THESIS

IMPLEMENTATION OF GRAYWATER REUSE IN THE STATE OF COLORADO

Submitted by

Jillian Vandegrift

Department of Civil and Environmental Engineering

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Master's Committee:

Advisor: Sybil Sharvelle

Scott Glick
Neil Grigg

ABSTRACT

IMPLEMENTATION OF GRAYWATER REUSE IN THE STATE OF COLORADO

The United States is expected to see large population growth in the coming years. The southwest region of the country will see dramatic effects due to a higher demand for water paired with concerns associated with climate change resulting in less runoff, increased temperatures and evapotranspiration, and decreased precipitation (Barnett et al. 2007). Water conserving methods such as low-flow fixtures and appliances are believed to be approaching their maximum water saving potential and new techniques are needed in order to protect the world's most valuable resource. Graywater reuse is a strategy gaining popularity because it is a low-strength wastewater that is easier and less expensive to treat than domestic wastewater (Winward et al 2008). Graywater, or water discharged from showers, bathtubs, laundry machines, and laundry and bathroom faucets, constitutes approximately 44% of total indoor water use at the household level (REUWS, 2012). The reuse of graywater for toilet flushing and irrigation has been well studied at the household level, however little research has been done regarding water reuse at commercial facilities.

Through a series of feasibility studies, water use at several business types was investigated in order to identify facilities that could benefit from simple water reuse methods. Conclusions from these studies show that research labs, hotels, and gyms have the potential to reduce their demand on municipal water by up to 21%. Overall, businesses that have balanced water use tendencies between graywater demand and graywater supply resulted in the largest estimated potential water savings. In contrast, businesses such as office buildings do not

typically generate large amounts of graywater and therefore are not often ideal candidates for graywater reuse, unless there is on-site laundry effluent available for reuse.

Water conservation also has its downfalls in terms of implementation. In the western region of the United States, water allocations and water rights are a serious consideration for municipalities. The City of Fort Collins Utilities was interested in investigating the potential impacts to return flows associated with graywater reuse. Adoption of graywater reuse in existing, and new and redevelopment populations in Fort Collins was estimated to be between 5-10%, and 80-100%, respectively. Results of the impact to return flows study show the City of Fort Collins could see a maximum reduction in return flows of 5.5% in realistic adoption rate scenarios. In hypothetical adoption rate scenarios, calculations were made in order to capture the effects of 100% adoption in existing, new and redevelopment areas of Fort Collins. Though this adoption rate is highly improbable, it illustrates the potential impacts that newer developing cities may see if graywater reuse is integrated as part of the infrastructure planning process. 100% adoption of graywater reuse resulted in an estimated 21% reduction from base flows to the wastewater treatment plant.

Additionally, implementation of graywater reuse will be dependent upon city/county local ordinances when Regulation 86 is finalized in the future. In order to assist the development of a city ordinance for Fort Collins, as well as promote graywater reuse, a series of Best Management Practices documents and graywater factsheets were created with educational intentions. Recommendations for design criteria and permit requirements were provided in another series of documents attached in the appendices of this report.

Operational experience was beneficial in terms of making the appropriate design criteria recommendations for graywater legislation. The graywater reuse system for toilet flushing at

Aspen Residence Hall on Colorado State University's campus provided several valuable operational experiences when it underwent the first actual implementation period in the spring of 2014. The first operational period was generally successful aside from a few instances of unexpected malfunctions and equipment failures resulting in foul odors in student's toilets. Automatic chlorine residual monitoring was utilized in order to protect public health, and chlorine residuals were present during unexpected occurrences. Student survey results show mixed feelings towards the graywater reuse system, however most negativity was attributed to the isolated malfunction incidents and not normal operation periods. The fall of 2014 will serve as another pilot-phase period in which necessary system improvements will be made prior to start-up, and more frequent monitoring of chlorine residuals in student's toilet will occur in order to better gauge the functionality of the system.

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IPC: International Plumbing Code
UPC: Uniform Plumbing Code
GPD: Gallons per day
Gpcd: Gallons per capita daily
GPF: Gallons per flush
EPA: Environmental Protection Agency
BOD: Biochemical Oxygen Demand
COD: Chemical Oxygen Demand
SOP: Standard Operating Procedure
WHO: World Health Organization
QMRA: Quantitative Microbial Risk Assessment
DALY: Disability adjusted life-years
MLE: Modified Ludzack-Ettinger

1.0 INTRODUCTION

1.1 Background and Motivation

Alternatives for water conservation are in high demand due to a dwindling freshwater supply and growing populations in the United States. Climate change is affecting the freshwater supply by causing less runoff due to increasing temperatures and evapotranspiration, and decreasing precipitation (Barnett et al. 2007). The water supply shortage is especially prevalent in the southwestern region of the United States, where a high demand for water and a multiyear drought (1999-2007), along with climate change, are resulting in serious concerns regarding the sustainability of freshwater reserves in the long-term (McCabe et al. 2007). The Colorado River is a main source of water and hydropower delivered to a large population of the southwestern United States. The two main reservoirs in the Colorado River Basin, Lake Powell and Lake Mead, account for 85% of the storage capacity of the entire basin, and experts predict a 50% chance of these reservoirs running dry by 2021 if water use and allocations remain unchanged (Barnett et al. 2007). Scenarios such as these pose alarming threats to society, and many states have turned to conservation methods in hopes of preserving the world's most valuable resource. At present, greater than 80% of the State of California is experiencing severe drought conditions. The major reservoirs in the state collectively have 59% of the historical average levels. Current long-term forecast predictions do not show high likelihood of a wet weather pattern in the coming months (Wells, 2014).

Low-flow water use fixtures are promoted through efforts such as the U.S. Environmental Protection Agency's (EPA) WaterSense program which strives to provide consumers with easy and affordable ways to save water. Many states place irrigation restrictions during the hottest months of the year in order to limit unnecessary overwatering of crops and lawns. Additionally, water reuse strategies are becoming more popular as the realization of the water supply and. demand issue grows into a pertinent and timely concern.

In Big Spring, Texas, the ongoing drought has caused such a drastic shortage in water supply that they have turned to indirect potable reuse methods; essentially treating wastewater to drinking water quality and introducing it back into the drinking water supply. In May of 2013, the Colorado River Municipal Water District opened a $14 million advanced water treatment plant that accomplishes the termed "toilet to tap" technology in order to supplement Big Spring's drinking water supply (Wythe, 2013). The water at the plant undergoes the treatment train twice and adds three advanced processes to the method before mixing 5-20% of the twice-treated water with surface water and sending it to the Big Spring drinking water treatment plant (Wythe, 2013). Technologies such as these are effective yet costly and complex, requiring a large amount of planning and funding to arrive at the finished product.

Graywater and reclaimed water reuse are also effective means of conserving freshwater. Graywater is defined as "untreated wastewater excluding toilet – and in most cases - dishwasher and kitchen sink wastewaters." (Sheikh, 2010). Wastewater from the toilet, dishwasher, and kitchen sink is termed "blackwater" (Sheikh, 2010). Graywater has lower quantities of pathogens (Elmitwalli and Otterpohl, 2007) and organics (Pidou et al. 2007) than blackwater due to the absence of toilet discharge and food particles from the dishwasher and kitchen sink, however, still requires adequate treatment such as disinfection to protect public health. Graywater can be used for indoor toilet and urinal flushing as well as outdoor irrigation given that it is distributed in subsurface drip lines rather than used with spray irrigation fixtures. Graywater constitutes approximately 44% of total indoor water use at the household level and toilet water accounts for 25% of total indoor water use (REUWS, 2012). Reusing graywater for indoor toilet flushing can reduce potable water demand by up to 25%. Irrigation demand historically averages at approximately 100 gallons per capita daily (gpcd) (Mayer et al. 1999), but the average person does not generate enough graywater to meet the entire irrigation demand so supply is typically supplemented with freshwater unless the yard is xeriscaped. Utilizing the entire stream of household graywater for irrigation can reduce potable water use by up to 44% during the growing season (REUWS, 2012).

In May of 2013, Governor Hickenlooper legalized the use of graywater in the State of Colorado by signing HB13-1044. In order to see the largest benefits from the reuse of graywater, it is necessary to study and understand the most effective treatment methods for both small and large-scale systems, the most practical and feasible applications of graywater reuse, the entities that can potentially see the largest amount of water saved, and the impacts that graywater reuse will impose on current water use allocations and water rights.

1.2 Research Objective

This research project aims to investigate graywater reuse as an approach to water conservation through the exploration of hypothetical systems at commercial facilities and operational experiences at a residence hall. Given the current status of graywater reuse legislation in the State of Colorado, this research aims to assist in the development of a city ordinance by providing informative material and defining regulatory criteria and possible barriers to implementation The tasks of the research project are listed in bulleted format:

- Complete a series of feasibility studies regarding graywater/reclaimed water reuse at local Fort Collins businesses by utilizing collected water use data to estimate potential water savings at each business (Chapter 3).

- Predict the impact to return flows associated with graywater reuse for both the current and future projected populations of the City of Fort Collins service area under varying graywater reuse adoption scenarios (Chapter 4).
- Formulate graywater factsheets and best management practices documents, and make recommendations regarding what a city ordinance for graywater reuse should include to the City of Fort Collins (Chapter 5).
- Continue progress on the pilot graywater reuse system for toilet flushing in Aspen Hall at Colorado State University, including performing the necessary system updates and executing and monitoring the first actual implementation period in which students were actively flushing residence hall toilets with treated graywater (Chapter 6).

2.0 BACKGROUND AND LITERATURE REVIEW

The 2014 National Climate Assessment predicts substantially hotter, more frequent, intense, and longer lasting droughts for major river basins such as the Colorado River basin, presenting difficult obstacles for managing water resources in the southwestern region of the United States (Garfin et al. 2014). Rising temperatures and changes to precipitation patterns and snowpack will have drastic effects on the southwestern region's growing population of 56 million people, expected to increase to 94 million by the year 2050 (Hoerling et al. 2013). Figure 2.1 shows the decrease in snowpack water equivalent in the southwestern region of the United States from 1971-2099.

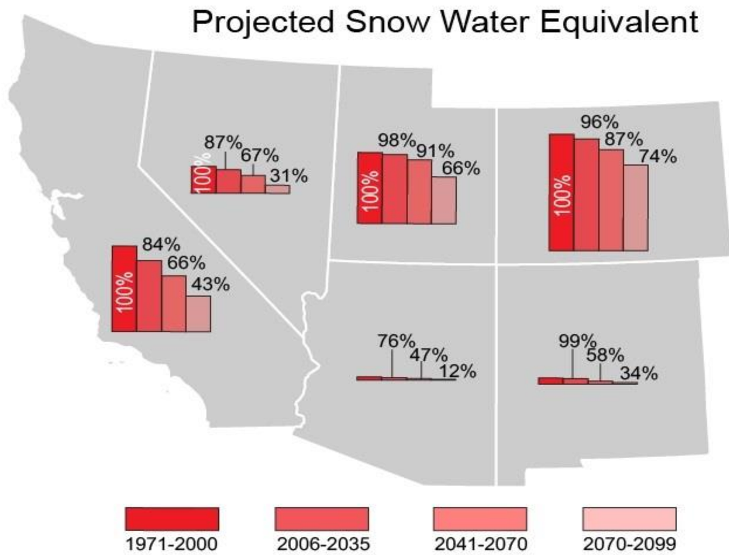


Figure 2.1 Snowpack Water Equivalent Extracted from Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment (Hoerling et al. 2013)

Daunting population and precipitation predictions for the future along with aging water and wastewater infrastructure result in the need for water reuse technologies which are economically feasible and relatively easy to install, operate, and maintain. Low-flow water use fixtures and appliances have resulted in a declining water use trend in North America over the past 20 years (Coomes et al. 2010), however this trend is believed to be reaching its asymptotic limit due to low-flow devices approaching their maximum amount of water saving potential (Hodgson, 2012). Graywater and reclaimed water reuse are effective alternatives to large, complex, and costly projects by relying on a decreased freshwater demand rather than an increased freshwater supply. This chapter will provide an overview of graywater quantity and quality, typical treatment processes, as well as a brief summary of current graywater regulations across the United States. Additionally, this chapter will explore current graywater/reclaimed water reuse installations in various locations around the U.S.

2.1 Graywater Quantity

Graywater is considered to be effluent water from laundry, showers, and bathroom sinks, but excluding toilet wastewater (Bergdolt et al. 2011). Most definitions also exclude kitchen wastewaters from the dishwasher and kitchen sink; however there are some studies and state regulations that differentiate "light" and "dark" (including kitchen discharges) graywater from one another (Li et al. 2008, Travis et al. 2008, Yu et al. 2013, Washington State Dep. Of Health). Graywater generation rates are usually predictable, however vary slightly between person to person because grooming tendencies are specific to the individual (Eriksson et al. 2002). Historically, graywater has comprised approximately 50% of residential wastewater (Mayer, 1999), however, due to the popularity of low-flow water use fixtures and appliances, now comprises approximately 44% of indoor water use (REUWSU Fort Collins, 2012). Figure 2.2 shows the most recent Residential End Use Water Study Update data specifically pertaining to the City of Fort Collins. Of note is that variability in indoor water use for cities across North America is low, and is much higher for outdoor water use (Heaney et al. 2006).

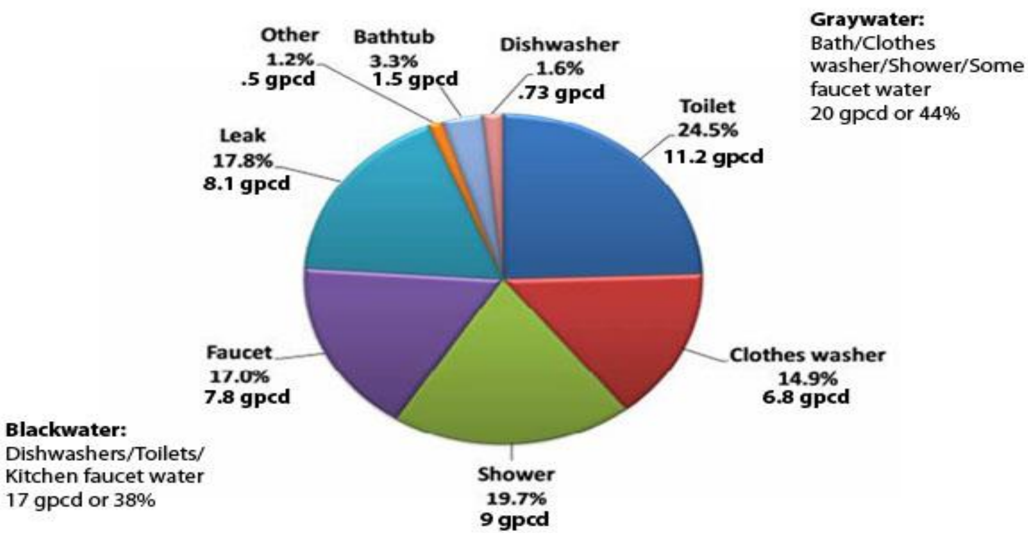


Figure 2.2 Average Indoor Residential Water Use for the City of Fort Collins (REUWSU Fort Collins, 2012)

2.2 Graywater Quality

Graywater is characterized as a low-strength wastewater due to the absence of toilet effluent and dishwasher/kitchen sink discharges, however still contains the presence of organics from food particles and pathogens measured in the form of indicator organisms from fecal matter (Winward et al. 2008). Graywater quality, just as the quantity, is variable from location to location depending upon the sources, personal hygiene habits, and season (Eriksson et al. 2002). Pathogenic presence in graywater is due to human contact and a function of human health and behavior (Wiles, 2013), and therefore requires disinfection as a means of pathogen inactivation during the treatment process. Counts of total and fecal coliforms increased from 10^0-10^5 / 100 mL to greater than 10^5/ 100 mL within 48 hours of graywater storage time in past studies, indicating the need to address advanced treatment when reusing graywater (Dixon et al. 2000). The microbial bacteria commonly of concern due to the associated public health risks include: *Escherichia coli*, *Salmonella*, *Shigella*; protozoan such as *Giardia* and *Cryptosporidium*; viruses such as enteroviruses, hepatitis A, rotavirus, and Norwalk virus (Roesner et al. 2006). The chemical parameters of graywater commonly of interest are biochemical oxygen demand (BOD), chemical oxygen demand (COD), and the nutrients nitrogen (N) and phosphorous (P) (Sharvelle et al. 2013). Finally, the physical parameters commonly of interest in graywater include temperature, color, turbidity, and suspended solids (Sharvelle et al. 2013). Table 2.1 summarizes the typical characteristics of graywater according to various published literature articles.

Table 2.1 Typical Characteristics of Graywater (Compiled from Eriksson et al. 2002, Friedler 2004, Gross et al. 2007, Christova-Boal et al. 1996, Tchobanoglous et al. 2003, Metcalf and Eddy, 2003.)

Typical Graywater Characteristics						
Parameter	**Units**	**Source**				
		Eriksson et al. 2002	Friedler, 2004	Gross et al. 2007	Christova-Boal et al. 1996	Tchobanoglous et al. 2003, Metcalf and Eddy 2003
		Residential Laundry and Bathroom Graywater	Residential Laundry and Bathroom Graywater	Residential Laundry and Bathroom Graywater	Residential Laundry and Bathroom Graywater	Untreated Domestic Wastewater
COD	mg/L	100-725	230-1340	702-984	--	250-800
BOD	mg/L	76-380	173-462	280-688	48-290	110-400
Turbidity	NTU	28-1340	--	--	50-240	--
Total Suspended Solids	mg/L	54-280	78-303	85-285	48-250	120-400
Total Nitrogen	mg/L	5-21	--	25-45.2	1-40	20-85
Total Phosphorous	mg/L	0.1-2	--	17.2-27	.062-42	4-15
Total Coliform	CFU/100 mL	$56\text{-}2.4 \times 10^{7}$	--	--	$500\text{-}2.4 \times 10^{7}$	$10^{6}\text{-}10^{9}$
E.Coli	CFU/100 mL	$100\text{-}2.82 \times 10^{7}$	--	--	--	--

2.2.1 Graywater Treatment Processes

There has been a significant amount of research done regarding the type and extent of treatment required for the reuse of graywater. Often times, the extent of treatment required is determined by local laws and regulations and can vary from state to state and even city to city. There is no uniform international or national regulation for water quality of graywater intended for reuse (Li et al. 2009; Sharvelle et al. 2013). For graywater applications that require secondary treatment due to the likelihood of human contact, there are multiple treatment technologies available. Treatment can be based on biological processes (membrane bioreactors, rotating biological contractors, and constructed wetlands), or chemical/physical processes such as a simple combination of filtration and disinfection (Wiles, 2013). The treatment works will also differ depending on the scale and size of the graywater system (small-scale vs. commercial or multi-residential). Due to high amounts of organics in graywater considered medium to high-strength, biological treatment is sometimes preferred because the processes are capable of achieving 10 mg/L BOD concentrations in treated graywater (Winward et al. 2008).

In a study done by Maimon et al. 2014, the parameters primarily effecting graywater quality were determined through a quantitative microbial risk assessment (QMRA) using microbial quality measured in household graywater samples in combination with exposure scenarios outlined by surveys and literature data. The study concluded that three main factors had the most effect on graywater quality: type of treatment, skills of system designer, and the inclusion/exclusion of kitchen water in graywater storage. In treatment systems that were professionally designed and installed, the average *E. coli* counts were within acceptable risk levels according to WHO (World Health Organization) guidelines (WHO, 2008) under all exposure scenarios, even without disinfection. In poorly designed and/or inadequately installed systems, *E.coli* counts resulted in calculated risks exceeding the acceptable risk of 10^{-6} DALY (disability-adjusted life years) person^{-1}·year^{-1} as regulated by the WHO guidelines (Maimon et al. 2014). Therefore, recommendations for treatment processes include both physical treatment and disinfection when there is potential for human contact with graywater, and exclusion of kitchen wastewaters from graywater reuse systems. Additionally, there is little consistency amongst graywater regulations in the U.S. concerning microbiological standards. For example, the State of Utah requires the weekly median *E. coli* concentration measurements to be non-detectable (Sharvelle et al. 2013). On the other hand, states such as Massachusetts and Texas require fecal coliforms to be less than 14 and 20 CFU/ 100 mL in graywater being reused for toilet flushing, respectively (Sharvelle et al. 2013).

Overall, the goal of treatment is to reduce the suspended solids, organic content, and the microorganism concentrations present in the raw graywater (Li et al. 2009). However, the different treatment systems for graywater are variable and range from simple systems to complex systems (Sharvelle et al. 2013). Simple systems typically utilize storage and filtration whereas the more complex treatment works utilize physical and/or biological processes to remove organic carbon, paired with disinfection (Sharvelle et al. 2013). The most complex systems produce the highest quality water, however it is important to also consider the reliability of the system and the maintenance requirements (Sharvelle et al. 2013). Where graywater reuse systems are intended to be used for restricted access outdoor irrigation, the treatment processes do not have to be as advanced because human contact is not likely. Disinfection is likely not required in these situations (Sharvelle et al. 2013).

2.3 Graywater Reuse Regulations

One of the biggest obstacles concerning graywater reuse in the United States is that each jurisdiction is in charge of developing their own set of graywater regulations that fit within a statewide framework (WHO, 2006). As a result, there are differences between permitting requirements, water quality requirements, and allowable uses from jurisdiction to jurisdiction (Yu et al. 2013). Furthermore, some states have different requirements specific to the end-use application whether it be indoor toilet flushing or outdoor subsurface irrigation. Figure 2.3 below shows a map of the United States categorized by type of graywater/wastewater regulations.

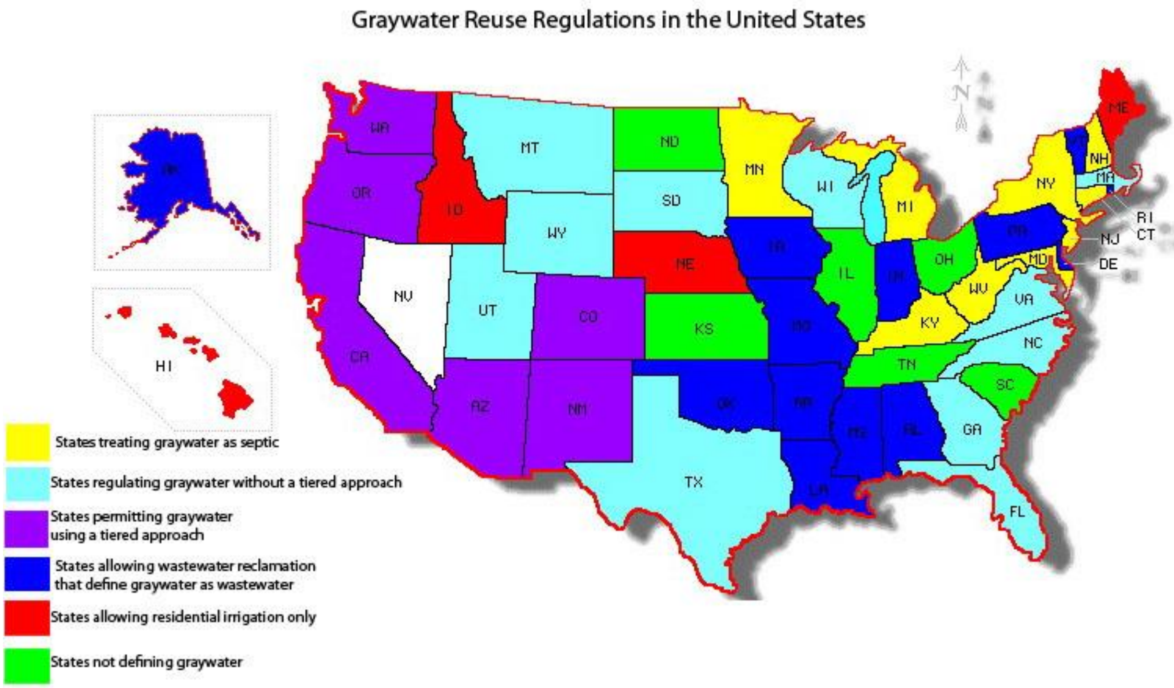


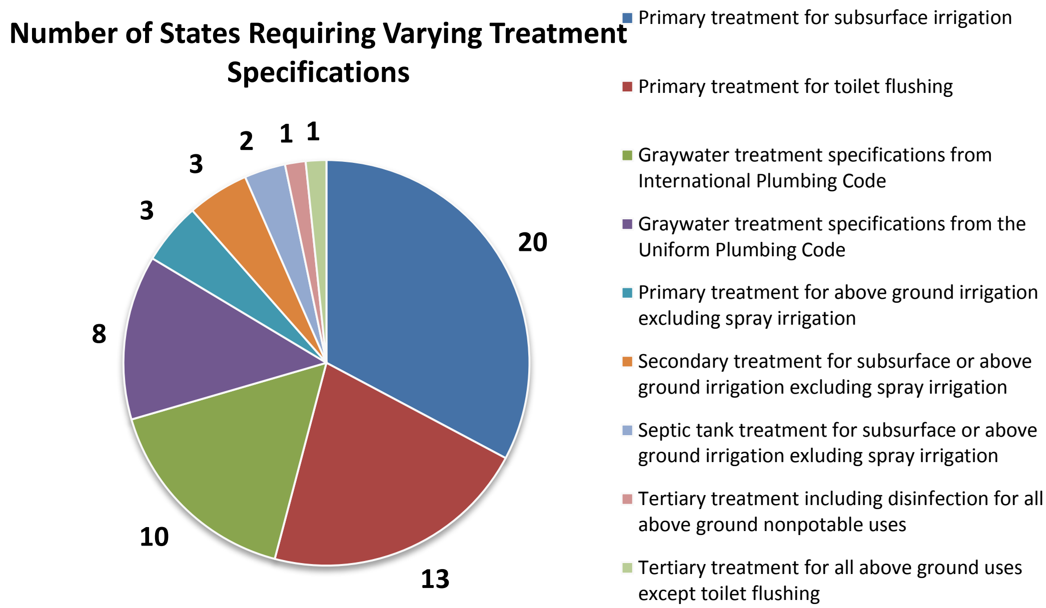
Figure 2.3 Graywater Reuse Regulations in the United States (Adapted from Table 4.1 State Analysis of Graywater/Wastewater Regulations, Sharvelle et al. 2013)

Yu et al. 2013 suggests that the inconsistency in graywater regulations from state to state could be attributed to the lack of consistency when defining graywater. Conflicting definitions can often lead to a strained legal process. For example, five out of the 41 states that have a regulatory definition of graywater define graywater only in their plumbing code, whereas 14 define graywater only in other state regulations (Yu et al. 2013).Other barriers regarding graywater reuse include the lack of data on the appropriate quality for toilet flushing, and the lack of national guidance and support for forming consistent graywater guidelines (Sharvelle et al. 2013). Additionally, there are two widely adopted plumbing codes exist in the U.S: International Plumbing Code (IPC), and Uniform Plumbing Code (UPC). These plumbing codes specify the extent of treatment and also differ in requirements present in the code, creating yet another obstacle for lessening the confusion associated with graywater reuse (Yu et al. 2013). Table 2.2 shows the differences in treatment specifications between the two widely adopted plumbing codes, and Figure 2.4 shows the vast discrepancy in graywater reuse regulations pertaining to treatment processes and end use applications across the United States. In Figure 2.4, primary treatment refers to gravitational settling of suspended solids achieved in storage tanks, whereas secondary treatment refers to biochemical oxygen demand (BOD) removal (Yu et al. 2013). Additionally, Table 2.3 summarizes the graywater regulation approach taken by the states that currently allow graywater reuse in the United States.

Table 2.2 Treatment Requirements Specified by End Use Application between IPC and UPC (Adapted from Figure 8, Yu et al. 2013)

Code	Pre-Storage Filter	Storage Tanks	Potable Water Makeup	Media Filters	Disinfection	Dye	Allowable Applications
Uniform Plumbing Code		√		√			Subsurface Irrigation/Subsurface Disposal
International Plumbing Code	√	√					Subsurface Irrigation/Subsurface Disposal
International Plumbing Code	√	√	√		√	√	Toilet/Urinal Flushing

Table 2.3 Summary of Graywater Regulations in the United States (Adapted from Sharvelle et al. 2013)



States that Allow Graywater Reuse	End Uses Allowed	Water Quality Requirements	Tiered or Non-Tiered Approach
Arizona	Irrigation &Toilet Flushing	None for Tier 1-2 Site Specific for Tier 3 Irrigation Use	Tiered: 3 Tiers
California	Irrigation &Toilet Flushing	None for Tier 1-2, Site Specific for Tier 3 Toilet Flushing	Tiered: 3 Tiers
Colorado*	Irrigation &Toilet Flushing	Yes	Category A-E
New Mexico	Irrigation &Toilet Flushing	None for Tier 1, Yes for Tier 2 Irrigation and Toilet Flushing	Tiered: 2 Tiers
Oregon	Irrigation &Toilet Flushing	Tier 1-3 Irrigation requirements, None for Tier 1-2 Toilet Flushing, Yes Tier 3 Toilet Flushing	Tiered: 3 Tiers
Washington	Irrigation &Toilet Flushing	None for Tier 1-2, Yes for Tier 3 Irrigation	Tiered: 3 Tiers
Florida	Irrigation &Toilet Flushing	Yes	Non-tiered, not based on scale
Georgia	Irrigation &Toilet Flushing	Yes	Non-tiered, not based on scale

Massachusetts	Irrigation &Toilet Flushing	Yes	Non-tiered, not based on scale
Montana	Irrigation &Toilet Flushing	No	Non-tiered, not based on scale
North Carolina	Irrigation &Toilet Flushing	Irrigation: No Toilet Flushing: Yes	Non-tiered, not based on scale
South Dakota	Irrigation &Toilet Flushing	No	Non-tiered, not based on scale
Texas	Irrigation &Toilet Flushing	Yes	Non-tiered, not based on scale
Utah	Irrigation &Toilet Flushing	Yes	Non-tiered, not based on scale
Virginia	Irrigation &Toilet Flushing	Yes	Non-tiered, not based on scale
Wisconsin	Irrigation &Toilet Flushing	Yes	Non-tiered, not based on scale
Wyoming	Irrigation &Toilet Flushing	No	Non-tiered, not based on scale
Hawaii	Irrigation	No	Non-tiered, Residential Subsurface Irrigation Only
Idaho	Irrigation	No	Non-tiered, Residential Subsurface Irrigation Only
Maine	Irrigation	No	Non-tiered, Residential Subsurface Irrigation Only
Nevada	Irrigation	No	Non-tiered, Residential Subsurface Irrigation Only

2.4 Water Reuse in the United States

2.4.1 Current Large Scale On-site Water Reuse Installations

A number of successful on-site water reuse installations are not necessarily utilizing only graywater. In fact, some on-site reuse systems can treat "blackwater" to tertiary standards and use the fully reclaimed water for indoor toilet flushing or irrigation.

Living Machine, San Francisco Public Utilities Commission

San Francisco, California, has been at the forefront of developing and incentivizing water reuse in the past several years. In 2012, The Non-potable Water Program was established through the adoption of an ordinance in the City of San Francisco. The Non-potable Water Program strives to promote the use on-site alternate water sources for non-potable applications. The Non-Potable Water Program website (http://www.sfwater.org/index.aspx?page=686) includes access to the specific article developed for the City of San Francisco Health Code regulating alternate water sources for on-site reuse, and also includes educational materials in the form of guidebooks, interactive water calculators, and informational case study factsheets. San Francisco Public Utilities Commission (SFPUC) has recently integrated an on-site Living Machine® system into the newly constructed administration offices building. The Living Machine® technology accepts all wastewater from the facility after being collected and passed through primary treatment. The Living Machine® accelerates treatment by passing the wastewater through constructed tidal wetlands in the lobby and outdoor landscaping areas of the building – requiring only 1,000 square feet of green space to process approximately 5,000 gallons of wastewater every day (Living Machine, 2012). Controlled by a computer, the system fills and drains the constructed wetlands with wastewater and alternates between anoxic and aerobic conditions providing the "tidal" patterns to the technology. The media within the Living Machine® basins allows for the growth of biofilm on the surface of gravel beads – the microorganisms then consume nutrients present in the wastewater (Living Machine, 2012). Upon exiting the Living Machine®, water is then passed through two sets of filtration devices and disinfected using both ultraviolet radiation and chlorine (for residual) before being used for indoor toilet flushing and outdoor irrigation. SFPUC estimates that this system will save up to 750,000 gallons of potable water annually (Living Machine, 2012). Figure 2.5 shows a schematic and photograph of the Living Machine® system installed at the SFPUC administration offices.

Figure 2.5 Photograph of Living Machine® Constructed Tidal Wetlands (left), Schematic of Living Machine® Technology (right) (Living Machine, 2012).

US Army Base, Fort Carson, Colorado Springs, Colorado

The U.S. Army's Fort Carson located near Colorado Springs, Colorado, is a 373,000 acre base with 9 million square feet of facility space and 4 million square feet of private family housing occupied by approximately 20,000 civilians and military personnel (NREL, 2009). Fort Carson has a large on-site wastewater treatment plant and for more than 30 years has used effluent from the wastewater treatment plant to irrigate the 180 acre turf at the Fort Carson golf course (NREL, 2009). Effluent from the wastewater treatment plant is distributed to a holding pond via six miles of pipeline before being used for irrigation. The facility also has a carwash reuse system utilizing a closed-loop treatment process to recycle the carwash water used to clean large military vehicles. The carwash discharge is sent through a grit and oil separation basin, sand filters, and extended aeration treatment system as part of the closed-loop recycled water process (NREL, 2009). Fort Carson saves approximately 300 million gallons of potable water per year; 100 million gallons used for turf irrigation, 200 million gallons for the carwash facility, and an additional 3 million gallons used for wastewater processes at the wastewater treatment plant. Cost savings from these three conservation systems reach approximately $682,000 annually (NREL, 2009). Figure 2.6 shows the carwash reuse system in operation at the Fort Carson Army base.

Figure 2.6 Fort Carson Army Base Closed-Loop Carwash Water Recycling Process (NREL, 2009).

Gillette Stadium, Foxborough, Massachusetts

Gillette Stadium, located in Foxborough, Massachusetts, is another facility operating an on-site wastewater treatment plant and water reuse system. Gillette Stadium is home to the New England Patriots NFL team and therefore has drastic population variances depending on the game schedule. When the stadium is full, it serves more than 75,000 people. Construction on this 1.3 MGD facility started in 1999, finished in 2000, and has been in operation since (WERF, 2010). Due to zoning restrictions and community arguments against an expanded centralized wastewater system, the developers of Gillette Stadium turned to water reuse to overcome the lack of regional infrastructure and the lack of a sufficient water supply (WERF, 2010). Effluent water from the on-site treatment plant is used for toilet flushing and when in excess, is recharged to the groundwater system using subsurface infiltration chambers (WERF, 2010). In this on-site treatment system, all wastewater from the stadium and surrounding commercial development area flows through a gravity collection system and is pumped to the on-site treatment plant. The treatment works consists of a Modified Ludzack-Ettinger (MLE) membrane bioreactor utilizing continuous flow, suspended growth, anoxic-aerobic processes followed by ultrafiltration and ozone disinfection. The system has a 1 million gallon equalization tank to account for fluctuating flows during stadium events. Because of the nature of the facility and the variable strength of wastewater collected, extensive treatment utilizing the previously listed processes was chosen by the project designer-builder team, Applied Water Management, and is permitted through the Massachusetts Department of Environmental Protection under the State Pollution Discharge Elimination System. Water reuse standards for the State of Massachusetts were not developed until the project was already in operation (WERF, 2010). This innovative facility decreases potable water demands at Gillette Stadium by 75% (WERF, 2010). Figure 2.7 is a photo of the wastewater treatment plant at Gillette Stadium.

Figure 2.7 Gillette Stadium On-site Wastewater Treatment Plant (American Water, 2012)

2.4.2 Current On-site Graywater Reuse Installations

After reviewing the available literature it became apparent that there are only a few large-scale graywater reuse installations for indoor toilet flushing in the United States, but a much larger number internationally (Friedler et al. 2005, Nolde, 2000, Mourad et al. 2011). Graywater reuse for outdoor irrigation is more common than toilet flushing applications due to the less complex and less costly nature of the design, installation, and operation of irrigation reuse systems. There are a significant amount of single-residential applications of graywater irrigation, but there are not many large-scale applications, and there is not widespread adoption across the United States.

La Palma Correctional Facility

La Palma Correctional Facility in Eloy, Arizona, has a large-scale graywater reuse system used for toilet flushing. La Palma and two adjacent facilities collect shower water from approximately 6,500 inmates. The treatment works used for this system consists of filtration and disinfection with chlorine. The system is not designed to achieve removal or organic matter (e.g. BOD). Water use for toilet flushing in prisons (20 gallons per capita daily (gpcd)) is approximately 8 gpcd higher than the toilet flushing value reported in the Residential End Uses Water Study Update - Site Report for the City of Fort Collins published in 2012 (11.2 gpcd) . The increase in toilet water use in prisons is likely due to the frequent use of in-cell toilets for clothes washing, drink cooling, and trash and contraband disposal by La Palma inmates (Bush, 2009). Reusing graywater for toilet flushing therefore saves nearly 20 gallons of potable water per inmate per day, or a combined 48 million gallons of potable water annually (hEochaidh, 2009).Water quality monitoring requirements include weekly sampling for fecal coliforms in toilet water, with a non detect measurement required on single samples. Figure 2.8 shows the system used for graywater recycling at La Palma Correctional Facility as well as a map of the property.

