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What Is The Economic Feasibility Of Implementing Grey Water Infrastructure At The Citywide Level?

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This Master's Project

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By

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Abstract

This paper examines the challenges and economic feasibility of implementing grey water recycling systems at a citywide scale. Past and present conditions of fresh water scarcity are discussed, and how scarcity will be exacerbated by climate change. Previous technological developments and initiatives are discussed, and how they are implemented to reduce fresh water scarcity. Challenges, examples and costs of implementing grey water systems are detailed; in general results indicate that large projects (such as apartment complexes and multistory buildings) are only economically feasible (as opposed to single-family homes), decentralized (on-site) systems also appear to be more economically feasible due to cost savings of energy and piping required to convey grey water and waste water for treatment and installing a grey water system in new construction is less costly than retrofitting a building.

Additional costs associated with determining the economic feasibility of grey water systems are nuanced, for example water rates make a large difference on the payback period of the project and lifestyle of the occupant (differing water amount and detergent uses). The average project cost ranged from $447,289 to $4,411, payback period ranged from 10-16 years and only a positive Net Present Value (NPV) was determined for a multistory building. For a city such as San Francisco, implementing grey water systems in single-family homes and multistory buildings would cost approximately $1.8 billion dollars

Introduction

Global warming and its impacts have created the need to conserve water in the face of increasing drought and irregular weather. Global warming has led to the weather to be more erratic and less predictable (Schwartz and Randall, 2003) and the current drought is one of the most severe historically (NOAA, 2016). Many cities have tapped into ground water resources to meet the population's needs due to lack of rainfall and water that has been previously saved in reservoirs. The continued unsustainable use of water combined with population increases, and prolonged drought will result in fresh water depletion. Rainfall deficits are already severe in California, and the current El Nino storms this year will likely not end the drought since many areas have an average deficit of 1-2 feet of rainfall (Accuweather.com, 2015).

Water management thus far has been focused on meeting the future projected needs of the population, and expanding infrastructure to meet those needs, which is not a sustainable practice. Water is considered a renewable resource, until aquifers are pumped to the point of land subsidence. In the future, this will limit the amount of ground water recharge in wet years (Gleick, 1998). Expanding water infrastructure to meet the growing population's needs is an unsustainable way to manage water; rather the focus should be on meeting needs within the available resources and infrastructure.

Past efforts to reduce water use has been achieved through the use of water mandates, initiatives, water rationing, and technological advancements. Although these past efforts succeeded in reducing water use, the continued drought will call for a greater decrease. Reclaimed water reuse has been limited but aided through technological advancements and legislation. Grey water use has been aided through technological advancements in water treatment and conveyance, such as using grey water for watering landscapes. Currently, grey water recycling is not widely used, greatly studied or regulated in many cities. It has been determined that grey water infrastructure when installed can result in significant water savings, yet regulations and guidelines for treatment and installation have not been established (Yu et al, 2013).

Grey water is water that comes from showers, bathroom faucets and clothes washers. Grey water may comprise 50-80% of residential wastewater, in Arizona it is estimated that the average household generates approximately 30,000 to 40,000 gallons of grey water per year (Al-Jayyousi, 2003). There is debate on whether to include water from kitchen sinks and dishwashing machines due to the particles from food that contribute contaminants to the wastewater. Kitchen water contains more contaminants compared to other sources of grey water due to oils, greases, surfactants, microorganisms, and solids from food and detergents (Friedler, 2004). Various states in the U.S. vary on whether kitchen water is included in the definition of grey water, 14 of the 36 states that address grey water that originates from a kitchen, exclude kitchen water (Yu et al, 2013). Grey water is variable as far as quality, mainly due to the variety of detergents used in a household; detergents can make treatment for reuse more difficult (Al-Jayyousi, 2003) because it can alter the effectiveness of the chemicals used to treat the grey water. Grey water quality is variable, which makes meeting the high levels of treatment required for indoor water use difficult.

