bis, B., Hernandez, F., Koksis, T., Balasz, B., Chiru, E. (2006). *Handbook on feasibility studies for water reuse systems*. (AQUAREC, Ed.). EESD Programme, European Commision.

Vander Ploeg, C. G. (2011). *Water Pricing - Seizing a public policy dilemma by the horns*.

Vekshin, A. (2014, July 23). California Water Prices Soar for Farmers as Drought Grows. *Bloomberg*. San Francisco. Retrieved from http://www.bloomberg.com/news/2014-07-24/california-water-prices-soar-for-farmers-as-drought-grows.html

Verlicchi, P., Al Aukidy, M., Galletti, a., Zambello, E., Zanni, G., & Masotti, L. (2012). A project of reuse of reclaimed wastewater in the Po Valley, Italy: Polishing sequence and cost benefit analysis. *Journal of Hydrology*, *432-433*, 127–136. doi:10.1016/j.jhydrol.2012.02.024

Water Environment Federation, American Public Health Association, & American Water Works Association. (2006). Standard Methods for the Examination of Water and Wastewater. Retrieved September 08, 2014, from http://www.standardmethods.org/

Waterwise Systems. (2009). Greywater: Running Costs. Retrieved December 08, 2014, from http://www.waterwisesystems.com/products/greywater-gardener-230/running-costs

Westcot, D. W. (1997). *Quality control of wastewater for irrigated crop production*. Rome.

WesTech. (2014). Pressure filters. Retrieved December 01, 2014, from http://www.westech-inc.com/en-usa/products/pressure-filters

Winpenny, J., Heinz, I., & Koo-Oshima, S. (2010). *The wealth of waste : The economics of wastewater use in agriculture*. Rome.

Winward, Avery, L. M., Stephenson, T., & Jefferson, B. (2008). Chlorine disinfection of grey water for reuse: effect of organics and particles. *Water Research*, *42*(1-2), 483–91. doi:10.1016/j.watres.2007.07.042

Winward, G. P. (2007). *Disinfection of grey water*. Cranfield University.

World Health Organization. (2006a). *Guidelines for the safe use of wastewater, excreta and greywater Volume 4: Excreta and greywater use in agriculture*. France.

World Health Organization. (2006b). *Overview of greywater management Health considerations*. Amman.

World Health Organization. (2006c). *WHO guielines for the safe use of wastewater, excreta, and greywater: Volume 1 policy and regulatory aspects* (Vol. I). France.

WRI [World Resources Institute]. (2005). *Freshwater Resources*. Washington.

Yu, Z. L. T., Deshazo, J. R., Stenstrom, M. K., & Cohen, Y. (2011). *Cost-Benefit Analysis of Onsite Residential Graywater Recycling – A Case Study : the City of Los Angeles* (pp. 1–8). Los Angeles.

Appendices

Appendix A - water quality testing procedures

BOD_5

Reagents Preparations – BOD Nutrient Solutions

Apparatus:

HACH HQ 30d probe
BOD bottles (300 mLs)
100 and 50 mL graduated cylinders
Nalgene 10 L plastic bottle (dispensing biological dilution water)

Chemicals and Reagents:

BOD Poly Seed Innoculum (HACH Catalogue # 29275147) - Inter Lab

Prepare the following solutions in 1 L of distilled water. Transfer the listed chemicals to a 1 L partially filled volumetric flask. Mix well and use ultrasonication if needed. After transferring and mixing then top up the volumetric flask to the mark.

Each solution is used to treat a volume of distilled water (1.0 mL of nutrient solution per liter of distilled water)

Phosphate Buffer

8.5 grams of KH_2PO_4 (potassium hydrogen phosphate)
21.8 grams of K_2HPO_4 (potassium phosphate, dibasic)
33.4 grams of $Na_2HPO_4 .7H_2O$ (sodium phosphate, dibasic)
1.7 grams of NH_4Cl (ammonium chloride)

Ferric Chloride Solution

0.25 grams of $FeCl_2.6H_2O$ in 1 liter of distilled water

Calcium Chloride Solution

27.5 grams of $CaCl_2$ in 1 liter of distilled water

Magnesium Sulphate

22.5 grams of $MgSO_4.7H_2O$ in 1 liter of distilled water

Preparation of Biological Dilution Water (10 L)

First, thoroughly clean and fill a 10 L Nalgene container with 10 L of distilled water. Add 10 mLs each of the nutrient solutions and then bubble air in the water for about an hour. Let the solution sit for another hour. This is used for sample dilutions and preparation of the "seed" water.