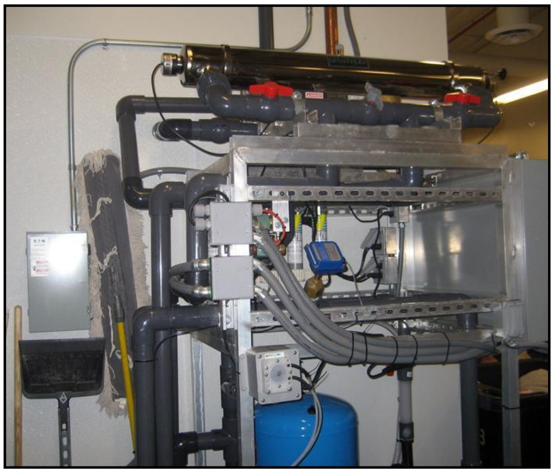


Figure 2.8 Left: Valentine Engineering Recycling Equipment. Right: La Palma Correctional Facility in Eloy, Arizona Facility Map (Photo Courtesy of Chuck Graf, 2014)

<u>Laundry-to-Landscape Program</u>

In 2011, San Francisco Public Utilities Commission implemented a program called Laundry-to-Landscape after state regulations were revised to legally allow the use of laundry water for outdoor irrigation purposes (SFPUC, 2012). Due to commonly enforced outdoor lawn watering restrictions, drought stricken California can fine residents up to $500 for wasting unnecessary potable water for irrigation use. The laundry-to-landscape system is designed to distribute graywater via gravity flow from only the laundry machine, through 1-inch tubing, to landscape areas outside the residence. Figure 2.9 shows a design schematic of the Laundry-to-Landscape program promoted through the San Francisco Public Utilities Commission. This system works within the confines of the existing plumbing, does not require pipe cutting, and does not require the installer to obtain a permit before constructing their system, given that it does not include a storage tank or pump (SFPUC, 2012). The main requirement is a three-way valve allowing for laundry effluent to either be sent outside, or sent to the sewer when potentially harmful chemicals or feces are present in the laundry wash water (SFPUC, 2012). San Francisco Public Utilities Commission decided to incentivize this program by offering a $112 subsidy for the first 150 single-family residences that meet the requirements for a laundry-to-landscape system. The criteria listed in the Laundry-to-Landscape program application are: Have a working clothes washing machine on-site, have a yard that is level with, or below, the location of the washing machine, and prove property ownership or provide property owner approval for the installation of such a system (SFPUC, 2012). Water savings from this type of graywater reuse are variable depending on outdoor irrigation water consumption, however can reach a potable water reduction of up to approximately 15%. When installed by the homeowner or renter, system cost is typically a couple hundred dollars, and can reach $1000-$2000 if professional installation is the chosen route (SFPUC, 2012). The City of Long Beach, California, also implemented a “Laundry to Landscape” Pilot Program in 2011 in which 33 homes were selected through a lottery to have graywater systems installed in their household. The systems installed divert water from the laundry machine into mulch basins where the landscape is irrigated (City of Long Beach, 2013).

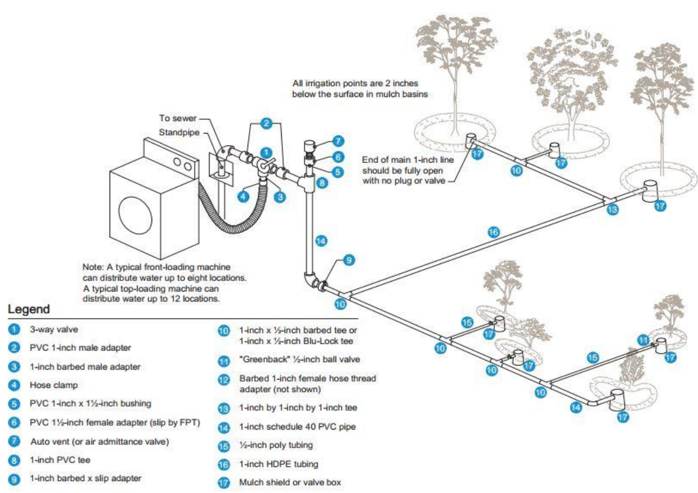


Figure 2.9 Laundry-to-Landscape Design Schematic promoted through San Francisco’s Laundry-to-Landscape Program (SFPUC, 2012).

US Air Force Communications Facility

Greyter Water Systems, a commercial manufacturer of graywater reuse systems for toilet flushing and/or irrigation, provide complete water collection and treatment works in an “out-of-box” format. The Greyter technology has systems designed for large and small scale commercial applications, and is expected to release the Greyter HOME system for residential graywater reuse in 2015 (Greyter Water Systems, 2014). The US Air Force Cannon Communications Facility in Clovis, New Mexico, selected the semi-commercial Greyter system designed to collect and treat graywater for 10-15 occupants. The US Military launched a ‘Net Zero’ initiative including water as one of the three pillars, along with energy and waste, striving to produce as many resources as they use. The 42,000 square-foot Cannon Communications Facility graywater reuse system will help with these efforts by collecting effluent from ten on-site showers and using the filtered graywater for outdoor lawn irrigation (Greyter Water Systems, 2014). Graywater from the showers gravity flows to the Greyter system located in the basement of the facility, through a pre-filter and a series of four 100 micron filters before distributed between three secondary holding tanks where disinfection occurs. The system is connected to potable water lines used to supplement freshwater when graywater supply is low. It is estimated that up to 132,086 gallons of potable water could be saved annually using this system (Greyter Water Systems, 2014).

2.5 Summary

Graywater reuse is increasing in popularity across the United States since water conserving fixtures are reaching their maximum potential savings but the demand for freshwater is growing. A big obstacle concerning graywater is that there is no uniform international or national regulation for water quality of graywater intended for reuse (Li et al. 2009; Sharvelle et al. 2013).

Other barriers regarding graywater reuse include the lack of data on the appropriate quality for toilet flushing, and the lack of national guidance and support for forming consistent graywater guidelines (Sharvelle et al. 2013). Research is needed to overcome these implementation barriers. The available literature regarding water reuse for non-potable purposes in the United States mainly focuses on household sources and applications (Karpiscak et al. 1990, Finley et al. 2009), outdoor irrigation systems utilizing municipally treated wastewater effluent (Kalavrouziotis et al. 2007, Chen et al. 2013), and the public health risks associated with graywater and reclaimed water quality (Rose et al. 1991, Dixon et al. 1999, Sharvelle et al. 2012). Internationally, a larger number of experimental and theoretical studies have been done exploring water reuse for multiple applications such as toilet flushing and outdoor irrigation (Al-Jayyousi et al. 2003, Christova-Boal et al. 1996). There is a need for research investigating the amount of graywater generated, and the feasibility of on-site water reuse governed by commercial facility type in the United States.

3.0 COMMERCIAL WATER REUSE FEASIBILITY STUDIES IN FORT COLLINS, COLORADO

3.1 Introduction

It is important to consider commercial facilities when researching water reuse methods and applications because they use a large portion of the highly-treated municipal supply of freshwater in the United States (EPA, 2012). Entities interested in water reuse may advantageously benefit by reducing potable water demand through implementation of on-site water reuse to meet non-potable demands. The available literature regarding water reuse for non-potable purposes in the United States mainly focuses on household sources and applications (Karpiscak et al. 1990, Finley et al. 2009), outdoor irrigation systems utilizing municipally treated wastewater treatment plant effluent (Kalavrouziotis et al. 2007, Chen et al. 2013), and the public health risks associated with graywater and reclaimed water quality (Rose et al. 1991, Dixon et al. 1999, Sharvelle et al. 2012). Internationally, a larger number of experimental and theoretical studies have been done exploring water reuse for multiple applications such as toilet flushing and outdoor irrigation (Al-Jayyousi et al. 2003, Christova-Boal et al. 1996). There has been little research done investigating the amount of graywater generated, and the feasibility of on-site water reuse governed by commercial facility type in the United States. Estimating the potential potable water savings at commercial facilities in the United States will assist the decision making process for interested businesses.

The City of Fort Collins Utilities expressed interest in researching commercial customers within their service area who may be good candidates for water reuse in efforts to promote water conservation and reduce the strain on freshwater supplies and local wastewater treatment plants. Commercial water users are the largest users of water in the city and thus implementation of on-site reuse to meet non-potable demands at such facilities creates great potential for water demand reduction. The feasibility of water reuse at a given facility is gauged by several factors such as graywater generation, plumbing layouts, water quality of the reusable portion of water, the desired use of treated graywater, the cost of implementing a reuse system, the corresponding payback period, and the estimated percent reduction in potable water use. The success of on-site water reuse is dependent upon the nature of the business and the activities that take place in each business's building, therefore a variety of businesses were investigated in order to make broad conclusions regarding which facility types are practical for reuse systems. The objective of this study is to identify graywater sources and reuse applications at commercial facilities which can be simple, yet effective methods of water conservation. This study explored the generation of graywater sources including laundry, shower, bathtub, and laundry room and bathroom faucet water, and any similar low-strength discharge with similar general water quality characteristics as graywater, at commercial facilities. This study did not include any businesses wishing to reuse their full stream of wastewater containing toilet and/or kitchen wastewater. Instead, this study was geared towards identifying commercial facilities in the City of Fort Collins that could potentially reuse the less contaminated portions of wastewater, such as graywater and minimally contaminated process waters. The type of businesses invited to participate in the feasibility study included fitness facilities, carwashes, laundromats, hotels, research laboratories, large office complexes, multi-residential apartment homes, and beer breweries. Those who exhibited interest in the study and in water reuse at their facility were included in the study but will not be identified by name. Ultimately, a fitness facility, hotel, research laboratory, office complex, recreational pool, and two beer breweries participated in the study.

3.2 Background on Colorado Regulations for Reclaimed and Graywater Use

It is necessary to differentiate the two applicable water reuse regulations in the State of Colorado to accurately identify which regulation a given reuse system may fall under, depending on the end use application. Regulation 84 is the Reclaimed Water Control Regulation and was adopted in the year 2000, with subsequent amendments in 2004, 2005, 2007, and 2013. Regulation 84 for reclaimed water specifies the relevant requirements and concentration limits for the treatment and reuse of domestic wastewater. The allowable reuse applications under Regulation 84 are: Landscape irrigation, agricultural irrigation, fire protection, and industrial and commercial uses (5 CCR § 1002-84). Reclaimed wastewater available for reuse can include all or part of the wastewater generated at a facility so long as the wastewater has not been treated and released to state waters prior to reuse, or so long as the wastewater has not already been treated at a domestic wastewater treatment plant and used for landscape irrigation or process water (5 CCR § 1002-84). Regulation 86 is the result of the signing of HB13-1044 in May, 2013, and is titled Graywater Control Regulation. The regulation drafting and stakeholder involvement process is currently underway and therefore is subject to change. However, the draft Graywater Control Regulation defines graywater as effluent water from bathtubs, showers, bathroom and laundry room sinks, and laundry machines, and will allow graywater to be reused for indoor toilet and urinal flushing, and outdoor subsurface irrigation (5 CCR § 1002-86). Though the Reclaimed Water Control Regulation allows the use of treated domestic wastewater, the Graywater Control Regulation will not allow the reuse of toilet or kitchen wastewater.

3.3 Study Approach and Methods

Several businesses within the Fort Collins Utilities service area were contacted and presented with an introduction to this water reuse feasibility study. Taking into account that some businesses may hesitate to participate due to concerns that their water use data might be scrutinized, the introductory letter emphasized the promotion of on-site water reuse by Fort Collins Utilities, and encouraged participation in the study. Meetings were held at each facility that expressed interest to communicate the information and data needs essential to estimating potential water savings. In most cases, a tour of the facility was given so the fixture locations and plumbing layout could be noted. Reusable water sources and potential end use applications were acknowledged after discussing the business's list of water uses and/or any current on-site water reuse methods. In a few cases, businesses originally expressed interest in exploring on-site water reuse methods but then upon investigation realized that insufficient graywater generation would result in an impractical, and potentially costly water reuse system with an unjustified payback period and negligible water savings. The two office buildings investigated were quickly identified as inappropriate fits for graywater reuse, one office building was not elaborated on in this study because results from the initial meeting on water reuse showed very low graywater generation.

Data needs were identified after the discussion and tour of the facility, and were typically site specific due to varying sources of reusable water and desired end use applications from business to business. Generally, businesses were asked to track down values for the list of data needs presented in Table 3.1.

Table 3.1 General Data Needs for Commercial Customer On-site Water Reuse Feasibility Studies

On-site Water Reuse Commercial Customer Feasibility Studies, City of Fort Collins, Colorado	
Data Needs	
Fixture Counts	Toilets
	Urinals
	Showers
	Bathtubs
	Sinks
	Laundry Machines
	Dishwashers
	Lab ware
	Spray Nozzles
Fixture Flow Rates	
Manufacturer and Model Number Information (If flow rates unknown)	
Size of Irrigable Land	
Daily Occupancy of Facility	
Total Annual Water Use	
Reusable Water Quality	Chemicals
	Hazardous Wastes
	Biological Load
	Organic Matter
Water Sample (If quality is unknown and waste stream constituents are estimated to be significant)	

Each local business that participated in the commercial customer water reuse feasibility study had unique and site specific water reuse possibilities. In each scenario, the necessary data was obtained and entered into a comprehensive Excel spreadsheet which calculated the site specific water balance between graywater supply and demand; the estimated potential water savings were the main output of the spreadsheet. In some cases, water use data was sent by a staff member on a monthly basis and compiled in supplemental spreadsheets to calculate averages over the study period. The following sections outline the reuse strategies explored and the estimated potential water savings at each business individually. It is important to note that some educated assumptions were made when real data could not be obtained, measured, or the business was unsuccessful in gathering specific values. All assumptions and missing information were estimated using knowledge from the facilities staff members, relevant literature, or applicable research experiences with water reuse.

3.3.1 Recreational Pool

Recreational swimming pool facilities typically have on-site showers, faucets, and toilets in their locker rooms. The frequent use of these water fixtures make swimming pools a theoretically viable candidate for graywater reuse systems provided the graywater generated meets the reuse application demand. The facility investigated includes an indoor pool with male and female locker rooms on main level, and an additional full bathroom on the second level. An estimated 350 visitors attend the pool daily for swimming lessons and open swimming sessions. The average total water use at the pool facility is 2,250,939 gallons/year (6167 GPD). The graywater sources at the pool facility include effluent from locker room showers. The facility has 16 on-site showers with 2 gallon per minute (GPM) showerheads. This study investigated graywater reuse for toilet and urinal flushing as the end use application, meaning this scenario would fall under Regulation 86. The facility has 12, 1.6 gallon per flush (GPF) toilets on-site and 6, 0.125 GPF urinals on-site. To determine potential water savings, some assumptions were required due to the absence of data that could not be collected over a short period of time. It was assumed that the average length of each individual taking a shower was four minutes (It is assumed showers before pool use are significantly shorter than the duration taken in a residence, which averages 8 minutes (REUWS, 1999)), and that 50% of all visitors take a shower. It was also assumed that equal amounts of male and female visitors attend the pool, and each visitor flushes either one toilet or one urinal each visit. These assumptions were made after speaking with employees of the facility and taking into account their estimates. In addition, assumptions on fixture water use were compared to actual data on total water use for common sense validation.

3.3.2 Office Complex

A 2012 study done by the EPA categorized end uses of water in office buildings across the United States. The study concluded that 37% of office water use is attributed to restroom purposes, 28% cooling and heating, 22% landscaping, and 13% kitchen and dishwashing purposes (EPA, 2012). Office buildings could benefit from water reuse by reducing operating costs and energy costs associated with heating water (EPA, 2012). Water reuse systems that provide an alternative water source for heating and cooling are of interest because 28% of total water demand in office buildings is used for heating and cooling purposes (EPA, 2012). It is of interest to look at the sectors of water use in office buildings to calculate if the percent of graywater generated aligns with the toilet flushing, cooling tower, or outdoor irrigation demands.

The site under investigation is a particularly large office building complex that is occupied by approximately 1,700 employees daily. Total water use at this facility is approximately

30,825,550 gallons/year (84,455 GPD). This office building complex has an on-site gym and the Colorado Program Manager stated that employees frequently shower after using the gym. However, there is no on-site laundry. The identified graywater source at this facility is effluent from 20 showers located inside the building. The showerheads have a flow rate of 2 GPM. In efforts to measure frequency of shower use, shower users marked a tally on the form located in the male and female locker rooms every time they showered for a two-week period. The tally approach measured an average of 43 total showers/week in the male and female locker rooms, collectively. This shower frequency value equates to an average of 0.5% of office occupants that shower daily at the facility. It was assumed that the average length of shower was eight minutes (REUWS, 1999). The office building investigated has two large cooling towers on-site and water use data from the cooling towers was provided by the Chief Operating Engineer of the facility.

3.3.3 Research Laboratory

Research laboratories use a considerable amount of potable water for large cooling demands, process loads, and through the use of low-efficiency laboratory equipment (EPA,2005). Potable water used for cooling in multipurpose laboratories makes up 30%-60% of the total water use (EPA, 2005). Research laboratories could potentially use less municipally treated water for cooling if alternative water sources are of sufficient quantity, however, the feasibility of reuse would depend on the quality of the alternative sources. When using reclaimed water for cooling tower makeup, the main water quality concerns are biological growth and scaling. When nutrients are present in the reclaimed water, there is the potential for biofilms to grow and interfere with heat transfer. Calcium, magnesium, sulfate, alkalinity, phosphate, silica, and fluoride are all constituents of concern with respect to scaling in the cooling towers (EPA, 2012). The 2012 Guidelines for Water Reuse report by the EPA specifies guidelines for reclaimed water quality as an alternative source in cooling towers. The suggested guidelines include secondary treatment (activated sludge, trickling filters, rotating biological contractors) and disinfection (possibly preceded by coagulation and filtration) to achieve: pH value between 6-9, ≤ 30 mg/L BOD and TSS, ≤ 200 fecal coliform/100mL, and a 1 mg/L Cl_2 residual (EPA, 2012). Raw graywater can be treated using biological treatment processes to reach effluent BOD concentrations of approximately 10 mg/L and 2.8 log reduction of *E. Coli* (Winward et al. 2008).The chemical and biological constituents used in a laboratory would inevitably be present in the waste stream and may be a threat to public health, the cooling tower equipment, or may be impractically expensive to treat. The large research laboratory investigated in this study exhibits water use trends similar to those of many multipurpose laboratories. The average total annual water use at this facility is 724,200 gallons (1,984 GPD). The identified graywater sources at this research laboratory include autoclaves, glassware washers, and dishwashers used to clean laboratory materials. The laboratory safety and occupational health specialist provided estimates regarding the frequency of use of autoclaves, glassware washers, and dishwashers on a daily or weekly basis, stating that use of this equipment is not always consistent and may be dependent upon current laboratory experiments and procedures. The manufacturer and model numbers of the autoclaves, glassware washers, and dishwashers were also provided and used to find the associated flow rates in the user manuals. In conjunction with the frequency of use estimates provided by building staff, the flow rates were used to estimate water use in these appliances. Though there was no sample given to analyze water quality, the facility states that the main constituents in wastewater streams from autoclaves, glassware washers, and dishwashers are plant hormones and growth media which is a potential concern for reuse in cooling towers. A potential reuse application at this facility is to use treated wastewater from autoclaves, dishwashers, and glassware washers, in the two cooling towers located on the top floor. Cooling tower water use data was obtained through water meter reading monthly reports sent by the facilities manager at this laboratory.

3.3.4 Fitness Facility

Fitness facilities tend to generate a lot of graywater due to frequent use of the on-site showers and laundry machines used to wash gym towels. It is estimated that full-service fitness facilities can use up to 20,000 GPD of potable water depending on the size of the facility and the daily attendance rates (Jones, 1999). Water reuse at fitness facilities is dependent upon the relevant reuse applications that exist on-site and the corresponding non-potable water demands, because graywater supply from showers and laundry machines is typically sufficient for toilet flushing and outdoor irrigation. The fitness facility investigated includes a gym with cardio equipment, weight-lifting machines, a free weight area, studio classrooms, child care, a full-length basketball court, male and female locker rooms, a four-lane 25-meter swimming pool, and a small café. This athletic facility sees approximately 1,100 visitors each day, 364 days of the year. This athletic facility has an average water use of 2,565,164 gallons/year (7,028 GPD). The available graywater sources include effluent from showers and laundry machines used for washing towels on site. The facility has 14 showers and one industrial sized washing machine that washes 24 loads daily. Showers and laundry make up the largest portion of the monthly water use at this facility, whereas the small café and pool contribute very little to overall water use. The facility does not have any outdoor land to irrigate, therefore the graywater reuse applications explored were indoor toilet and urinal flushing in the locker rooms. The facility has 14, 1.6 GPF, toilets and three, 0.125 GPF, urinals on-site. In this scenario, assumptions made include: 50% of gym attendees flush either one toilet or one urinal, the ratio of male to female visitors is one-to-one, 25% of gym visitors shower while at the gym, and the average length of shower at the gym is four minutes. Assumptions on fixture water use were compared to actual data on total water use for common sense validation.

3.3.5 Hotel

Hotels use a large amount of potable water for purposes such as showers, toilets, laundry, kitchen cooking and dishwashing, heating and cooling, and others. In the Seattle Public Utilities service area, lodging facilities make up only 1% of commercial water accounts, however use a total of 5% of all commercial municipal water (O'Neill et al. 2002). This indicates that hotels generally use more potable water than other commercial facilities and/or institutions in relation to number of commercial water accounts. Hotels are of interest when researching on-site water reuse potential because they typically have large amounts of graywater generated. The hotel investigated has 254 rooms and is usually occupied at full or near-full capacity. The identified graywater source at this facility is effluent from on-site laundry machines. The facility has two industrial-sized washing machines that run approximately 15 times daily. Although showers, bathtubs, and faucets are prevalent uses of water in this hotel, the current plumbing layout for all 8-floors would be too complicated and costly to retrofit for a graywater collection and treatment system. Hotels that have not yet been built and could incorporate graywater reuse into the building design could potentially see water savings from graywater reuse for toilet flushing.

In this situation, however, the facility's laundry machines, located on the main level, could utilize a system redirecting effluent to outdoor landscaping areas. There is near 1 acre of irrigable land on the hotel property that is currently supplied by drip irrigation lines using potable water, meaning this scenario would fall under Regulation 86. It was assumed that 27,000 gallons of water/week is needed to irrigate the 1 acre plot of land located in the City of Fort Collins. This assumption was made using the Small Acreage Irrigation Guide written by Byelich et al. 2013. Laundry water use was estimated by utilizing the manufacturer and model numbers of the industrial-sized washing machines to find the total water use per cycle, and multiplying the total water use by the average value of 15 loads per day provided by the chief engineer of the facility. Toilet use was estimated by utilizing the number of rooms (estimated daily occupancy) in conjunction with the average toilet demand of seven flushes (11.2 gpcd at 1.6 GPF). Shower demand was estimated in the same fashion as toilet demand (9 gpcd) from Figure 2.2.

3.3.6 Beer Brewery 1

Breweries use a considerable amount of freshwater in the beer making process and the packaging process, including the cleaning of bottles (Lambooy, 2010). The brewing company Heineken set goals in 2010 aiming to reduce the amount of water used in the beer making process. In order to make one hectoliter of beer, up to seven hectoliters of freshwater were historically required. Heineken set goals to reduce the water used in the beer making process to 4.6 hectoliters of water for every 1 hectoliter of beer by the end of 2010 (Lambooy, 2010). Other breweries are also making efforts to reduce potable water consumption, such as New Belgium Brewery in Fort Collins, Colorado. In 2013, New Belgium used an average of 4.31 hectoliters of water to make one hectoliter of beer. New Belgium set goals to use an average of 3.5 hectoliters of water for every hectoliter of beer by the year 2015 (New Belgium, 2014). Breweries can also reduce water consumption by utilizing on-site reuse systems. The wastewater produced during the beer making process has notable concentrations of organic and inorganic constituents and requires full wastewater treatment (Simate, 2014), however the quality of wastewater produced during packaging processes is of interest for water reuse systems. The water used in packaging processes may potentially be viewed as graywater because in some situations is minimally contaminated wash water containing cleansing materials and only small amounts of beer. The first beer brewery investigated currently reuses municipal water three times for hot vacuum pump cooling, bottling rinsing, and external bottle spraying before sending the water to drain. The total water use at this facility in 2012 was 7,886,000 gallons (21,606 GPD). The on-site water source at this beer brewery is effluent from the external bottle rinse off. At this brewery, six, 0.4 GPM, spray nozzles operate approximately 16 hours daily. The external bottle rinse off water, already reused three times, could be reused once more for outdoor irrigation. The brewery currently irrigates 5.2 acres of property using municipal water distributed through spray irrigation lines during the seven-month irrigation season. Information regarding external bottle rinse off water use and irrigation water use was provided by the facility's maintenance and engineer staff.

3.3.7 Beer Brewery 2

This facility had a total water usage of 38,048,500 gallons in 2012 (104,243 GPD). The water sources available for reuse at this facility are effluent from the canning and bottling rinse off lines, as well as effluent from the one dishwasher used to clean taster glasses from frequent tours given to the public. The dishwasher runs an average of 10 loads per day, six days a week. The rinse off line operates approximately 100 hours per week. Information on water use in the dishwasher and rinse off line was provided by the facility manager. Possible reuse applications include using the canning and bottling rinse off water to irrigate a portion of their property. The location of the lift station where effluent water flows is a potential roadblock in this application. The lift station is located in the back of the building whereas the irrigable portion of the property is located at the front of the building. The reuse system would therefore require additional and potentially costly piping. During the irrigation season, this facility waters utilizing both drip and spray irrigation systems. Reusing dishwasher effluent for toilet flushing in public restrooms is a second potential application. The facility has both male and female restrooms conveniently located on the tour route. The toilets are 1.4 GPF. The frequency of use in the public restrooms is unknown, however, staff members at this facility estimate that two-thirds of visitors make a restroom stop at least once during the tour.

This facility also expressed interest in using discharge from their on-site process wastewater treatment plant to irrigate their landscape, as opposed to a reuse system utilizing the water sources discussed above. The regulatory requirements for this type of application would need to be explored further because the water used for irrigation would have subsequently been treated at a full-service wastewater treatment plant. This use would likely fit well under Regulation 84.

3.4 Results of Commercial Customer Water Reuse Feasibility Studies

3.4.1 Recreational Pool

Shower water makes up approximately 511,000 gallons/year of total water use. Toilets and urinals are estimated to account for approximately 110,184 gallons/year and therefore are the limiting factor in amount of potable water that could be saved by reusing graywater for toilet and urinal flushing since there was not interest in meeting irrigation demand with graywater. By meeting 100% of toilet and urinal demand with treated graywater, the facility would see a 5% reduction in total potable water use. Table 3.3 summarizes potential water reuse feasibility at this facility. Estimated shower water use at this particular facility exceeds the amount of water used for toilet flushing by approximately 18% (Figure 3.1), implying that graywater supply would consistently be in excess. The miscellaneous water use (Figure 3.1) may be attributed partially to the water used in the pool itself.

Table 3.3 Summarized Results of Commercial Customer Water Reuse Feasibility Studies

Business	On-Site Water Sources	Possible Uses	Total Water Use (gallons/year)	Graywater as % of Total Water Use	Estimated Percent Reduction in Potable Water Consumption	Recycled Water Category	Irrigation Water Available from Graywater (assuming graywater can be used for irrigation) (gallons/day)	Irrigation Area that could be served by graywater in Colorado (Acres)
Recreational Pool	Showers	Toilet and Urinal Flushing	2,250,939 gallons/year	25%	5%	Graywater	1,530	0.57
Office Building	Showers	Cooling Towers	30,825,550 gallons/year	0.66%	0.16%	Reclaimed Water	563	0.21
		Toilet Flushing			0.66%			
Research Laboratory	Autoclaves, glassware washers, dishwashers	Cooling Towers	724,200 gallons/year	42%	21%	Reclaimed Water	844	0.32
Fitness Facility	Showers and Laundry Machines	Toilet Flushing	2,565,164 gallons/year	89%	7%	Graywater	6,771	2.53
Hotel	Laundry Machines	Outdoor Irrigation	11,870,280 gallons/year	25%	6%	Graywater	8,278	3.09
	Showers	Toilet Flushing			7-8%			
Beer Brewery 1	External Bottle Rinse Off Effluent	Outdoor Irrigation	7,886,000 gallons/year	11%	7%	Reclaimed Water	2,304	0.86
Beer Brewery 2	Canning and Bottling Line Effluent, Dishwasher Effluent	Outdoor Irrigation, Toilet Flushing	38,048,500 gallons/year	19%	9%	Reclaimed Water	19,806	7.40

In water reuse systems, the water balance between graywater generation and graywater demand is an important factor and impacts the design of the treatment system. In this scenario, a reuse system for toilet and urinal flushing may be impractical due to a constant surplus of graywater. Because pool facilities often require swimmers to shower before and after using the swimming pool, it likely that other pool facilities, especially ones with on-site laundry, will not have a large enough toilet demand to justify collecting shower and/or laundry graywater. Also, the amount of water used for one shower exceeds the amount of water used for one toilet or urinal flush, and it is unlikely that visitors use the restroom multiple times per visit. Though irrigation was not a potential end use at this particular facility, graywater could be a substantial source of irrigation water at other recreational pools with property to irrigate, thereby reducing the demand on potable water during the growing season. Theoretically, using 9,800 gallons per week of shower graywater (all shower wastewater from the facility) could sufficiently irrigate a .52 acre plot of land without the need for any potable water. If graywater from both showers and faucets was used for irrigation, a 0.57 acre plot of land could sufficiently be irrigated.

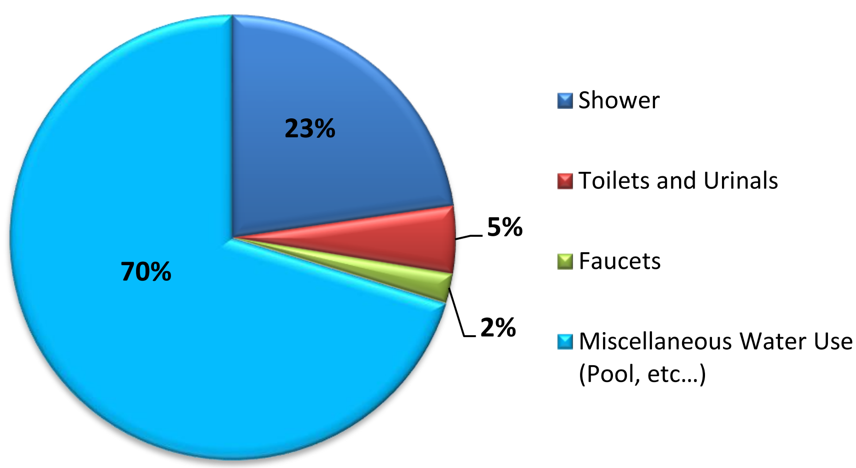


Figure 3.1 Categorized Recreational Pool Water Use (Estimated)

3.4.2 Office Building

If graywater was available for use after treatment, the cooling towers could rely less on domestic potable water and utilize recycled water as an alternative source. Water reuse for toilet and urinal flushing proved to be unjustifiable due to the layout of the plumbing in the facility, however would hypothetically be a good candidate for graywater reuse applications in other office facilities. Water used for showers is estimated to generate only 137.6 GPD of graywater, or 50,224 gallons/year (Figure 3.2). With cooling tower use vastly exceeding shower water use at a rate of 47,121 GPD, reusing graywater could only reduce the total potable water demand by 0.16% (Table 3.3). If graywater from showers and faucets was hypothetically used for toilet flushing, this facility could see a 0.66% reduction on potable water demand. Though it was initially thought that frequent shower use could create substantial amounts of graywater, the water balance shows otherwise. Graywater reuse feasibility at this location is limited by small amounts of graywater generation and a much larger graywater demand and would be impractical due to negligible water savings. In cases where irrigable land is present, the graywater supply likely would come nowhere close to the irrigation demand, although irrigation demand figures were unattainable for this facility. This was a particularly large office building complex with large cooling tower demands. Smaller complexes with on-site laundry may find that shower and laundry effluent match up closely with toilet demand. As a generalization, the amount of people and corresponding amount of water used for showers at office building complexes is usually much lower than toilet demand, because the majority of people use the restroom more than once during the work day. However, the addition of laundry water to the graywater stream may make water reuse feasible.

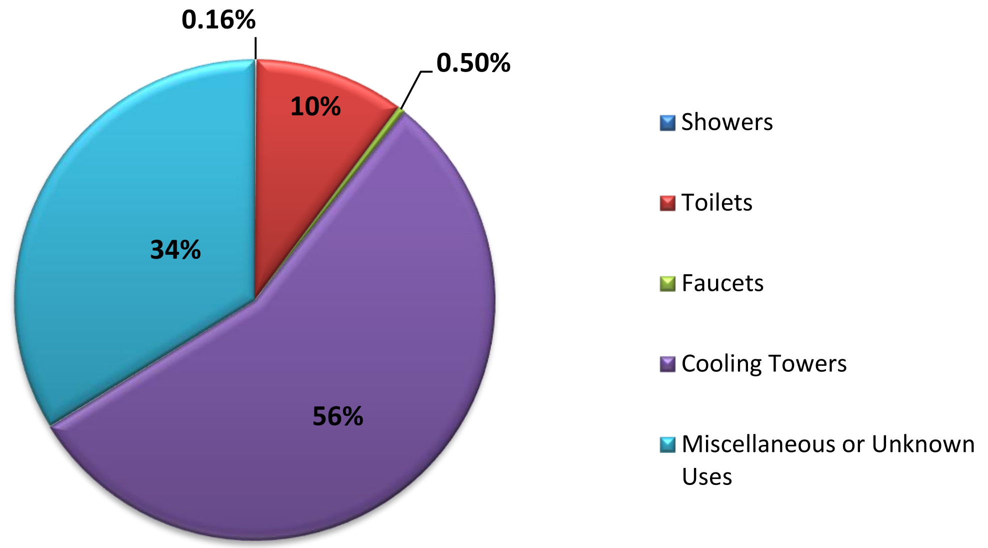


Figure 3.2 Office Building Water Use (Estimated)

3.4.3 Research Laboratory

Average total monthly water use at this facility is 724,200 gallons per year (1,984 GPD). Water use in cooling tower #1 and #2 averaged 12,200 GPD and 213 GPD, respectively, over a six-month period at this facility. Laboratory equipment including autoclaves, glassware washers, and dishwashers use an estimated 25,380 gallons on a monthly basis. If treated effluent from laboratory processes was reused as an alternative water source for the two on-site cooling towers, this facility could see potable water reductions of up to 21% (Table 3.3), provided that the water quality meets the reclaimed water guidelines set forth by the EPA (Figure 3.3). Plant hormones and growth media present in the laboratory waste stream would need to be further explored regarding their effect on water quality. There was no literature found investigating this topic.

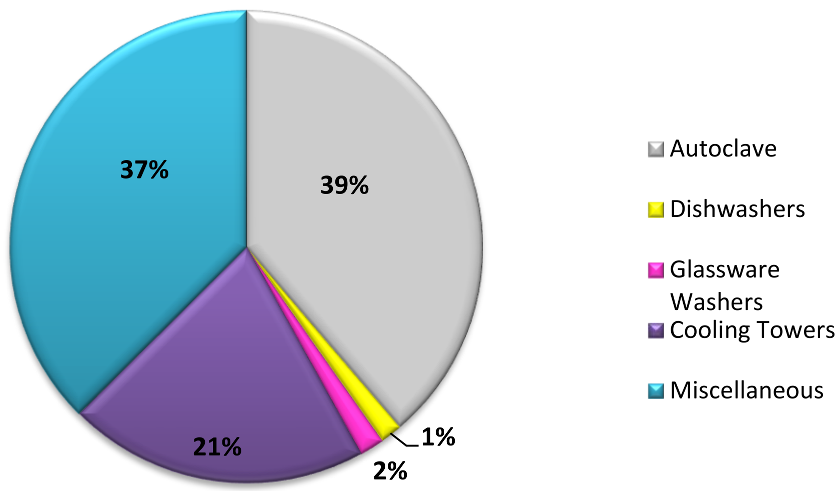


Figure 3.3 Research Laboratory Water Use (Estimated)

3.4.4 Fitness Facility

This fitness facility has an average water use of 2,565,164 gallons/year (7,028 GPD). Estimated shower water use accounts for 1,204,500 gallons/year, and estimated laundry water use accounts for 1,016,160 gallons/year. Estimated toilet water use accounts for 173,147 gallons/year (Figure 3.4). It should be noted that laundry and shower use vastly exceed the toilet demand, likely because most people do not use the restroom more than once while at the gym, and a four-minute shower uses much more water than one toilet or urinal flush. By reusing graywater for toilet and urinal flushing, this athletic facility could see a 7% reduction in potable water use (Table 3.3). However, if the facility had irrigable land nearby, much larger water savings could be achieved. Fitness facilities most always have large amounts of graywater generated from showers, laundry machines, and faucets, and in this scenario, those three sources accounted for 89% of water use. In a hypothetical case where a 2-acre property located outside an athletic center had an irrigation demand of 54,000 gallons/week during the irrigation season, laundry and shower effluent could likely provide up to 80% of those water demands utilizing graywater.