This paper will focus on the economic feasibility of installing grey water systems at a citywide scale by looking at challenges, implementation thus far, and examples of grey water case studies and systems from around the world. Economic feasibility will also be evaluated by estimating the payback periods and Net Present Values (NPV) of various projects detailed in the literature, then projects costs are applied to residential and multistory buildings in a city, using San Francisco, CA as an example. In the future, cities with available budget can create incentives and water policies to make implementation of grey water systems streamlined.

Background and Justification

Many countries are experiencing drought as a result of climate change and local dry conditions could exacerbate water scarcity and quality issues. With and increasing population, and increase in urban environments as a result, cities are growing at an alarming rate. The United States population according to the United States Census Bureau was 321,418,820 in 2015 (United States Census Bureau, 2014), and is estimated to reach approximately 416 million by 2060 (United States Census Bureau, 2014). Cities are one of the most unsustainable water users due to their once through system, as opposed to a closed loop system of reusing a resource such as water (Agudelo-Vera, 2012). Linear metabolism systems use resources at a high rate and produce a large amount of wastes and pollution, while circular metabolism emulates a natural ecosystem in which, consumption of resources are low due to recycling and reuse of resources (Agudelo-Vera, 2012).

The increased urbanization to accommodate the growing population will increase the unsustainable use of water: an examination of grey water use to meet the increased demand should be considered in water management plans. Decentralized grey water treatment systems can create a closed-loop system in which, waste water generated onsite is treated onsite for reuse in a household or at the community level (Al-Jayyousi, 2003). Centralized systems will require more energy to pump grey water to a treatment plant and back to the user, the increase in energy use will also increase emissions associated with the energy use. Simple grey water systems can be piped from the shower directly to the toilet to solely meet flushing needs, which would result in increased potable water savings and would not require major retrofitting costs to install. There are many alternatives to consider when installing grey water system; this paper will outline a few examples.

Initiatives and technology developments implemented to save water that have been successful in generating water savings, for example: low flow toilets, automatic toilets and faucets, dual flush toilets, waterless urinals, faucet aerators, low flow shower heads, water efficient washing machines and desalination plants, but grey water use has been limited to watering landscapes and should be expanded to include flushing toilets as well. As defined, grey water could be applied to three non-potable uses: watering landscapes, flushing toilets and laundry (Yu et al., 2011). Applying grey water to as many uses as possible will result in a sustainable use of water.

When considering the sustainable use of resources, the Three Pillars of Sustainability, also known as the Triple Bottom Line should be taken into account: Environmental, Economic and Social (Pope et al, 2004). The Triple Bottom Line is an assessment that is used to minimize unsustainable practices and meet the three objectives. The Environmental objective is to use resources in a sustainable manner, meaning the use of resources will not hinder future generations from using the same resources. The Economic objective measures the fiscal impact of a project or action taken. The Social objective measures the impact to a neighborhood, community, city etc., for example a project could take away a community park in which, there is a loss to the community's recreational facilities, or a project could increase GHG emissions and dust locally, thus, decreasing the local air quality (this impact is also an environmental impact). An analysis of grey water should include an examination of all pillars. The economic, social and environmental effects have been considered in the economic and financial analysis completed by Liang and van Dijk (2010) in Figure 1.

Figure 1. Economic, Social and Environmental Costs and Benefits (Liang and van Dijk, 2010).