Nutrient Solutions

1) Phosphate Buffer
2) Ferric Chloride solution
3) Calcium Chloride solution
4) Magnesium Sulphate solution

Preparation of Bacterial Seed Water (500 mLs)

To make the seed water open the BOD poly seed capsule and transfer the entire contents into 500 mLs of biological dilution water. Bubble air through the water for 1 hour.

Note: Bran, which acts as the carrier for the microorganism, will neither dissolve nor inhibit microbial activity, but must be settled out of the Polyseed solution prior to use.

Domestic Water Sample - BOD Preparation

Transfer 300, 100 and 30 mLs of each sample into separate BOD glass bottles. The 300 mL sample should fill the bottle close to the top. With the 100 and 30 mLs samples replicates, add biological dilution water to top up the water to the top of the bottle.

Prepare blanks that consist of full BOD bottles of the dilution water (total of 4 bottles).

1) Two bottles of blank biological dilution water that are not spiked with the seed.
2) Two bottles of blank biological dilution water that are spiked with seed.

Spike each bottle except the non seeded blanks with 4 mLs of bacterial seed solution.

Initial Dissolved Oxygen Measurements ($IDO_{Day\ 0}$)

After spiking, prepare to measure the IDO using the dissolved oxygen instrument (HACH HQ 30d)

First after removing the top from the BOD sample bottle, insert the special plastic liner into the top of the bottle. This prevents spillage of the sample water as the probe is inserted into the sample. Once the probe is inserted, then press the green button to

initiate the measurement process. The signal needs to stabilize and the instrument's display will indicate when this event occurs. This usually takes up to 40 seconds. Take this final reading as the $IDO_{DAY\ 0}$ (Initial Dissolved Oxygen at day zero).

Replace the top on the bottle and add a small amount of water onto the top of the bottle if needed. Cap with the plastic cap over the glass stopper as this minimizes evaporation and oxygen infusion into the sample.

Place the samples in the 20 ^{0} C incubator for 5 days.

Measurement and Calculations of BOD at Day 5

Remove the samples from the incubator and then proceed with the $DO_{Day\ 5}$ measurements.

Measure the dissolved oxygen as previously describe in the method and record the $DO_{Day\ 5}$ data for the 300, 100 and 30 mLs samples.

When measuring the seeded blank, an acceptable value must be less than 1.0 mg/L $DO_{Day\ 5}$ before proceeding with further testing. Take an average of the duplicate readings to assess the blanks. This is an indication of clean blanks.

The blank water that has not been spiked with seed must be below 0.2 mg/L $DO_{Day\ 5}$

Reference Method: Standard Methods 21st Edition 2005 – Method 5210B

Fecal Coliform

Lab Preparations

Prior to any sample preparation, all lab apparatus used in the critical steps of the analysis must be sterilized by autoclaving. Each sample has a separate set of lab apparatus as listed:

1) Plastic 100 mL graduate cylinders (1 per sample)
2) Plastic 10 mL graduated cylinders (1 per sample)
3) Plastic 1.0 mL pipette tips (1 per sample)
4) Solution of coliform dilution water ($MgCl_2$ and KH_2PO_4) – used for all samples in the batch
5) Stainless Steel Vacuum Filtration device – used for all samples in the batch
6) Stainless Steel Tweezers – used for all samples in the batch

Autoclave in plastic autoclave bags all pipette tips, graduated cylinders, dilution water, tweezers and the vacuum filter device at 121° C for 20 minutes at the slow vent setting. Make sure to add enough water at the bottom of the autoclave (up to the lip of the

autoclave's inner housing). If autoclaving just the glassware and cylinders then a 10 minute autoclave time is sufficient.

Plastic Sampling Bottles (125 mLs)

Each sampling bottle used for fecal coliform water collection must be autoclaved prior to being sent out into the field. First add 100 uL of 10% sodium thiosulphate (removes residual chloride) to each plastic bottle and leave the caps loose. Autoclave the bottles at 121° C for 20 minutes and set the autoclave to the slow vent setting. This sterilization step is essential.

Preparation of 1 % Rosolic Acid in 0.2 N NaOH

This solution is stable if stored at 4 to 8° C for up to 2 months and must be prepared fresh if the solution has expired. The colour of a freshly prepared and good solution of rosolic acid is distinctively reddish. An expired solution is brownish in colour.

To prepare a 0.2 N NaOH solution, add 1.6 grams of NaOH and dissolve with distilled water in a 200 mL volumetric flask. Mix the solution well.

Weigh out 0.25 grams of Rosolic acid and transfer to a 25 mL volumetric flask. Top up the flask with the 0.2 N NaOH solution and mix well. Store the solution in the 4 to 8°C refrigerator.