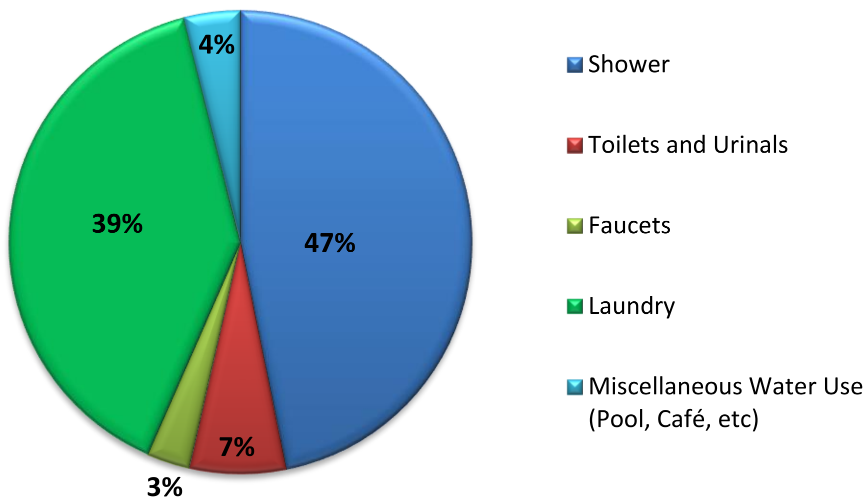


Figure 3.4 Categorized Water Use at the studied Fitness facility (Estimated)

3.4.5 Hotel

The total annual water use at this facility is approximately 11,869,308 gallons (32,519 GPD). The estimated use of laundry machines accounts for 168,000 gallons/month and the irrigation demand was estimated as approximately 108,000 gallons/month (Byelich et al. 2013) during the growing season (7-months).Reusing laundry machine effluent for outdoor subsurface or drip irrigation could be a beneficial system at this hotel facility, reducing potable water demand by up to 6% annually (Figure 3.5). During the growing season potable water use would be reduced by 11% on a monthly basis (Table 3.3)As a hypothetical scenario, collecting shower water from hotel rooms and using it for toilet flushing would result in savings of 7%, but would require some supplemental potable water makeup. Collecting both laundry water and shower water for reuse would meet the total toilet flushing demand and would result in savings of 8%.

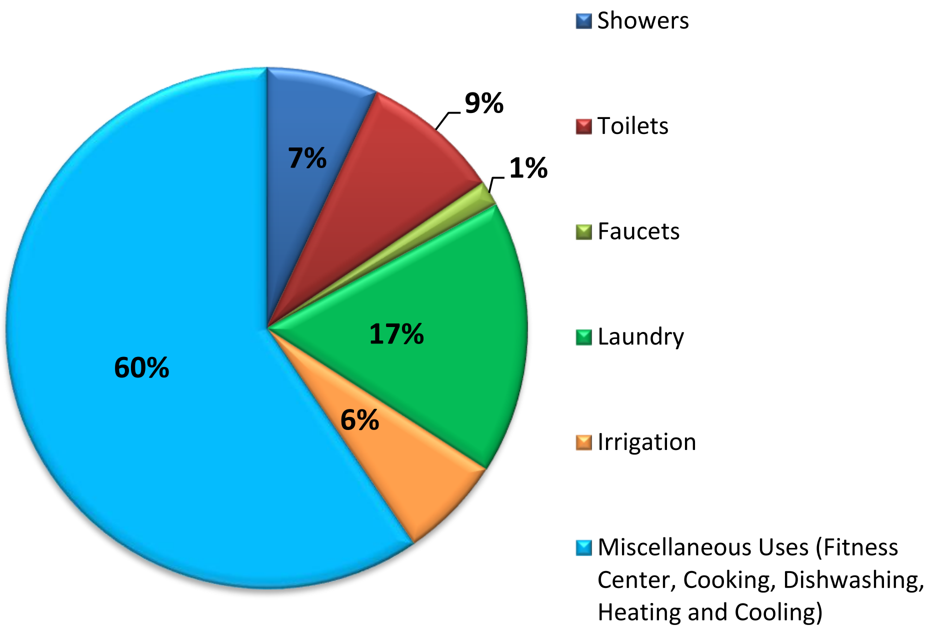


Figure 3.5 Categorized Water Use at the studied Hotel (Estimated)

3.4.6 Beer Brewery 1

The total water use at this facility in 2012 was 7,886,000 gallons (21,606 GPD). Water for irrigation reaches a demand of 2,520 GPD during the seven-month irrigation period from April to October. The facility uses approximately 2,304 GPD in the external bottle rinse off process. The demand for irrigation exceeds the reusable water generation by approximately 200 GPD, but the reuse system could supplement with city water to reach the necessary demand. A water sample of the external bottle rinse off was analyzed and resulted in a measured Chemical Oxygen Demand (COD) value of 700 mg/L, signifying a high organic content in the waste stream attributed to the beer present on the outside of bottles before rinse off. Regulation 84 for reclaimed water requires wastewater to undergo secondary treatment, and therefore BOD limits placed on wastewater effluent would apply. Colorado Regulation 62 for effluent limitations requires a BOD_5 30-day average in effluent wastewaters of 30 mg/L or lower (5 CCR 1002-62). The facility could see a potable water reduction of approximately 7% if external bottle rinse off water is reused for outdoor irrigation (Table 3.3). Toilet demand is incorporated into the miscellaneous portion of the pie chart of Figure 3.6 because it is unknown, however estimated to be low based on the number of visitors and staff approximated by maintenance and engineer workers at the facility. It is important to note that the percentages of water used for the beer making process and additional water uses at this facility are unknown, and therefore accounted for within the miscellaneous portion of the pie chart.

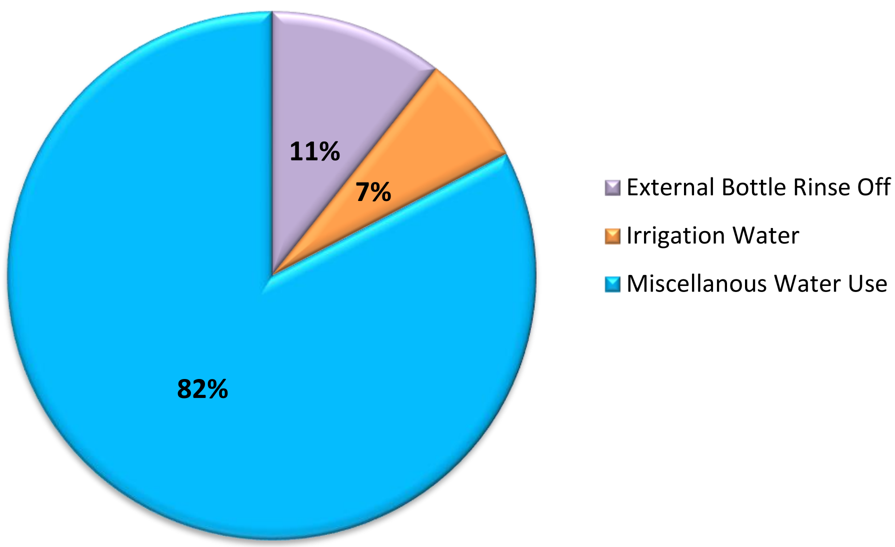


Figure 3.6 Categorized Water Use at Beer Brewery 1 (Estimated)

Note: The percentages of water used for the beer making process and additional water uses at this facility are unknown, and therefore accounted for within the miscellaneous portion of the pie chart.

3.4.7 Beer Brewery 2

This facility had a total water usage of 38,048,500 gallons in 2012 (104, 243 GPD), and uses an estimated average of 465,616 gallons of potable water/month during the seven month irrigation season. The dishwasher used to wash taster glasses only uses an estimated 624 gallons of potable water per week, whereas the canning and bottling rinse off line uses an estimated 139,200 gallons of potable water per week. The facility has both male and female restrooms conveniently located on the tour route that have an estimated toilet demand of approximately 224 GPD, six days out of the week. When examining the two reuse application possibilities, the balance between supply and demand of dishwasher effluent vs. toilet water use, and canning and bottling line rinse off effluent vs. irrigation water use, were calculated. Because the amount of dishwasher effluent is only near half of the water used in toilet flushing, a reuse system for this purpose would be impractical. However, the canning and bottling line rinse off produces just 20% more water than is needed for outdoor irrigation (Figure 3.7). A reuse system capturing canning and bottling line rinse off water and utilizing it for outdoor irrigation could reduce potable water consumption at this facility by 9% (Table 3.3).

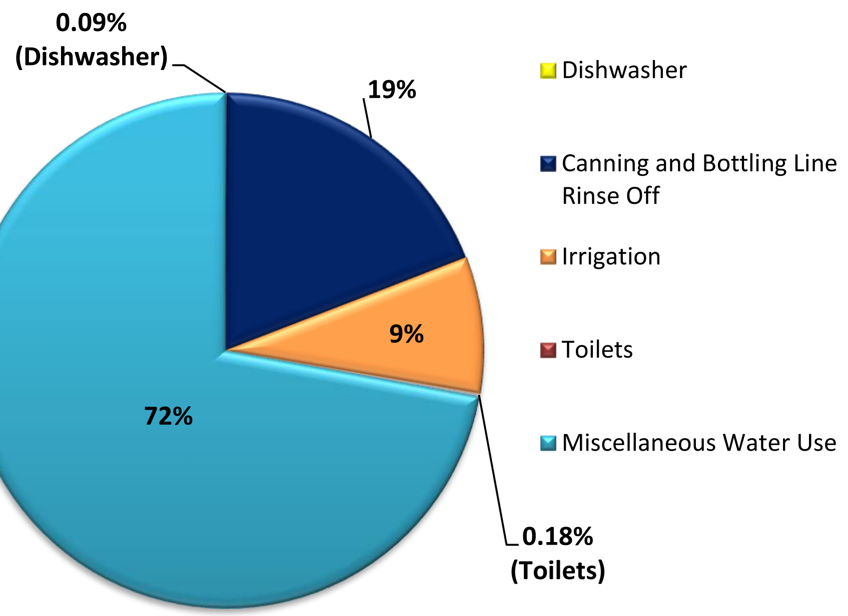


Figure 3.7 Categorized Water Use at Beer Brewery 2 (Estimated)

3.5 Study Conclusions

This goal of this study was to gauge feasibility of on-site water reuse at a variety of commercial facility types in the Fort Collins Utilities service area. The study primarily focused on calculating the water balance between graywater sources and the corresponding end use applications to evaluate the site specific practicality of water reuse. The plumbing layouts, regulatory codes, and water qualities were considered and explored (Table 3.3), yet were not always investigated in-depth. Cost estimates were outside the scope of this study. The study results predict estimated potential water savings at each individual site if the identified water reuse method were to be implemented and constructed.

The research laboratory investigated in this study has the highest estimated percent potable water consumption reduction, 21%, out of all the sites investigated. The water balance calculated for the office building implies that this type of facility (even when showers are used on-site) is typically not ideal for water reuse systems, predicting a water savings of only 0.08%. Office buildings with on-site laundry, however, could potentially meet toilet flushing demand if shower and laundry graywater were combined. In general, cities who are interested in promoting water conservation in their corporate sector should especially look into graywater reuse at hotels, fitness facilities, and research laboratories due to their sufficient graywater generation and feasible end use applications. Though not covered in this study, laundromats could be a good fit for water reuse utilizing effluent clothes washing water for outdoor irrigation and should be explored further. It should be noted that the practicality of the identified on-site water reuse systems also depends on the total cost of implementation in relation to the amount of water savings expected. If further investigation shows the costs of implementation outweigh the benefits of water conservation, then the particular reuse system in question is most likely impractical. There is no ‘one size fits all’ formula for water reuse systems because each entity has unique water use characteristics. However, this study provides valuable water balance information for other pools, office buildings, fitness facilities, research laboratories, hotels, breweries, or similar facility types, interested in investigating water reuse at their business. For those facilities that are likely to see negligible water savings by reusing graywater or similar low-strength wastewaters, fully reclaimed water reuse utilizing domestic wastewater may increase water savings and is always a strategy to explore.

4.0 ESTIMATING ADOPTION OF GRAYWATER REUSE AND POTENTIAL IMPACTS TO RETURN FLOWS IN FORT COLLINS, COLORADO

4.1 Introduction

The western portion of the United States manages water in a unique and complex way, abiding by prior appropriation rights that are historically complex and controversial (Anderson et al. 2005). Whereas water conservation is usually seen as a benefit to water reduce municipal water demand, managing water resources with prior appropriation rights can discourage and hinder the true water saving potential of water conservation approaches, in worries of losing water rights (Anderson et al. 2005). The western United States is expected to see the largest population growth out of all the regions in the near future, therefore resulting in larger freshwater demands to sustain urban areas, agriculture, and ecosystems (Garfin et al. 2014). The City of Fort Collins Utilities plans to adopt the regulations governing graywater reuse when they are finalized, and was interested in exploring the water rights implications in the form of impacts to return flows associated with graywater reuse. The reuse of graywater implies a reduced effluent flow to local wastewater treatment plants, and also less reliance on freshwater supplies. Many cities in the front range of Colorado are concerned that promotion of graywater reuse in their city will result in violations to water rights. For example, the City of Fort Collins must demonstrate that wastewater discharged meets a certain flow rate each month to ensure compliance with water rights. The City of Fort Collins Utilities can gauge the effect that graywater reuse will have on their current water rights and water allocation concerns by looking at the percent reduction of flows to wastewater treatment plants under various graywater adoption scenarios. The objective of this research was to estimate the adoption of graywater reuse in the Fort Collins Utilities service area, and use the predicted values to calculate the impacts to return flows associated with graywater reuse in both the present and future. Population projections were taken into account to capture the effects of graywater reuse in both the present and the future. Impacts to return flows associated with graywater adoption were determined in the form of percent reduction from base flows to the local wastewater treatment plants.

4.2 Approach and Methods

4.2.1 Estimating Graywater Reuse Adoption Rates in Fort Collins, Colorado

The regulation and drafting process for Regulation 86, the Graywater Control Regulation, is ongoing and the regulation has not been implemented yet. It is of interest to estimate the amount of the population that may adopt graywater reuse when it is finally legalized to estimate impacts to local return flows. In 1999, the Soap and Detergent Association conducted a study sent to 100,000 nationally representative households, and found that only 7% of U.S. households were reusing graywater at that time (The NPD Group, 1999). However, graywater adoption rates vary by region because of the differences in climate patterns throughout our country. The western portion of the United States has larger concerns regarding the availability of freshwater reserves, and therefore has a larger concentration of households reusing graywater than eastern regions. Figure 4.1 depicts graywater use by region amongst total graywater users in the United States. Additionally, Figure 4.2 breaks the regions up further into percent of households in each state using graywater. To predict graywater adoption in Colorado, California and Arizona were chosen as representative states because they are thought to exhibit similar climactic and lifestyle characteristics as Colorado. From the survey, it was estimated that 13.9% of households in California use graywater, whereas 3.6% of households in Arizona use graywater (The NPD Group, 1999). Therefore, the chosen adoption rates (5% and 10%) fall between these two values.

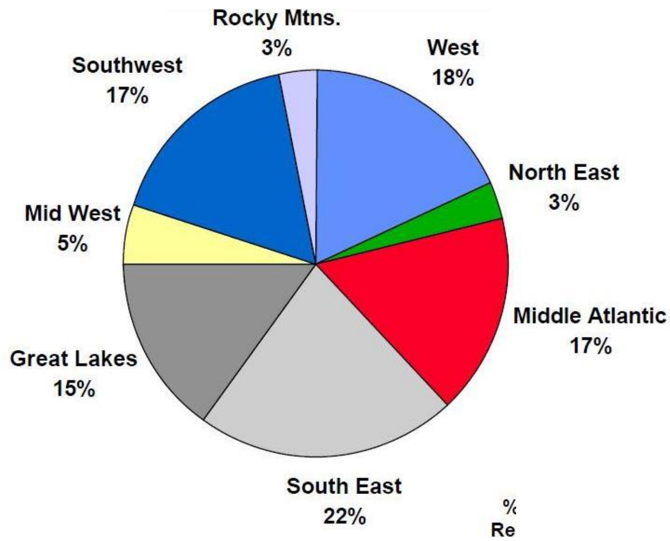


Figure 4.1 Regional Graywater Reuse Among Graywater Reusers (Photo credit: The NPD Group, 1999)

	% of Households Reusing Graywater*	US Households	Indexed to US Households
	%	%	
Alabama	1.3	1.5	87
Arizona	3.6	1.7	212
Arkansas	1.5	1.1	136
California	13.9	9.7	143
Colorado	1.6	1.4	114
Connecticut	0.4	0.9	44
Delaware	0.1	0.3	33
District of Columbia	0.2	0.3	67
Florida	6.1	5.1	120
Georgia	2.2	2.2	100
Idaho	0.4	0.6	67
Illinois	2.4	4.4	55
Indiana	1.6	2.2	73

Figure 4.2 % Households Resuing Graywater by State Vs. Total US Households (Photo Credit: The NPD Group 1999)

Three adoption rate scenarios were identified for the City of Fort Collins Utilities service area. The adoption rate scenarios were developed in order to reveal the 'worst case scenario', i.e.

the largest impact and associated largest reduction in return flows. The adoption rate scenarios identified were:

1. 5% adoption in existing development, 80% adoption in new and redevelopment areas.
2. 10% adoption in existing development, 100% adoption in new and redevelopment areas.
3. 100% adoption in existing development, 100% adoption in new and redevelopment areas.

4.2.2 Fort Collins Population Statistics and Water Use Data

Population information for Fort Collins including the existing population and projections for new and redevelopment populations were provided by the City of Fort Collins Utilities. Additionally, data on base flows to the Drake and Mulberry domestic wastewater treatment plants was provided by Fort Collins Utilities. The average graywater generation rates, toilet demands, and water use trends were obtained from the Residential End Uses of Water Study – Fort Collins Site Report Update from 2012 produced by the American Water Works Association. The adoption rate scenarios described above (4.2.1) were utilized in addition to end-use application scenarios outlining the percentage of the 'graywater adopting public' that reuse graywater for toilet flushing or irrigation.

Table 4.1 shows the population information used for this study. Table 4.2 shows the graywater generation and water use information for the City of Fort Collins.

Table 4.1 Fort Collins Utilities Service Area Population Statistics

Fort Collins Service Area PopulatioInformation	
Category	**Population**
Existing Population	125,751
Projected Future Population (2035) New Development	17,681
Projected Future Population (2035) Redevelopment	7,373
Total Future Population (2035)	150,805

Table 4.2 Graywater Generation and Indoor Water Use (REUWS, 2012)

Graywater Generation and Indoor Water Use Information	**GPCD**
Average per Capita Indoor Demand	45.7
Average per Capita Graywater Generated	19.9
Average Toilet Flushing Water per Capita	11.2

The goal of scenario setup was to identify the possible percentages of the entire population in the Fort Collins service area that will adopt graywater reuse, and further subcategorize these percentages by end-use applications such as 100% adopting toilet flushing, 100% adopting irrigation, or 25% adopting toilet flushing and 75% adopting irrigation (Figure 4.3).

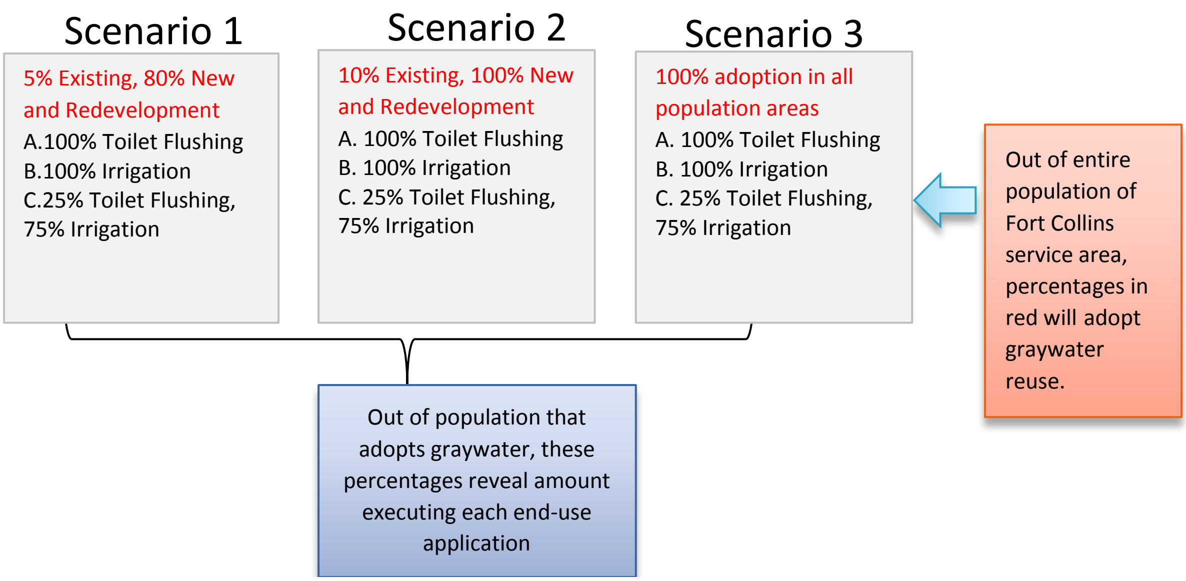


Figure 4.3 Adoption Rate Scenarios in Fort Collins, Colorado

Scenario 1:5% adoption in existing development, 80% adoption in new and redevelopment areas

A. 100% of population that adopt graywater reuse use graywater for toilet flushing.

B. 100% of population that adopt graywater reuse use graywater for irrigation.

C.25% of population that adopt graywater reuse use graywater for toilet flushing, 75% of population that adopt graywater reuse use graywater for irrigation.

Scenario 2: 10% adoption in existing development, 100% adoption in new and redevelopment areas.

A. 100% of population that adopt graywater reuse use graywater for toilet flushing.

B. 100% of population that adopt graywater reuse use graywater for irrigation.

C.25% of population that adopt graywater reuse use graywater for toilet flushing, 75% of population that adopt graywater reuse use graywater for irrigation.

Scenario 3: 100% adoption in Existing, New and Redevelopment Areas

A. 100% of population that adopt graywater reuse use graywater for toilet flushing.

B. 100% of population that adopt graywater reuse use graywater for irrigation.

C.25% of population that adopt graywater reuse use graywater for toilet flushing, 75% of population that adopt graywater reuse use graywater for irrigation.

Irrigation return flows associated with subsurface irrigation were neglected since return flows would be also be associated with irrigation using municipal water in the same amount. The irrigation season was assumed for be seven months from April-October.

4.2.3 Governing Equations for Impact to Return Flow Calculations

The governing equations used in the comprehensive spreadsheet developed to calculate the impacts to return flows associated with graywater reuse used several inputs displayed in the tables below. Table 4.3 exhibits the portion of the spreadsheet in which varying adoption rates can be entered to view the associated impacts to return flows. Table 4.4 exhibits the average base use as measured by the City of Fort Collins water meters, from the years 2008-2013. Table 4.5 shows the graywater generation and indoor water use information from Table 4.2 presented in monthly figures in AF/Month.

Table 4.3 Graywater Reuse Maximum Estimated Adoption Rates in Fort Collins

Population Category	Maximum % Adoption
Existing	0.05
New Development	0.8
Redevelopment	0.8

Table 4.4 Average Base Use City of Fort Collins Data 2008-2013

Month	Base Water Use	Units
28 Day Month	0.0079	AF/capita
30 Day Month	0.0084	AF/capita
31 Day Month	0.0087	AF/capita

Table 4.5 Monthly Graywater Generation and Indoor Water Use Data (REUWS, 2012)

Month	AF/Month		
	Average Per Capita Indoor Demand	Average Per Capita Graywater Generated	Average Toilet Flushing Water per Capita
January	0.0043	0.0019	0.0011
February	0.0039	0.0017	0.0010
March	0.0043	0.0019	0.0011
April	0.0042	0.0018	0.0010
May	0.0043	0.0019	0.0011
June	0.0042	0.0018	0.0010
July	0.0043	0.0019	0.0011
August	0.0043	0.0019	0.0011
September	0.0042	0.0018	0.0010
October	0.0043	0.0019	0.0011
November	0.0042	0.0018	0.0010
December	0.0043	0.0019	0.0011

Scenario A and B Equations: 100 % Toilet Flushing and 100% Irrigation

1. *Contributing Population = (Existing Population * Existing Maximum Adoption %) + (New Development Population * New Development Maximum % Adoption) + (Redevelopment Population * Redevelopment Maximum % Adoption)*

2. *Base Flows to WWTP (AF/Month) = Average Base Use City of Fort Collins Data 2008-2013 (AF/Month) *Total Population*

3. [1]*Graywater Generated (AF/Month) = Average Per Capita Graywater Generated (AF/Month)*Contributing Population*

4. *Toilet Demand (AF/Month) = Average Toilet Flushing Water Per Capita (AF/Month) * Contributing Population*

5. *Graywater Not Utilized for Toilet Flushing (AF/Month) = Graywater Generated – Toilet Demand*
6. *Flows to WWTP with Graywater Reuse (AF/Month) = Base Flows to WWTP – Toilet Demand*

7. *Return Flow % Reduction from Base Flows = ((Base Flows to WWTP – Flows to WWTP with Graywater Reuse)/(Base Flows to WWTP))* 100*

[1]For Scenario B, Irrigation graywater is not collected during non-irrigation months. Irrigation occurs April-October.

<u>Scenario C Equations: 25% Toilet Flushing, 75% Irrigation</u>

1. *Contributing Population = (Existing Population * Existing Maximum Adoption %) + (New Development Population * New Development Maximum % Adoption) + (Redevelopment Population * Redevelopment Maximum % Adoption)*

2. *Population Contributing to Toilet Flushing = Contributing Population * 25%*

3. *Population Contributing to Irrigation = Contributing Population * 75%*

4. *Base Flows to WWTP (AF/Month) = Average Base Use City of Fort Collins Data 2008-2013 (AF/Month) *Total Population*

5. *Toilet Demand (AF/Month) = Average Toilet Flushing Water Per Capita (AF/Month)* Population Contributing to Toilet Flushing*

6. *[1]Irrigation Graywater (AF/Month) = Average Per Capita Graywater Generated (AF/Month) * Population Contributing to Irrigation*

7. *Flows to WWTP with Graywater Reuse (AF/Month) = Base Flows to WWTP – Toilet Demand – Irrigation Graywater*

8. *Return Flow % Reduction from Base Flows = ((Base Flows to WWTP – Flows to WWTP with Graywater Reuse)/(Base Flows to WWTP))* 100*

[1]For Scenario C, Irrigation graywater is not collected during non-irrigation months. Irrigation occurs April-October.

4.3 Results and Discussion

4.3.1 Current Impacts to Return Flows

Impacts to return flows based on an existing (2014) population of 125,751 in the City of Fort Collins Utilities service area were determined for adoption rates of 5%, 10%, and 100%. It is important to note that when current scenarios were explored, there was no new and redevelopment population. It is also important to note that any impacts to wastewater return flows would be the same impacts as those in the form of reduction on demand for supply water. Figure 4.4 shows a graphical depiction of the impact to return flows categorized by end-use application, and compared to the base use (or flows to the wastewater treatment plants without graywater reuse) for Scenario 1, 5% adoption in existing. The graph shows very little difference in return flows to the wastewater treatment plants on a monthly basis associated with 5% of the existing development adopting graywater reuse. The percent reduction between base use and flows to the wastewater treatment plants in this scenario barely exceeds 1% (Figure 4.11); implying minimal reductions in return flows will likely not have an effect on any water rights concerns.

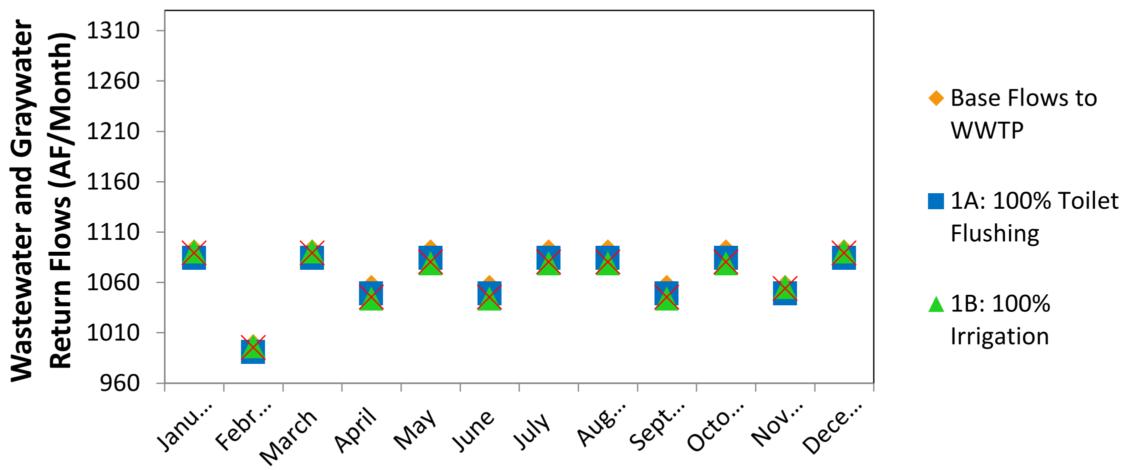


Figure 4.4 Current Impacts to Return Flows, Scenario 1 (2014) 5% Adoption in Existing

Figure 4.5 shows the impacts to return flows associated with Scenario 2, 10% adoption of graywater reuse in the City of Fort Collins. As expected, this scenario outlines larger reductions in return flows in contrast to 5% adoption, however still does not pose any negative water rights implications for the City of Fort Collins Utilities. If 10% of existing development were to start reusing graywater, the municipality could expect to observe a maximum difference in return flows of 2.8% (Figure 4.11).

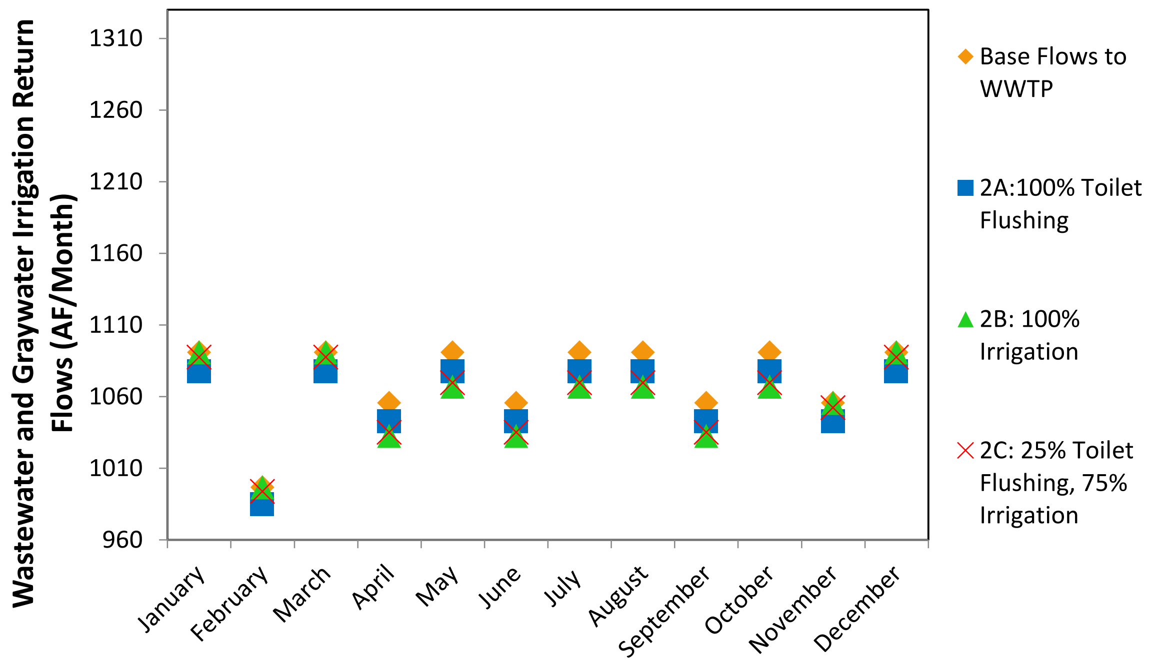


Figure 4.5 Current Impacts to Return Flows, Scenario 2 (2014) 10% Adoption in Existing

Figure 4.6 shows the impacts to return flows associated with Scenario 3, 100% adoption of graywater reuse in the City of Fort Collins. As expected, this scenario outlines larger reductions in return flows in contrast to Scenario 1 and 2, and begins to exhibit the extent of return flow reductions that may pose negative implications for the City of Fort Collins water allocations. If 100% of existing development were to start reusing graywater, the municipality could expect to observe a maximum difference in return flows of 21% (Figure 4.11).

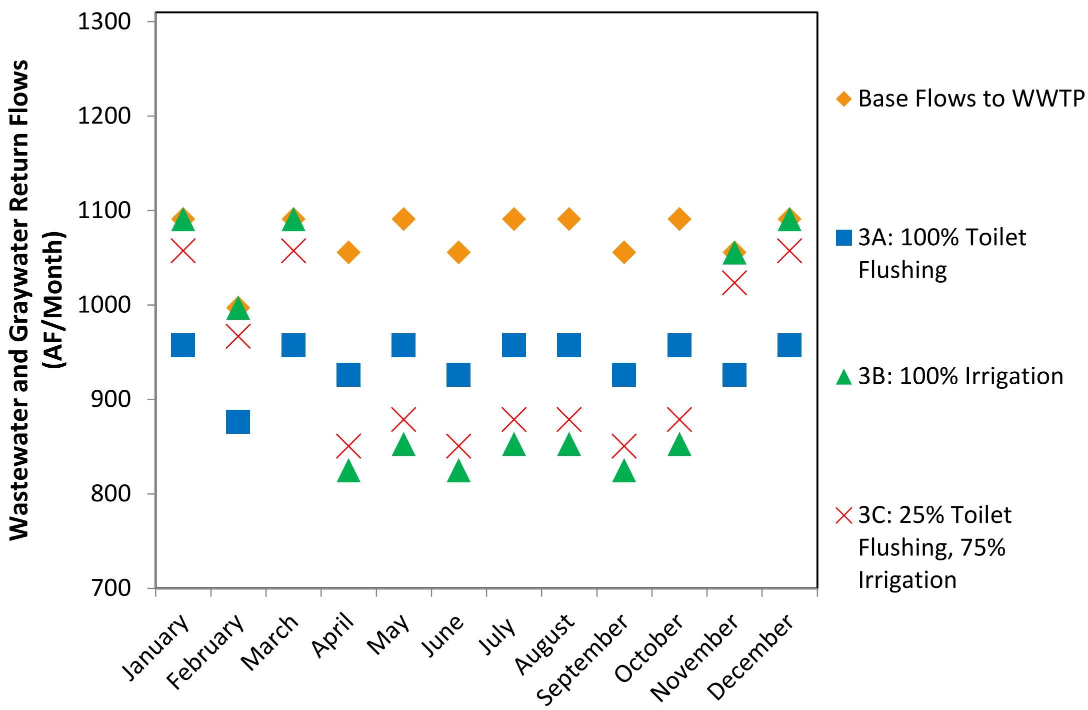


Figure 4.6 Current Impacts to Return Flows, Scenario 3 (2014) 100% Adoption in Existing, New and Redevelopment

4.3.2. Future Impacts to Return Flows

Future impacts to return flows were calculated using an existing population of 125, 751, a future new development population of 17,681, and a future redevelopment population of 7,373. These projections were provided for the year of 2035. Because water conservation is an increasingly popular concept, it is expected that future new and redevelopment projects will highly consider water reuse at their facilities; some facilities may even incorporate water reuse into the original layout and design as a building efficiency requirement. For these reasons, new and redevelopment adoption rates were assumed to either be 80% or 100%. Though adoption rates have the realistic possibility of being less than these predictions, the concluding calculations will capture the impacts to return flows assuming the most extreme situation. Figure 4.7 shows the impacts to return flows associated with a 5% adoption in existing development and an 80% adoption in new and redevelopment areas in 2035. It can be seen in Figure 4.7 that base flows to the wastewater treatment plant increase by approximately 200 AF/month from the year 2014 to the year 2035 due to increased total population. In this scenario, return flows within the City of Fort Collins Utilities service area would see a maximum reduction of nearly 4% (Figure 4.11), or approximately 48 AF/month. Municipalities deal with extremely large figures of water use, and 48 AF/month is unlikely to be a threat to any water allocations or water rights of concern. It should be noted that irrigation end-use applications and the combined adoption scenario of 25% toilet flushing and 75% irrigation have larger reductions in return flows because they utilize a larger portion of the collected graywater. The amount of toilet demand per capita (11.2 gpcd) is usually lower than the amount of graywater generated (19.9 gpcd) (REUWS, 2012), therefore some graywater is ultimately returned to the sewer and does not affect return flows in the toilet flushing application.

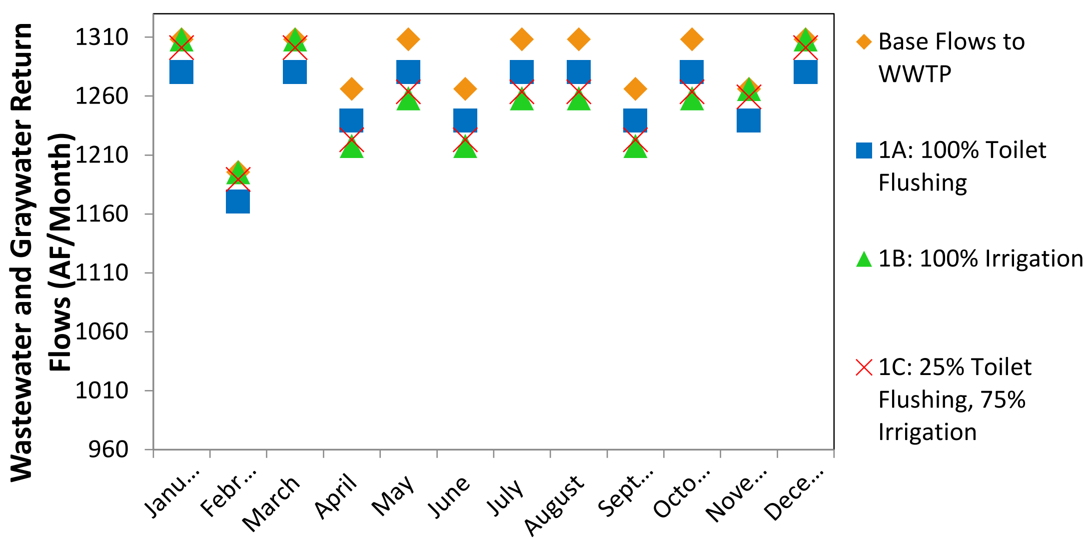


Figure 4.7 Future Impacts to Return Flows, Scenario 1 (2035) 5% Adoption in Existing, 80% New and Redevelopment

Figure 4.8 shows the future impacts to return flows associated with graywater reuse for Scenario 2, 10% adoption in existing development, and 100% adoption in the new and redevelopment areas of the Fort Collins Utilities service area. This scenario could result in a 5.5% reduction in return flows (Figure 4.11). Although this situation poses the highest impact to return flows, a 5.5% reduction is equivalent to a difference of 70 acre-feet of water per month, which is not an unreasonable amount of water to 'lose' in return flows.