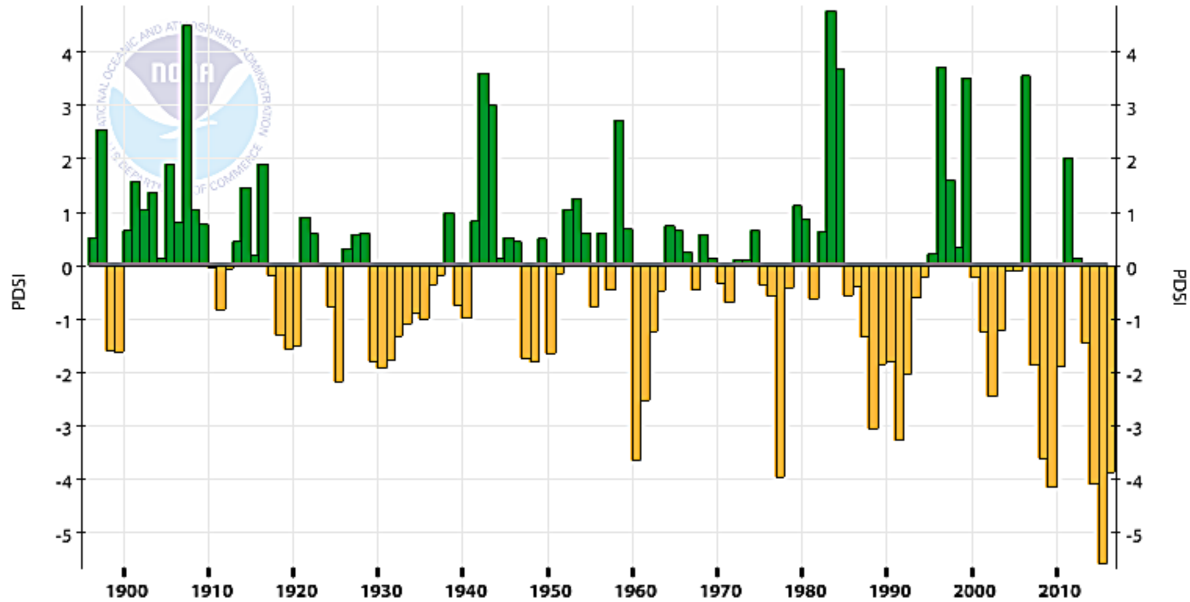
Economic cost	Initial investment
	Operation and maintenance cost
Environmental cost	Noise pollution
	Air pollution
Social cost	Health risk
Economic benefits	Cost saving on constructing pipes
	Cost saving on water distribution
	Cost saving on water purification
	Reuse of pollutants
Environmental benefits	Increase of water availability
	Increase in the level of rivers
	Avoidance of overexploitation of water-bearing resources
Social benefits	Raising social awareness

It has been established that grey water systems can aid in meeting water demands of the growing population sustainably, however the economic viability of implementing grey water systems needs to be accessed. This paper will examine the parameters driving the need for grey water use, past water saving efforts and the challenges of implementing grey water systems. Through this analysis, I will determine the economic feasibility of grey water implementation at the citywide scale.

Past Conditions and Water Scarcity

Droughts are cyclical and occur between wet years, but during extreme droughts that are of significant length, drought can have a drastic impact on available water resources. The Palmer Drought Severity Index (PDSI) developed by meteorologists and used by the National Oceanic and Atmospheric Administration has a drought index, which shows in comparison to historical droughts, that the current drought in California is the worst in over a century (Figure 2).

Figure 2. The Palmer Drought Severity Index calculated for California over the past 110 years (NOAA, 2016).



Drought has many impacts, one of the main concerns being the decreased availability of usable water for potable water use from groundwater, streams, snowpack and reservoirs (Mckee et al, 1993). Water is a public resource, which makes regulation necessary, but difficult to implement especially since the economic valuation of water is low to the individual (Hanemann, 2005), meaning the value of water is low for individuals and does not encourage limited use. Much like the carbon footprint, which measures ones carbon emissions contributed to the atmosphere and air quality impacts, there is a water footprint that measures the water resources that an individual or household uses. The water footprint of humanity from 1996-2005 was studied; the result was that the water footprints of China, India and the United States were the largest accounting for approximately 38% of the water footprint globally

(Hoekstra, 2012). With excess water usage and large water footprints, water use regulations should assist in decreasing water use, especially from large water users.

Regulation of water use is often done by enacting mandates by the State, and mandates are implemented by cities. Despite water savings of some individuals, the tragedy of the commons is there are individuals that continue to use resources at their normal consumption rate and/or in excess of basic needs. During past droughts, water use regulation was achieved through mandatory water rationings. In San Jose, CA, water rationings were mandated for a 30% reduction and residents were allocated 9 units per household, residents that exceeded their allocated units were fined (San Jose Mercury News, 2015).