Fecal Coliform Media Preparation in 47 m.m. Petri Dishes

Prepare the media by adding the following to an erlenmeyer flask of 100 mLs distilled water:

1) 3.7 grams of Difco m FC Broth Base powder (BD Chemicals - Ref 288320)
2) 1.3 grams of Bacteriological Agar (Fisher – Cat #: J2400-C)
3) 1.0 mL of 1% Rosolic acid solution (solution should be reddish in color so discard and make a new solution if it is brownish in color)

Microwave and agitate until dissolved but don't over boil. Mix well and prepare the media testing dishes before the media gels. Using a plastic 5 mL pipette dispenser, transfer the warm media solution into separate 47 m.m. petri dishes. Carefully dispense and avoid introducing air bubbles on the surface of the gel.

Partially cover the dish with the cap and allow the media to solidify prior to use by leaving the petri dishes sit at room temperature for about 10 minutes.

Coliform Rinse Water (Phosphate Buffer)

This water is used to rinse the vaccum apparatus between samples and must be autoclaved prior to use.

Prepare two stock solutions as follows:

1) Magnesium Chloride – take 40.5 grams of $MgCl_2.6H_2O$ and dissolve into 100 mLs of distilled water.

2) Phosphate Buffer – weigh 4.25 grams of KH_2PO_4 into 50 mLs of distilled water and then adjust the pH to 7.2 with 1 N NaOH. Add another 100 mLs of distilled water to make up the final volume to 150 mLs.

To make the coliform rinse water, add 1.0 mL of each stock into a liter of distilled water and autoclave at 121° C for 20 minutes with the autoclave set to the slow vent setting.

<u>Sample Filtering and Preparation</u>

In order to cover a range of low to high levels, each sample is processed in a series of dilutions (100 mL, 10 mL and 1 mL sample aliquotes). So for each sample, there are three petri dishes prepared that must be carefully labeled prior to sample filtration. Keep a detailed record of sample labels and identification of petri dishes.

Do a method blank sample which is 100 mLs of filtered coliform dilution water.

Filter, under vacuum, 1.0 mL, 10 mLs and 100 mLs of each sample on to individual 0.45 uM gridded filters. With the 1 mL sample, first add about 10 mLs of the dilution water into the vacuum filtration device (without vacuum) and then add the 1 mL aliquote of sample. Apply vacuum after this step. This helps evenly distribute the sample onto the 47 m.m. gridded filter.

After filtering the sample, remove the filter using sterilized tweezers and place the filter onto a 47 m.m. media petri dish. Each filter is carefully placed into the dish face up. Take care so that no air pockets are present between the filter and the media. The treated filters/petri dish is then placed on the lab bench upside down.

Rinse the vaccum filter cassette with rinse water a couple of times and flame the tweezers between the sample aliquots.

Also after each sample, rinse the vacuum filter cassette with ethyl or methyl alcohol and using a bunsen burner, lightly flame the top portion of the filter cassette and the tweezers to prevent the possibility of cross contamination.

Caution: Ethyl alcohol is very flammable and when ignited can be difficult to see. Handle this solvent with due care and keep beakers and containers away from the Bunsen burner flame.

All the prepared samples are then placed in a 45° C oven and incubated for 24 hours before counting the coliform colonies.

Record the time of incubation and do not exceed the 24 hour time limit. If the incubation time of 24 hours is exceeded then the results can be invalid if there is a saturation of colonies on the petri dishes.

The colonies are identified by their distinctive blue color. Count the number of colonies and express the results as fecal coliforms per 100 mLs of water (FC/100 mL).

The final calculation is determined by close examination of all three sample levels. If the 100 mL sample has a smear of coliform counts (an over whelming number on the dish) then the 10 mL or 1 mL sample is counted and the final reported results adjusted accordingly.

Reference Method: Standard Methods 21st Edition 2005 – Section 9-59 to 9-60 # 9222

Total Suspended Solids

Apparatus Required:
Drying Oven (105°C)
Muffle Furnace (550°C)
Balance (four/five place readings)
Numbered Aluminum Weigh Boats
Glass Fiber Filters*
Filtering Apparatus – either syringes and filter holders (in the field) or a vacuum set up

Procedure:

Before Going Into the Field

1. Pre-combust the filters at 450°C for 4 hours in a muffle furnace to remove any organic carbon on the filter surface.
2. Cool filters by storing in a desiccator overnight to prevent moisture build-up on the filter surface.
3. Measure the masses of the filters are measured on a 4 or 5 place balance and record.
4. Store the filters in petri dishes with a label on which an identification number, and spaces for the recording of the site, date, volume filtered is printed.