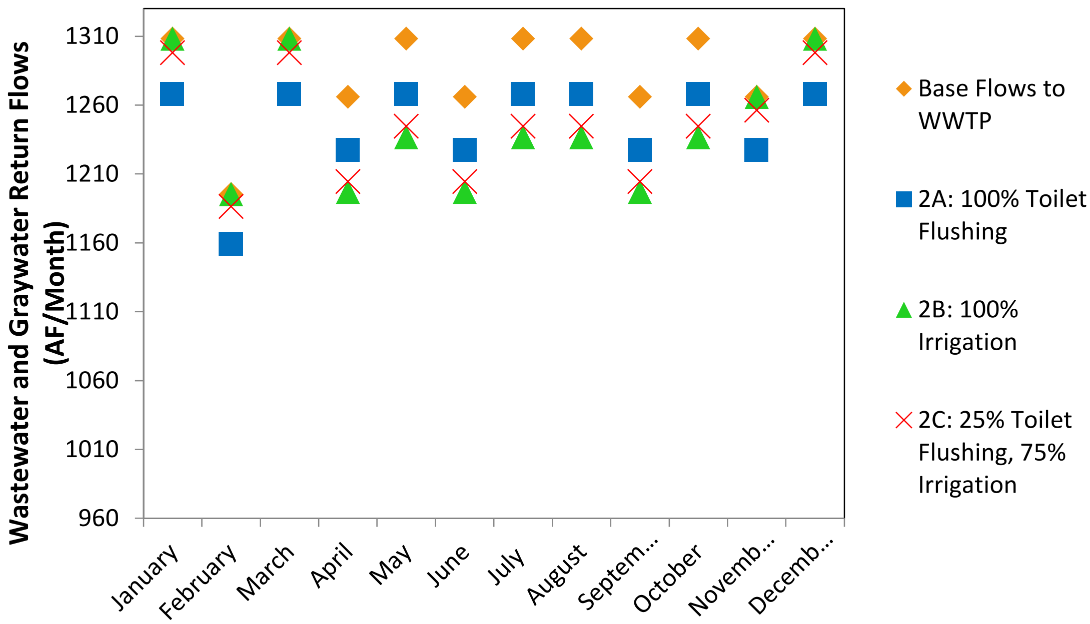


Figure 4.8 Future Impacts to Return Flows, Scenario 2 (2035) 10% Adoption in Existing, 100% New and Redevelopment

Figure 4.9 shows the future impacts to return flows associated with graywater reuse for Scenario 3, 100% adoption in existing development, and 100% adoption in the new and redevelopment areas of the Fort Collins Utilities service area. While this scenario is not realistic, it represents the potential impact in areas that are expected to have a large amount of new and redevelopment. This scenario could result in a 21% reduction in return flows (Figure 4.11). This situation poses the highest impact to return flows; a 21% reduction is equivalent to a difference of 286 acre-feet of water per month, which is when the water rights concerns may start to come to light. However, it is important to note that this scenario is unlikely to happen and is a demonstration of how much graywater reuse could affect the city if everyone were to implement this strategy. Also of note is that in new development areas, historical return flows from wastewater facilities have not been established and therefore decreasing wastewater flows is not as much of a concern in these areas as is for existing development areas with historical wastewater discharge.

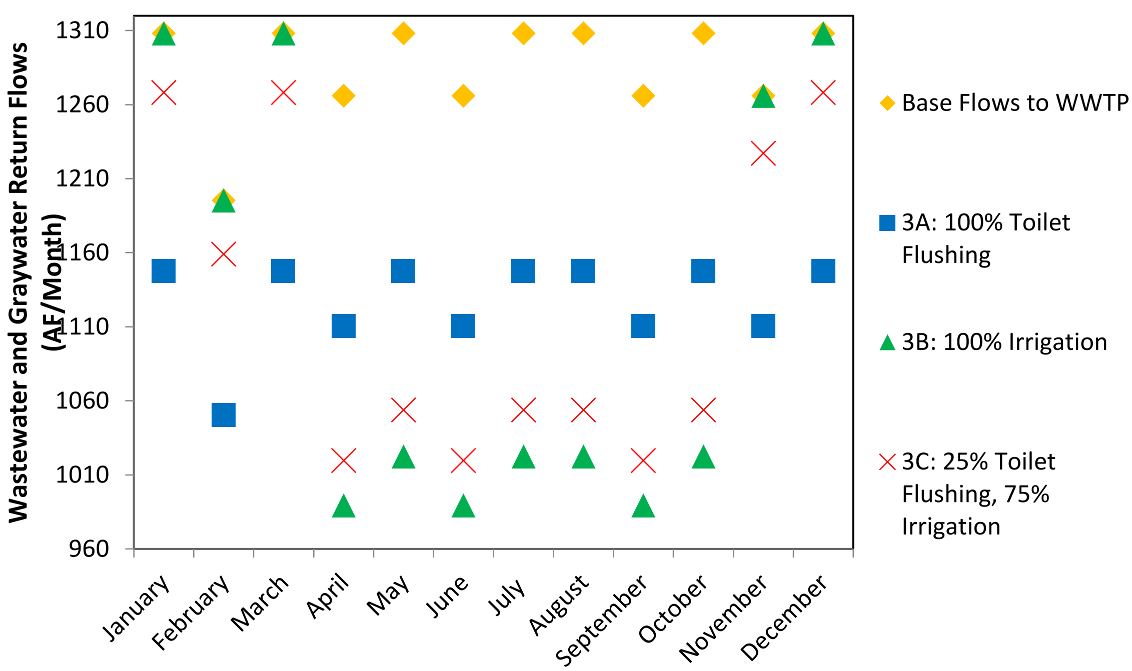


Figure 4.9 Future Impacts to Return Flows, Scenario 3 (2035) 100% Adoption in Existing and New and Redevelopment

4.3.3 Realistic Impacts to Return Flows

Because graywater reuse systems for toilet flushing have a higher possibility of human contact, they are usually more complex treatment systems that are more expensive and harder to construct (Bergdolt et al. 2011). Thus, it is expected that a smaller portion of the amount of people who are expected to adopt graywater reuse will do so for indoor toilet flushing. Irrigation systems are easier to construct and operate, making them a more viable choice for a larger number of people. The reuse scenario, 25% of those adopting graywater reuse using graywater for toilet flushing and 75% using graywater for irrigation, was developed to capture this concept. Figure 4.10 outlines a scenario comparing base flows to 5%, 10% and 100% adoption rates in 2014 and 2035. This graph shows that in the likely event that a smaller portion of graywater is reused for toilet flushing than is used for irrigation, the impact to return flows is very minimal. In this graph, the vertical distances between identical data point shapes (comparing squares to other squares for the same month) indicate the difference between base flows with and without graywater reuse, also known as the percent reduction in return flows. For example, in April of 2035, return flows are 60 acre-feet lower than base flows due to graywater reuse, resulting in a 4.9% base flow reduction (Figure 4.11). As expected, Scenario 3 C: 100% Adoption in existing and new and redevelopment areas show the lowest wastewater and return flows associated with graywater reuse, at around 850 AF/month in 2014 and 1020 AF/month in 2035.

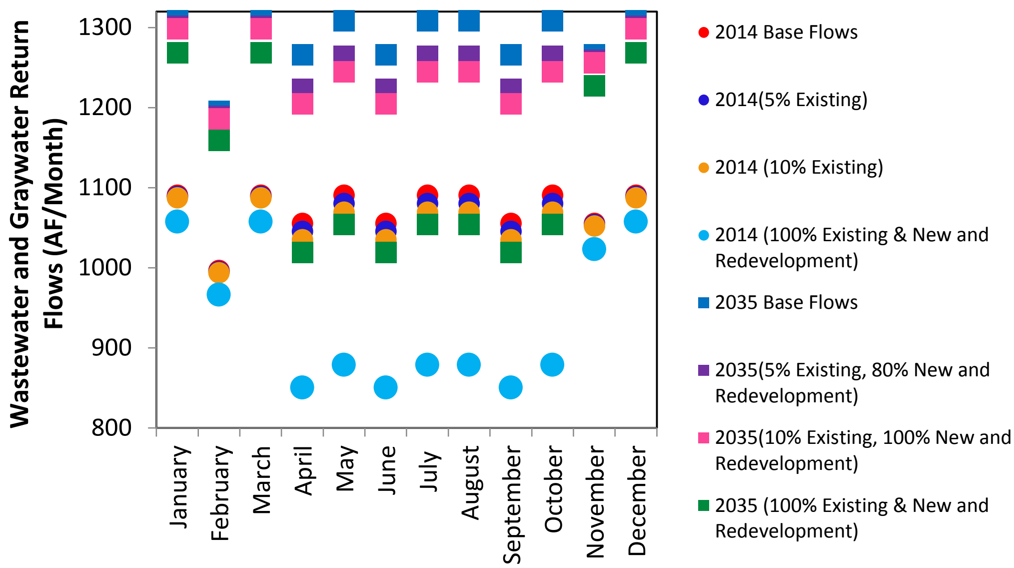


Figure 4.10 Impact to Return Flows for 25% Toilet Flushing, 75% Irrigation in 2014 and 2035

4.4 Summary and Conclusions

Projected impacts to return flows associated with graywater reuse in Fort Collins, Colorado are minimal in Scenarios 1 and 2, reaching a maximum reduction of 70 AF/month or 5.5% (Figure 4.11). In particular, Scenario 2B: 10% adoption in existing, 100% in new and redevelopment areas, with 100% irrigation, reach the *highest* impacts due to the fact that graywater generation is typically lower than irrigation demand, meaning all of the graywater collected is used to meet irrigation demand. Captured in the "A" portion (100% Toilet Flushing) of all scenarios is the fact that toilet demand is lower than irrigation demand and lower than graywater generation rates, and therefore some of the graywater collected ultimately ends up being returned to the wastewater collection system. Scenario 3 was developed to mimic and illustrate the improbable situation in which 100% adoption occurred in all population areas. In all three scenarios, water demand on the freshwater supply will be reduced in the same amount that wastewater is produced; meaning impacts to return flows are equivalent to reduction in demand on the front end. Of note is that graywater reuse reduces municipal demand by the same percentage by which wastewater production is impacted. Therefore, there is an opportunity for applying source water not withdrawn for municipal supply to meet downstream water needs that may not be met through wastewater discharge.

Figure 4.11 summarizes the possible percent reduction in return flows for each of the adoption scenarios described above. In the case that 10% of the existing Fort Collins population adopted graywater reuse (Scenario 2), and every new or redevelopment plot was using graywater by 2035, return flows would reduce by ~5.5%, or 70 acre-feet/month. This situation would likely not have any negative effects on water rights. Fort Collins Utilities encompasses land that, for the most part, is already being utilized. With only a small amount of vacant land, there is a smaller amount of expected population growth within their service area. In newer cities that are currently being developed, there is a possibility of larger reductions in return flows due to graywater reuse. In a hypothetical scenario (Scenario 3) developed to capture this concept, the Fort Collins Utilities case study was used and it was assumed that 100% of the existing and projected populations adopt graywater reuse. This scenario would result in a return flow reduction of 21%, or 286 acre-feet/month. Of note is that in most cases, in new cities or development areas there is not a historical precedent for generation of wastewater flows and therefore a decrease in wastewater discharge from that projected without graywater reuse is not likely to create water rights issues. Graywater reuse results in the preservation of source waters, meaning water that would normally be withdrawn is left in the original flows. In summary, water rights issues become less complex in new development areas where graywater reuse is most likely to be adopted.

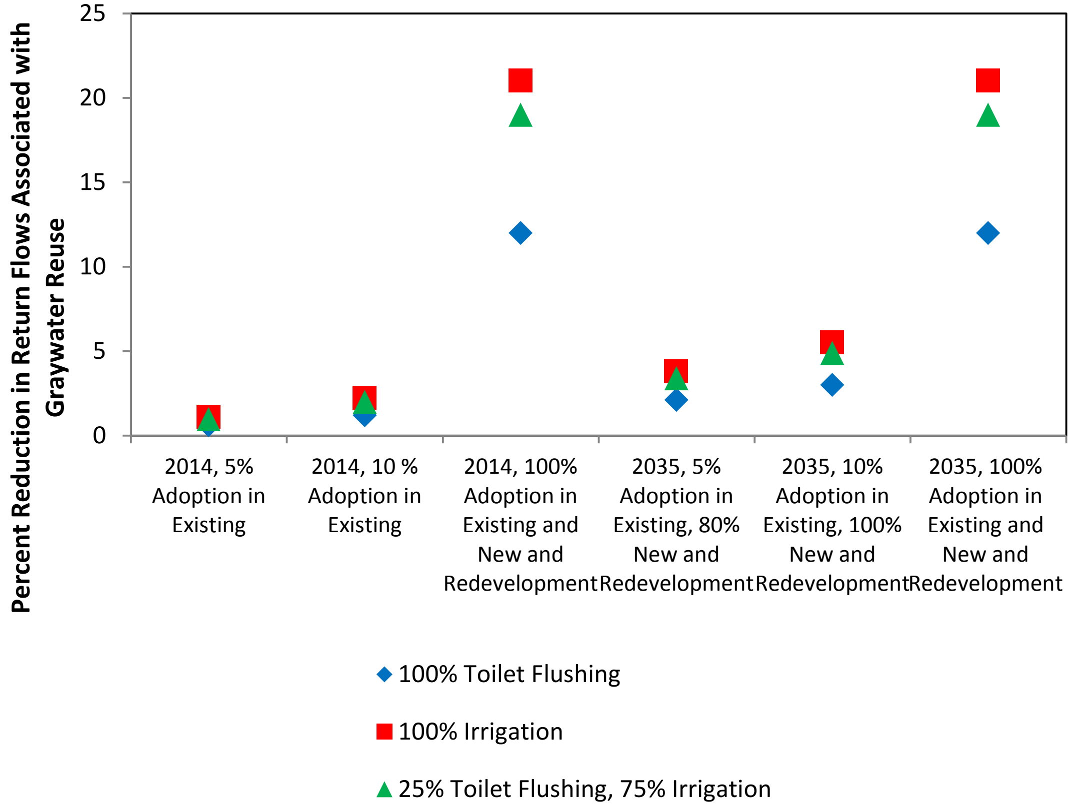


Figure 4.11 Percent Reduction in Return Flows Associated with Graywater Reuse in Fort Collins, Colorado for Scenarios 1, 2, and 3 in 2014 and 2035

5.0 RECOMMENDATIONS FOR THE CITY OF FORT COLLINS GRAYWATER USE ORDINANCE

5.1 Introduction

In May of 2013, Colorado Governor John Hickenlooper signed House Bill 13-1044 legalizing the use of graywater in the state. The regulation drafting process for Regulation 86, Graywater Control Regulation, began in August, 2013 and is currently still underway. The process has included stakeholder workgroup efforts characterized as “Use/Treatment” and “Local Implementation” being led by the Colorado Department of Public Health and Environment Water Quality Control Commission. Regulation 86 will identify the allowed sources of graywater, the approved uses of graywater, and will describe the minimum requirements and standards for reusing graywater in non-potable applications (5 CCR § 1002-86).

When implemented, cities and counties around the State of Colorado will have the opportunity to choose whether they will implement graywater reuse within their local regulations, and it will be at their discretion to adopt any or all of the graywater uses and design criteria described in Regulation 86. Additionally, cities and counties will have to abide by the minimum requirements outlined by the formal regulation, however can implement more stringent requirements if desired (5 CCR § 1002-86).

The City of Fort Collins expects to adopt graywater reuse into their local regulations and expressed interest in exploring what a city ordinance for graywater use should include. Based on an extensive literature review, operational experiences, and involvement in the stakeholder process for Regulation 86, recommendations regarding graywater use have been developed in the form of Best Management Practices documents, graywater factsheets, and criteria to include in a city ordinance. A complete process map for graywater projects at the city, county, and state level will be developed pending the completion of Regulation 86 in the future. Additionally, a model city ordinance for graywater use will be developed when all regulatory hurdles in the State of Colorado are resolved.

5.2 Deliverables for the City of Fort Collins Utilities

5.2.1 Best Management Practices

Best Management Practices (BMPs) are techniques that, when implemented, will reduce potential issues associated with a graywater reuse system with the intention of protecting human health and environmental quality. They are designed to increase safety, ease of use, and promote successful application of graywater reuse systems. The BMP documents developed cover subsurface and drip irrigation applications, toilet flushing, and general considerations. The specific BMP bullet points originate from operational experiences with graywater use, the available literature on graywater use, other states/counties that have previously adopted graywater use and implemented BMPs such as Arizona and California, and the draft of Regulation 86 released on June 30, 2014 which specifies control measures required for graywater use. The BMP documents cover topics that are crucial to a functioning graywater system and are geared towards the graywater user and/or operator therefore should be read and followed in their entirety by any individual or business that is planning on implementing graywater reuse. The BMP documents for general considerations, subsurface and drip irrigation, and toilet flushing can be found in Appendix A, B, and C, the end of this report. These documents will be available for public use.

5.2.2 Considerations for Inclusion in a City Ordinance

Two documents titled 'Considerations for Inclusion in a City Ordinance Allowing Toilet Flushing with Graywater' and 'Considerations for Inclusion in a City Ordinance Allowing Subsurface or Drip Irrigation with Graywater' were created for the City of Fort Collins Utilities in order to assist the city ordinance development process. Whereas the Best Management Practices documents were developed to assist the general public in implementing and operating successful graywater reuse systems, the 'Considerations for Inclusion in a City Ordinance' documents were developed for administrative purposes and are intended to be used as recommendations for development of a city ordinance when graywater use is adopted by the City of Fort Collins. For example, the 'Considerations for Inclusion in a City Ordinance Allowing Subsurface or Drip Irrigation with Graywater' includes a bullet point outlining the necessary design components for a graywater storage tank, including the minimum tank volume and plumbing requirements. The BMP document for subsurface and drip irrigation does not state these same criteria because it is assumed that the responsible party will, prior to constructing, obtain the appropriate information regarding design components and complete a graywater permit application including system drawings and specifications to be submitted to the City of Fort Collins for review. The BMP document rather states the allowed graywater storage time for use in subsurface or drip irrigation. The 'Considerations for Inclusion in a City Ordinance Allowing Toilet Flushing with Graywater' and 'Considerations for Inclusion in a City Ordinance Allowing Subsurface or Drip Irrigation with Graywater' can be found in Appendix D and E attached to the end of this report.

5.2.3 Recommendations for Graywater Permit Requirements

The current draft of Regulation 86 states that the city or county ordinance or resolution "must include a requirement for a searchable tracking mechanism that is indefinitely maintained by the local agency" and that the ordinance or resolution "must include a requirement for a local agency to develop a graywater design criteria document" and that the ordinance or resolution "must include a requirement and process for the local agency to approve or deny the installation of new graywater treatment works or modification of an existing graywater treatment works" (5 CCR § 1002-86). The 'Recommendations for Permit Requirements' document outlines what should be included in a graywater system permit including the design submittal requirements such as calculated irrigation areas, system drawings, and proof of operations and maintenance manual. Recommendations were provided in efforts to employ a minimally invasive permitting system. It is predicted that graywater adoption will be hindered if very stringent permitting systems exist requiring frequent system monitoring, inspection, and submittal of water quality measurements. However, the importance of tracking newly installed graywater systems is also recognized from a municipality standpoint. The 'Recommendations for Permit Requirements' document can be found in Appendix F at the end of this report.

5.2.4 Graywater Use Factsheets

Instructional factsheet I entitled 'The Basics of Graywater Use for Irrigation and Toilet Flushing' was developed to familiarize and educate the reader about graywater reuse for irrigation and toilet flushing. Instructional factsheet I includes the three Best Management Practices documents attached as appendices. Instructional factsheet II entitled 'How to Install a Graywater Use System for Outdoor Irrigation' was developed to provide step-by-step guidance for the installation of a graywater reuse system for irrigation, including links to more detailed instructions for each step. When used together, the factsheets provide a comprehensive review of graywater use for irrigation and toilet flushing including guidance through the decision-making and design process. These instructional factsheets will be available for public use and are attached in Appendix G and H at the end of this report.

5.3 Summary

The City of Fort Collins intends to adopt Regulation 86, Graywater Control Regulation, when it is finalized in the future. Recommendations for criteria within the city ordinance have been developed in a two-document series and will be given to the City of Fort Collins Utilities for use. When a city ordinance is developed after the regulation is adopted, it will be important to provide the residents of Fort Collins with accurate information regarding the decision-making, design, and installation process for graywater reuse systems. A series of documents listed below have been developed to both assist the City of Fort Collins in their ordinance drafting process, and assist residents of Fort Collins interested in graywater reuse.

- Best Management Practices documents
    - General Considerations (Appendix A)
    - Subsurface and Drip Irrigation (Appendix B)
    - Toilet Flushing (Appendix C)
- Considerations for Inclusion in a City Ordinance
    - Allowing Toilet Flushing with Graywater (Appendix D)
    - Allowing Subsurface or Drip Irrigation with Graywater (Appendix E)
- Recommendations for Graywater Permit Requirements (Appendix F)

- Graywater Use Factsheets
    - The Basics of Graywater Use for Irrigation and Toilet Flushing (Appendix G)
    - How to Install a Graywater Use System for Outdoor Irrigation (Appendix H)

6.0 ASPEN RESIDENCE HALL PILOT-SCALE GRAYWATER REUSE SYSTEM FOR TOILET FLUSHING

6.1 Introduction

A demonstration graywater treatment system for toilet flushing at Aspen Residence Hall on the Colorado State University campus has been operating for research purposes since the fall of 2012. Various approaches for filtration and disinfection of graywater were investigated from spring of 2011 through spring of 2012 before the most appropriate design was identified and finalized (Hodgson, 2012). From the fall of 2012 to the spring of 2013, pathogen disinfection and regrowth studies were performed using a plumbed demonstration toilet, and the resulting long-term system performance was evaluated (Wiles, 2013). In the fall of 2013, a variance was approved by the Colorado State Plumbing Board to continue operation of the pilot-scale treatment system given that all plumbing to and from the system was brought up to code. The Graywater Control Regulation (Regulation 86) is currently still in the drafting phases and thus a variance was required for legal approval of the system. The system was inspected by a State Plumbing Board representative and necessary updates were performed by Colorado State University Facilities Management plumbers. The goal of this portion of the pilot-scale graywater reuse project was to assess the results of the first actual operational period where students were flushing with treated graywater in their residence hall rooms. The graywater reuse system is connected to 14, first-floor rooms in Aspen Residence Hall and collects graywater from the total occupancy of the 14 rooms (occupancy varies from year to year), however students were given the opportunity to choose if they wanted their toilets to be flushed with treated graywater. This chapter provides the results of the first operational period from both a design standpoint and student opinion standpoint, and outlines the suggested improvements for the future operation of this system.

6.2 Transitioning to Full-Scale Student Flushing Period

6.2.1 System Description

The graywater reuse system for toilet flushing at Aspen Residence Hall collects water from 14, first-floor residence hall rooms. The current system is designed to process 300 GPD of graywater, however the actual amount processed when the system is in full-operation mode depends on the number of students flushing with graywater. The system design goal was to construct a cost-effective graywater reuse system for toilet flushing while ensuring safety and eliminating public health risks. Graywater from student's showers and sinks is collected in a storage tank before gravity flowing through a coarse filter where is it then dosed with chlorine. Graywater enters the disinfection tank and is dyed blue before being pumped to student's toilets (Figure 1).The design consists of coarse filtration through a Matala medium density filter chosen because of its low operating costs and minimal maintenance requirements in contrast to sand filters and cartridge filters (Hodgson, 2012). Disinfection occurs through the volumetric injection of chlorine (sodium hypochlorite) into the raw graywater stream en route to the disinfection contact tank. Chlorine was selected as the disinfectant because experimental studies showed chlorine provided a greater inactivation of *E.Coli*, *S. enterica*, *P. aeruginosa*, and MS2 in contrast to UV or ozone disinfection (Hodgson, 2012). The system updates introduced between the fall of 2013 and spring of 2014 include: Online chlorine residual monitoring using the Chemtrac HydroACT600 multi-parameter chlorine analyzer and total chlorine probe, blue-dye injection using a Stenner fixed output peristaltic metering pump, a pressure booster tank, labels for all graywater piping including flow directions, and copper distribution piping replacements for PVC pipes identified by the State Plumbing Board inspector. Additionally, the automatic flush timer used to previously simulate students flushing toilets was disconnected. In full operation mode, no flush simulations are needed.

A treatment process schematic can be seen in Figure 6.1 and an updated photograph of the graywater system in Figure 6.2.

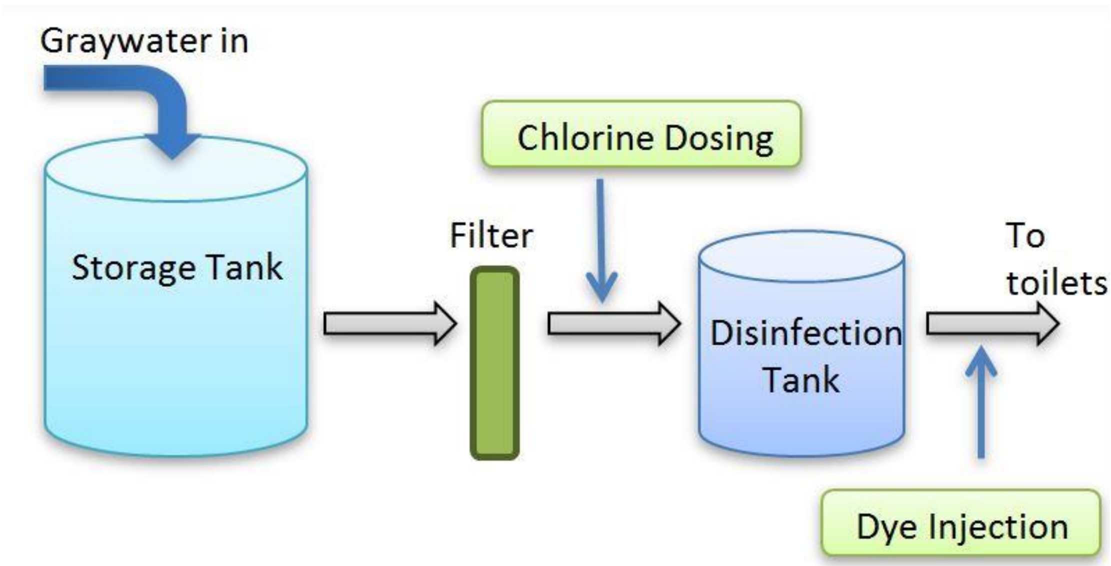


Figure 6.1 Graywater Treatment Process Schematic

1) **Influent Graywater** – Untreated graywater from showers and sinks
2) **Coarse Filters A, B, and C** – Three coarse Matala filters filter the graywater before entering the composite tanks, and after the composite tank before the disinfection tank
3) **Disinfection Tank** – 65 gallon tank stores treated graywater for toilets
4) **Chemical Tank** – 15 gallon chemical tank stores NaOCl (Clorox Bleach) solution
5) **Blue-Dye Tank**- 15 gallon tank stores diluted Brac Blue dye (Not pictured)
6) **Chemical Pump 2**- Stenner fixed output peristaltic metering pump doses blue-dye into the graywater (Not pictured)
7) **Master Pump** – Grundfos pressure booster pump distributes treated graywater to toilets
8) **Pressure Tank**
9) **Chemical Pump 1** – Stenner fixed output peristaltic metering pump doses chemical into graywater
10) **Pump Control Module (PCM)** – Stenner control module meters chemical dose of peristaltic pump
11) **Solenoid Valve # 1, 2, and 3** – Electronic solenoid valve controls influent freshwater into the disinfection tank
12) **Solenoid #4** – Electronic ball valve controls influent graywater from composite tank into the disinfection tank
13) **Ultrasonic Level Sensor** – Flowline ultrasonic level controls the graywater ball valve and freshwater solenoid valve to refill disinfection tank when necessary
14) **Composite Tank** – 300 gallon tanks (A and B) collects, composites and settles initial graywater. B is not utilized currently.
15) **Flow Water Meter 1** – Records the amount of water passing through the meter and works with chemical pump to dose chlorine volumetrically.
16) **Chemical Injection** – Point at which chlorine is dosed in-line
17) **Chemtrac Total Chlorine Probe and Flow Cell** – Measures chlorine residual in disinfection tank and is reported on the chlorine analyzer.
18) **Control Panel** – Cabinet in which electrical components used for automation are connected
19) **Multi-Parameter Chemtrac Chlorine Analyzer** – HydroACT 600 measures chlorine residual in the disinfection tank and logs hourly chlorine residual online
20) **Test Toilet**- Demonstration toilet used for laboratory studies
21) **Backflow Preventer**- Protects against cross contamination between freshwater and treated graywater
22) **Distribution Valve** – Allows treated graywater to be distributed to students toilets
23) **Manual Bypass Valve**- Manual valve turned to the open position bypasses system
24) **Treated Effluent** – Graywater that has been filtered and disinfected and is ready to be used for toilet flushing

6.2 Updated Graywater Reuse Treatment System located in Aspen Residence Hall

Graywater from student showers and bathroom sinks is collected in one of the 300-gallon storage tanks located in the basement of Aspen Residence Hall. Appendix I at the end of this report contains the Standard Operating Procedure (SOP) for the graywater reuse system at Aspen Residence Hall. The other 300-gallon storage tank is not currently utilized and is for future use if laundry water effluent is utilized as an additional graywater source. The storage tank accomplishes settling of large debris and is designed for a graywater residence time of 24 hours based on a typical graywater production rate of 295 gallons. The storage tank releases graywater through a coarse Matala filter before passing through flow meter #1 (Figure 6.1), signaling chemical pump #1 to dose sodium hypochlorite in the raw graywater stream. The release of graywater is triggered by the ultrasonic low water level sensor; when water level 2 (Figure 6.3) is sensed, solenoid valve #4 opens allowing graywater to flow to the disinfection tank designed for a 1-hour contact time. If graywater supply is insufficient and water level 3 (Figure 6.3) is sensed, the freshwater solenoid valve #3 opens allowing supplemental potable water to flow into the disinfection contact tank until water level 1 (Figure 6.3) is reached. When a drop in water pressure below 35 PSI occurs, the master pump receives a run signal. The master pump runs until

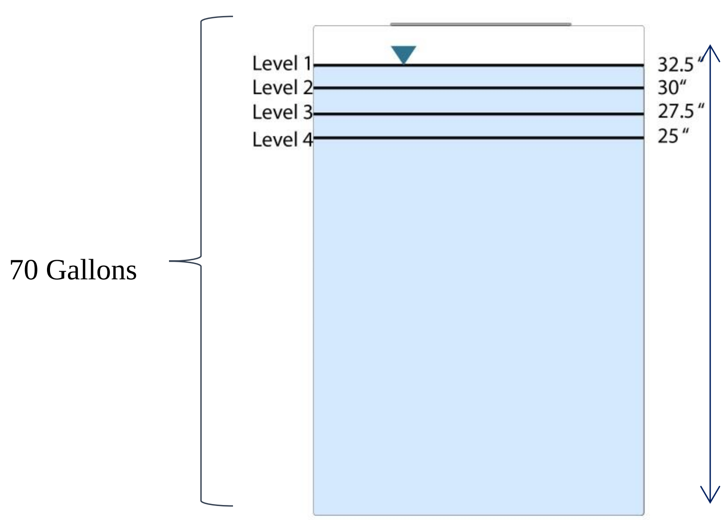


Figure 6.3 Ultrasonic level sensor design. (Adapted from Hodgson, 2012.)

a pressure of 46 PSI is reached and is protected from frequent cycling by the pressure expansion tank located immediately downstream of the pump. Graywater distributed by the master pump passes through flow meter #2, signaling chemical pump #2 to inject a vegetable based blue-dye into the treated graywater at a preset rate. Treated blue graywater is then distributed to student toilets for flushing.

The chlorine concentration in the disinfection tank is maintained between 1 and 5 mg/L utilizing the Chemtrac HydroACT600 chlorine analyzer and total chlorine probe. The ideal range of chlorine residual needed to prevent pathogenic regrowth in toilets, yet prevent against pipe and toilet component corrosion, was explored by Hodgson, 2012 and Wiles, 2013 and was determined to be between 1.5 mg/L and 4 mg/L. Graywater in the disinfection tank constantly cycles through the flow cell containing the total chlorine probe located on the wall behind the disinfection tank. The total chlorine probe is connected to the chlorine analyzer located in the control panel which displays the current chlorine residual concentration in the disinfection tank. The current chlorine residual concentration is also reported on a web interface accessible with the appropriate login information. The system is protected from distributing insufficiently treated graywater to student toilets through the use of non-latching and latching alarms and backflow prevention. In the occurrence of a threshold value being reached, non-latching alarms are sent to the assigned graywater plumber indicating maintenance is required; an increase or decrease of the chlorine dose will be needed depending on the specific alarm. Latching alarms remove power from the treatment system and close solenoid valve #2, eliminating the potential of public health risks by distributing domestic potable water to student toilets through solenoid valve #1. Non-latching alarms occur at low and high chlorine residual concentrations of 1.5 mg/L and 4 mg/L, respectively. Latching alarms occur at low and high chlorine residual concentrations of 1.0 mg/L and 5 mg/L, respectively. When the chlorine residual concentration is brought back into the ideal operating range, the alarms shut off and normal operations ensue. Chlorine residual concentrations are logged on a micro SD chip located in the chlorine analyzer, and are transferred to a master spreadsheet once per month to ensure state compliance and safety.

6.2.2 Educational Outreach and Student Participation

The graywater reuse system for toilet flushing at Aspen Residence Hall is a demonstration pilot project, approved for the purposes of research. Because of this, participation of the students living on the first floor of Aspen Residence Hall was voluntary for the spring 2014 semester, and will also be voluntary for fall 2014 and spring 2015. The students were presented with an educational presentation in the fall of 2013 outlining the need for water conservation, the health concerns associated with graywater reuse, the benefits of graywater reuse, and a description of the graywater system in Aspen Residence Hall. They were also given a tour of the system. The students left with an informational hand-out along with a participation form, and were asked to identify if they would like to opt in or out of the program. Taking into account that some rooms are double occupancy, if one of the two roommates declined participation, the room was not connected to the graywater system. Additionally, the students were informed that they have the ability to opt out of the program at any time if they are unhappy with the experience. Those who agreed to participate also agreed to reflect on their experience with graywater following the first operational semester in the spring of 2014. In total, 17 students agreed to participate in the program and 3 declined.

6.2.3 Timeline of Graywater Reuse System Operations

In the fall of 2013, necessary updates to the system were performed by Colorado State University Facilities Management. When the students arrived following winter break for the spring 2014 semester, the water closets in the rooms of participating students were switched to allow treated graywater for flushing. The system was in complete operation mode from February 7th, 2014 to May 5th, 2014, with intermittent periods of flushing with domestic potable water for maintenance and troubleshooting purposes. Student surveys were distributed at the beginning of May, 2014 and results were compiled following the system shut-off date (see Appendix J for example survey).

6.3 Results and Discussion

6.3.1 Operational Experiences

This subsection will discuss operational experiences between the fall of 2013 and the spring of 2014, and identify areas that require improvements before the next operational period begins in the fall of 2014. Subsection 6.3.3 will discuss the possible solutions to areas that require improvements.

After the system was switched to allow students to flush with treated graywater, the total chlorine probe almost immediately began to display erratic readings. The graywater reuse system was tested in order to gauge the accuracy of the total chlorine probe and chlorine analyzer. In order to perform tests, a bypass of the graywater system was accomplished by allowing solenoid #2 (Figure 6.1) to distribute domestic potable water to student toilets. With the absence of the automatic flush timers, tests were performed by manually flushing graywater from the disinfection tank throughout the day to allow additional raw graywater to flow from the storage tank. During these tests, it was noted that the total chlorine probe was reporting different results than when testing chlorine levels in the disinfection tank with an alternative DPD colorimetric chlorine method (Hach Model #CN-66T).. It became apparent that fats, oils, and greases present in the raw graywater stream have tendencies to block the membrane portion of the total chlorine probe, resulting in erratic readings. After speaking with Chemtrac technical support, it was suggested to implement frequent rinsing of the chlorine probe with domestic potable water to remove the material blocking the membrane. The total chlorine probe began to operate accurately with these maintenance requirements which have been added to the SOP (Appendix I). Testing of chlorine residuals in the furthest downstream toilet from the treatment system occurred on a bi-weekly basis and was performed by Colorado State University Environmental Services employees as a quality performance metric and for research purposes (Figure 6.4). The employees were trained on the DPD colorimetric procedure and were asked to report results on a logging form. These tests were done to measure the discrepancy between chlorine residuals reported in the demonstration toilet and chlorine residuals reported in the student toilet being tested. Future testing of the system in fall 2014 will be conducted by an experienced member in the field, and will occur on a weekly basis to obtain a higher quantity of measurements. The data points imply that residual concentrations in the demonstration toilet were consistently higher than those measured in the student's toilets. The accuracy of the measurements made in the student toilets is in question due to the inexperience of those individuals performing the sample analysis. In addition, one measurement of residual chlorine was taken by the graduate student in the toilet furthest downstream from the graywater system on April 22, 2014. The chlorine residual in this instance measured 3 mg/L. Figure 6.4 also shows events in which normal operations were compromised due to operational issues, discussed below.