Current State Conditions and the Looming Water Crisis

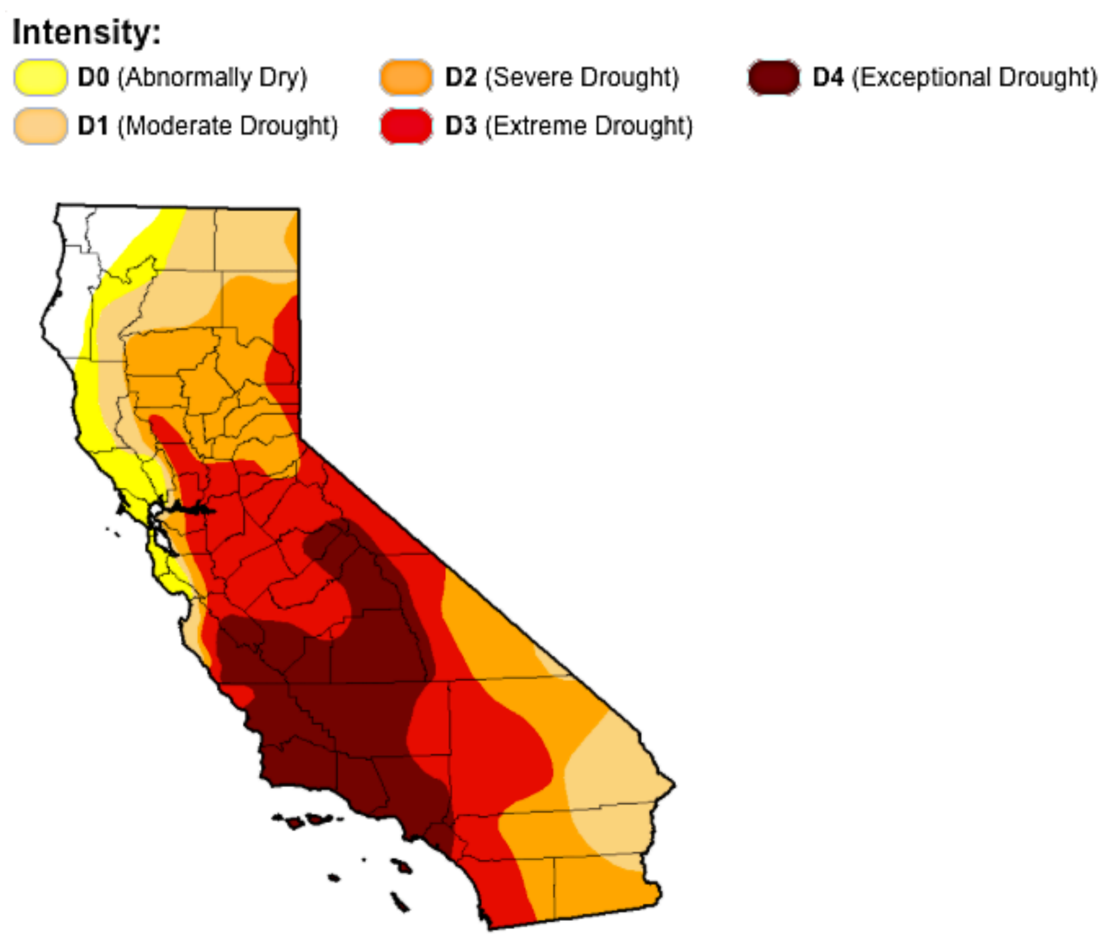
Governor Brown has taken steps to ensure secure water resources in the face of the drought. In 2013 Brown assembled a Drought Task Force to prepare for water scarcity with consideration of climate change effects (Office of Governor Edmund G. Brown Jr., 2014). Currently, California is in the fourth year of an extreme drought, a drought state of emergency was called in 2014, directing state officials to mitigate against the drought conditions (Office of Governor Edmund G. Brown Jr., 2014). Climate change will lead to a fresh water shortage due to the unpredictable rainfall and increased erratic weather patterns, and increased warming will increase evapotranspiration that will decrease the ability to store fresh water (The Guardian, 2012). Global warming issues continue to increase due to anthropogenic additions and burning of fossil fuels.