Filtering

1. Record in the field book the identification number of the filter and the volume of water that was filtered. Also record this information on the petri dish label. Keep the filter in this dish until you get back to lab.

2. If you do not want to filter in the field, take a 2L sample of the water back to the lab and us a vacuum set up to filter the water. *Remember to record the filter number and volume filtered.*

In the Lab

1. Place the filter(s) into a numbered, pre-weighed aluminum weigh boat(s). Record both the filter number and the weigh boat identification in a lab book.
2. Place the weigh boat(s) into the 105°C drying oven for at least twelve hours. Cover the boat(s) with a sheet of aluminum foil to prevent foreign material from falling onto the filter surface.
3. Place the boat(s) into a desiccator to cool. Record the weight of the room temperature filter + weigh boat.
4. Place the boat(s) into a ***preheated and stabilized***, 550°C muffle furnace for two hours.
5. Cool filters + weigh boat(s). Depending on the muffle furnace demand at camp, either a) remove hot filter + weigh boats, and allow them to cool in a GLASS desiccator, or b) turn off furnace and cool filter + weigh boat(s) in furnace. Once filters are cool enough to handle, record the room temperature weight of the filter + weigh boat.
6. Discard the filter.

Reference Method: Standard Methods 21st Edition 2005 – Method 2540D

Appendix B - rainwater collection data

Daily precipitation data from the UBC climate station (Black & Christen, 2011) was aggregated into weekly precipitation, recorded in mm. This data is shown in Table B.1.

Table B.1: Weekly precipitation data (mm) at UBC from 1991-2013

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1991	0.0	57.4	29.0	0.3	97.8	41.4	38.6	14.2	38.1	4.1	18.3	25.1	6.6	73.4	26.2
1992	43.2	70.1	0.5	7.1	0.0	0.0	0.0	0.0	0.0	12.2	11.9	0.3	3.0	4.3	5.6
1993	0.0	0.0	0.0	69.9	33.3	0.0	6.1	4.6	0.3	25.9	8.1	48.3	32.5	18.8	34.8
1994	0.0	0.0	8.6	0.0	0.8	0.8	37.1	48.5	46.2	58.2	4.8	42.7	14.7	5.3	41.7
1995	50.6	10.1	80.0	26.7	50.6	46.0	5.5	83.7	31.3	18.4	52.4	49.7	12.0	1.8	35.0
1996	47.8	83.7	23.9	19.3	7.4	58.0	32.2	23.9	12.9	50.6	6.4	10.1	8.3	55.2	24.8
1997	28.4	12.7	26.4	4.6	23.9	0.3	21.1	7.6	15.5	13.7	9.1	36.1	6.9	0.8	1.0
1998	0.0	0.0	89.2	85.6	27.6	20.2	37.7	34.0	33.1	28.5	29.4	13.8	8.3	20.2	12.9
1999	27.2	40.0	87.6	40.8	66.3	91.8	12.8	32.3	106.3	24.7	50.2	23.0	23.0	10.2	11.9
2000	31.5	70.6	46.8	16.2	12.8	25.5	11.9	0.0	33.2	47.6	0.0	9.4	7.7	4.3	0.9
2001	47.6	8.5	40.8	18.7	19.6	14.5	6.0	4.3	20.4	10.2	30.6	6.8	37.4	15.3	13.6
2002	38.7	28.8	29.8	23.7	31.3	30.2	6.5	57.7	0.0	15.6	30.6	16.9	9.7	3.8	46.1
2003	56.8	9.8	6.8	49.0	26.8	3.0	6.6	17.0	2.8	24.2	54.6	49.2	22.6	29.0	56.4
2004	24.8	53.6	56.4	19.6	42.0	25.2	19.0	24.2	15.0	43.0	3.6	11.2	28.0	12.2	0.4
2005	13.4	3.0	36.0	193.0	21.4	34.8	5.0	1.0	0.2	20.0	6.8	42.2	44.6	47.0	41.6
2006	60.0	48.8	77.4	62.2	56.0	51.8	6.6	1.4	18.8	3.6	44.4	15.6	39.2	20.0	16.4
2007	90.6	8.4	58.4	36.4	17.0	19.6	39.2	38.6	20.2	79.0	47.2	74.8	2.0	10.6	18.6
2008	23.4	55.8	22.0	2.4	24.6	36.2	23.6	3.2	12.6	18.2	18.6	24.6	16.0	12.0	17.0
2009	39.4	109.0	1.8	0.4	23.2	5.0	3.6	7.0	33.2	6.8	21.8	26.2	17.4	43.6	20.4
2010	30.4	18.2	65.2	2.8	6.4	7.2	17.4	15.8	38.8	5.8	17.4	10.8	18.2	26.4	27.2
2011	7.2	45.6	45.2	33.2	36.4	26.4	22.0	31.6	9.4	18.4	30.2	24.0	13.2	41.6	36.4
2012	39.6	41.2	4.4	37.6	39.0	21.8	21.6	32.6	51.8	24.2	31.8	31.8	11.0	26.4	9.0
2013	28.8	53.6	0.6	21.8	5.6	13.2	5.4	38.6	43.0	8.4	52.6	22.0	0.0	34.0	29.0