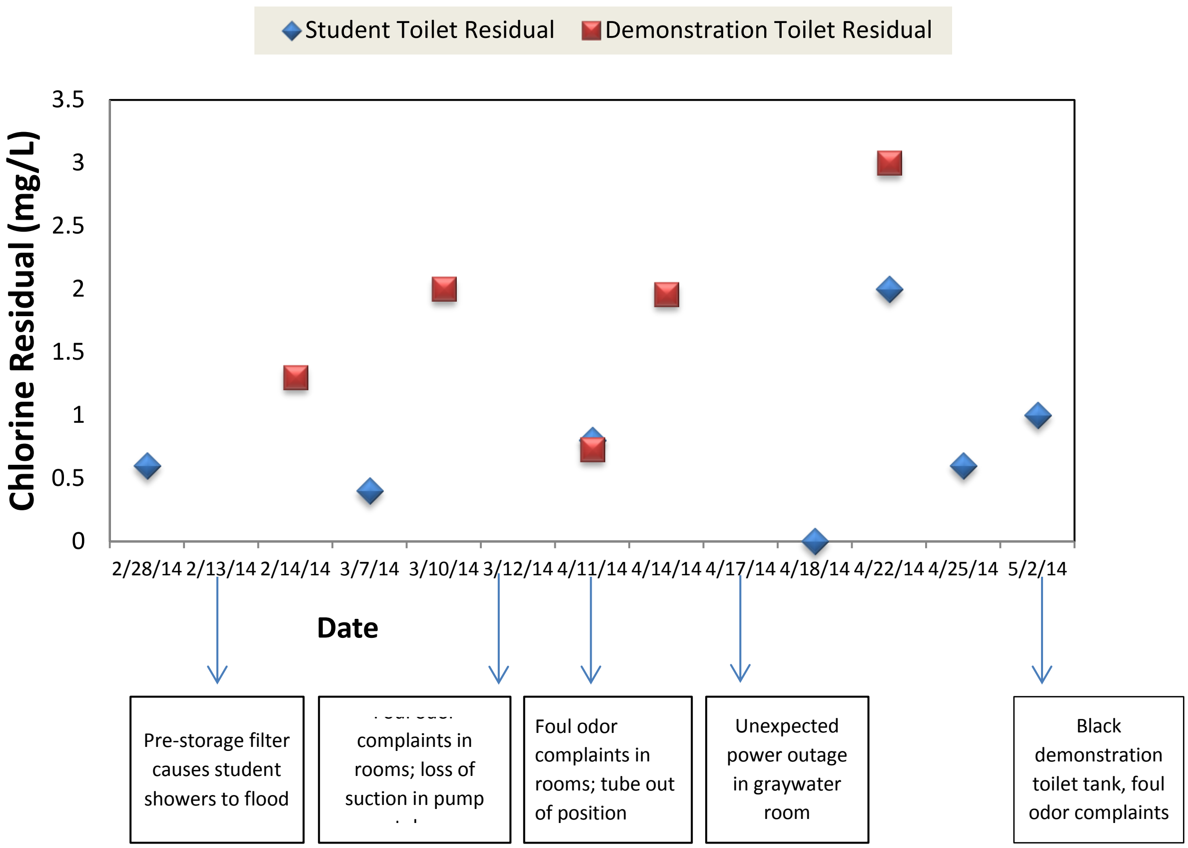


Figure 6.4 Chlorine Residual Concentration Measurements in Demonstration Toilet and Student Toilets

Several instances of equipment malfunctions and unexpected obstacles resulted in student complaints of foul odors and/or a loss of the appropriate chlorine residual in the disinfection tank.

On February 13, 2014, a student called to report that their shower was clogged and would not drain. Upon inspection of the system, it was apparent that the coarse Matala pre-storage filter had clogged due to large amounts of hair and debris. The pre-storage filter was backwashed and ultimately removed from system. Subsequently, there were no more instances of flooded showers.

This filter was required by the CO plumbing board to be in compliance with IPC (IPC 2006, Appendix C, C101.1). System designers and plumbers were concerned about the potential for this filter to clog prior to its installation. A recommendation has been made to the CO plumbing board to add an exemption to not require a filter prior to the storage tank in graywater systems intended for toilet flushing.

On March 12, 2014, students connected to the graywater system called and complained of foul odors in their toilets (Figure 6.4). Upon inspection of the system, it was discovered that the pump tube located in chemical pump #1 (chlorine injection) had broken and resulted in a loss of suction from the chemical tank to the treatment system; a period of time had occurred in which the chlorine pump was running but there was no chlorine being dosed in-line. The pump tube was replaced and chlorine dosing was reestablished. Pump tube replacement frequency requirements were added to the Aspen Residence Hall Standard Operating Procedure document (Appendix I). Of note is that a latching alarm was sent when the chlorine residual reached a value of 1 mg/L in the disinfection tank, switching the system to distribute potable water to the student's toilets. However, graywater with a sufficient chlorine residual when leaving the system may have remained in the distribution line for an extended period of time resulting in a dissipated chlorine residual and corresponding foul odors in the toilets.

On April 11, 2014, students called and complained of foul odors in their toilets (Figure 6.4). Upon inspection of the system, it was discovered that the tube in chemical tank #1 had positioned itself outside of the sodium hypochlorite solution and although the pump was running, chlorine was not being dosed in-line. The tube was repositioned in the correct manner and was anchored in that position for the remainder of the spring 2014 semester. A new chemical tank was purchased for use in fall 2014, eliminating the risk of this instance occurring in the future.

When the chlorine residual dissipated to under 1 mg/L, a latching alarm was sent and the student’s toilets were switched to potable water. However, graywater may have remained in the distribution piping long enough for the chlorine residual to dissipate and cause odors in the toilets.

On April 17, 2014, the graywater room was visited and it was discovered that an unexpected power outage had occurred, resulting in the disinfection tank being pumped dry. The unexpected power outage, later attributed to a breaker failure for unknown reasons, affected only part of the treatment system. The master pump was still receiving power and therefore was pumping treated graywater to toilets until empty because the ultrasonic level sensor was reporting low levels. However, solenoid valve #4 was affected by the power loss and remained closed, blocking raw graywater from flowing into the disinfection tank. The problem was mitigated by flipping three switches in the control panel, but it is recommended that the graywater room is switched to its own breaker to protect against other uses of electricity in the basement causing another breaker failure in the future. Because there were no calls regarding foul odors or a loss of water in the student’s toilets, it is believed the freshwater solenoid valve opened and provided municipal water to the toilets when power to the system was disrupted.

On May 2, 2014, students called and complained of foul odors in their toilets. Upon inspection of the system, it was discovered that the demonstration toilet tank was full of black, “gunky”, water. This event occurred post-treatment and may have been attributed to the release of stagnant water located around the bladder in the pressure booster tank, downstream of the disinfection tank and master pump. If not released from the pressure booster tank, the contaminated black water may have been a result of material clogging the master pump and dislodging itself. Chlorine in the contact tank of the treatment system was not impacted and therefore a low alarm was not triggered. The presence of the contaminated water in the demonstration toilet tank implies that this water could have also been distributed to the student's toilets. A method to test the release of stagnant water from the pressure booster tank is currently being developed and will be performed prior to system start-up in the fall of 2014.

Four of the five instances described above resulted in foul odor complaints in the student rooms. Though it was the first real operational period and obstacles were inevitable, foul odors are an aesthetic and water quality issue and have the potential to impact the reputation of the graywater reuse system in Aspen Residence Hall in a negative way. Negativity associated with the graywater reuse system was reflected in some of the survey results discussed in subsection 6.3.2, was undoubtedly a result of one or more of the unexpected events and malfunctions. It is therefore a new project goal to drastically reduce the amount of foul odor cases for future operation of this system.

In addition to these events, a few other operational experiences lend valuable information for future performance of the reuse system.

The latching alarm that occurs at 1 mg/L and enables the bypass of the graywater system poses problems for normal operation of the system. At 1 mg/L, the latching alarm sends a signal to distribute domestic potable water to student toilets, and removes power from the treatment process so that additional raw graywater cannot flow from the storage tank to the disinfection tank. The low latching alarm is then unable to correct itself and switch the system back to flushing with graywater because no further dosing of chlorine occurs in the disinfection tank when power is removed, and the chlorine residual eventually dissipates to 0 mg/L. The switch back to flushing with graywater will only occur when a chlorine residual of 1.5 mg/L is measured in the disinfection tank. The only way to cycle the disinfection tank in this instance is by manually draining water to the sewer via the valve at the bottom of the tank. In order to switch the system back over to graywater, it is therefore required to drain the disinfection tank of the insufficiently dosed graywater and remove the probe from the flow cell to force a reset. Upon returning the probe to the flow cell, the power to the treatment system will be restored and graywater will be able to flow into the disinfection tank. It should be noted that this event is only a problem in the case of a low latching alarm. If a high latching alarm is sent and the system is switched to domestic potable water, the disinfection tank will eventually drop in chlorine concentration to below 5 mg/L, and automatically switch back to the use of treated graywater for flushing.

It was observed that the head needed for graywater to gravity flow from the storage tank to the disinfection tank in the updated system is 39 inches. This means that unless the normal operating level of graywater in the storage tank is at or near the overflow line, graywater will not gravity flow to the treatment system. On most days, the system was operating at the overflow line and graywater was still able to flow to the treatment system. However, during periods of low student activity such as weekends, the graywater supply in the storage tank was often below the overflow line and therefore may have remained stagnant for longer than 24 hours, possibly resulting in higher strength graywater requiring a larger chlorine dose to treat to levels ensuring the safety of participating students. Figure 6.5 is a schematic showing the amount of head required in the storage tank. The issues associated with the amount of head required are also related to the residence time of untreated graywater in the storage tank, discussed below.

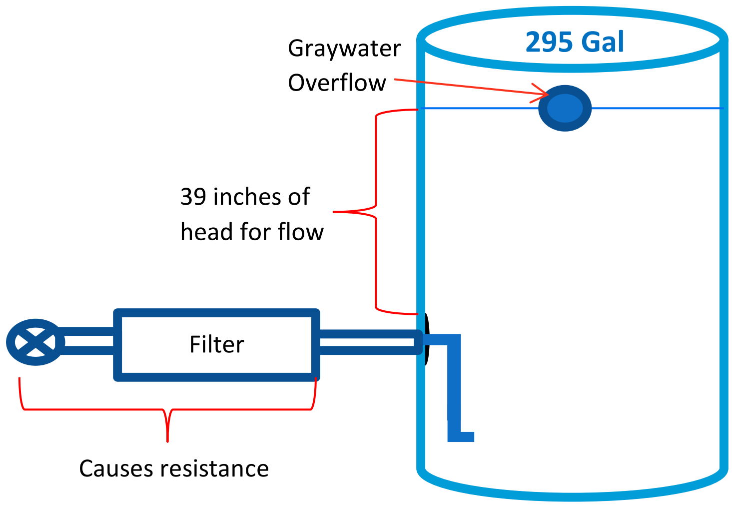


Figure 6.5 Schematic of Head Requirements in Graywater Storage Tank.

The graywater reuse system was designed to process 300 GPD, and during the research phases was forced to process this amount by 'flushing' every hour for four minutes (less frequently during the night) through the use of automatic flush timers. The 300-gallon storage tank and corresponding processing rate were decided upon by assuming a maximum occupancy on the first-floor of 28 students. The system was designed to account for peak operational demands consisting of all 28 students flushing a toilet once in a one-hour period (Hodgson, 2012). It has since been learned that the maximum occupancy on the first-floor is 25 students due to one single occupancy room and one show room. Occupancy in the remaining 12 rooms varies from year to year, although all 12 rooms are designed for double-occupancy. Additionally, flow meter readings from the first operational period show a processing average of 91 GPD, indicating that the amount of flushes per student per day is lower than the theoretical assumptions used to operate the demonstration system on automatic flush timers. A flow rate of 91 GPD is approximately equivalent to each of the 17 participating students flushing four times per day. A lower storage volume would be ideal due to the lower than expected use of graywater for toilet flushing.

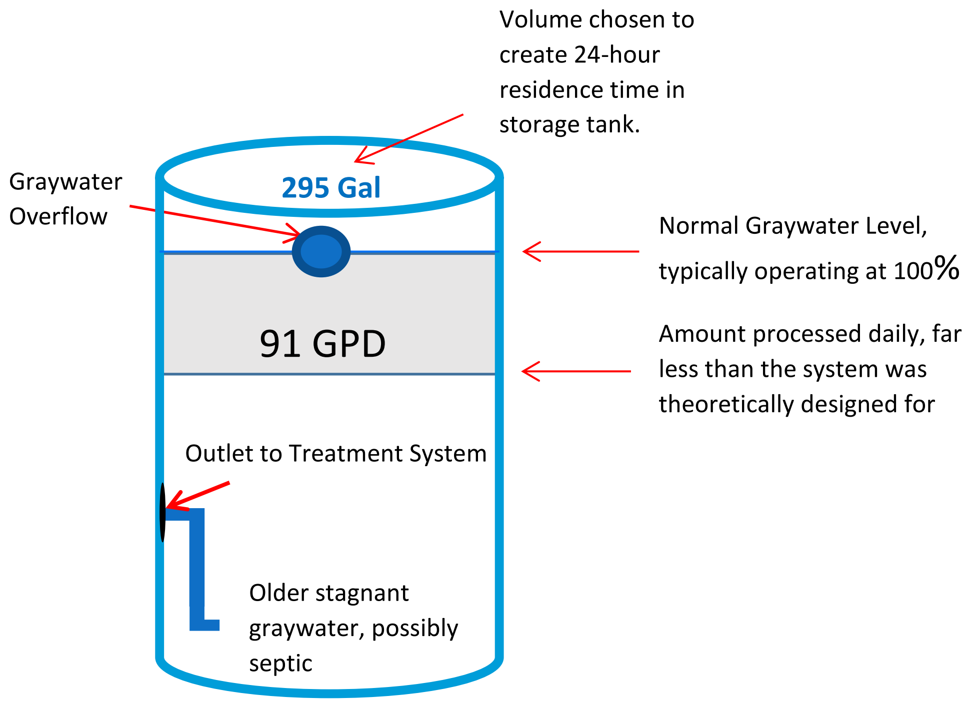


Figure 6.6 Schematic of Graywater Storage Tank Concerns

6.3.2 Student Survey Results

Upon completion of the spring 2014 semester, participating students were given a survey to reflect upon their experience with the graywater reuse system for toilet flushing at Aspen Residence Hall. When asked their opinion of the overall experience, the majority of students stated they were somewhat satisfied, whereas 2 students stated they were very unsatisfied and would not participate again (Figure 6.7). Additionally, students were asked if they would recommend using non-potable water for toilet flushing to others. The majority of students answered yes (Figure 6.8).

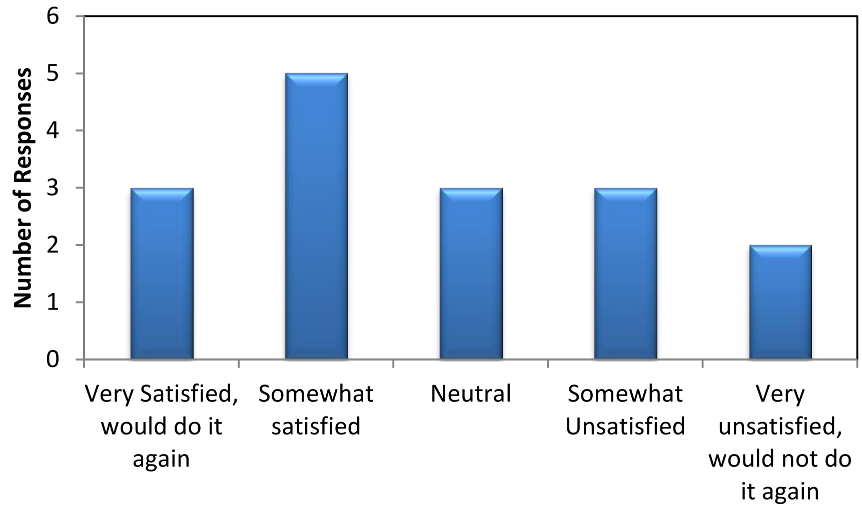


Figure 6.7 Satisfaction levels of Non-potable Water Use for Toilet Flushing

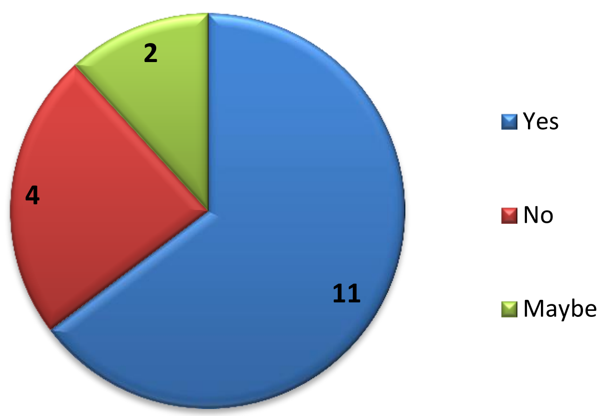


Figure 6.8 Number of students who would recommend non-potable water to others in an effort to preserve potable water supplies

Student survey results show that the majority of students feel the main difference between toilet flushing with municipal water and non-potable water is the odor (Figure 6.9). Due to the instances of unexpected foul odors, these results were anticipated.

Additionally, students expressed that only sometimes was the graywater displeasing, and similar to Figure 6.9, results show the main displeasure can be attributed to the four foul odor instances in student toilets (Figure 6.10).

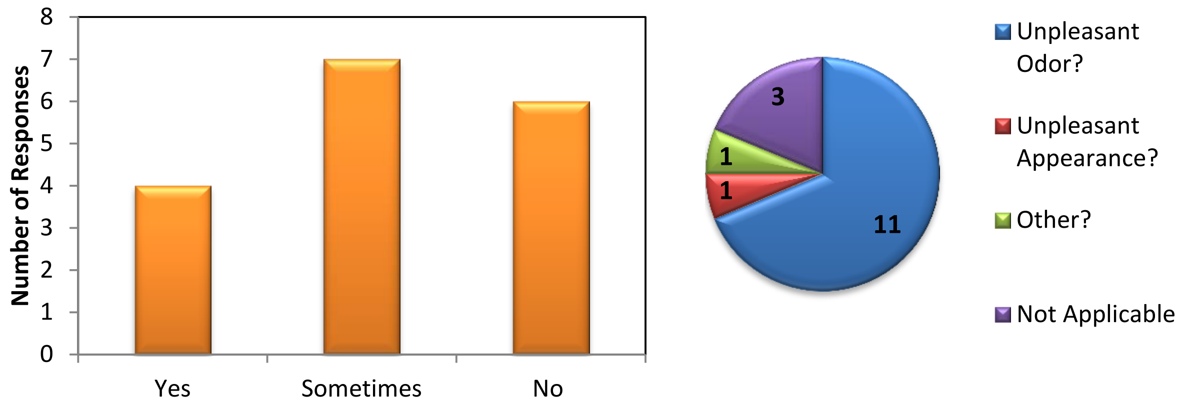


Figure 6.9-6.10 Left: Was the non-potable water in the toilet displeasing? Right: Reasons for displeasure using non-potable water for toilet flushing

The majority of students did not believe or did not have an opinion of whether or not the unpleasant aesthetics that occurred in isolated incidents were the result of a certain cleaning schedule (Figure 6.11).

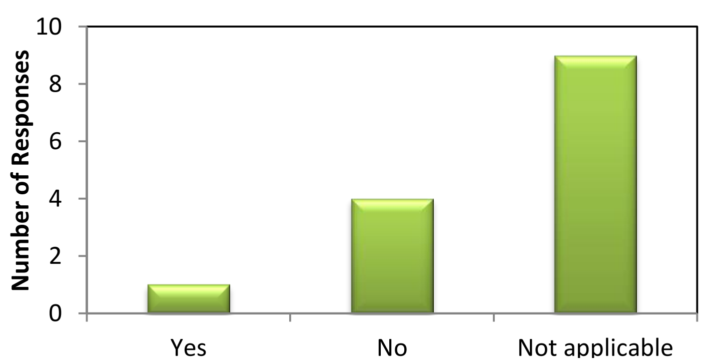


Figure 6.11 Opinion regarding unpleasant appearance coinciding with a certain time in the cleaning schedule

Because of the potential human contact associated with graywater, it was of interest if any students felt that sickness throughout the spring 2014 semester was in any way related to graywater reuse (Figure 6.12). It does not appear that there were any instances of pathogenic activity in the graywater causing student sickness. These results were expected due to the disinfection of raw graywater prior to being distributed to toilets.

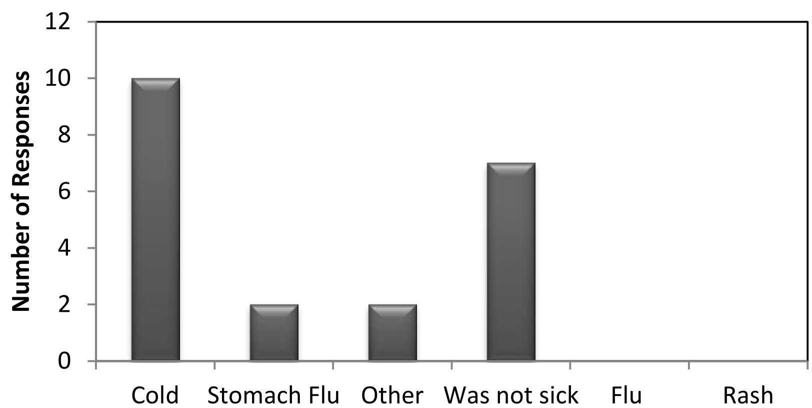


Figure 6.12 Frequency of student illness by type for the Spring 2014 semester

Students were also asked if reusing graywater for toilet flushing resulted in an increased awareness of certain scenarios exhibited in Figure 6.13. 14 students stated that they did not feel any change in awareness occurred throughout spring 2014 semester (Figure 6.13). Students noted that changes in the non-potable water were most noticeable after spring break (Figure 6.14).

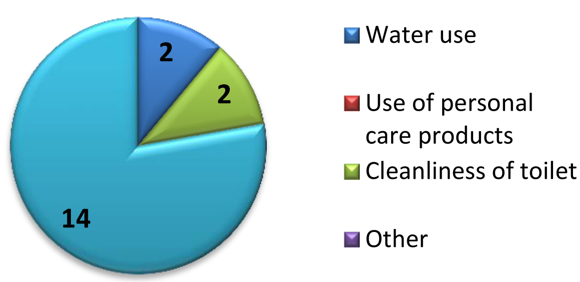
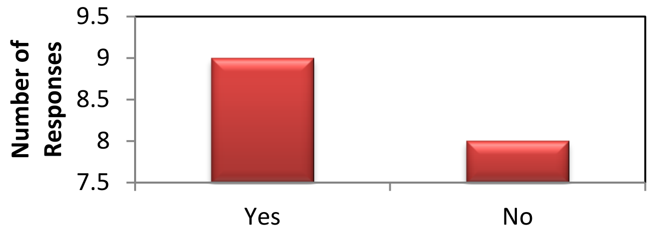


Figure 6.13 Awareness of scenarios based on non-potable toilet flushing experience



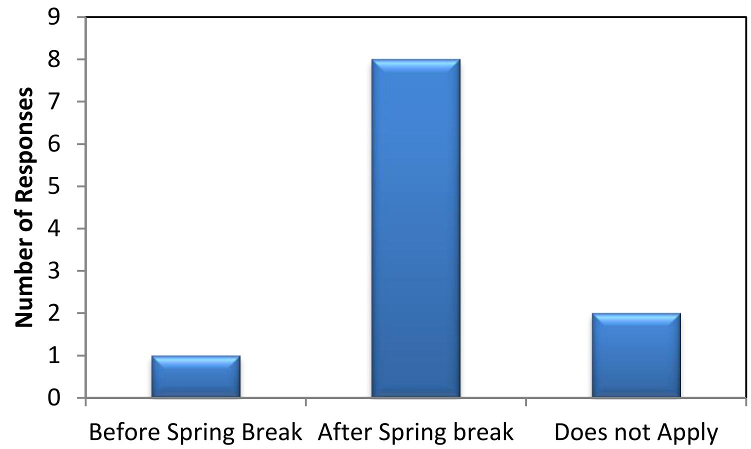


Figure 6.14 Top: Opinion on differences in non-potable water before/after spring break. Bottom: Time in which differences in the non-potable water were apparent.

The results of the survey imply an overall mixed feeling towards the graywater reuse experience. Four students answered that the non-potable water in their toilet was displeasing, seven answered that the non-potable water in their toilet was sometimes displeasing (Figure 6.10), and of those 11 students, 100% attributed the displeasing characteristic to foul-odors (Figure 6.10). When asked their overall satisfaction level with using non-potable water in place of potable water in their toilets, 3 students said they were very satisfied with the experience and would participate again, whereas 2 students said they were very unsatisfied with the experience and would not do it again (Figure 6.7). It was decided that students will once again have the opportunity to opt in or out of the graywater reuse system for the fall 2014 and spring 2015 semesters. Following the completion of the spring 2015 semester, the system will be reevaluated and it will be decided if participation will remain voluntary or become mandatory for future students.

6.3.3 System Recommendations for the Future

There are a few areas in which the system design could benefit from improvements. The improvements have been identified in efforts to ensure that the system operates requiring minimal maintenance while still protecting public health and safety, and if implemented, will allow for a more enjoyable graywater reuse experience for the participating students. It is important to have a properly functioning graywater reuse system because the possibility of human contact is increased when reusing the graywater for indoor toilet flushing. Based on the operational experiences and student survey results from the fall of 2013 and spring of 2014, it has been decided that the fall of 2014 will serve as another "pilot phase" of the project, meaning that more research is needed in order to finalize the most appropriate design for this graywater reuse application.

It is suggested that a higher range total chlorine probe is purchased for the graywater system. Currently, the Chemtrac total chlorine probe measures within the 0.01-5 mg/L range. It is recommended that a total chlorine probe with an operating range of 0.01-10 mg/L is implemented in order to measure chlorine residuals greater than 5 mg/L. In order to avoid the low latching alarm at 1 mg/L, the system should be maintained at a higher chlorine concentration. When doing so, it is necessary to have an upper measurement limit of greater than 5 mg/L so the true value in the disinfection tank can be known. The cost of a new total chlorine probe would be $1,905.

The storage tank design in the graywater reuse system has two main areas of concern. The first area of concern is that the head required for gravity flow is 39 inches, meaning the system will only operate when the graywater supply is at the overflow line. The large amount of head required is likely due to the plumbing updates that occurred in the fall of 2013, including downsizing of the pipe diameters and the resistance caused by the design of the filter with flow meter #1 and solenoid valve #4. The second area of concern is that the design of the graywater system may operate more smoothly with a smaller storage tank due to the lower amount of graywater being processed per day than was expected. Two alternative solutions were proposed in order to address these concerns. The first alternative includes purchasing a smaller, 160-gallon storage tank. The tank would need to be raised on a platform in order to achieve the required head for gravity flow. The 160-gallon volume would result in a shorter graywater residence time while still being able to provide treated graywater to toilets during peak demand periods at maximum occupancy. Additionally, the system is protected with supplemental potable water lines to assist operations when graywater supply is low. Figure 6.15 is a schematic with the proposed design for a new graywater storage tank.

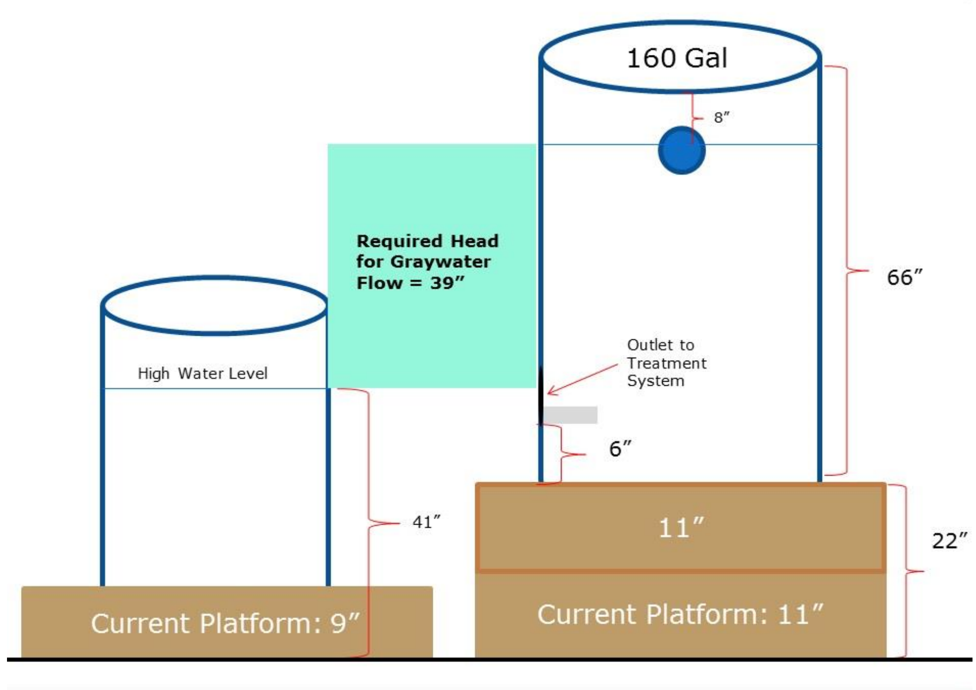


Figure 6.15 Schematic of Proposed Graywater Storage Tank Design

The second alternative discussed is to purchase a small pump for use in the graywater storage tank. The pump would negate the need for 39 inches of head because the system would no longer rely on gravity flow to the disinfection tank. The pump would be a more cost-effective approach, but would likely serve as a temporary fix to the problem for the second "pilot phase" operating period. At present, the pump alternative is being pursued. A small transfer pump will be used instead of gravity flow between the storage tank and the disinfection tank. The pump will likely require a float switch or an ultrasonic level sensor to avoid the storage tank being pumped dry. An outside contracting company will be hired to perform system updates before it is turned on in for the Fall 2014 semester.

To address the issue that occurred on May 2, 2014, a tank will be ordered to replace the existing bladder tank. This issue occurs post-treatment and therefore is crucial to solve before further operations continue. A 4.5 gallon Flow-Thru tank by Flexcon will be installed; this tank will not result in the stagnation of graywater in efforts to avoid the release of contaminated graywater into post-treatment distribution lines.

In addition to the above recommended design modification, it is necessary to measure the chlorine residual concentrations more frequently and in a greater number of student toilets in the fall of 2014 to evaluate the difference between residual chlorine measured in the system and in student toilets. It is highly recommended that a qualified individual is responsible for the sample analysis of the chlorine residual concentrations.

Updates to the Standard Operating Procedure (SOP) have been completed taking into account the operational experiences of spring 2014 (See Appendix I). Equipment replacements and maintenance requirements were added to the maintenance activity table in the SOP (See Appendix I). Additionally, a comprehensive Operations and Maintenance manual has been created for the graywater system at Aspen Residence Hall. The O&M manual contains all major components of the graywater reuse system and their relevant user manuals and guidance documents. A training video for future operators of the updated graywater system was created and posted to YouTube.

6.4 Summary

The graywater reuse system for toilet flushing at Aspen Residence Hall received a variance from the State Plumbing Board in the fall of 2013 which outlined necessary updates to the system in order to continue operations for research purposes. The necessary updates were completed and the students were flushing with treated graywater by February, 2014. The end of year survey results indicate that participating students had mixed feelings regarding their experience with graywater reuse. While operation was generally successful, several instances of foul odor complaints can be attributed to unexpected system malfunctions and equipment breakages; these concerns were addressed by troubleshooting the issue and providing solutions for the future. Design improvements were also recommended in efforts to increase the functionality of the graywater reuse system. Water savings from the first complete operating period reached 8,200 gallons over 90 days.

The fall of 2014 semester will serve as another pilot phase operating period for the graywater reuse system in efforts to finalize the design and sort out areas of concern.

7.0 CONCLUSION

Populations in the southwestern region of the United States are projected to grow exponentially over the coming years, increasing 68% from 56 million to 94 million by 2050 (Hoerling et al. 2013). Growing populations result in higher demands for freshwater supplies, yet climate change is expected to result in more frequent and severe droughts that will place added stress on already over-used water resources (Garfin et al. 2014). Severe droughts will lead to a decreased surface water supply and therefore pose future challenges for urban areas, agriculture, and ecosystems, particularly in the semi-arid and arid regions of the United States (Garfin et al. 2014). In recent years, water utilities across North America have seen a reduction in water use at the household level, often attributed to the implementation of water-conserving appliances such as low-flow showerheads, faucets, and toilets (Coomes et al. 2010). However, water conservation through the use of low-flow fixtures can only go so far, and it is believed that these low-flow fixtures have reached their maximum level of water savings. It is therefore necessary to study other water conservation strategies in order to be prepared for decreased surface water supplies in the near future.

Graywater is a strategy that has recently gained popularity because it is a lower strength wastewater than domestic wastewater and therefore is easier to treat (Winward et al. 2008). Graywater typically refers to effluent from showers, bathtubs, laundry machines, and laundry and bathroom faucets. Graywater constitutes approximately 44% of total indoor water use at the household level and toilet water accounts for 25% of total indoor water use (REUWS, 2012). Reusing graywater for indoor toilet flushing can reduce potable water demand by up to 25%. Irrigation demand historically averages at approximately 100 gallons per capita daily (gpcd) (Mayer et al. 1999), but the average person does not generate enough graywater to meet the entire irrigation demand so supply is typically supplemented with freshwater unless the yard is xeriscaped. Utilizing the entire stream of household graywater for irrigation can reduce potable water use by up to 44% during the growing season (REUWS, 2012).

7.0.1 Commercial Water Reuse Feasibility Study Conclusions

Though the reuse of graywater at the household level for toilet flushing and irrigation has been well-documented in the relevant literature, there has been little research done regarding the reuse of graywater, or similar quality wastewaters, at commercial facilities. The City of Fort Collins Utilities was interested in exploring commercial water reuse at facilities within their service area. Based on the results of the recent commercial reuse feasibility studies (Chapter 3), cities interested in exploring commercial water reuse should target businesses such as hotels, gyms, and research labs to maximize water savings and practicality of on-site reuse systems. These types of businesses generate a substantial graywater supply and have similar end-use application water demands. In this study, the research lab could see potential water savings of up to 21% by reusing graywater in their cooling towers. In contrast, unless office building complexes have on-site laundry, their graywater generation rates typically will not meet the toilet demands therefore resulting in negligible water savings. Every facility has independent and unique water use characteristics, but this study provides general guidance for estimating potential water savings in the commercial sector.

7.0.2 Impact to Return Flows Conclusions

Typically, water conservation provides positive community benefits by reducing the amount of freshwater withdrawals and reducing the strain on wastewater treatment plants, however, municipalities are challenged with a fine-line balance between positive water conservation and potential negative implications to downstream water users. Water rights laws and rules that govern water use in the western portion of the United States can be barriers to implementing water conservation methods and can hinder actual potential water savings because agencies do not want to compromise historic water rights (Penland et al. 2012). Many municipalities must use wastewater discharge as a return flow to demonstrate that water is supplied in the amount it should be to downstream water users. This is a concern because graywater reuse does decrease wastewater flows. The City of Fort Collins Utilities was interested in determining the implications to water rights by examining the impacts to return flows associated with graywater reuse within their service area. Adoption of graywater reuse in existing, and new and redevelopment populations in the City of Fort Collins was estimated to be between 5-10%, and 80-100%, respectively, if not less. These adoption rates were used to develop scenarios to estimate the largest possible impact to return flows. Additionally, various scenarios of end-use applications were used to determine impacts to return flows in both the present and future, accounting for projected population changes. Results of this study show that the City of Fort Collins could see a maximum reduction in return flows of approximately 5.5% in the scenario that 10% of existing development, and 100% of new and redevelopment areas adopted graywater reuse. In the hypothetical situation where 100% of the population adopts graywater reuse, return flows to the local wastewater treatment plants would reduce by 21%. This situation demonstrates what may occur in new development areas. Graywater reuse results in the preservation of source waters, meaning water that would normally be withdrawn is left in the original flows. In turn, water rights issues become less complex in new development areas where graywater reuse is most likely to be adopted because they have the opportunity to purchase less water up front.

7.0.3 Recommendations for Graywater City Ordinance Conclusions

House Bill 13-1044 was signed by the Colorado Governor, John Hickenlooper, in May of 2013. HB13-1044 legalized the use of graywater for beneficial purposes in the State of Colorado. The drafting and stakeholder involvement process for Regulation 86, Graywater Control Regulation, is currently underway being completed by the Colorado Department of Public Health and Environment Water Quality Control Commission. Regulation 86 will describe the minimum requirements and standards for reusing graywater in non-potable applications (5 CCR § 1002-86). Cities and counties will have the opportunity to choose whether they will implement graywater reuse within their local regulations, and it will be at their discretion to adopt any or all of the graywater uses and design criteria described in Regulation 86 (5 CCR § 1002-86). The City of Fort Collins Utilities expects to adopt graywater reuse into their local regulations, and was interested in exploring what a city ordinance for graywater reuse should include. Based on an extensive literature review, operational experiences, and involvement in the stakeholder process for Regulation 86, recommendations regarding graywater reuse were provided to the City of Fort Collins Utilities in the form of Best Management Practices factsheets and documents outlining design and treatment considerations for inclusion in a city ordinance. Additionally, factsheets titled 'The Basics of Graywater Reuse for Toilet Flushing and Outdoor Irrigation' and 'How to Install a Graywater Reuse System for Outdoor Irrigation' were developed in order to assist interested parties in the decision, design, construction, and operation processes of implementing a graywater reuse system.