Population growth continues to place pressure on natural resources; there is a need to expand urbanization and infrastructure to places where there are little fresh water resources. The California Water Project is a prime example of a system that brings water from Northern California (where there are fresh water resources) to Southern California (where there are little to no fresh water resources and drier climate) to serve 29 urban and agricultural water suppliers (Department of Water Resources, 2010). The State Water Project is so large, that it resulted in severe environmental impacts: loss of salmon spawning habitat, dam failure, pumping plants decrease numbers of bass and salmon and alteration of the Bay-Delta estuary habitat resulting in loss of species (Department of Water Resources, 2008). The alteration of habitat and loss of wetlands caused by the State Water Project is devastating one of the richest estuaries in the U.S (Sjovold and Krieger, 2016).

The traditional approach to water management has been supported by economic and population growth, water management will have to change to be adaptable to climate change (Gleick, 1998). Two water districts in San Francisco hold the lowest average totals of 46 gallons of water per day (Los Angeles Times, 2016), while the average gallons of water used per day in a Los Angeles household is 243. Los Angeles had a drier climate and it is speculated that much of this water is used to water landscapes, up to over 50% of this potable water can be saved if a grey water system was installed to irrigate landscapes (Grey Water Corps 2009). Water management should be focused on those especially that use excess amounts of water.

The United States Drought Monitor for California displays that large portions of California are currently in extreme or exceptional drought (Figure 3). These current conditions are important to consider because water is a necessity and is not completely a renewable resource, due to the fact that the resource is being consumed quicker than it is being replenished. The State Water Project is currently not meeting it's contracts, and uses a system called 'paper water' to grant early allotments of water, before the annual snow melt and rain have been accounted for, this mismanagement of water in California will exacerbate the local drought conditions (Sjovold and Krieger, 2016).

Figure 3. California Drought Conditions (US Drought Monitor, 2016).



Introduction to Water Savings Technologies

Technology has been used to augment fresh water resources and to save potable water. Low flow toilets, sink aerators and low flow showerheads all help in potable water savings. A majority of water conservation efforts focus on water conservation, rather than water recycling. Cities are discovering that wastewater is a resource that is underutilized; emerging technologies are desalination, water reclamation and reuse, and fog collection (Gleick, 2000). Grey water, so far has been used to limit the amount of fresh water used to water landscapes. Many international cities have begun to adopt grey water to flush toilets in large office buildings, airports and apartment complexes.

Desalination plants take ocean water and remove salt to make into potable water. There are limitations to implementing new water technologies such as cost, scale, and lead time (Ehrlich, 1971). Desalination plants are expensive to build, energy intensive, may have adverse environmental impacts, and often generates water that is high in cost to the customer. According to Lattemann and Höpner (2008), desalination plants open intake systems can result in the loss of aquatic species, large amounts of pretreatment chemicals and byproducts are often washed into the ocean, and thermal desalination plants will increase the local ocean temperatures. Although desalination plants can produce large amounts of potable water, the costs may not outweigh the benefits.