Table B.1: Weekly precipitation data (mm) at UBC from 1991-2013

Week	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1991	0.0	11.7	6.4	36.1	5.8	11.2	2.5	4.6	38.6	10.9	2.5	0.3	11.9	22.6	4.1
1992	31.8	30.7	50.5	11.4	0.0	0.0	5.1	0.0	42.9	0.0	0.8	44.5	7.1	0.0	6.4
1993	24.1	32.8	38.9	23.1	9.9	20.3	21.8	20.8	19.6	29.5	11.7	2.3	11.9	2.8	1.5
1994	15.0	11.9	4.8	1.0	0.5	0.5	2.0	0.5	8.1	1.8	0.3	1.3	0.0	0.0	0.0
1995	23.0	9.2	0.9	12.0	23.0	0.0	0.0	10.1	17.5	17.5	1.8	8.3	0.0	0.0	0.0
1996	49.7	68.1	12.9	17.5	37.7	19.3	0.5	0.0	0.8	0.5	0.5	1.0	0.0	4.8	0.0
1997	23.6	3.8	0.0	0.3	0.0	7.1	11.4	5.3	0.5	14.2	6.6	9.7	15.7	0.0	2.0
1998	3.7	7.4	0.0	79.1	26.7	13.8	76.4	0.0	12.0	0.9	21.2	11.0	80.0	15.6	0.0
1999	8.5	18.7	11.9	17.0	21.3	15.3	0.0	29.8	5.1	20.4	9.4	34.9	1.7	0.0	2.6
2000	3.4	13.6	17.0	17.9	8.5	23.0	33.2	4.3	31.5	18.7	0.0	15.3	4.3	0.0	10.2
2001	36.6	16.2	9.3	0.9	25.8	0.2	29.1	17.4	5.5	5.8	13.8	0.0	7.7	1.5	21.3
2002	10.4	14.5	2.5	6.4	25.3	7.5	18.6	2.8	0.0	6.4	21.8	3.1	14.7	0.0	0.0
2003	18.6	46.6	4.6	0.0	17.2	24.2	0.8	0.0	2.4	2.8	0.4	5.6	17.2	3.2	0.0
2004	4.4	10.6	1.0	10.0	2.8	11.2	40.2	7.4	17.4	0.0	0.0	1.0	8.8	0.6	1.6
2005	24.8	0.0	0.0	6.2	15.8	37.8	0.2	17.2	15.4	15.4	6.6	4.2	39.4	9.2	0.0
2006	29.8	6.2	7.2	12.8	0.2	5.0	14.2	22.8	40.8	1.6	0.4	0.0	0.0	12.6	1.6
2007	17.6	29.4	27.4	0.4	27.6	0.6	0.0	54.4	8.0	12.6	3.6	0.4	0.2	53.8	3.8
2008	14.6	2.4	16.2	1.0	24.0	6.4	0.0	28.2	12.8	0.2	0.0	1.8	0.0	0.0	0.4
2009	16.0	0.2	4.4	20.6	26.0	4.4	13.4	0.0	0.0	1.0	10.6	0.0	11.8	0.0	4.6
2010	7.4	16.0	30.6	1.2	0.0	18.6	22.6	29.8	18.6	36.2	0.6	7.6	0.2	0.0	0.4
2011	12.6	7.2	14.4	29.8	28.8	3.4	13.6	12.0	0.2	12.4	3.0	3.4	2.8	23.0	2.6
2012	9.2	23.2	30.2	19.4	0.0	7.0	14.2	22.8	17.8	17.6	22.4	10.2	17.6	0.2	6.0
2013	37.0	2.8	0.0	14.6	7.8	16.8	25.6	0.4	1.8	11.2	18.2	0.0	0.0	0.0	0.0