7.0.4 Aspen Residence Hall Graywater Reuse System for Toilet Flushing Conclusions

The graywater reuse system for toilet flushing at Aspen Hall on Colorado State University's campus underwent the first actual implementation period in the spring of 2014 semester where students residing on the first-floor of Aspen Hall were flushing toilets with treated graywater. After the system was brought up to State Plumbing Board code in the fall of 2013, the system was turned on-line and students who chose to participate in the program had their rooms connected to the graywater system. The first operational period showed mixed results from a design standpoint and from a student opinion standpoint. In general, chlorine residual targets in both the disinfection tank and the student’s toilets were met. Operation was generally successful aside from the few instances of unexpected malfunctions and equipment breakages that resulted in complaints regarding the aesthetics of the graywater. In these instances, chlorine residuals were still present and therefore it is not likely that pathogens were present. Additionally, the design of the storage tank can benefit from some improvements (Chapter 6). It is apparent that students who felt negativity towards the graywater reuse experience were impacted by the foul odor instances, therefore is a system goal to drastically reduce foul odor complaints, ideally to zero. The fall 2014 will hence serve as another pilot phase operating period and students will once again have the decision to opt in or out of the program.

There are several issues associated with the implementation of graywater reuse in the State of Colorado. These issues include the approved uses of graywater as stated and likely to be finalized, in the draft version of Regulation 86 released on June 30, 2014, the proposed on-site treatment requirements, and the requirement of permitted graywater reuse systems. Additionally, inconsistencies between graywater regulations and definitions, as well as plumbing codes, from state to state inhibit widespread adoption of graywater reuse. The Graywater Control Regulation will also require cities and counties to develop their own ordinance or resolution adopting all, or part of, Regulation 86. Each individual city or county will be responsible for assigning duties to the identified local agencies that will monitor, track, inspect, and enforce the criteria associated with graywater reuse. This level of involvement from municipalities and local agencies may stray cities or counties away from adopting graywater reuse as a water conservation strategy.

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APPENDIX A

Best Management Practices for Graywater Use

Considerations for Graywater Collection System

Best Management Practices are techniques that, when implemented, will reduce potential issues associated with a graywater reuse system with the intention of protecting human health and environmental quality. They are designed to increase safety, ease of use, and promote successful application of graywater reuse systems. The Best Management Practices listed here are intended to be general. Best Management Practices documents for 'Subsurface and Drip Irrigation' and 'Toilet Flushing' are also available and contain specific details related to those end uses. In addition to this document, please read the appropriate Best Management Practices document in regards to your chosen graywater reuse application.

- Become familiar with state and local regulations and permitting requirements for graywater reuse systems. Information can be found by accessing the Graywater Reuse Database; please follow the download instructions at the bottom of this page.
- Ensure that the graywater reuse system conforms to state and local graywater reuse guidelines.
- The graywater reuse collection and treatment system must conform to your local and state plumbing code requirements. There are two plumbing codes that provide requirements for reusing graywater, the International Plumbing Code (IPC) and the Uniform Plumbing Code (UPC), and different states and counties adopt different codes. It is necessary to determine which code is followed in your state and/or local government, and follow the specifications provided. IPC: Link UPC: Link
- Use a licensed plumber early in the design process.
- Do not use water from the kitchen/dishwasher with the graywater reuse system.
- Water used to wash diapers or similarly soiled or infectious garments shall not be used and shall be diverted to the sewer. A valve can be placed after the laundry machine to control diversion of graywater to sewer systems. See Figure 1 for a photograph of a 3-way valve.
- Label and color all pipes and outlets according to code requirements to indicate graywater plumbing.
- Wherever there is the potential for graywater to enter into potable water distribution systems (e.g. when potable water is used to supplement graywater), protect potable water sources with backflow preventers and graywater identification labels.
- Limit human contact and exposure to graywater.

To download the Graywater Reuse Database: Navigate to this link, https://www.watereuse.org/product/10-02-1, click 'download' at the bottom of the page, and follow the prompts to create an account in order to complete the download.

- Avoid contact with mouth or face when performing maintenance on a graywater reuse system. Wash hands immediately after handling graywater and wear gloves when performing system maintenance activities.
- Do not allow children to play around the storage tank.
- Don't drink or allow pets or animals to drink graywater.
- Tanks should be covered and sealed.
- Graywater storage tanks should include overflow to sewer, ventilation, and a drain.
- Consider that what is used or washed in the sink will end up in the graywater reuse system. A slop sink should be used that connects directly to the sewer to avoid pouring toxic chemicals down the graywater drains such as bleaches, paints, artificial dyes, solvents, acidic and alkaline substances, or other toxic chemicals.

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Figures

Figure 1: 3-way Valve

APPENDIX B

Best Management Practices for Graywater Reuse

Subsurface and Drip Irrigation

Best management practices are techniques that, when implemented, will reduce potential issues associated with a graywater reuse system with the intention of protecting human health and environmental quality. They are designed to increase safety, ease of use, and promote successful application of graywater reuse systems. The Best Management Practices listed here are intended for subsurface and drip irrigation applications. Best Management Practices documents for 'General Considerations' and 'Toilet Flushing' are also available and contain specific details related to those end uses. In addition to this document, please read the appropriate Best Management Practices document in regards to your chosen graywater reuse application.

Graywater may only be used on landscape through subsurface or drip irrigation because sprinklers provide an opportunity for viruses and bacteria to become airborne, leading to potential contact with humans or animals. **Subsurface irrigation** involves direct application of graywater to the root zone of plants using perforated lines or emitters buried below the ground surface. **Drip irrigation** applies water to the base of the plant under a minimum of 3-4 inches of landscape material (e.g. mulch or rock), preventing graywater exposure to humans and animals. Some states (e.g. CO) consider drip irrigation as subsurface irrigation as long as graywater is applied under a layer of landscape material.

If you have decided to use graywater for subsurface or drip irrigation, these Best Management practices should be followed:

- Graywater should not be stored for longer than 24-72 hours, depending on temperature, treatment and plumbing code requirements (see the graywater storage tank shown in Figure 4 on the bottom right side of the following page).
- Graywater generated should be used on-site. Don't allow graywater to pond or run off the property or facility from which it was generated.
- Only use subsurface or drip irrigation, absolutely no spray irrigation. See Figure 1 for an example of subsurface irrigation emitters. See Figure 2 for an example of a drip irrigation system and drip emitters.
- A minimum of 4 inches of mulch, rock, or other landscape cover should be placed over the drip irrigation lines. Organic mulch breaks down and blows away over the years and needs to be replenished periodically.
- Avoid direct contact with soil irrigated with graywater for 24 hours after graywater application.
- Graywater should not be used for food crops except fruit or nut trees. Don't eat fruit that has fallen to the ground.

- Ensure that the seasonal high water table (during the irrigation season) is a minimum of 5 feet below the irrigation area.

- A filter should be used to remove solids before the pump per irrigation system manufacturer recommendations.

- Review the specific filtration requirements for the drip irrigation system you intend to install. Most drip irrigation systems require a filtration of 120 - 150 mesh (110 to 125 microns). Sand filters can also be used for filtration (see Figure 3 on bottom left of following page).
- Don't irrigate with graywater while it is raining or when the ground is saturated.
- Don't irrigate with graywater near a drinking water well.
- If plants show signs of having burned tips (discolored leaf or needle tips), wilting or are looking unhealthy, consider flushing them with freshwater occasionally. Make sure the emitters are working properly. Relative tolerance of landscape plants to graywater irrigation can be seen below in Tables 1 and 2.
- You may need to supplement irrigation with freshwater during the hottest months.
- If potable water is used to augment graywater for irrigation, a method of backflow prevention for the potable water source is required.
- Use soaps and detergents with low amounts of salt and boron in them. Typically liquid detergents have fewer salts than the powder detergents.
- Avoid use of products containing antimicrobials such as triclosan and triclocarban. These are often contained in hand soaps.
- Avoid using bath salt in the bath tub.
- If a hose is used to transport graywater during any step of the process, that hose should not be used for any other purpose.
- Some companies with commercially available graywater reuse systems for subsurface and drip irrigation include: *Flotender, Greywater Reuse Systems, Netafim, Nutricycle Systems, ReWater® System.* Other companies may exist that provide graywater irrigation systems and we do not endorse any specific providers.

Table 1: Relative Tolerance of Plants Irrigated with Graywater (Adapted from Sharvelle et al. 2012)

Tolerant	Moderately Tolerant	Moderately Sensitive	Sensitive
Hackberry	California Valeriana	Himalayan border jewel	Scotch pine
Four-wing saltbush	Plum tree	Mugo pine	Hass avocado
Globe mallow		Bearded iris	Lemon tree
Honey mesquite			
Desert daisy			
Juniper			
Rose of Sharon			
Chrysanthemum			
St. Augustine grass			

Table 2: Plant Impacts Associated with Graywater Irrigation (Adapted from Sharvelle et al. 2012)

Plants that have positive impacts from graywater irrigation	Plants that have negative impacts from graywater irrigation
Bermudagrass	Lemon tree
Peach	Hybrid Rose
Black-eyed Susan	

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Figures

Figure 1: ReWater® Graywater Emitters

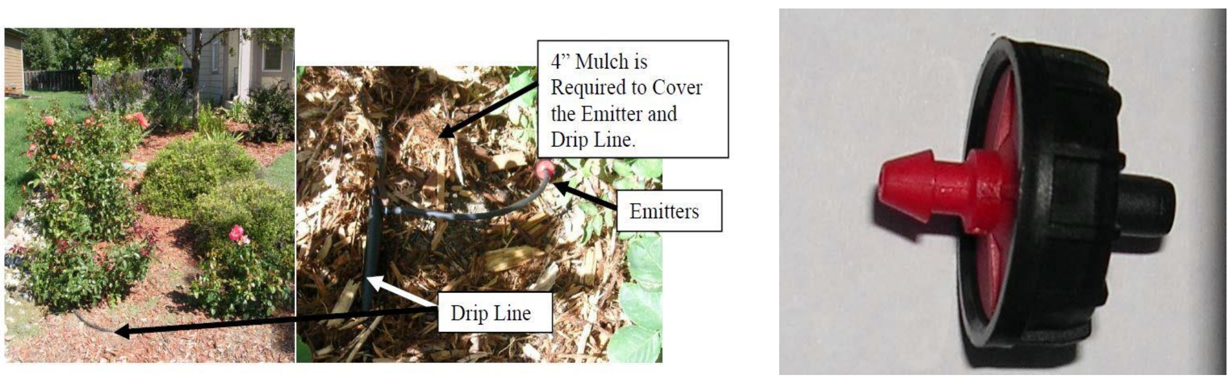

Figure 2: Left: Drip Irrigation System, Right: Drip Irrigation Emitter

Figure 3: ReWater® Graywater Reuse System for Irrigation using a sand filter

Figure 4: Storage Tank for Subsurface Irrigation Graywater System

APPENDIX C

Best Management Practices for Graywater Use

Toilet Flushing

Best Management Practices are techniques that, when implemented, will reduce potential issues associated with a graywater reuse system with the intention of protecting human health and environmental quality. They are designed to increase safety, ease of use, and promote successful application of graywater reuse systems. The Best Management Practices listed here are intended for toilet flushing applications. Best Management Practices documents for 'General Considerations' and 'Subsurface and Drip Irrigation' are also available and contain specific details related to those end uses. In addition to this document, please read the appropriate Best Management Practices document in regards to your chosen graywater reuse application.

Graywater reuse for toilet flushing requires treatment including a combination of filtration and disinfection since there is a potential for graywater to come in contact with people and animals. If you decide to use graywater for toilet flushing, these best management practices should be followed:

- Invest in a commercially produced graywater system for toilet reuse.
    - Some companies with commercially available graywater toilet reuse systems: *Macdee, Sloan Valve, Wahaso, Greyter Water Systems, Water Saver Technologies.* Other companies may exist that provide graywater reuse systems for toilet flushing and the authors do not endorse any specific providers.
- Make sure that selected treatment system meets water quality or treatment requirements as stipulated by your state.
- Graywater treatment systems for toilet flushing can require substantial maintenance. Follow the manufacturer's maintenance recommendations for the installed treatment system.
- A connection to a municipal or well water supply is typically needed to supplement freshwater when the graywater supply is low. Use a backflow preventer when there is a connection to a potable water line (see the backflow preventer in Figure 1 on the next page).
- A certified plumber should be involved in the installation of the commercially available graywater treatment system and all plumbing to and from the system.
- The color of the graywater pipe must be different than potable water supply pipes and must conform to local plumbing code, which typically requires purple pipe to be used for treated graywater.
- Graywater supplied to toilets should be dyed to indicate it is not potable. Use a food-grade, vegetable based, blue or green dye. Graywater dyed blue can be seen in Figure 2 on the next page.
- All plumbing code requirements for valves, air breaks, backflow preventers, and venting must be followed. The International Plumbing Code (IPC) and Uniform Plumbing Code (UPC) provide

requirements for reusing graywater for toilet flushing, and different states and counties adopt different codes. It is necessary to determine which code is followed in your state and/or local government, and follow the specifications provided. See Figure 3 for a graywater reuse system for toilet flushing which meets all plumbing code requirements.

- It is crucial to maintain a disinfection residual in treated graywater to prevent regrowth of pathogens in the pipes and the toilet.
- If chlorine is chosen as a disinfectant, dosing needs to be precise and accurate to ensure a residual is maintained, yet concentrations do not exceed 4 mg/L. High concentrations of chlorine can result in damage to toilet components.
- Switch to potable water prior to departure when away for two or more nights.
- It is good practice to keep the lid of toilets closed when not in use and when flushing.

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Figures

Figure 1: Backflow Preventer

Figure 2: Graywater dyed blue in toilet

Figure 3: Graywater Reuse System for Toilet Flushing in Aspen Hall at Colorado State University

APPENDIX D

Considerations for Inclusion in a City Ordinance Allowing Toilet Flushing with Graywater

Guidance Document

The CDPHE Water Quality Control Commission Regulation 86 for Graywater Use is currently still in the drafting phases and therefore is subject to change. The information provided in this document is based off on the draft version of Regulation 86, released on June 30, 2014.

Graywater Collection and Storage

- Graywater generated must be used only on the property or facility from which it was generated.
- The maximum storage period for graywater used for toilet flushing is 72 hours based on ICP. However, a maximum storage time of 24 hours is recommended for stable operation of the graywater treatment system.
- The storage tank must be a minimum of 50 gallons.
- The graywater, if collected from a non-domestic source, must have a chemical composition typical of graywater from domestic households.
- All plumbing requirements as outlined in the International Plumbing Code (IPC) or Uniform Plumbing Code (UPC) must be met. Fort Collins follows the IPC standards. The plumbing code can be accepted with exceptions. One possible exception is that filters should be placed after the storage tank, not before the tank as specified in IPC code.
- It should be evident that the owner or operator of the graywater system strives to limit human exposure to graywater.
- The graywater system must include a tank to collect and store graywater. The storage tank must be covered, water tight, vented to the atmosphere, and have access openings for inspection and cleaning.
- If the storage tank is located outside, it must be placed on a 3-inch concrete slab or on dry, level, compacted soil and have a downturned screened vent. Tanks may not be located outdoors if freezing temperatures are observed. The storage tank may not be located in direct sunlight.
- All pipes, outlets, and tanks must be labeled to indicate graywater plumbing and in accordance with requirements from the plumbing code (IPC or UPC). Labeling includes

pipe color, arrows indicating direction of flow, graywater fixture identification, and appropriate signage signifying the use of graywater at that location. All components of the graywater treatment system must meet the adopted plumbing code requirements.

- The graywater system, if installed in a 100-year floodplain, must meet or exceed requirements of the Federal Emergency Management Agency and the local emergency agency. The system must be designed to minimize or eliminate infiltration of floodwaters into the system and discharge into the floodwaters.

- The graywater system must be sited outside of a floodway designated in a 100-year floodplain.

- A diverter valve must be installed at a convenient location to allow for easy switching between the graywater system and the sewer system. The diverter valve must be labeled appropriately and watertight.

- If an on-site wastewater treatment facility for blackwater exists, the graywater treatment system must not interfere with the design, treatment, or capacity of the on-site wastewater system.

Graywater Treatment for Toilet Flushing

- The graywater system for toilet flushing should be a commercially available manufactured treatment system.

- The treatment system should include filtration (minimum size 230 mesh or 60 microns) and disinfection.

    - CSU recommends a filter of minimum size 80 mesh.

- Detectable residual disinfectant should be maintained.

- The graywater must be dyed blue or green using a food grade, vegetable based dye to indicate nonpotable water.

- Wastewater from the graywater treatment system which includes, but is not limited to, raw graywater, filter backwash water, and unused treated graywater, must be disposed of directly to the sewer system or appropriate on-site wastewater system.

- A supplemental freshwater supply line must exist within the graywater treatment system for use when graywater supply is low; the water service shall be protected against backflow with a reduced pressure principle backflow prevention zone assembly, a reduced pressure principle fire backflow prevention assembly, or an approved air gap, to protect the public water supply.

- No piping bypassing the storage tank or treatment section should exist within the graywater system.

- Owner should provide a plan for switching to potable water when leaving for more than two nights.

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APPENDIX E

Considerations for Inclusion in a City Ordinance Allowing Subsurface or Drip Irrigation with Graywater

Guidance Document

The CDPHE Water Quality Control Commission Regulation 86 for Graywater Use is currently still in the drafting phases and therefore is subject to change. The information provided in this document is based on the draft version of Regulation 86, released on June 30, 2014.

Graywater Irrigation System Components

- The graywater system must include a tank to collect and store graywater. The storage tank must be covered, water tight, vented to the atmosphere, and have access openings for inspection and cleaning. Note: Based on the current draft of Regulation 86, laundry-to-landscape systems are allowed and do not require a tank.

- If the storage tank is located outside, it must be placed on a 3-inch concrete slab or on dry, level compacted soil and have a downturned screened vent. The tank may not be located in direct sunlight.

- The tank must be a minimum of 50 gallons.

- All pipes, outlets, and tanks must be labeled to indicate graywater plumbing and in accordance with requirements from the adopted plumbing code (International Plumbing Code (IPC) or Uniform Plumbing Code (UPC)). Labeling includes pipe color, arrows indicating direction of flow, graywater fixture identification, and appropriate signage signifying the use of graywater at the point of use.

- A diverter valve must be installed at a convenient location to allow for easy switching between the graywater system and the sewer system. The diverter valve must be labeled appropriately and watertight.

- If an on-site wastewater treatment facility for blackwater exists, the graywater treatment system must not interfere with the design, treatment, or capacity of the on-site wastewater system

- Graywater flow may be blocked for a number of reasons (i.e., plant roots, build-up of silt and lint. A properly built graywater system will direct the overflow into the sewer system rather than onto the ground.

- When both a graywater and potable water irrigation system exist on a single property or facility, the water service shall be protected against backflow with a reduced pressure principle backflow prevention zone assembly, a reduced pressure principle fire backflow prevention assembly, or an approved air gap, to protect the public water supply.

- No piping bypassing the storage tank or treatment process should exist within the graywater system.

- A filter of size 230 mesh or 60 microns may be required. However, most drip irrigation systems require a filtration of 120 - 150 mesh (110 to 125 microns).

- All plumbing requirements as outlined in the International Plumbing Code (IPC) or Uniform Plumbing Code (UPC) must be met. Fort Collins follows the IPC standards. The plumbing code can be accepted with exceptions. Some recommended exceptions include:

    - Filters should be placed after the storage tank, not before the tank as specified in IPC code.
    - The storage time for irrigation systems can be extended to 72 hours (instead of 24 hours).

- Installer should provide a plan for winterization of the graywater system and shut down for departure from residence for more than 2 nights.

Graywater Irrigation

- Graywater generated must be used only on the property or facility from which it was generated.

- A minimum of 3 inches of landscape cover must be placed over the drip irrigation system. Organic mulch breaks down or is blown away over the years and periodically needs to be replenished.

- The graywater, if collected from a non-domestic source, must have a chemical composition typical of graywater from domestic households.

- Irrigation applications must be subsurface or drip irrigation, absolutely no spray irrigation.

- Graywater must not be used for food crop irrigation except fruit or nut trees.

- The total weekly amount of irrigation may not be greater than 1.2 times the weekly evapotranspiration rate of the irrigation area. The net ET_o (including average rainfall) for Fort Collins is 37 inches annually. The appropriate irrigation areas for a family of 3, 4, 5, and 6 are 100, 130, 160, and 190 square feet, respectively.

- The irrigated area must not be located on slopes greater than 30%.

- Keep the graywater irrigation field 2 feet from any structure and the storage tank 5 feet from any structure. The storage tank must be kept 5 feet from any property lines and the irrigation field must be kept 1.5 feet from any property lines.

- The irrigation seasonal high water table is a minimum of 5 feet below the irrigation area.

- The graywater system, if installed in a 100-year floodplain, must meet or exceed requirements of the Federal Emergency Management Agency and the local emergency agency. The system must be designed to minimize or eliminate infiltration of floodwaters into the system and discharge into the floodwaters.

- The graywater system must be sited outside of a floodway designated in a 100-year floodplain.

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Washington State Department of Health, *Guidance for Performance, Application, Design, and Operation and Maintenance: Tier Two and Three Graywater Subsurface Irrigation Systems, Chapter 246-274 WAC.* June 2012. DOH Publication #337-063.

APPENDIX F

Fort Collins Graywater Regulations

Recommendations for Permit Requirements

Jillian Vandegrift, Sybil Sharvelle, Larry Roesner

The CDPHE Water Quality Control Commission Regulation 86 for Graywater Use is currently still in the drafting phases and therefore is subject to change. The information provided in this document is based off of the draft version of Regulation 86, released on June 30, 2014.

- **Identification of type of system**
  - Category A: Single family, clothes washer only, subsurface irrigation, <400 GPD
  - Category B: Single family, subsurface irrigation, <400 GPD
  - Category C: Non-single family, subsurface irrigation, <2,000 GPD
  - Category D: Single family, indoor toilet and urinal flushing, <400 GPD
  - Category E: Non-single family, indoor toilet and urinal flushing, flow not limited

- **Design submittal with the following information:**
  - The graywater uses
  - Graywater treatment system location
  - Design flow calculations

    Calculated using fixture flow rates and based on maximum occupancy OR the following values:

    Traditional fixtures: 25 gpd/occupant for showers, bathtubs, and wash basins and 15 gpd/occupant for clothes washers.

    Water saving fixtures: 20 gpd/occupant for showers, bathtubs, and wash basins and 8 gpd/occupant for clothes washers.

  - Fixtures that are the source of the graywater
  - Design of the plumbing and/or irrigation system
  - Soil analysis information (for Category C) CONTAINING:

    Site and soil evaluation:

    - Site information: site map and location of proposed graywater irrigation area in relation to minimum horizontal setback distances
    - Soil investigation: Completed by visual and tactile evaluation of soil profile test or percolation (drainage) test.
    - Irrigation rates may not exceed the maximum allowable soil loading rates in Table 13-2 based on the finest textured soil in the lower 24 inches of suitable soil.

Table 13-2: Soil Type Description and Maximum Hydraulic Loading Rate

Soil Type	USDA Soil Texture	USDA Structure - Shape	USDA Soil Structure-Grade	Percolation Rate (MPI)	Loading Rate for Graywater (gal./sq. ft./day)
0	Soil Type 1 with more than 35% Rock (>2mm); Soil Types 2-5 with more than 50% Rock (>2mm)	--	0 (Single Grain)		Not suitable without augmentation 1.0 with augmentation
1	Sand, Loamy Sand	--	0	5-15	Not suitable without augmentation 1.0 with augmentation
2	Sandy Loam, Loam, Silt Loam	PR (Prismatic) BK (Blocky) GR (Granular)	2 (Moderate) 3 (Strong)	16-25	0.8
2A	Sandy Loam, Loam, Silt Loam	PR, BK, GR 0 (none)	1 (Weak) Massive	26-40	0.6
3	Sandy Clay Loam, Clay Loam, Silty Clay Loam	PR, BK, GR	2, 3	41-60	0.4
3A	Sandy Clay Loam, Clay Loam, Silty Clay Loam	PR, BK, GR 0	1 Massive	61-75	0.2
4	Sandy Clay, Clay, Silty Clay	PR, BK, GR	2, 3	76-90	Not suitable
4A	Sandy Clay, Clay, Silty Clay	PR, BK, GR 0	1 Massive	91-120	Not suitable
5	Soil Types 2-4A	Platy	1, 2, 3	121+	Not suitable

- Simple schematic of graywater collection and distribution system including a list of products and components (for commercially purchased systems, this should be provided by the technology manufacturer)
- Contact information for legally responsible party and professional engineer or operator
- Signature of legally responsible party
- Drawing indicating irrigation area minimum horizontal setback distances are met (for irrigation systems), Table 13-1.

Table 13-1: Graywater System Locations

Minimum Horizontal Distance Required from:	Graywater Storage Tank	Irrigation Field
Buildings	5 feet	2 feet
Property line adjoining private property	5 feet	1.5 feet
Water supply wells	50 feet	100 feet
Streams and lakes	50 feet	100 feet
Sewage pits or cesspools	5 feet	5 feet
OWTS disposal field	5 feet	4 feet
OWTS tank	5 feet	5 feet
Domestic potable water service line	5 feet	5 feet
Public water main	10 feet	10 feet

☐ **Graywater irrigation area**
Calculated using LA=GW/(CF x ET x PF) where:
LA = Landscaped area (sq. ft.)
GW = Estimated graywater daily flow (gallons per week)
CF = .62 (sq. ft. x inch/gallon)

ET = Evapotranspiration rate (inches/week)

- Fort Collins Peak Monthly Use ET for Pasture Grasses = 5-6.5 inches depending on climatic zone (NRCS Colorado & USDA, Irrigation Guide) (Link, Page 8)

PF = Plant factor, 0.5

- [ ] **Construction inspection**

- [ ] **Proof of operation and maintenance manual** CONTAINING:

Operation and Maintenance Manual:

- **General description**: A graywater treatment works description including: equipment list, design basis data including but not limited to, design volumes, design flow rates of each component and service area, system drawing, and process description.
- **Maintenance procedures**: Maintenance information for the graywater treatment works including but not limited to: component maintenance schedule, instructions for component repair, replacement, or cleaning, replacement component source list, testing and frequency for potable containment device, and instructions for periodic removal of residuals.
- **Target operating parameters**: Operational ranges for parameters including but not limited to: disinfectant concentration levels, filter replacement parameters, pressure ranges, tank level, and valve status under normal operation.
- **Start up and shut down procedures**: Step-by-step instructions for starting and shutting down the graywater treatment works including but not limited to: valve operation, any electrical connections, cleaning procedures, visual inspection, and filter installation.
- **Troubleshooting**: A guide for visually evaluating the graywater treatment works and narrowing any problem scope based on alarm activations, effluent characteristics, system operation, and history.
- **Control Measures**: A list of graywater control measures in which the graywater treatment works must be operated.

- [ ] **If Fort Collins decides reporting is required, permit must include the required parameters and required frequency**

- [ ] **Follow BMP's (Control measures/Design criteria listed in Regulation 86)**

- [ ] **A plan for winterization and shut down for out of town periods should be provided.**

References

5 CCR 1002-86, Graywater Control Regulation Draft, Water Quality Control Commission of Colorado Department of Public Health and Environment. June 30, 2014

Colorado Irrigation Guide, Natural Resources Conservation Service Colorado, United States Department of Agriculture, 2009. URL: Link

APPENDIX G

The Basics of Graywater Use for Irrigation and Toilet Flushing

General Overview Factsheet

Instructional Factsheet I

Jillian Vandegrift, Sybil Sharvelle, Larry Roesner

"Graywater is defined as the portion of domestic wastewater that is not toilet water and does not contain human waste. In the U.S., dishwater is usually separated from graywater due to high organics and foodborne pathogens"

Quick Facts about Graywater Use

- Graywater is defined as effluent water from hand sinks, showers, and washing machines.
- By reusing graywater for outdoor irrigation or toilet flushing, potable water use can be reduced by up to 35%.
- Graywater does not include effluent from toilets or dishwashers.
- Graywater reuse systems will require plumbing modifications, and in most cases require the assistance of a licensed plumber.
- Reusing graywater for outdoor irrigation is usually far less expensive than installing a graywater reuse system for toilet flushing.

Introduction to Graywater Reuse

The intent of this fact sheet is to familiarize and educate the reader about graywater reuse for irrigation and toilet flushing. It is important to understand the requirements for a graywater reuse system so that informed decisions regarding the installation can be made. This document should be read in its entirety before moving on to the design process. Another fact sheet, entitled 'How to Install a Graywater System for Outdoor Irrigation', provides more detail on designing and operating a system for outdoor irrigation. Please refer to the other document if you decide graywater reuse is right for you.

Graywater reuse is the process of separating graywater from other waste sources and then storing, treating, and using the graywater to supplement non-potable demands such as irrigation and/or toilet flushing. Typical sources of graywater include showers, hand sinks, and laundry machines. Graywater is considered a low strength wastewater. Graywater typically has lower levels of potentially harmful pathogens such as *E. coli* and *Salmonella* and lower levels of organics in contrast to domestic wastewater because toilet and kitchen waste are not collected in graywater reuse systems. The main quality concerns of graywater are organic matter, pathogens, turbidity, and total suspended solids. High levels of turbidity and total suspended solids are responsible for the poor aesthetics sometimes associated with graywater and also run the risk of harboring potentially harmful pathogens. Due to the risk of pathogens, each graywater application may require a different extent of treatment to ensure public health.

Graywater is collected in a home, multi-residential unit, or business using a dual plumbing system. Dual-plumbing is an additional plumbing system that allows graywater to flow to the storage/and or treatment system while allowing blackwater to continue to flow to the sewer. Reusing graywater can have several benefits including the overall reduction in potable water use and wastewater generation. Graywater also provides nutrients to plants without the use of synthetic fertilizer. Installation of graywater reuse systems requires plumbing knowledge, investment in equipment and materials, and possibly some additional construction costs for building retrofits. The following steps should be followed to install a graywater reuse system:

1) Determine the local laws and regulations for graywater reuse
2) Decide what to reuse the graywater for (irrigation, toilet flushing, or both)
3) Determine how much graywater you produce and whether it fits your reuse needs
4) Determine the plumbing installation, tank location, and required size of tank
5) Determine scheduled maintenance requirements

Is Graywater Reuse Something I should Consider?

It is important to be well informed on what is required to install and operate a graywater reuse system. Some of the most important considerations include:

* Local graywater laws – The State of Colorado allows graywater reuse. However, cities and counties are not required to allow graywater reuse. Therefore, you will need to know your local regulations for graywater reuse.
* Maintenance – Routine maintenance includes cleaning and replacing filters, replacing consumables, turning off and emptying the system when it is not in use, winterizing the system, and other manufacturer's recommendations.

* Existing plumbing – It is important to evaluate the plumbing requirements for a specific building before retrofitting plumbing for graywater. Many times, retrofitting will require removal of dry wall. In most cases, assistance of a licensed plumber is required.

* Graywater Generation – The amount of graywater that will be generated by the residence or business will need to be determined and evaluated if it is enough for the intended end use.

* Desired end use – Both irrigation and toilet flushing require plumbing considerations, storage, and equipment such as pumps, filters, irrigation emitters, additional treatment products such as disinfectants, etc…

* Treatment – Graywater contains organic matter, solids, nutrients, and pathogens. For irrigation purposes, treatment may be as simple as a coarse filter to remove solids. If exposure to humans and animals is likely (toilet flushing), a filtration and disinfection step is necessary.
* Budget – Installation of all necessary components can be expensive. Plumbing and manufactured systems can range from several hundred to several thousand dollars.

The decision tree seen below (Figure 1), can be used to determine whether a graywater reuse system is appropriate for you.

Graywater Generation

Graywater generation is dependent upon the water use and flow rates of fixtures in your home/business. Graywater typically accounts for approximately 44% of indoor water used in buildings where there are both washing machines and showers. Graywater reuse may not be feasible in buildings without shower and washing machine use because supply will be strictly limited. In instances where the graywater supply and demand are sufficient, potable water use can be reduced by up to 35%. See factsheet II, "How to Install Graywater Reuse System for Outdoor Irrigation", for more information on graywater generation.

Uses for Graywater

Most homes and/or businesses choose a single end use for graywater rather than installing a system for more than one use. Because toilet flushing requires disinfection, a graywater system for both toilet flushing and irrigation may require two tanks, one for storage and one for disinfection.

Reuse for Irrigation

Irrigation demand is typically the largest household water demand. In 1999, irrigation demand was estimated at 100 gallons per capita per day (gpcd) or approximately 60% of overall use on average measured in a Residential End Uses of Water Study (REUWS) done by the AWWA in 12 cities across the United States. In a 2012 REUWS site report for Fort Collins, Colorado, the average outdoor use was estimated at 51 gpcd. Irrigation demand is based on climate, region, irrigation area, and season, and will vary regionally. The average person only generates enough graywater to meet around 20 gpcd of their irrigation needs unless irrigated areas are xeriscaped. Subsurface or drip irrigation is required for graywater reuse because spray irrigation increases the potential for pathogens to become airborne and more likely to come in contact with humans and animals. See Figure 2 for a drip irrigation system utilizing graywater. Typically drip systems only require a coarse filtration system without disinfection. Most drip irrigation systems require a filtration of 120 - 150 mesh (110 to 125 microns). Irrigation of food crops is not recommended except for fruit or nut trees, but fruit that has fallen to the ground should not be eaten. More information specific to graywater reuse for irrigation is included in the section below, titled Best Management Practices. In addition, a fact sheet entitled 'How to Install a Graywater Reuse System for Outdoor Irrigation' is also available.

Reuse for Toilet Flushing

The average person uses about 11.2 gallons per day to flush their toilet and generates approximately 20 gallons per day of graywater (Figure 3) (REUWS, 2012). Thus, the graywater generated in a household generally exceeds the amount required for toilet flushing. As seen in Figure 3, shower (9 gpcd) or laundry (7 gpcd) effluent *alone* are not enough to meet toilet demand. Reuse of graywater for toilet flushing requires a disinfection step since there is increased potential for it to come in contact with humans and animals.

Typical treatment consists of a combination of filtration and disinfection to kill pathogens (i.e. bacteria and viruses) that are present in graywater. Commercially available systems are recommended for treatment of graywater to flush toilets. Completing the work for a toilet flushing reuse system requires the assistance of a certified, licensed, plumber. Reuse systems require a tank, filter, pump(s), disinfection, and a dye injection unit to indicate non-potable water. Reuse systems for toilet flushing also need potable water lines to the tank in order to be able to supplement with freshwater if graywater supply is low, allowing the system to operate at all times. A freshwater bypass line is typically installed to make sure that water is present in toilets when there is maintenance being performed on the system or in the instance that a power outage occurs. Backflow prevention is extremely important when connecting a graywater system to the potable water lines so there is not the potential for harmful pathogens in graywater to contaminate freshwater lines. Chapter 10 in this document provides examples of graywater reuse for toilet flushing systems. More information specific to graywater reuse for toilet flushing is included in the Best Management Practices.

When designing a graywater reuse system, you need to evaluate elevation differences within your plumbing, assess a tank location, and install a dual plumbing system to divert graywater to the reuse system or to the sewer.

Collection of Graywater for Use

Installing a dual plumbing system requires access to existing plumbing. See Figure 4 for a schematic depicting a dual plumbing system. New collection lines that allow graywater to flow to the graywater reuse system need to be installed. These new lines will separate the graywater from the existing blackwater lines, allowing the blackwater to still flow to the sewer main. In a one story home with an unfinished basement or crawl space, it may be simple to collect graywater for reuse.

However, retrofitting a two story home with a finished basement may require drywall removal to install a dual plumbing system. A simple way to reuse graywater in this case may be to collect graywater only from the laundry machine.

Components of a Graywater Reuse System

Storage tanks allow the graywater to be collected and stored until it is needed for reuse.

Components of a graywater tank should include graywater inlet lines, overflow lines, drain lines, and a vent (Figure 5). Graywater inlet lines are the plumbing that collect the graywater and convey it to the tank. Overflow lines are required in all graywater reuse systems to allow excess graywater in the graywater tank to flow to the main sewer line. Drain lines allow the graywater tank to be drained to the sewer for maintenance. Drain lines are also used to get rid of water that has not been used for 3 or more days (e.g. vacations, trips). See factsheet II for more details on graywater reuse system components.

Components of a Graywater Reuse System for Irrigation

- Graywater tank with labeled components (Figure 5)
- Coarse Filter
- Pump

Components of a Graywater Reuse System for Toilet Flushing

- Graywater tank with labeled components (Figure 5)
- Filter
- Disinfection treatment
- Disinfection contact tank
- Pump
- Blue or green dye injection

Common disinfection options are: Chlorine, ultraviolet (UV) light, iodine, hydrogen peroxide, and ozone.