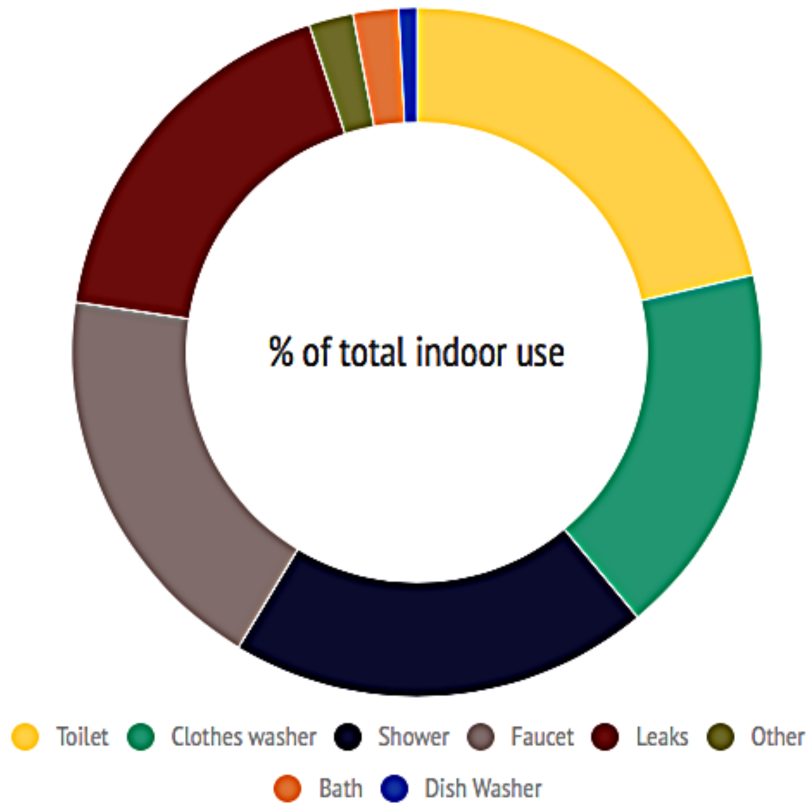
Grey water will aid in fresh water savings by proving non-potable resources; grey water recycling will also reduce the amount of water conveyed to centralized water treatment systems (Yu et al, 2013). Increased use of grey water will benefit the community, environment, and can be economical. Communities that live in dry arid regions can use reclaimed water for watering landscapes, and can further use grey water to flush toilets. The environment will benefit from the relieved stress on water resources, groundwater recharge can increase as well as reservoirs, resulting in lower water withdrawals from local rivers. The payback period was considered by Imteaz and Shanableh (2012), the water savings from dual flush toilets, flow restrictors, and water efficient washing machines clothes washers resulted in water savings ranging from 30-50% and had a payback period of 1.9 years. Thus, water saving technologies can save large amounts of potable water and the initial investment will be earned back in less than 2 years.

Overview of Water Saving Technologies and Water Augmentation

A. Low flow toilets, Automatic toilets, Dual flush toilets and Waterless urinals

According to the Regional Water Providers Consortium (2016), the average Americans uses 45% of household water in the bathroom, with 27% of water use for flushing toilets, according to KQED News, up to 21% of indoor water use comes from flushing toilets (Figure 4). With flushing of toilets ranging from 21-27%, there is potential for significant potable water savings if this water is replaced with grey water. In 1994 the United States passed legislation requiring all new toilets to reduce the water used when flushed by one-third (Gleick, 2000). Older toilets use 3.5-5 gallons per flush when new toilets use 1.6 gallons or less (Regional Water Providers Consortium, 2016).

Figure 4. Percent Indoor Water Use (KQED News, 2014).



Local water districts support water reductions by offering rebates for purchasing low flow toilets such as the East Bay Municipal Utility District (EBMUD) and Bay Area Water Supply & Conservation Agency (BAWSCA): BAWSCA offers a rebate for $125 to replace an old toilet with a qualified high efficiency toilet (Bay Area Water Supply & Conservation Agency, 2016) and EBMUD offers a rebate for $50 when an old toilet is replaced with a high efficiency toilet (East Bay Municipal Utility District, 2016). California requires installation of low flow toilets, beginning January 2014, for homes that were applying for permits to make upgrades to a home, and in 2017 will be required when a home is being sold (Wilson, 2013).

Automatic toilets and faucets were studied by Gauley and Koeller (2010): when installing sensor-operated urinals: water use decreased from 856 to 807 gallons per day, when manual toilets were replaced with sensory operated toilets: water use rose from 807 to 1,243 gallons per day and when installation of sensory operated faucets resulted in increased water use: from 654 to 856 gallons per day. Automatic faucets and toilets were found in this study to use more water than the original manual fixtures, automatic urinals did result in water savings. Toilets that are low flow save water as well as waterless urinals, but automatic technology does not save water as anticipated. Dual flush toilets are toilets that have two separate flush buttons for liquid or solid waste, which allows for further water savings.