Table B.1: Weekly precipitation data (mm) at UBC from 1991-2013

Week	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1991	0.0	40.4	2.0	0.0	155.4	8.1	9.4	0.0	0.0	0.0	0.0	5.8	20.6	18.0	51.3
1992	0.0	11.9	0.0	1.8	1.5	0.0	27.9	9.7	30.0	2.5	0.5	22.6	102.6	41.7	64.8
1993	23.6	0.0	15.2	6.6	0.0	9.1	26.6	1.3	0.5	0.0	0.8	2.3	61.0	1.5	21.1
1994	0.0	0.0	0.3	0.0	0.0	1.5	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	12.9
1995	40.5	29.4	23.0	22.1	0.0	4.6	4.6	0.0	0.0	25.8	29.4	64.4	47.8	23.0	5.5
1996	1.8	0.0	0.0	0.3	2.0	8.6	6.6	3.3	0.3	9.9	8.4	23.1	22.9	19.8	8.1
1997	0.0	1.0	0.0	0.0	0.0	0.0	7.4	9.1	14.0	22.1	8.9	7.1	6.1	16.0	16.0
1998	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	10.9	3.6	16.8	0.5	5.6	6.1
1999	7.7	1.7	18.7	4.3	4.3	6.0	0.0	0.0	15.3	0.0	22.1	16.2	4.3	111.4	44.2
2000	45.1	0.0	0.0	2.6	0.0	3.4	12.8	0.0	0.9	38.3	1.7	17.0	76.5	32.3	9.4
2001	34.5	0.5	0.0	63.6	13.2	3.5	1.8	24.0	15.6	2.0	52.0	44.0	32.9	34.4	4.4
2002	7.6	0.2	0.0	0.1	0.0	2.1	15.2	7.8	0.0	17.1	0.6	1.2	1.0	0.4	54.2
2003	0.2	3.8	2.2	0.4	0.0	12.0	14.0	12.0	0.0	0.6	50.6	164.8	26.6	12.4	0.0
2004	0.0	20.6	0.0	19.4	22.8	4.8	24.0	76.8	5.8	0.4	49.2	21.2	26.4	20.0	106.8
2005	0.0	0.0	0.0	16.6	0.8	7.2	0.4	5.2	0.2	44.8	23.2	72.4	18.8	39.2	61.2
2006	4.2	0.0	6.6	0.0	0.0	0.4	3.6	18.2	29.4	0.2	3.4	42.8	12.0	13.6	103.2
2007	0.0	1.2	3.0	7.2	3.4	11.8	4.2	7.8	14.0	16.8	0.2	94.4	7.8	16.0	30.8
2008	22.4	2.2	0.0	43.8	31.2	0.4	0.2	5.2	15.8	34.8	4.2	37.4	6.6	28.4	47.2
2009	0.0	4.2	23.6	0.0	0.2	21.4	17.8	20.0	0.0	33.2	0.0	55.6	42.4	48.8	30.8
2010	0.0	14.6	1.8	0.0	0.0	45.8	41.2	34.2	43.4	0.8	30.2	3.4	23.6	35.8	20.0
2011	2.4	0.0	0.0	0.0	16.8	0.2	0.2	16.6	27.0	15.8	13.8	15.8	22.2	21.8	4.8
2012	8.4	0.2	0.4	0.0	1.4	0.4	4.0	0.4	0.6	0.6	0.2	54.2	29.4	35.8	75.0
2013	4.0	2.0	0.2	0.0	31.2	9.4	6.6	51.6	53.0	25.2	1.8	0.8	1.4	57.2	19.4

Table B.1: Weekly precipitation data (mm) at UBC from 1991-2013

Week	46	47	48	49	50	51	52
1991	63.5	72.9	12.7	41.1	17.5	10.4	30.0
1992	7.4	58.2	32.5	4.8	39.9	28.4	26.2
1993	3.3	34.5	0.0	27.2	36.6	0.0	0.0
1994	40.5	53.4	22.1	74.5	20.2	60.7	108.6
1995	86.5	61.6	72.7	70.8	44.2	100.3	18.4
1996	17.8	5.3	27.9	25.9	14.7	13.2	2.8
1997	0.8	13.5	11.9	0.0	0.0	0.0	0.0
1998	34.5	21.1	20.8	26.7	108.8	26.4	63.8
1999	93.5	40.0	51.9	59.5	62.9	90.1	0.9
2000	6.0	1.7	40.0	40.0	0.9	17.0	26.4
2001	49.7	25.6	58.5	44.9	124.2	6.0	7.2
2002	39.0	63.6	0.6	1.0	65.2	12.4	35.2
2003	37.4	66.0	77.4	40.2	15.6	31.0	30.0
2004	15.8	24.2	53.4	51.2	52.0	25.4	43.4
2005	40.4	2.2	14.6	33.2	0.4	0.4	75.6
2006	106.2	73.8	41.0	26.2	15.2	62.4	60.4
2007	28.8	5.4	56.6	47.0	30.4	56.6	28.0
2008	28.0	14.6	47.4	20.0	51.2	9.2	32.4
2009	33.2	120.4	55.4	1.2	0.0	59.2	10.8
2010	24.4	50.4	27.8	35.4	78.0	18.0	48.4
2011	25.2	27.8	48.2	5.0	1.2	15.4	24.2
2012	24.6	32.0	47.8	43.8	34.0	56.6	61.0
2013	19.0	12.4	32.4	0.4	8.2	17.8	1.4

Once the data in Table B.1 was analyzed as described in Section 3.1.1, the 25th percentile of the precipitation data was used to calculate the potential rainwater collection volumes from the new UBC Farm Centre roof.