References

Arizona Department of Environmental Quality, *Using Gray Water at Home, 2010*. URL: Link

Bergdolt, J. *Graywater Reuse Guidance and Demonstration Using a Constructed Wetland Treatment System*. Colorado State University, 2011. URL: Link

Bergdolt, J.; Sharvelle, S.; Roesner, L. *Guidance Manual for Separation of Graywater from Blackwater for Graywater Reuse*. Colorado State University & Water Environment Research Foundation, 2011.URL: Link

Masters Plumbers and Mechanical Services Association of Australia and RMIT University, Australian Government-National Water Commission. *Urban Greywater Design and Installation Handbook, 2008.* URL: Link

Roesner,L.; Yaling, Q.; Criswell, M.; Stromberger, M.; Klein, S. *Long-Term Effects of Landscape Irrigation Using Household Graywater- Literature Review and Synthesis.* Colorado State University & Water Environment Research Foundation, 2006. URL: Link

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

Sharvelle, S.; Roesner,L.; Yaling, Q.; Stromberger. M.; Masoud, N.A. *Long-Term Study on Landscape Irrigation Using Household Graywater: Experimental Study.* The Urban Water Center, Colorado State University & Water Environment Research Foundation, 2012. URL: Link

Figures in Order of Appearance

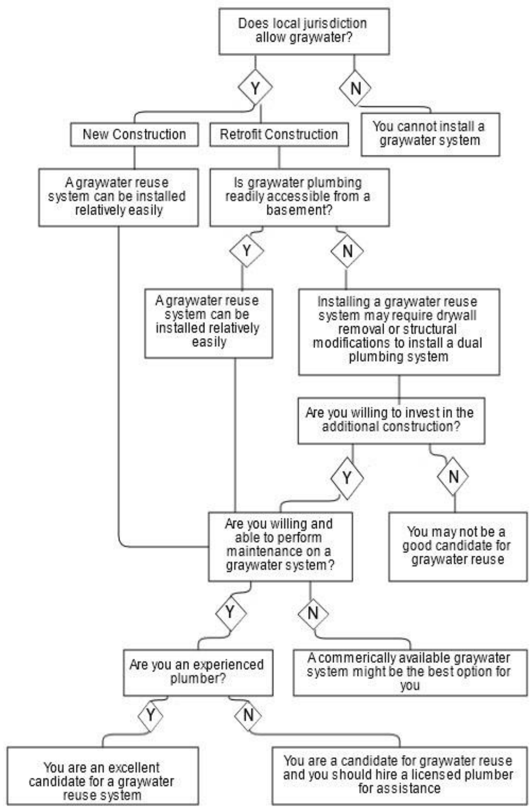

Figure 1: Decision Tree for Graywater Reuse

Figure 2: Drip Irrigation Utilizing Graywater

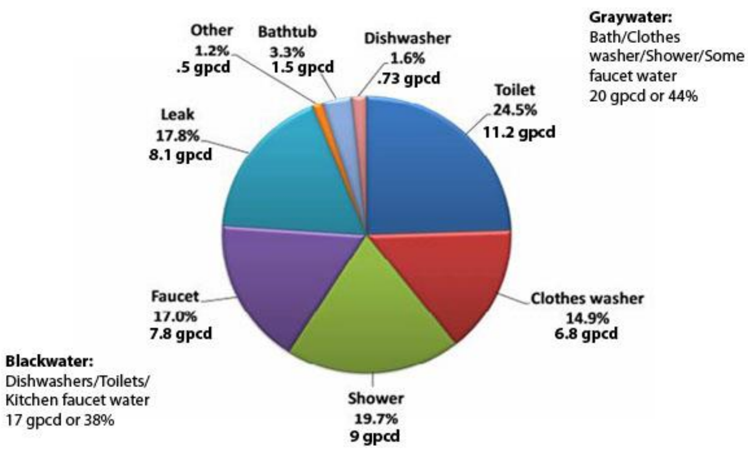

Figure 3: Average Indoor Residential Water Usage (REUWS Update –Site Report for Fort Collins, CO, 2012)

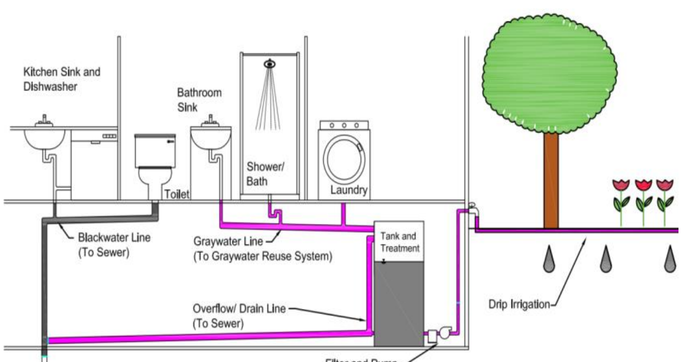

Figure 4: Dual Plumbing System

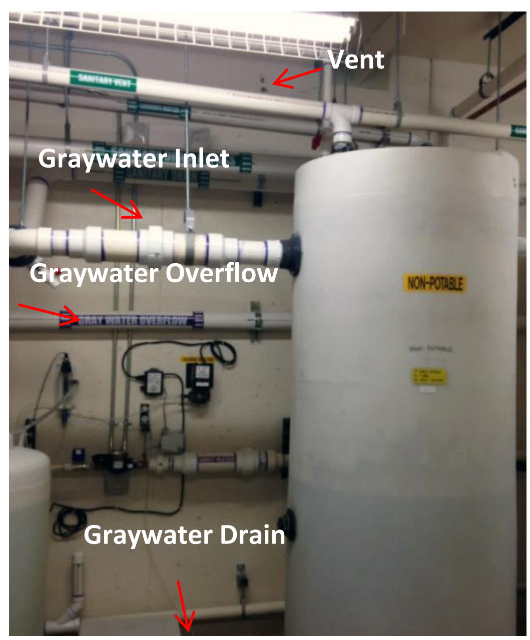

Figure 5: Graywater Tank and Components

APPENDIX H

How to Install a Graywater Use System for Outdoor Irrigation

Instructional Factsheet II

Jill Vandegrift, Sybil Sharvelle, Larry Roesner

Quick Facts on Installing a Graywater Reuse System

- There are three methods used for estimating graywater generation: Typical graywater generation rates, water meter readings, and specific flow rates from fixtures and typical length of use.
- The characteristics of the soil in your yard and the actual irrigation demand of your landscape need to be known in order to design and construct a successful graywater system for irrigation.
- Laundry-to-Landscape is a graywater reuse system for irrigation which captures graywater from the discharge hose of your washing machine and utilizes the graywater for irrigation without requiring pipe cutting or costly treatment systems.
- There is no "one design fits all", however, every graywater reuse system requires plumbing capable of diverting graywater for capture while allowing blackwater to continue to flow to the sanitary sewer using the original sewer system.
- Important components of a graywater tank include graywater inlet lines, overflow lines, drain lines, and a vent.
- Important components of the graywater reuse system for irrigation include filters, pumps, emitters, drip lines, supply lines, and hose bibs.

Instructional Guidance for Installing a Graywater Reuse System for Irrigation

- Methods of landscaping for graywater reuse
- How much graywater do you produce?
- Soil absorption and size of irrigated area
- Types of graywater irrigations systems
    - Laundry-to-Landscape system
    - Storage and distribution to drip/submerged irrigation
- Designing a dual plumbing system
- Graywater storage tank design
- Plumbing to irrigation and constructing the system
- Additional resources and references

Methods of Landscaping

Three methods of landscaping will be discussed as they relate to graywater use: Xeriscaping, landscaping, and turf lawns.

- *Xeriscaping* – Uses drought tolerant plants that typically require less water and maintenance. Xeriscaping is common with graywater systems because a graywater reuse system can usually meet the total irrigation demand for a xeriscaped yard.
- *Landscaping* – Refers to decorating an area of yard using ornamental flowers, bushes, and trees rather than turf grass. Landscaping can be irrigated with graywater using drip irrigation or subsurface emitters.
- *Turf Lawns* – Turf lawns such as Kentucky bluegrass require a substantial amount of water, as much as an inch to an inch and a half of water per week during the summer and up to two and a half inches of water per week during the hottest part of the summer. Buried drip irrigation systems are required for irrigating turf lawn using graywater. These systems are often costly and complex.

How Much Graywater Do You Produce?

Graywater generation rates need to be calculated for each specific home or business because hygiene habits are individualized. Additionally, the quantity of graywater produced varies based on the type of shower, bathtub, and washing machine. It is important to understand the amount of graywater your home/business produces to estimate the size of storage required, as well as the system's ability to meet end use demands. There are three methods used for estimating graywater generation: Typical graywater generation rates, water meter readings, and specific flow rates from fixtures and typical length of use.

- Using Table 1, graywater generation can be approximated based on typical fixture water use and the number or persons in the home or business.
- Using a water meter, record an initial reading and take another reading after seven days. Ensure that no irrigation takes place during that week. Average daily water use in gallons can be calculated by dividing (Initial reading – final reading) by 7. Assume approximately fifty percent of the water used is graywater.
- Measuring flow on fixtures and multiplying by the length of time spent using the fixtures will yield graywater production in gallons/day. Manufacturer's often list flow rates on the product or product website.
- Visit San Francisco's Water Use Calculator online to estimate water use in your home by following this link: http://www.sfwater.org/index.aspx?page=686

Sizing Irrigation Area

It is very important to understand the characteristics of the soil in your yard before designing and constructing a graywater system for irrigation. The maximum amount of graywater that can be applied to a given area can be estimated based on soil type. In addition, the appropriate amount of graywater to meet irrigation demand can be determined. Ideally, irrigation area should be determined to meet irrigation demand, also ensuring that graywater application does not exceed the maximum allowed to ensure graywater soaks into the soil without pooling or running off your property. There are three types of tests that can assist in evaluating the soil type in your yard. By clicking the link next to the text below, you will be directed to a PDF document with instructions on how to complete the tests.

1. Soil Ribbon Test: (San Francisco Graywater Manual, 2012) Link. Page 11

2. Laboratory Test: (San Francisco Graywater Manual, 2012) Link. Page 12
3. Drainage Test: (San Francisco Graywater Manual, 2012) Link. Page 12

Process to Determine Area Based on Irrigation Demand:

The amount of water needed for irrigation and the appropriate irrigation area (sq ft) can be determined using evapotranspiration (ET) rates. Evapotranspiration provides us with a value signifying how much water is required for plants to grow per month to account for soil moisture evaporation. You should use values corresponding to the region you reside in as ET rates vary greatly in different locations. This (Northern Water.org) link provides a good tool to find Northern Colorado ET data. For national ET data, visit this link. In addition to the ET rate for your area in inches/month, you will need to know the gallons of graywater flowing to the system per week. These values can then be plugged into the following formula to determine irrigation area in square feet:

Irrigation Area (square feet) = Graywater generated per week / (CF x ET x PF)

Conversion Factor = 0.62 square foot x inch / gallon

ET = Evapotranspiration (inches/week)

Plant Factor = 0.5

Process to Determine Minimum Allowable Irrigation Area:

1. Using Table 1, the amount of graywater generated per household per day can be calculated.
2. Using Table 2, the irrigation area can be determined using the amount of graywater calculated in Step 1 of this process and using the known soil type of the landscape intended to be irrigated with graywater.

Example Calculation:

Example 1, Minimum Allowable Irrigation Area

Fort Collins, Household of 3:
19.9 gallons of graywater generated per capita per day x 3 people = 59.7 gallons of graywater generated per day
Soil Type = 2, Sandy Loam, Loam, Silt Loam
Loading Rate for Graywater = 0.8 gallons per square foot per day

Minimum Allowable Irrigation Area (square feet) = 59.7 gallons of graywater per day / 0.8 gallons of graywater needed per square foot per day = 74.63 square feet

Please see (JustWaterSaversUSA,2011) this website to use a Graywater Irrigation Area calculator with site specific inputs.

Determining Irrigation Area

Discrepancies sometimes arise between the irrigation area determined from irrigation demand and the minimum allowable irrigation area determined by soil type. The irrigation area based upon the water requirements of the land during the growing season should be used *except* if this irrigation area is less than the minimum allowable area based on soil type, in which case the area calculated based on soil type should be used.

Types of Graywater Irrigation Systems

Laundry-to-Landscape

Laundry-to-Landscape is a graywater reuse system for irrigation which captures graywater from the discharge hose of your washing machine and utilizes the graywater for irrigation (see Figure 1). The hose leaving your washing machine is attached to a valve capable of switching between the graywater system and the sewer. In certain scenarios, such as the use of bleach in a load of laundry, the valve should be switched off to stop the flow of potentially harmful water to your yard. Laundry-to-Landscape is significantly less complex and less costly than other reuse systems for irrigation and enables you to reuse water without altering the existing plumbing in your home. This system works best when irrigating trees, bushes, shrubs, small perennials, and larger annuals. Laundry-to-Landscape is a popular system in cities such as San Francisco and Long Beach, California, and may not require a permit depending on your local jurisdiction. Some cities offer incentives for this program, so be sure to check if your city is one of them. The cost of this system ranges from a few hundred dollars if you do the installation yourself, to $1,000-2,000 for professional installation. To read more about laundry-to-landscape, as well as obtain a list of materials and step-by-step installation instructions, click (San Francisco Graywater Manual, 2012) here, page 16-26.

Storage and Distribution to Drip/Submerged Irrigation

Graywater reuse systems for irrigation can be designed to collect graywater from all household graywater sources and utilize a storage tank, filtration, and a pump to distribute the graywater to subsurface or drip irrigation lines. Figure 2 depicts the general process for storing graywater and distributing it to drip/submerged irrigation. The details regarding the components of the graywater irrigation system depicted in Figure 2 can be found in the sections below.

Designing a Dual Plumbing System

Before beginning to design your system, it is crucial to understand how graywater plumbing must be separated. Fundamental to this is the understanding of basic indoor plumbing. Please refer to Chapter 4 in *Guidance Manual for Separation of Graywater from Blackwater for Graywater Reuse,* or click (Bergdolt et al., 2011) here, page 4-1, to learn more about existing indoor plumbing, and always consult with a licensed plumber early in the design process. Implementing a graywater reuse system can be harder and more expensive to complete in retrofit situations, and therefore requires a different design method than graywater reuse systems for new construction. There is no "one design fits all", however every graywater reuse system requires plumbing capable of diverting graywater for capture while allowing blackwater to continue to flow to the sanitary sewer using the original sewer system. For more detailed information on the desired subject matter, listed below, please click the hyperlink next to the bullet point text.

- *Deciding on a tank location*: It is important to ensure the location of graywater sources is higher than the top of the tank. The overflow line must be located high enough above the sewer main so excess graywater can flow to the sewer. Follow this (Bergdolt et al., 2011) Link, and scroll to page 5-1. See Figure 3 below to see possible tank locations and styles.

- *Graywater reuse system for a new construction project*: Designing a graywater reuse system for new construction should be designed and completed when the house or business is being originally plumbed, before the drywall is installed. This allows the appropriate planning of tank location, elevation differences, and the dual plumbing system so the graywater reuse system functions properly. To view more detailed information, click this (Bergdolt et al., 2011) Link , navigate to page 5-5.

- *Graywater reuse system for an existing home or business (retrofitting):* Retrofitting often requires the removal of drywall to access plumbing; the plumbing lines will need to be cut and replaced so that there is a Graywater Main Line and a Blackwater Main line enabling graywater to flow to the storage tank or to the sewer. To learn more, follow this (Bergdolt et al., 2011) Link, page 5-6.

- *Designing the graywater plumbing to the tank*: Designing the horizontal component of the dual plumbing system from the graywater sources to the tank can be more straightforward with the use of plan and profile drawings. To access a guide outlining the design process, follow this (Bergdolt et al., 2011) Link, page 5-10.

Graywater Storage Tank Design

Storage tanks allow collection and storage of graywater until it is ready to be used. Important aspects of designing a graywater storage tank include reviewing the necessary components, determining an appropriate tank size, properly venting the tank, and designing the plumbing from the tank to the sewer.

Sizing the Tank

Storage tanks are typically sized larger than the amount of graywater generated daily to allow for the opportunity to collect larger flows. It is also important to consider the way you want the graywater system to run. For example, if you intend to irrigate daily, the tank should be 2-3 times the average daily graywater generation rate. Click (Bergdolt et al., 2011) here, page 6-2, for an example of how to calculate tank size for irrigation reuse. It is important to note that the tank "storage" volume is not the tank volume but instead the volume of water that can be stored without spilling through the overflow pipe. Minimum storage sizes can be determined by multiplying the daily graywater generation rate by the intended days of storage for the graywater system depending on how the system is going to operate and the desired end use application. For example, if the daily generation of graywater is 100 gallons per day and the graywater is going to be stored for 48 hours or 2 days, then the minimum storage tank size is 200 gallons. In contrast, if graywater is intended to be stored for 72 hours or 3 days, the minimum storage tank size is 300 gallons.

Components of a Graywater Tank

Figure 4 depicts the following important components of a graywater tank:

- Graywater inlet lines
- Overflow lines
- Drain lines
- Vent

Graywater inlet lines are the plumbing from the sources that convey the graywater to the storage tank. The graywater inlet line can be located anywhere on the side of the tank, but should be a minimum of 6" above the bottom of the tank to prevent inflow water from stirring up sediment. The size of the inlet should match the size of the sewer line that it is replacing. **Overflow lines** are required in all graywater reuse systems to allow excess graywater to flow back to the main sewer line. Overflow lines need to be as large as the sewer lines they connect into. Overflow lines should be located a few inches below the top of the tank so that it does not become pressurized. **Drain lines** allow the tank to be drained to the sewer. A valve should be placed on the drain line to turn off the flow to the sewer when the tank is in operation.

How to Vent the Graywater Tank

Vents are required at the tank to equalize pressure, prevent pressure buildup resulting from gas production, allow odors to dissipate outside, and allow the graywater system to perform properly. The vent needs to be installed from the tank to either the outside or to existing wastewater collection plumbing. The vent needs to be located above the overflow line to prevent water from blocking the vent plumbing. Click (Bergdolt et al., 2011) here, page 6-3, for more information on how to vent your tank.

Designing the Graywater Plumbing from the Tank to the Sewer

The next step in planning your graywater reuse system is to design the overflow line and drain lines from the tank to the sewer. There is a four step process, (Bergdolt et al., 2011) here, page 6-5, used to design the plumbing from the tank to sewer. Designing a dual-plumbing system is an iterative process and may take several times to complete. It is critical to have the drain line be a downward slope from the bottom of the tank until it reaches the sewer. It is equally important to ensure the drain line and overflow line are higher than the existing sewer to prevent blackwater backflow into the graywater tank. It is also necessary to consider if a pump is needed to help drain the tank in situations where the elevation difference does not enable flow to the sewer main. In most cases, the graywater sources or the sewer main cannot be raised in elevation, but by using this process, the tank locations and tank heights may be adjusted accordingly. Tank elevation can be raised using a higher platform. After finishing the design from the tank to the sewer, the next step is to complete the layout of the system with a licensed plumber. Identifying potential elevation and tank location issues is crucial to having a properly functioning system.

Plumbing to the End Use

Components for an Irrigation System
When installing a graywater reuse system for outdoor irrigation, there are required components that are necessary for the system to function properly. This includes filters, pumps, emitters, drip lines, supply lines, and hose bibs. See Figure 5 below for irrigation reuse system components.

Filtration

Filtration is needed to remove solids such as lint and hair, and is used to prevent blockages or damage to equipment. The recommended location for filters is after the storage tank but before the pump, allowing water to flow into the tanks and even if the filter gets clogged, excess graywater can return to the sewer through the overflow line. There are three kinds of filters that can be used for a graywater system, a coarse filter, bag filter, or sand filter. They are explained more in detail (Bergdolt et al., 2011) here, page 7-5.

Pumps

Pumps are required to transport the graywater to the end use, to overcome elevation differences, provide sufficient water pressure, and allow emitters to work properly. The two most common pumps are an irrigation pump or a submersible pump. It is important to understand how much pressure the system needs in order to find a pump that can supply water efficiently. Click (Bergdolt et al., 2011)here, page 7-9, for more information and example calculations regarding pumps and pressure.

Irrigation System

Subsurface irrigation and drip irrigation are the two methods to irrigate xeriscaping and landscaping. Drip irrigation applies a slow drip of graywater to the root zone of the plants using an emitter and requires a minimum of 3” of mulch or other landscape cover to limit human exposure to graywater. See Figure 6 below for a drawing of drip lines looped around a tree and the mulch placed over the drip line. Drip lines are typically made from polyethylene tubing which can come pre-punctured or non-perforated. Emitters can be purchased in different sizes but most commonly apply between 0.5 -2 gallons per hour.

If irrigating a turf lawn, it is recommended to use subsurface irrigation with emitters. Turf lawns require large amounts of water on the order of 2.5” per week during the summer. Irrigating a turf lawn is most appropriate when there is either a small amount of lawn or a large amount of graywater supply. Subsurface irrigation uses a special type of emitter so roots cannot grow and clog the apparatus. These emitters are attached to the drip hose and placed approximately every 18 inches to allow water to spread evenly across the irrigation area. See Figure 7 below for an example of ReWater emitters being installed under the surface to irrigate a turf lawn. To learn more about the irrigation systems, refer to Chapter 3 and Chapter 7 of (Bergdolt et al., 2011) this document.

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Bergdolt, J.; Sharvelle, S.; Roesner, L. *Guidance Manual for Separation of Graywater from Blackwater for Graywater Reuse*. Colorado State University & Water Environment Research Foundation, 2011. URL: Link

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Residential End Uses of Water Study Update – Site Report Fort Collins, Colorado. City of Fort Collins Utilities. Prepared by Aquacraft and National Research Center. August 2012. URL: Link

Residential End Uses of Water. American Water Works Association and AWWA Research Foundation. Copyright 1999. URL: Link

ReWater® Photo Reference: Link

'San Francisco Graywater Design Manual for Outdoor Irrigation'. San Francisco Public Utilities Commission, Water Resources Engineering, Inc., San Francisco Department of Building Inspection, San Francisco Department of Public Health. June 2012. URL: Link

' The Greywater Guide'. Just Water Savers USA. Ohio, 2011. URL: Link

Underground Graywater Storage Tank Photo Reference: Link

Additional Resources:

Cross Connection Control Manual: Link

Water Efficient Irrigation Ordinance Guidebook: Link

Long-Term Study on Landscape Irrigation Using Household Graywater: Experimental Study: Link

Figures in Order of Appearance

Table 1: Average Graywater Generation Rates

	Conventional Fixtures (Gallons per capita per day)[1]	Low Flow Fixtures (Gallons per capita per day)[2]	Fort Collins REUWS Data 2012 (Gallons per capita per day)[2]
Shower	**11.6**	**8.8**	**9**
Bath	**1.2**	**1.2**	**1.5**
Faucets	**3.6**	**3.6**	**2.6**
Laundry	**15**	**10**	**6.8**
Total	**31.4**	**23.6**	**19.9**

[1]Adapted from Residential End Uses of Water, Copyright 1999, American Water Works Association and AWWA Research Foundation.

[2]Adapted from REUWS Update, Fort Collins, 2012, AWWA and AWWA Research Foundation.

Table 2: Loading Rate for Graywater Categorized by Soil Type (Adapted from Regulation 86 Draft, June 2014, CDPHE WQCC 5 CCR 1002-86)

Soil Type	USDA Soil Texture	USDA Structure - Shape	USDA Soil Structure-Grade	Percolation Rate (MPI)	Loading Rate for Graywater (gal./sq. ft./day)
0	Soil Type 1 with more than 35% Rock (>2mm); Soil Types 2-5 with more than 50% Rock (>2mm)	--	0 (Single Grain)		Not suitable without augmentation 1.0 with augmentation
1	Sand, Loamy Sand	--	0	5-15	Not suitable without augmentation 1.0 with augmentation
2	Sandy Loam, Loam, Silt Loam	PR (Prismatic) BK (Blocky) GR (Granular)	2 (Moderate) 3 (Strong)	16-25	0.8
2A	Sandy Loam, Loam, Silt Loam	PR, BK, GR 0 (none)	1 (Weak) Massive	26-40	0.6
3	Sandy Clay Loam, Clay Loam, Silty Clay Loam	PR, BK, GR	2, 3	41-60	0.4
3A	Sandy Clay Loam, Clay Loam, Silty Clay Loam	PR, BK, GR 0	1 Massive	61-75	0.2
4	Sandy Clay, Clay, Silty Clay	PR, BK, GR	2, 3	76-90	Not suitable
4A	Sandy Clay, Clay, Silty Clay	PR, BK, GR 0	1 Massive	91-120	Not suitable
5	Soil Types 2-4A	Platy	1, 2, 3	121+	Not suitable

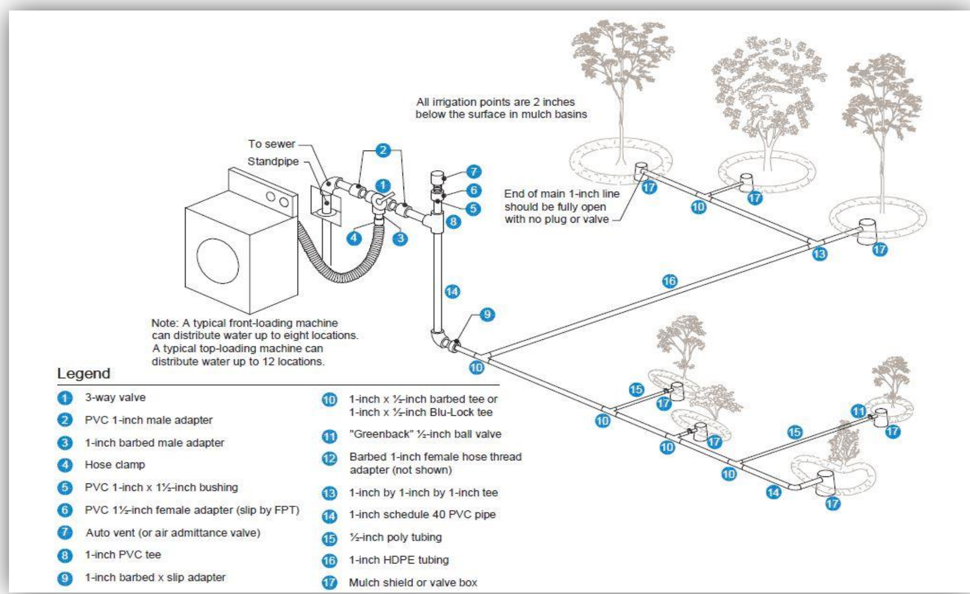

Figure 1: Schematic of Laundry-to-Landscape system promoted through San Francisco's Laundry-to-Landscape Graywater Program (SFPUC, 2012)

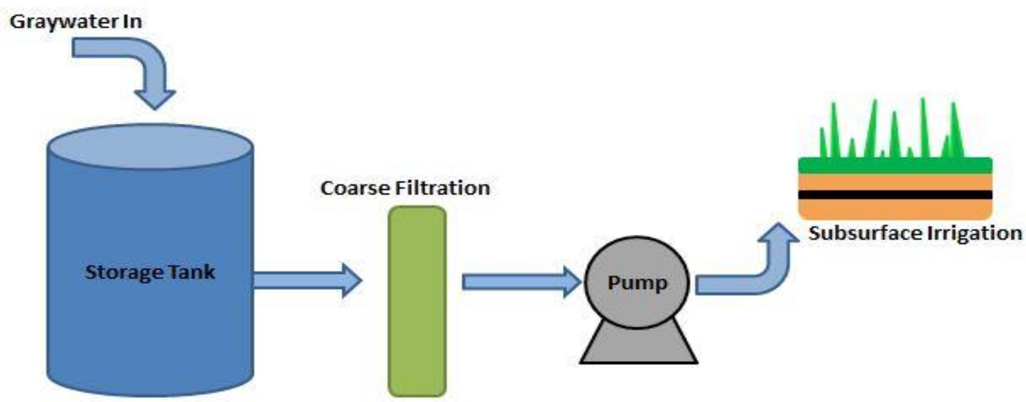

Figure 2: General Process Schematic for Graywater Subsurface Irrigation

Figure 3: Photograph (left to right) Indoor, outdoor, and underground storage tanks (Bergdolt, 2011 URL: Link)

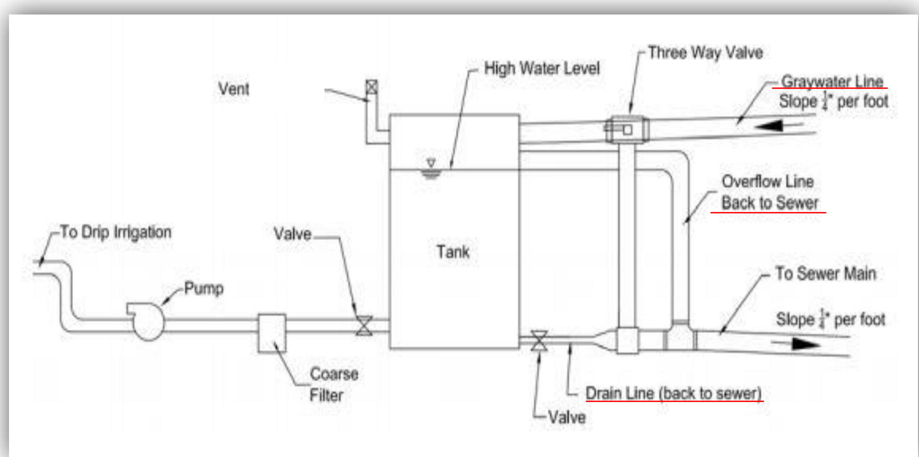

Figure 4: Graywater tank components (Bergdolt, 2011 URL: Link)

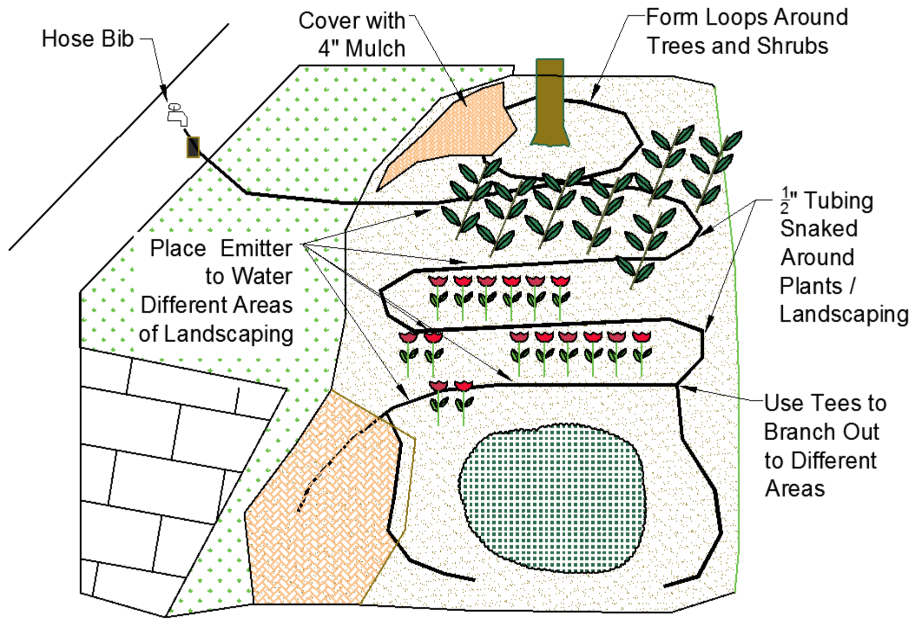

Figure 5: Drip irrigation depiction (Bergdolt, 2011 URL: Link)

Figure 6: ReWater emitters (left) and emitters being installed under turf lawn for subsurface irrigation (Rewater®, 2014 Link)

APPENDIX I

Standard Operating Procedure for the Graywater Reuse for Toilet-flushing System at Aspen Residence Hall

October 23, 2012
By
Brock Hodgson

Updated March 11, 2013
By
Kristen Wiles

Updated April 17, 2014
By
Jillian Vandegrift

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List of Tables

A. **Purpose and Applicability.**

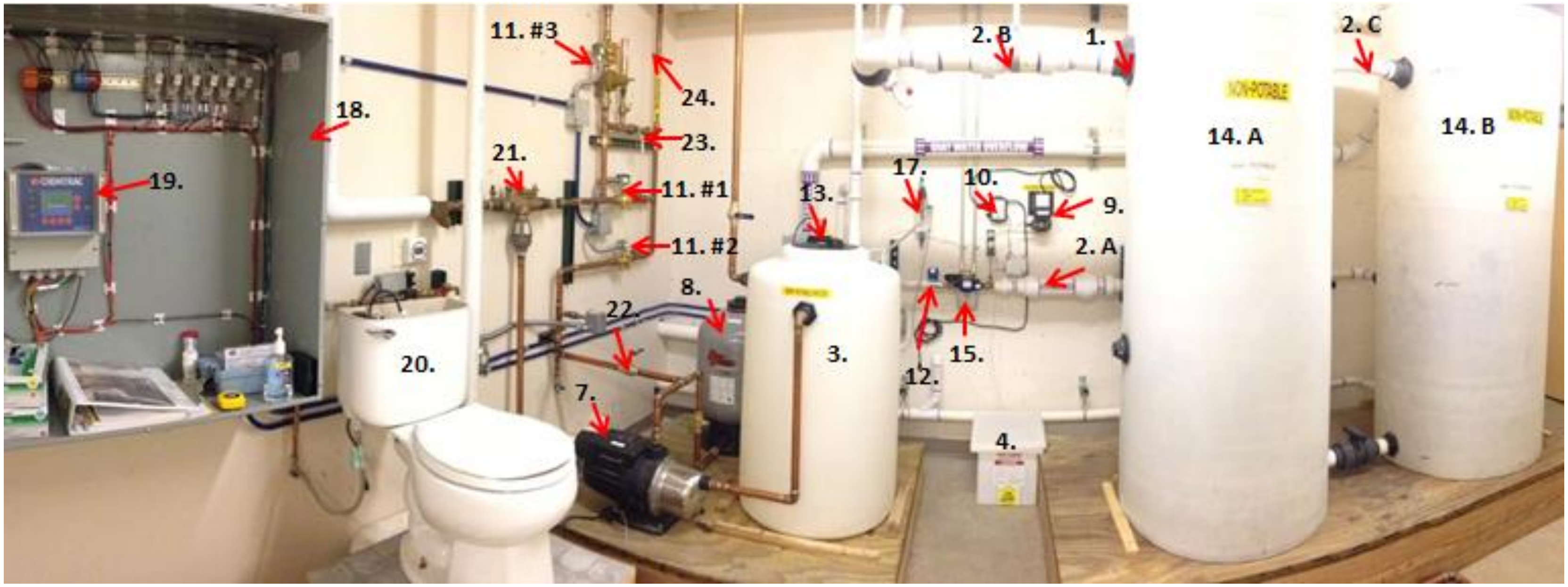
The purpose of this Standard Operating Procedure (SOP) is to provide guidance for the operation and troubleshooting of a graywater reuse for toilet flushing system at the Aspen Residence Hall. The SOP is necessary to ensure proper system operation of the collection, treatment and distribution of graywater for toilet flushing. This manual provides information on system start-up, routine maintenance and system monitoring. Please also refer to the Operations and Maintenance Manual located in the Aspen Hall Graywater room for instructions and further guidance.