Waterless urinals are not frequently implemented due to difficulty in maintaining the urinal, despite the potential to use zero water in facilities. Caltrans completed a pilot study at a few of their rest stations to determine the success of installing waterless urinals: water savings were between 178,507– 2.7 million gallons of water in 2015, yet issues ranged from odor to discoloration of the urinal if it was not properly maintained (Caltrans Division of Engineering Services Water and Wastewater branch, 2015). Caltrans concludes from their study that training needs to be given when waterless urinals are installed so they can be properly maintained to prevent issues from arising.

B. Faucet Aerators and Automatic faucets

Bathroom and kitchen faucets can use up to 16% of household water (Regional Water Providers Consortium, 2016). Low flow aerators can cut water flow rates by up to 50% (Facilities Net, 2014) compared to faucet aerators that do not limit the water flow from the tap. Federal plumbing standards require that kitchen and bathroom faucets should use more than 2.2 and 2.5 gallons per minute (GPM) respectively, when older aerators can use up to 5 GPM (Regional Water Providers Consortium, 2016). Installation of a faucet aerator is easy and aerators are inexpensive to purchase. The previously mentioned study by Gauley and Koeller (2010) found that automatic faucets increase water use. Flow restriction is more useful in water savings compared to automatic faucets.

C. Rain barrels

Rain barrels are used to catch rainwater, fog drip and rain that falls off rooftops, and can typically hold about 55 gallons of water. In arid regions such as California, it has a low annual precipitation of 37 cm/ year (Yu et al, 2011), therefore rain barrels will not help meet non-potable water demands for watering landscapes. Although, in region where rainfall is plentiful, rain barrels can aid in fulfilling watering needs for landscaping. Rain barrels have been promoted to catch rainwater for watering landscapes or rain barrels can be used in addition to grey water to fulfill all landscaping needs, as well as various non-potable water needs indoors. There are incentives offered from agencies such as BAWSCA, BAWSCA offers a $100 rebate to purchase a rain barrel (Bay Area Water Supply & Conservation Agency, 2016) for homes in San Mateo County.

D. Desalination plants

Desalination plants are located along coasts, and they consume ocean water, which is processed to remove salt ions to make potable water. Desalination of seawater or brackish water is hindered due to high infrastructure costs, the high amount of energy required to treat the water and the infrastructure required to transport treated water to areas that are not near coast/ the treatment plant (Gleick, 2000). A desalination plant in Carlsbad, CA generates 50 million gallons of fresh water per day. The cost of water-generated form the Carlsbad desalination plant is twice the rate at which the Metropolitan Water District of Southern California charges due to the process of desalination being energy intensive and costly.

Desalination plants cause concern for environmentalists due to the water discharged into the ocean after desalination and water being sucked into the plant. Additional desalination plants in California are not likely to be developed soon; the Carlsbad project resulted in 14 lawsuits and over 10 years of negotiations (The Sacramento Bee, 2015). Despite the opposition in California, desalination plants are widely adopted in international countries such as Israel and Saudi Arabia (The Sacramento Bee, 2015). Desalination plants can help to augment the potable water source, but is not necessarily a sustainable practice.

E. Water mandates

In April 2015, Governor Brown mandated a 25% water reduction for cities in California; a month later the State Water Board adopted this regulation to implement the 25% reduction of potable water use (State Water Resources Control Board, 2016). In addition to these mandates there has been state funded toilet replacement and turf removal programs, in addition to what local incentives individual cities may offer to reduce water use. In a February, 2016 press release by the State Water Resources Control board (2016), it was announced that California missed Governor Brown's water reduction goals by just 0.2%, so far California is 4% shy of reaching water savings of 1.2 million acre-feet of water.