The capture area of the new farm centre roof was determined to be 2578.6 m^2. Assumed monthly rainwater collection efficiencies from sloped roofs are shown in Table B.2 (Regional District of Nanaimo, 2012).

Table B.2: Assumed monthly rainwater collection efficiencies

Month	Assumed collection efficiency (%)
Jan	85%
Feb	85%
Mar	85%
Apr	50%
May	65%
Jun	75%
Jul	65%
Aug	65%
Sep	75%
Oct	75%
Nov	85%
Dec	85%
Total	**0.75**

The following calculation was completed to determine the gallons of rainwater could potentially be captured that week.

$$precipitation\ (mm) \times \frac{catchment\ area\ (m^2)}{1000\ (\frac{mm}{m})} \times \frac{264.172\ gal}{m^3} \times collection\ efficiency\ (\%)$$

Appendix C - greywater treatment system cost

A capital cost estimate breakdown for the greywater treatment system described in Section 3.1.9 can be seen in Table C.1.

Table C.1: Capital cost estimate breakdown for a greywater treatment and distribution system

Line Item	Number of units	Cost
Engineering design	1	$ 7,000.00
Permitting	1	$ 500.00
Lamella clarifier	1	$ 13,260.00
Storage tank	1	$ 3,519.73
Pressure filtration	1	$ 15,000.00
Pumps	2	$ 10,000.00
Piping	1	$ 4,000.00
Construction		$ 20,000.00
Subtotal		$ 73,279.73
20% contingency		$ 14,655.95
PST		$ 6,155.50
Total		$ 94,091.17

Based on the current price that the UBC Farm pays for irrigation water, it would take years to recoup the cost of installing the above greywater treatment and distribution system. Payback periods were calculated by assuming that the full capital cost of the system would be paid in the first year of system operation. It was assumed that the total 5000 gallons of greywater collected would be used each week, corresponding to a water savings of $709 a year, as described in 3.1.9. Given a relatively inexpensive maintenance costs of $200 per year, this means that each year $509 are recouped against the initial capital cost of the

system. The cumulative net cash flow for the system can be seen in Table C.2, showing a payback period (positive cash flow) of 185 years.

Table C.2: Payback period for a greywater treatment and distribution system at the UBC Farm showing positive cash flow after 185 years, given a water price of \$0.897/ m³ for water during June through September, and \$0.7176/m³ during the off-season (October to May)

Year	Cash inflow - cash outflow	Cumulative net cash flow
1	-\$ 93,382.18	-\$ 93,382.18
2	\$ 508.99	-\$ 92,873.20
3	\$ 508.99	-\$ 92,364.21
4	\$ 508.99	-\$ 91,855.22
5	\$ 508.99	-\$ 91,346.23
6	\$ 508.99	-\$ 90,837.24
7	\$ 508.99	-\$ 90,328.25
8	\$ 508.99	-\$ 89,819.26
9	\$ 508.99	-\$ 89,310.27
10	\$ 508.99	-\$ 88,801.29
...	...	...
181	\$ 508.99	-\$ 1,764.20
182	\$ 508.99	-\$ 1,255.21
183	\$ 508.99	-\$ 746.22
184	\$ 508.99	-\$ 237.23
185	\$ 508.99	\$ 271.75

Using current water prices for agriculture in other countries, the same greywater system would have a different payback period. Payback periods for the system in California and Australia can be seen in Table C.3 and Table C.4.