B. **Definitions**

Refer to Figure 1 for labeled components of the Graywater Treatment System

1) **Influent Graywater** – Untreated graywater from showers and sinks
2) **Coarse Filters A, B, and C** – Three coarse Matala filters filter the graywater before entering the composite tanks, and after the composite tank before the disinfection tank
3) **Disinfection Tank** – 65 gallon tank stores treated graywater for toilets
4) **Chemical Tank** – 15 gallon chemical tank stores NaOCl (Clorox Bleach) solution
5) **Blue-Dye Tank**- 15 gallon tank stores diluted Brac Blue dye (Not pictured)
6) **Blue-Dye Pump**- Stenner fixed output peristaltic metering pump doses blue-dye into the graywater (Not pictured)
7) **Master Pump** – Grundfos pressure booster pump distributes treated graywater to toilets
8) **Pressure Tank –** (Not pictured)
9) **Chemical Pump** – Stenner fixed output peristaltic metering pump doses chemical into graywater
10) **Pump Control Module (PCM)** – Stenner control module meters chemical dose of peristaltic pump
11) **Freshwater Solenoid Valve (#3)** – Electronic solenoid valve controls influent freshwater into the disinfection tank (not pictured)
12) **Solenoid #4** – Electronic ball valve controls influent graywater from composite tank into the disinfection tank
13) **Ultrasonic Level Sensor** – Flowline ultrasonic level controls the graywater ball valve and freshwater solenoid valve to refill disinfection tank when necessary
14) **Composite Tank** – 300 gallon tank collects, composites and settles initial graywater (not pictured)
15) **Pulse Water Meter** – Records the amount of water passing through the meter and works with chemical pump to dose chlorine volumetrically.
16) **Chemical Injection** – Point at which chlorine is dosed in-line
17) **Chemtrac Total Chlorine Probe and Flow Cell** – Measures chlorine residual in disinfection tank and is reported on the chlorine analyzer.
18) **Control Panel** – Cabinet in which electrical components used for automation are connected
19) **Multi-Parameter Chemtrac Chlorine Analyzer** – HydroACT 600 measures chlorine residual in the disinfection tank and logs hourly chlorine residual online
20) **Test Toilet**- Demonstration toilet used for laboratory studies
21) **Backflow Preventer**- Protects against cross contamination between freshwater and treated graywater

22) **Distribution Valve** – Allows treated graywater to be distributed to students toilets
23) **Manual Bypass Valve-** Manual valve turned to the open position bypasses system
24) **Treated Effluent** – Graywater that has been filtered and disinfected and is ready to be used for toilet flushing



25) **Influent Graywater** – Untreated graywater from showers and sinks
26) **Coarse Filters A, B, and C** – Three coarse Matala filters filter the graywater before entering the composite tanks, and after the composite tank before the disinfection tank
27) **Disinfection Tank** – 65 gallon tank stores treated graywater for toilets
28) **Chemical Tank** – 15 gallon chemical tank stores NaOCl (Clorox Bleach) solution
29) **Blue-Dye Tank**- 15 gallon tank stores diluted Brac Blue dye (Not pictured)
30) **Chemical Pump 2**- Stenner fixed output peristaltic metering pump doses blue-dye into the graywater (Not pictured)
31) **Master Pump** – Grundfos pressure booster pump distributes treated graywater to toilets
32) **Pressure Tank**
33) **Chemical Pump 1** – Stenner fixed output peristaltic metering pump doses chemical into graywater
34) **Pump Control Module (PCM)** – Stenner control module meters chemical dose of peristaltic pump
35) **Solenoid Valve # 1, 2, and 3** – Electronic solenoid valve controls influent freshwater into the disinfection tank
36) **Solenoid #4** – Electronic ball valve controls influent graywater from composite tank into the disinfection tank
37) **Ultrasonic Level Sensor** – Flowline ultrasonic level controls the graywater ball valve and freshwater solenoid valve to refill disinfection tank when necessary
38) **Composite Tank** – 300 gallon tanks (A and B) collects, composites and settles initial graywater. B is not utilized currently.
39) **Flow Water Meter 1** – Records the amount of water passing through the meter and works with chemical pump to dose chlorine volumetrically.
40) **Chemical Injection** – Point at which chlorine is dosed in-line
41) **Chemtrac Total Chlorine Probe and Flow Cell** – Measures chlorine residual in disinfection tank and is reported on the chlorine analyzer.
42) **Control Panel** – Cabinet in which electrical components used for automation are connected
43) **Multi-Parameter Chemtrac Chlorine Analyzer** – HydroACT 600 measures chlorine residual in the disinfection tank and logs hourly chlorine residual online
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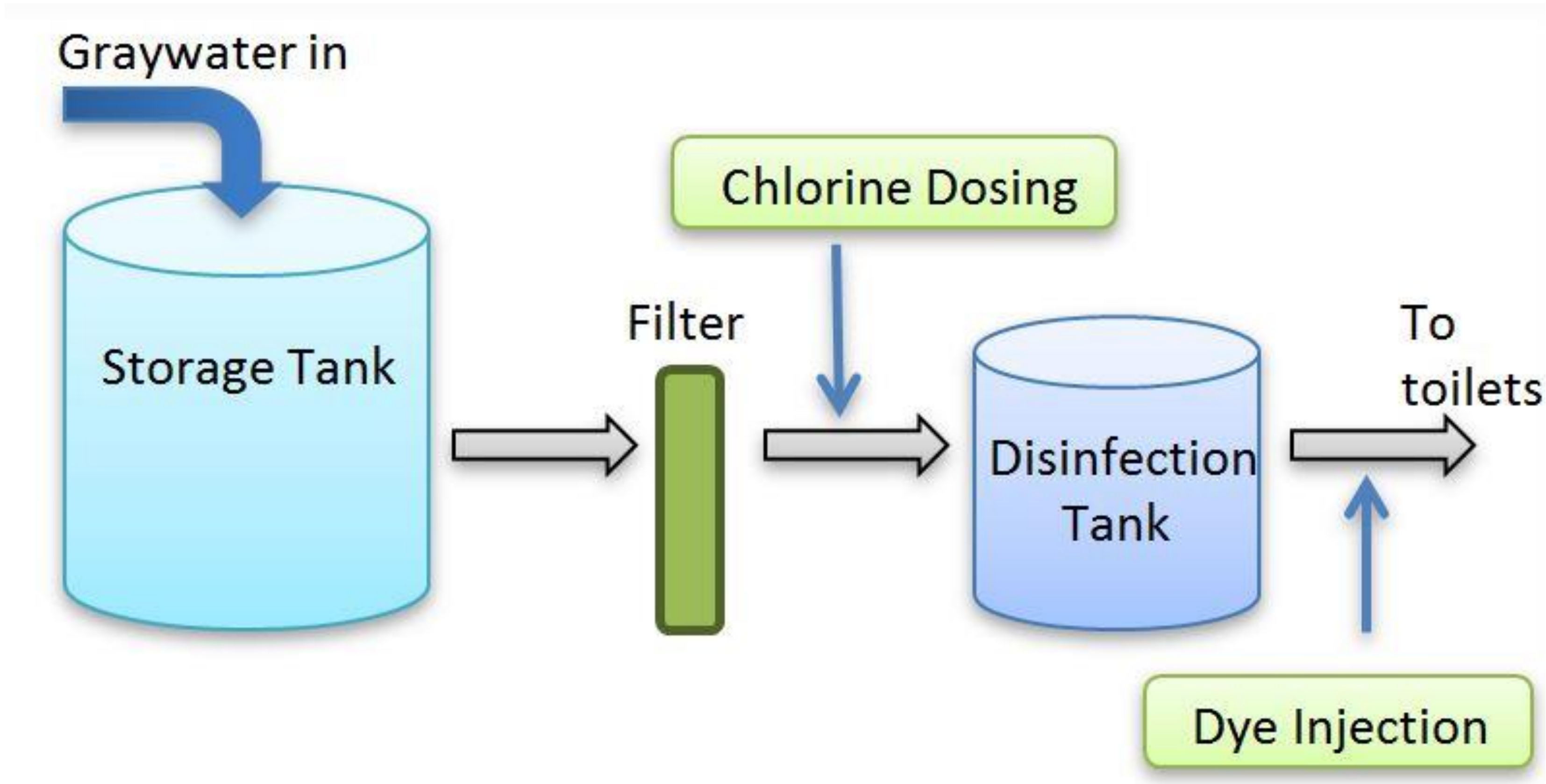

Graywater in
Storage Tank
Filter
Chlorine Dosing
Disinfection Tank
To toilets
Dye Injection

C. Health and Safety Warning

1) Contact with untreated graywater presents potential health risks due to possible pathogens in the water. Minimize contact with untreated graywater.
2) Sodium hypochlorite (NaOCl) poses health risks if mishandled. Follow proper storage and handling outlined on chemical label.
3) Wear gloves and safety goggles to minimize health and safety risks.

D. System Start-Up

1) Collect graywater in the composite tank. This will take approximately 24 hours. Close the valve directly ahead of the filter to prevent graywater from flowing into the disinfection tank at this time. Close the sanitary drain bypass valve to ensure the graywater flows into the composite tank.
2) Prime master pump. If the pump has been primed recently and still has water in the pump no re-priming is necessary. It is best practice to drain pump during periods of prolonged downtime.
3) Ensure that the chemical tank is full of 8.25% NaOCl (Clorox Bleach) solution. The solution can be made using a 1:7.5 bleach solution to potable water ratio. When filling from empty, add 2 gallons of bleach and fill with water until the 15 gallon line. If a different concentration (other than 8.25%) is used the chemical dose will need to be adjusted based on selected NaOCl concentration.
4) Provide power to the treatment system by turning on both light switches in the control panel titled 'Pump' and 'Controls'. Make sure all cords are plugged into their corresponding outlets. (Do Not Open Graywater Influent Line!). This provides power to all system components. The disinfection tank will fill with freshwater.
5) Prime the chemical pump. Unplug the chemical pump from the PCM and provide the chemical pump with power until the NaOCl has been pumped from the chemical tank into the dose-line. This should be observable through the clear pump tubing.
6) Prime the blue-dye injector pump. This can be done in the same manner as step 5 above. Ensure the blue-dye is filled to the 15-gallon line and is diluted appropriately.
7) Plug the peristaltic pump back into the PCM and ensure that the dose level of the PCM is set according to the predetermined chlorine dose. Setting should be 40% on the PCM dial. Note that this may change based on graywater composition but should remain relatively constant throughout the semester. All necessary chlorine dose adjustments are controlled with the PCM.
8) If necessary, change the electrolyte gel in the Total Chlorine Probe. Ensure that the probe is ½-1 inch above the bottom of the flow cell. Turn the valve on the flow cell to align with the black indicator marks.
9) Plug the flow cell pump into the electrical outlet marked LBB38.
10) The probe will need 2-12 hours to polarize. Let the freshwater flow through the flow cell until the probe is polarized. At this point, calibrate the probe by selecting the calibration tab on the Chemtrac Analyzer. Wait 30 seconds for the calibration to appear. Test the chlorine in the disinfection tank using the DPD colorimetric kit (see Appendix A3). Input the value on the analyzer and select 'Finish'.
11) Turn on the master pump. The indicator light will change from red to green and the pump will complete the priming process.
12) Open the manual valve directly upstream of filter A at this time. Once the pump turns on and distributes water to toilets, the low water level will signal the

electronic valve to open and allow graywater to flow from the composite tank into the disinfection tank.

13) At this time the system is primed and ready to distribute treated graywater to the toilets. Open the 'distribution valve', labeled D.V. and located to the right of the master pump, and the system is operating normally.

E. Maintenance

Table 1 (located in Appendix A) provides a list of monitoring and maintenance activities, the frequency at which they should be performed, the duration of each activity and who should perform the activity.

1) Weekly monitoring
    i. It is paramount to maintain chlorine in the chemical reservoir. The chemical reservoir should be checked on a weekly basis and refilled if half empty. The reservoir must be refilled with NaOCl (Clorox Bleach) solution (See System Start-Up Step 3). Do not refill with a different concentration of bleach, this will require a dose a change on the PCM. Additionally, the blue-dye tank should be inspected and refilled if more than ¾ empty. The concentrated Brac Blue Dye should be diluted according to instructions provided in Appendix A2.
    ii. To manually check the residual chlorine in the disinfection tank (as opposed to reading the level indicated on the chlorine analyzer), begin by opening the sample tap port to the right of the master pump. A sample can also be taken by unscrewing the lid on the disinfection tank, but the lid must be replaced immediately to assure the Echopod level sensor reads the proper water level. Test the residual chlorine using the Colorimetric Chlorine Test Kit from Hach (Model #CN-66T). Chlorine residual should be at least 1.0 mg/L. If below 1.0 mg/L, increase the dose slightly on the PCM.
2) Changing of Electrolyte Gel in Total Chlorine Probe
    i. The electrolyte gel in the total chlorine probe membrane cap needs to be replaced every 2-3 months. Follow the instructions in the O&M 'Probe' tab to replace the electrolyte gel. The gel should be stored on the top of the electrical cabinet in the Aspen Hall graywater room at all times, along with the blue abrasive paper.
3) Replacing the Total Chlorine Probe Membrane Cap
    i. The membrane cap needs to be replaced every 12 months. See the 'Total Chlorine Probe Operations Manual' in the Aspen Hall O&M Manual located in the graywater room for instructions.
4) Cleaning Scum/buildup on Total Chlorine Probe
    i. The chlorine probe occasionally reports erratic readings. This is most likely due to fats, oils, or scum blocking the membrane and consequently reporting inaccurate chlorine residuals. The probe should be swished in freshwater gently to remove anything blocking the membrane. Be careful not to touch the membrane. This should occur once every one to two weeks depending on probe behavior. If unsure, check chlorine readings against an alternative chlorine residual testing method such as the DPD Colorimetric Kit or chlorine residual test strips.

ii. Frequent sounding of low/high alarms may indicate erratic readings. If alarms are sounding on a regular basis, check chlorine residual with an alternative method. If there is discrepancy between the reading you observe and the reading on the analyzer, see the 'Troubleshooting' section of the Total Chlorine Probe Operations Manual located in the Aspen Hall O&M Manual, or call Chemtrac Technical Support.

5) Periodic cleaning of coarse filter (Filter A, B, and/or C)
    i. The coarse filter should be removed and cleaned occasionally. This should be done at the end of each semester or as needed. Additional cleaning may be necessary when the graywater fill rate between the composite tank and disinfection tank is significantly slower than initial system start-up or if a spike in chlorine demand is observed or larger solids are seen in the disinfection tank. In this case remove the filter and backwash by rinsing the filter with freshwater into a floor drain. If the filter is not cleaned after backwashing dispose of the old filter and install a new one.
6) Replacement of Pump Tube in Chemical Dosing Peristaltic Pump
    i. The pump tube located in the pump head casing of the chlorine/dye dosing peristaltic pumps needs to be replaced every 12 months (It is an 8" long tube with a black fitting on each end). Pump tubes can be ordered from the Stenner Pump Company website in packs of two. Follow the instructions in the shipment box of the replacement parts (or in the Aspen Hall O&M Manual) to replace the pump tube.
7) Short-term System Downtime
    i. If the student body is going to be gone for a known short period of time (<2 weeks, ex. Fall break) temporarily shut down the system. Three days before the break, stop collecting graywater and empty the composite tank by *slowly* draining it. Close the influent graywater valve to the disinfection tank and open the valve for bypass to sewer. The system will now operate on freshwater only and prevent prolonged storage of graywater in the toilet tanks over the break.
8) Long-term System Downtime
    i. If the student body is going to be gone for a long period of time (>2 weeks, ex. winter break) shut down the system according to the short-term procedure outlined above. Additionally, once the system is no longer in use turn off the system and empty the disinfection tank and master pump. It is a good practice to remove and clean the coarse filter at this time. Follow steps in Section H below.
9) Cleaning of composite tank
    i. The composite tank should be cleaned at the end of each semester and rinsed before system startup. This should be done when graywater is not being collected. Empty the composite tank *slowly*, use a hose and spray nozzle with freshwater to rinse the side walls of the tank and wash settled solids out of the tank drain. Fill the composite tank with fresh water, add 180 mL of bleach and let sit overnight. The next day, drain and rinse the composite tank.

F. System Monitoring

1) Low water level in the disinfection tank
    i. If water is below the low water level then there is an issue with water supplies to the disinfection tank. Check to see if there is graywater in the

composite tank, if so then there is an issue with the ultrasonic switch or graywater ball valve. A low water level also indicates an issue with the freshwater make up supply this could result from an electrical or mechanical issue in the ultrasonic switch or freshwater solenoid valve.

2) Master pump working properly
    i. A green ready light indicates the pump is on and operating under normal conditions. A red light indicates an issue has occurred and the pump shut off. This will occur if insufficient water was supplied to the disinfection tank or if the electrical connection to the pump was interrupted. If there is a red light, check if there is sufficient water in the disinfection tank and that nothing is blocking the master pump water supply or if the electrical supply was interrupted from the plug or breaker. Once the error is resolved, turn the pump on and ensure that a green indicator light is achieved.
    ii. The pressure switch located directly downstream of the master pump will switch the entire system to potable water if low enough pressure is sensed. Slow filling in the master pump may be the result of this switch to potable water. Check master pump and use Grundfos instructions in the O&M manual if needed.
3) Empty chemical reservoir
    i. In the case that the chemical reservoir is empty or an issue occurred with the delivery of chlorine to the graywater, refill the chemical reservoir and make sure the chemical pump is primed. It might be necessary to drain and refill the disinfection tank with potable water.

G. Quality Control and Quality Assurance

1) Chlorine Residual levels logged in the Chemtrac Chlorine Analyzer should be transferred to an Excel spreadsheet via USB Flash Drive every two weeks. This spreadsheet should be comprehensive and kept up to date at all times.

2) The upper and lower (located on the copper distribution piping near the ceiling, and after the filter in route to the disinfection tank, respectively) water meter readings should be read and recorded on a weekly basis. These recordings will be used to calculate annual water savings.

H. System Shut Down

1) Close the sanitary drain valve and open the sanitary drain bypass to stop collecting graywater in the composite tank.
2) Close both potable water valves located on the copper piping directly above both tanks to prevent potable water from entering the tanks.
3) Unplug the peristaltic pump and the flow cell pump on the outlet near the flow cell.

4) Place the chlorine probe in a sealed vile with tap water and one or two drops of bleach after rinsing the electrolyte gel out of the membrane cap. Store in a dark place.
5) Empty the composite tank *slowly* by opening the valve at the bottom of the tank.
6) Once the composite tank is empty, open the valves at the bottom of the disinfection tank and let the water empty to the sewer.
7) Leave the valve to sewer open allowing water from the filter to drain to the sewer.
8) Close the valve to sewer.
9) Open the sampling port between the composite tank and filter A and use a bucket to collect any water left in the line.
10) Close the distribution valve immediately downstream of the pump and open the sampling port near the toilet and allow water to drain from the lines.
11) Unplug the blue-dye dosing peristaltic pump.
12) If the graywater system is to be left empty, see Section I: 'Sequence of Operations' for control panel light switch positions and continue to step 13. If potable water is to be used in the system, continue to step 15.
13) Turn the potable water valve above the disinfection tank back open and allow the disinfection tank to fill with potable water. Ensure the potable water valve to the composite tank is in the closed position. At this point the system will now operate with City water. However, it is not considered potable because tanks and lines have not been disinfected and tested. Non-potable signs must remain at each toilet. Do not switch the feed lines at each toilet.
14) Switch feed line at each toilet to potable water supply.
15) Turn off the alarms and thresholds on the Chemtrac Chlorine Analyzer so notifications are not sent out during system down time. Go to the 'settings' button on the menu screen of the analyzer and turn the alarms and thresholds for 'Total Chlorine' to the off position.

I. Sequence of Operations

SEQUENCE OF OPERATIONS

Aspen Hall Gray Water Control Sequence:

Normal Operation:
The chlorine concentration in Tank #1 (disinfection tank) is maintained at a setpoint of approximately 2.5 ppm. The chlorine in Tank #1 is measured continuously using the Chemtrac sensor. Chlorine is injected into graywater entering Tank #1 via Chemical Pump #1 at a preset rate. Chemical pump gets an injection signal from Flow Meter #1.

Pump #1 uses on/off control. System pressure is sensed using a sensor integral to the pump. A drop in pressure below 35 PSI gives Pump #1 a run signal. When pressure reaches 46 PSI, Pump #1 stops. Pump #1 is prevented from frequent cycling by the pressure tank (expansion tank) immediately downstream of the pump's discharge.

The graywater sent to the building system is injected with blue dye downstream of Pump #1. Dye is injected via Chemical Pump #2 at a preset rate. Chemical pump #2 gets an injection signal from Flow Meter #2.

Four solenoid valves are as follows:
Solenoid #1 potable water
Solenoid #2 treated graywater
Solenoid #3 supplemental potable water
Solenoid #4 partially treated graywater (influent to disinfection tank)

Under normal operation, the solenoid valves are as follows:

- Solenoid #1 (NO) is shut, isolating domestic potable water from the building system.
- Solenoid #2 (NC) is open, connecting the gray water system to the building system.
- Solenoid #3 (NC) is shut.
- Solenoid #4 (NC) opens when liquid level in Tank #1 drops to 30".

Water level in Tank #1 is controlled at a setpoint of 32.5" (adj.). Level is monitored using an ultrasonic level sensor. A drop in Tank #1 level below 30" (adj.) opens Solenoid #4 to allow Tank #1 to be filled from Tank #2. At a level of 32.5 (adj.) Solenoid #4 is shut. When the water level in Tank #1 drops to 27.5" solenoid #3 opens to supplement with potable water.

Low Chlorine in Tank #1:
At a chlorine concentration of 2.0 ppm (adj.) in Tank #1, a non-latching alarm is generated and sent to the building DDC. Alarm resets at 2.5 ppm (adj.).

At a chlorine level of 1.0 ppm (adj.) in Tank #1, a latching alarm is generated and sent to the building DDC. The chlorine sensor continues to measure the chlorine concentration in Tank #1. Power is removed from Pump #1. Solenoid #2 is shut, isolating the gray water system from the building system. Solenoid #1 opens and sends domestic potable water to the building system. Chemical Pump #2 is disabled. At a chlorine level of 1.5 ppm (adj.) in Tank #1, alarm may be manually reset and system may be manually restarted.

High Chlorine in Tank #1:
At a chlorine level of 4.85 ppm (adj.) in Tank #1, a latching alarm is generated and sent to the building DDC. The chlorine sensor continues to measure the chlorine concentration in Tank #1. Power is removed from Pump #1. Solenoid #2 is shut, isolating the gray water system from the building system. Solenoid #1 opens and sends domestic potable water to the building system. Chemical Pump #2 is disabled. At a chlorine level of 4.5 ppm (adj.) in Tank #1, alarm may be manually reset and system may be manually restarted.

Low Water Level in Tank #1:
A drop in Tank #1 level below 28" (adj.) opens Solenoid #3 to allow Tank #1 to be filled with domestic potable water. At a level of 32.5" (adj.) Solenoid #3 is shut.

Loss of Power:
On loss of power to the system, Solenoid #1 (NO) opens to send domestic potable water to the building system. Solenoids #2, #3, and #4 (NC) shut.

Pump Off, Controls On (pump switch in control panel to "off", controls switch to "on")
Dye pump continues to operate, chlorine analyzer remains on, flow cell pump runs continuously.
Solenoid #1 opens, feeds potable water directly to toilets
Solenoid #3 opens when water level in Tank #1 drops to 30" to feed supplemental potable water to tank.

Pump On, Controls Off (pump switch in control panel to "on", controls switch to "off")
Dye pump continues to operate, chlorine analyzer remains on, flow cell pump runs continuously.
Solenoid #1 opens, feeds potable water directly to toilets
Solenoid #2 closes to stop treated gray water from being pumped to toilets
Solenoid #3 remains closed
Solenoid #4 stays closed.

Pump Off, Controls Off (pump switch in control panel to "off", controls switch to "off")
Dye pump continues to operate, chlorine analyzer remains on, flow cell pump runs continuously.
Solenoid #1 opens, feeds potable water directly to toilets
Solenoids #3 and #4 remain shut

Appendix A: Graywater Treatment Schematic and Monitoring/Maintenance Activities

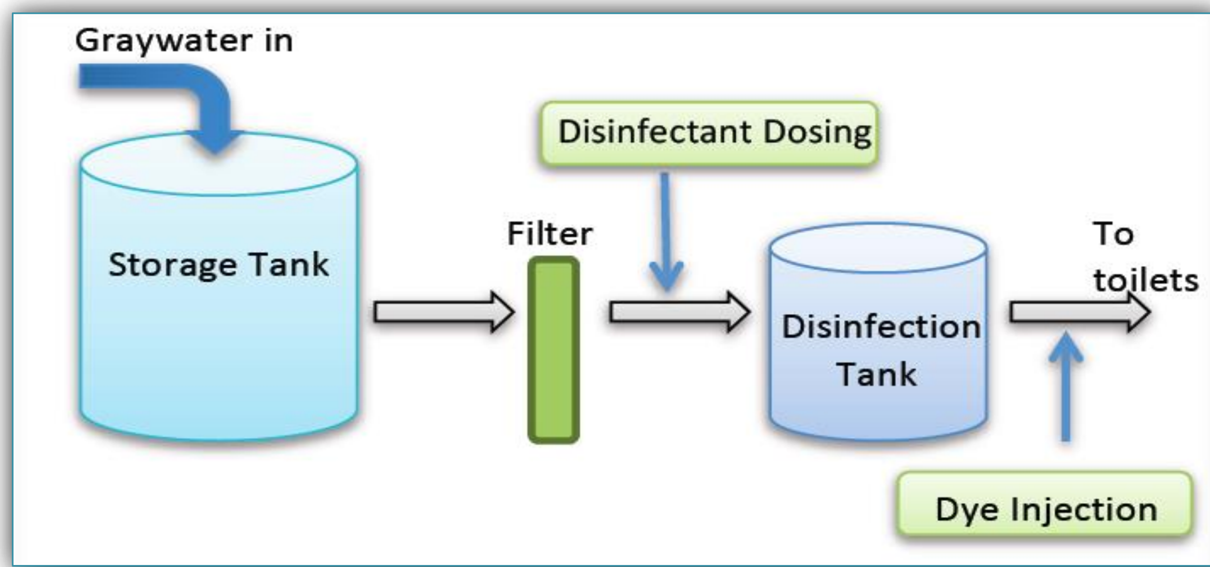


Figure 2: Graywater Treatment System Schematic

Table A1: Monitoring and Maintenance Activities

Activity	Frequency	Duration	Assigned to
Clean composite tank	Twice per year	1-1.5 hours	Plumber/Graduate Student Intern
Check chlorine residual in furthest toilet	Once per week	5 minutes	Environmental Services
Order DPD Reagent Powder Pillows from Hach Company (for 5mL sample)	Once per year	20 minutes	Graduate Student Intern
Clean coarse filter	4 times per year	20 minutes	Plumber/ Graduate Student Intern
Fill chemical reservoir	Once per week or as needed	5 minutes	Plumber /Graduate Student Intern
Fill blue-dye reservoir	Once per two months	20 minutes	Plumber/ Graduate Student Intern
Replace Pump Tube in Stenner Peristaltic Pumps	Once per year	30 minutes	Plumber/ Graduate Student Intern
Total Chlorine Probe Cleaning (E.4)	Once per week	10 minutes	Plumber/ Graduate Student Intern
Replace Electrolyte Gel in Total Chlorine Probe	Once per two-three months	30 minutes	Plumber/Graduate Student Intern

Replace Membrane Cap in Total Chlorine Probe	Once per year	30 minutes	Plumber/Graduate Student Intern
Chlorine Residual Logging Transfer of Data to Spreadsheet	Once per two weeks	15 minutes	Graduate Student Intern/ Tim Broderick
Low/High Alarm: Checking for Reason and Mitigating Issues	When Alarm sounds	Depending	Graduate Student Intern/Gary Jack
Recording upper and lower water meter readings	Once per week	5 minutes	Graduate Student Intern
General system monitoring	Once per week	5 minutes	Plumber/ Graduate Student Intern
System start up	Twice per semester	1 hour	Plumber/ Graduate Student Intern
System shut down	Twice per semester	1 hour	Plumber /Graduate Student Intern

Important Contact Information:

Gary Jack
Colorado State University Facilities Management
Gary.Jack@colostate.edu
Work: (970)-491-7171

Susanne Cordery-Cotter
Environmental Engineer/ Project Oversight
Facilities Management
Work: (970)-491-0117
Susanne.Cordery-Cotter@colostate.edu

Tim Broderick
Chair of Graywater Project Team
Work: (970)-491-3871
Tim.Broderick@colostate.edu

Sybil Sharvelle
Faculty and Research Advisor for Graduate Student Intern
Work: (970)-491-6081
Sybil.Sharvelle@colostate.edu

Jillian Vandegrift
Graduate Student
Jillian.vandegrift@colostate.edu

Appendix B

Blue-Dye Dilution Instructions

Note: Due to the very high concentration of this dye, please wear rubber gloves to ensure that it does not dye skin and/or clothing as it will be very hard to get off.

The blue-dye tank is a 15 gallon tank but does not require a large amount of dye to provide a blue color to the student's toilets. The demonstration toilet (when flushed) will always give an accurate showing of the color of water that is being distributed to the student's toilets. To check for appropriate color, flush the toilet and observe the water coming in. The water color should be gauged based on the two examples below:

This color is on the light end of the spectrum but is okay as long as some of the turbidity in the water is masked by the color.

This color is too dark and risks leaving blue dye stuck to the porcelain of the toilet, as well as the possibility of ruining clothing if water is splashed.

Instructions:

The appropriate blue dye can be ordered via this link:
http://www.newwatersystems.com/products/category.asp?cid=156

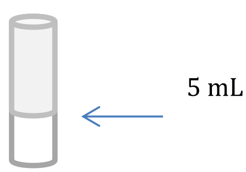
One liter of Brac Blue should dye 188, 650 gallons of water. If the Brac Blue dye cannot be found online, it is okay to use blue food coloring or another similar product as long as it is approved by one of the graywater team members.

Using a pipette or beaker, add 7 mL of dye per gallon of freshwater added to the 15-gallon blue-dye tank located in the corner of the graywater room. Stir with something long and disposable such as a plastic pipette. Flush the demonstration toilet a few times in order to see the color of blue that will be appearing in the students toilets. Adjust as necessary. If more than 7mL of dye per gallon of freshwater is added, check the chlorine residual in the demonstration toilet (after being flushed) using the DPD colorimetric kit approximately 5 times and record any differences between the residual measured in the toilet and the residual measured in the disinfection tank. It is important to realize that the blue dye can have an affect on chlorine demand and lower the residual by small amounts. If too much dye is used, there may not be enough of a residual in the student's toilets to ensure safety.

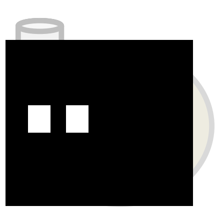
Appendix C

Aspen Hall Chlorine Residual Testing Instructions

1. Wearing rubber gloves, fill one of the clear plastic tubes to the first (5-mL) line with sample by dipping the tube into the toilet bowl.

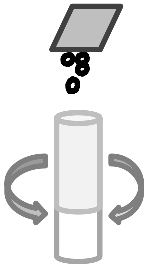


2. Insert the tube into the left opening of the comparator.

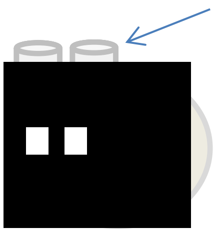


3. Fill another tube to the first 5-mL line with sample from the toilet.

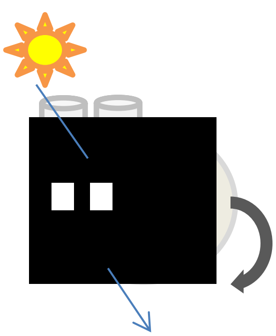
4. Add one DPD Free Chlorine Reagent Powder Pillow to the second tube. Swirl to mix. Note: It is easiest to open the powder pillows by holding the top end and flicking the silver packaging with your fingernail. Then, when ripped open, the powder will not spill all over the ground.



5. Insert the second tube into the right opening of the comparator.



6. Hold the comparator so that a daylight or fluorescent light source is directly behind the tubes. Rotate the color disc until the colors in the front windows match. The best match might occur between two color segments.



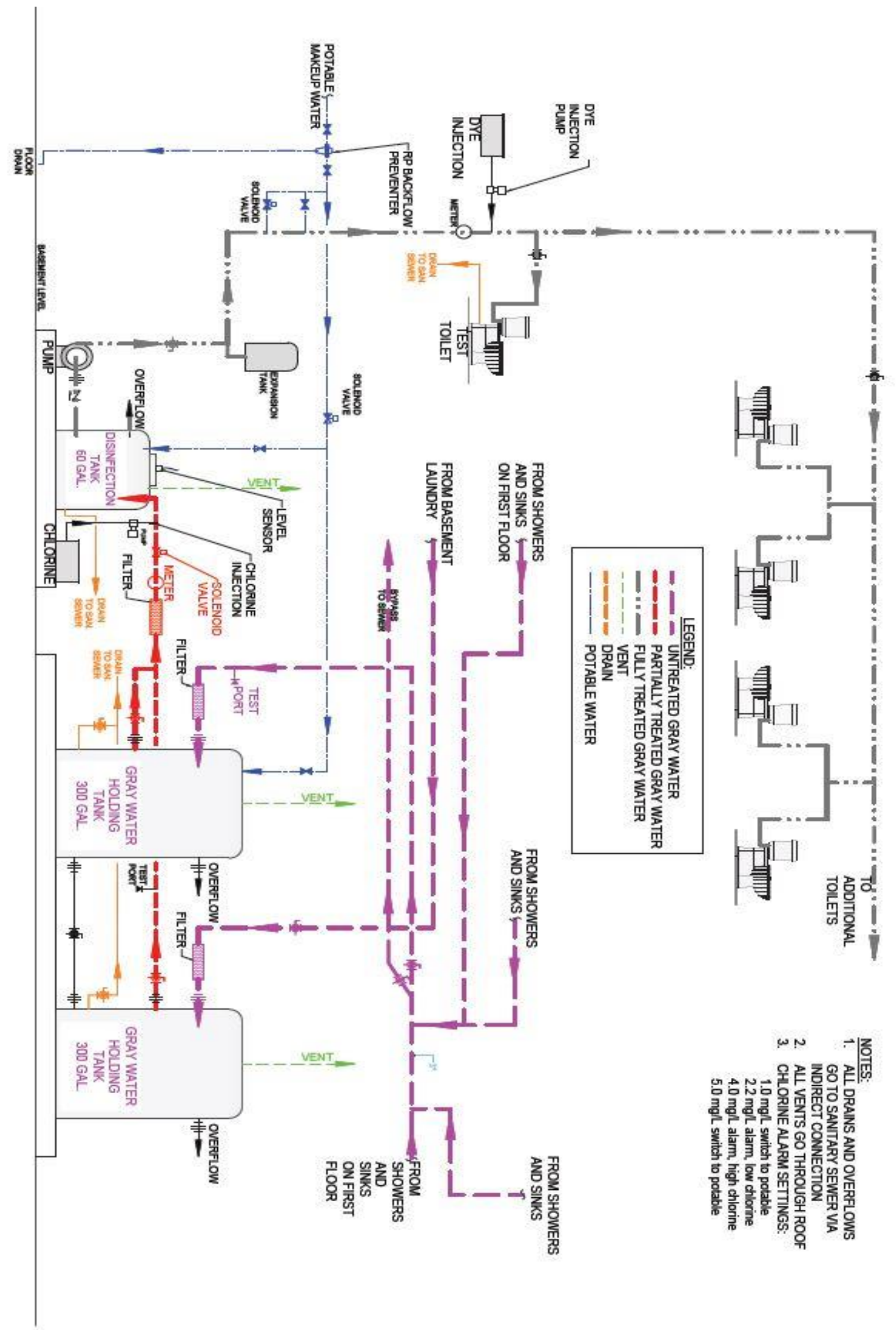
7. Read the result in mg/L and record on the form given to you. If the best match occurs between two color segments, determine the value halfway between the two printed numbers.

9. Pour out the samples in both tubes into the toilet and flush. Rinse both tubes with domestic potable water and place back into the storage container.

Appendix D: Aspen Hall Graywater Treatment System Troubleshooting Guide

Symptom	Possible cause	Corrective action
Chlorine concentration on analyzer too low	Chlorine solution depleted or not feeding properly	Check chlorine solution tank contents, refill if empty. Check peristaltic pump tubing (should be less than 1" off bottom of tank and free of clogs), replace tubing if cracked, bent, pinched or obstructed. Check injector, clean and/or replace if clogged.
	Chlorine injection system out of service, need time to repair.	Switch system over to potable water by flipping main switch in control panel
	Analyzer sensor problem	Clean the sensor (make sure rubber band covers the sensor hole before replacing, see manual) Calibrate the sensor.
	Analyzer and/or sensor out of service, need time to repair	Switch system over to potable water by flipping main switch in control panel
Chlorine concentration on analyzer too high	Chlorine pump controller out of adjustment	Adjust % knob on controller to lower setting, check chlorine after an hour, and adjust further if necessary.
	Analyzer sensor problem	Clean the sensor (make sure rubber band covers the sensor hole before replacing, see manual) Calibrate the sensor.
	Analyzer and/or sensor out of service, need time to repair	Switch system over to potable water by flipping main switch in control panel
	Overdose at disinfection tank	Drain disinfection tank to lower level, fill with potable water, allow system to run for a few hours and recheck.
Odors at toilets in resident rooms	Chlorine injection system or analyzer malfunctioning	Check chlorine solution tank contents, refill if empty. Check peristaltic pump tubing (should be less than 1" off bottom of tank and free of clogs), replace tubing if cracked, bent, pinched or obstructed. Check injector, clean and/or replace if clogged. Check analyzer accuracy by testing disinfection tank with chlorine test kit or test strip.

Appendix E: Detailed Schematic of Aspen Hall Treatment System



Appendix F: Useful Websites and Technical Support

To view the **chlorine residual** online:

Log in to : https://secure.colostate.edu/dana-na/auth/url_1/welcome.cgi

Type in the IP address: 129.82.182.7

Use the following credentials:

Chemtrac Technical Support: 800-442-8722 or 770-449-6233

Chemtrac Total Chlorine Probe Replacement Parts: http://chemtrac.com/contact-chemtrac/

- Electrolyte gel
- Blue abrasive paper
- Membrane caps

To order filter media:

http://www.matalausa.com/cat26.html

Color: Green

Stenner Pump Replacement Parts:

http://www.sunplay.com/Stenner-Pump-Tubes-UCCP205-Two-Pack-p/uccp205.htm

Appendix J:

Aspen Hall Graywater Reuse System

Students, thank you for your participation in the Aspen Hall Graywater Reuse Project. After using the graywater system for a semester, we would like to know about your experience. Attached to this form is a voluntary survey with eight questions and an area to leave us comments or concerns you may have. The answers you provide will help us gauge overall attitude towards the project, and will allow us to make the appropriate changes, if necessary, to ensure an enjoyable graywater reuse experience. We appreciate your participation! If you are willing to fill out this survey, please print and sign your name below. You do not have to participate in the survey even if you lived in a room connected to the graywater.

'I agree to participate in this voluntary survey regarding the Graywater System for toilet flushing at Aspen Hall'

Print name: ______________________________

Sign name: ______________________________

Aspen Hall Graywater Toilet Flushing System Survey

1) Overall, were you satisfied with using non-potable water for toilet flushing instead of potable water?

☐Very satisfied, would do again

☐Somewhat satisfied,

☐Neutral

☐Somewhat Unsatisfied

☐Very unsatisfied, would not do again

2) Would you recommend using non-potable water to others in an effort to preserve potable water supplies?

☐Yes

☐No

☐Maybe

3) Were there major differences in using non-potable water for toilet flushing?

☐Yes

☐No

If yes, please check any differences you noticed.

☐ Different odor

☐ Different appearance

☐ Does not apply

4) Did you find the non-potable water in the toilet displeasing?

☐Yes

☐No

☐Sometimes

If you answered yes or sometimes, what did you find displeasing about using non-potable water for toilet flushing?

☐Unpleasant odor?

☐Unpleasant appearance?

☐Other (please list): ______________________

☐Not applicable

5) If you checked that the non-potable had an unpleasant appearance, did the unpleasant appearance coincide with a certain time in the cleaning schedule?

☐Yes, please explain

☐No

☐Not applicable

6) How many times were you ill during the spring semester?

☐Cold

☐Flu

☐Stomach Flu

☐Rash

☐Other (please list): ______________________

☐Was not sick

7) Did using non-potable water for toilet flushing make you more conscious of:

☐Water use

☐Use of personal care products

☐Cleanliness of toilet

☐Other (please list): ______________________

☐No change

8) Did you notice differences in the non-potable water before/after Spring break?

☐Yes

☐No

If you answered yes, when did you notice a difference (check all that apply):

☐Before Spring Break

☐ After Spring Break

☐ Does not apply

General Comments, Concerns, Questions, etc…

Colorado State University

Housing & Dining Services