Table C.3: Payback period for a greywater treatment and distribution system in California showing positive cash flow after 58 years, given a water price of $1.859/m³

Year	Cash inflow - cash outflow		Cumulative net cash flow	
1	-$	92,254.48	-$	92,254.48
2	$	1,636.69	-$	90,617.79
3	$	1,636.69	-$	88,981.10
4	$	1,636.69	-$	87,344.41
5	$	1,636.69	-$	85,707.71
6	$	1,636.69	-$	84,071.02
7	$	1,636.69	-$	82,434.33
8	$	1,636.69	-$	80,797.64
9	$	1,636.69	-$	79,160.95
10	$	1,636.69	-$	77,524.25
...		...		...
54	$	1,636.69	-$	5,509.81
55	$	1,636.69	-$	3,873.11
56	$	1,636.69	-$	2,236.42
57	$	1,636.69	-$	599.73
58	$	1,636.69	$	1,036.96

Table C.4: Payback period for a greywater treatment and distribution system in Australia showing positive cash flow after 2 years, given a water price of $73.5/m³

Year	Cash inflow - cash outflow		Cumulative net cash flow	
1	-$	21,473.17	-$	21,473.17
2	$	72,418.00	$	50,944.83

For the UBC Farm to have a reasonable payback period of 10 years for the greywater system, the price of water would need to be approximately $10/m³. This payback period calculation can be seen in Table C.5.

Table C.5: Payback period for a greywater treatment and distribution system at the UBC Farm showing positive cash flow after 10 years, given a water price of $10/m³

Year	Cash inflow - cash outflow		Cumulative net cash flow	
1	-$	84,211.17	-$	84,211.17
2	$	9,680.00	-$	74,531.17
3	$	9,680.00	-$	64,851.17
4	$	9,680.00	-$	55,171.17
5	$	9,680.00	-$	45,491.17
6	$	9,680.00	-$	35,811.17
7	$	9,680.00	-$	26,131.17
8	$	9,680.00	-$	16,451.17
9	$	9,680.00	-$	6,771.17
10	$	9,680.00	$	2,908.83

Appendix D - questionnaire responses

The following tables show the number of respondents answering each questionnaire question in section 3.2.

Table D.1: Number of responses to question about the ways that the farm generates money and attracts customers

Response	Number of Respondents
Other	3
Seasonal events	10
Camping/Farm holidays	2
Wedding venue	6
Petting zoo	4
U-Pick	7
Farm tours	7
Café/restaurant	6
Farm store	11
Farmgate sales	12
Farmers market	4

Table D.2: Number of responses to question about whether a goal of the farm is to attract more people

Response	Number of Respondents
Yes	13
No	2
Not sure	1

Table D.3: Number of responses to question about challenges faced on the farm

Response	Number of Respondents
Cost of running the farm	15
Maintaining health of livestock/animals	11
Attracting customers	15
Poor soil quality	14
Lack of potable water resources	14
Treatment/storage of waste products	14

Table D.4: Number of responses to question about source of potable water for irrigation, other outdoor uses, and indoor uses

Response	Number of Respondents (Irrigation)	Number of Respondents (Other outdoor)	Number of Respondents (Indoor)
Municipal water supply	4	6	7
A well	7	7	8
A creek, lake or river	1	2	1
Other	3	0	0

Table D.5: Number of responses to question about concerns regarding enough freshwater now and 5 years from now

Response	Number of Respondents (Now)	Number of Respondents (5 years from now)
Very concerned	0	1
Fairly concerned	0	0
Moderately concerned	0	3
Slightly concerned	6	5
Not at all concerned	10	6

Table D.6: Number of responses to question about how wastewater is dealt with on the farm

Response	Number of Respondents
Municipal sewer	1
Septic tank	15
Lagoon	1
Composting toilet	1
Portable toilets	1

Table D.7: Number of responses to question about whether there is current water reuse, or whether water reuse has been considered

Response	Number of Respondents (Current reuse)	Number of Respondents (Considered reuse)
Yes	4	7
No	12	4
Not sure	0	1

Table D.8: Number of responses to question about obstacles facing greywater reuse

Response	Number of Respondents (Big obstacle)	Number of Respondents (Somewhat of an obstacle)	Number of Respondents (Not an obstacle)
Cost of installation	10	3	2
System reliability	5	6	3
Compliance with regulations	6	4	3
Public/customer perception	3	8	4
Concerns about safety	5	2	8
Collecting sufficient water	3	4	8
Having a use for the treated greywater	3	3	9
Other	2	0	1

Table D.9: Number of responses to question about potential uses for greywater

Response	Number of Respondents
Irrigation of food crops	6
Irrigation of fodder crops or pasture	7
Flower garden or lawn irrigation	11
Orchard or vineyard irrigation	1
Equipment washing	6
Toilet flushing	8
Other	1

Table D.10: Number of responses to question about whether farmers thought their customers would purchase produce grown with recycled water and treated wastewater

Response	Number of Respondents (Recycled water)	Number of Respondents (Treated wastewater)
Yes	6	1
No	2	8
Not sure	8	7

Table D.11: Number of responses to question about whether putting greywater reuse into the public's eye would help or hurt the farmer's business

Response	Number of Respondents
Help	9
Hurt	3
Both and/or neither	2