Water mandates have been successful thus far in decreasing water use in California, the drought still persist and limited water use in households and eliminating watering landscapes are encouraged. The water mandates and incentives have been focused on lawn removal, inefficient appliances, commercial car washes, but little to no focus on installation of residential grey water systems. Lawns can require up to 57 inches of water per year, which can't be met by rainfall, additionally sprinklers can be faulty and overwatering is a frequent practice that can lead to using 75,000 gallons per year (Association of California Water Agencies, 2016). To mitigate the large amounts of water that are used on landscapes, Lawn Be Gone programs have been offered by water conservation agencies, the incentive that BAWSCA offers is $4 per sq. ft. to replace lawns with drought resistant landscapes (Bay Area Water Supply & Conservation Agency, 2016).

According to Home Water Works (2016), clothes washers use 15-40% of the water in a typical 4-person household, older washers use 40-45 gallons of water per load, and high efficiency washers use 14 to 25 gallons of water per load. Pacific Gas & Electric Company (2016) offers rebates for high efficiency clothes washers, and offers up to $150 in rebates for Energy Star models. In order to comply with the mandated 25% reductions for California, cities have forbid washing cars with potable water, which means they have to get their car washed at a carwash. Due to California restrictions that cars are not allowed to be washed at home without a shut off nozzle, there are cities such as San Jose that completely ban washing cars at home making car washes acceptable since many use recycled water (Market Place, 2015). The State Water board's Office of Enforcement regularly receives reporting from water agencies and works with them to meet their water reduction goals.

Water saving technologies was taken into consideration by Memon et al (2005) of how it will affect recycling water systems. Grey water production will decrease, which will allow the pollutants in the water to increase, and thus increased treatment to meet water reuse standards and maintenance costs for the system. Ultra low flow toilets or dual flush toilets will decrease the need to use grey water for flushing toilets, thus the payback period on the system could take longer. Overall, water mandates are effective in water use reduction, but has not focused on water recycling as a measure. It is estimated that 30% of water consumption in households can be decreased by using grey water to flush toilets (Eriksson et al, 2002).

Challenges of Implementing Grey Water

Grey water is not greatly studied at this time and information about system installation is not easily accessible for those who wish to implement a grey water system in their homes. Permit costs required from cities can be high and the guidelines could be difficult to follow. According to Little (2000), permits could be cumbersome and costly for a homeowner, a confusing and complicated permit process can lead to "mental barriers" for homeowners to install grey water systems. Plumbing collects grey water before it mixes with black water (water from flushing toilets) and then is diverted to treatment to be used for non-potable uses. Installing a system such as this has to follow plumbing codes and water treatment requirements.

Retrofitting a home to install plumbing required for a grey water system can be complicated and costly. Retrofitting costs vary from building to building based on the materials used, labor hours, number of restrooms and number of levels a building has. Installing a grey water system in new construction will significantly lower the costs compared to retrofitting a building. Retrofitting a home can be cost prohibitive, it is best if grey water systems are installed during original construction.

Grey water must be treated to a tertiary degree and reach specific levels of coliforms, and turbidity to be used for indoor use (Yu et al, 2013). There are four criteria that must be met to use recycled water for flushing toilets: hygienic safety, aesthetics, environmental and economic (Li et al, 2009): For hygienic safety there are pathogens and bacteria that are a concern when treating grey water for reuse, the aesthetic quality is greatly improved when a filtration system removes suspended solids, there can be environmental concerns with using untreated grey water to irrigate landscapes with low water tables and a grey water system must be economically feasible otherwise it will not be used in the long term.

Grey water storage is a challenge because the storage time has to be brief otherwise water quality will decrease. Grey water storage allows solids to settle, allowing total suspended solids (TSS) to decrease, but chemical oxygen demand is reduced due to anaerobic activity, the result being the creation of odors when grey water is stored for over 48 hours (Dixon et al, 2000). Grey water consumption/ use is not as high as production, thus it is unfortunate that water storage has to be less than two days. Thus, it is a challenge using the extra grey water created if there are no landscapes to use it on.

A challenge with implementing grey water use is the public perception of grey water. There are some concerns that pathogenic viruses can be transmitted through grey water use (Eriksson et al, 2002) through contact with aerosols by flushing the toilet. It is likely that in a home, the grey water produced would contain the pathogens from the people living in the home. Pathogens cannot live without their host, which makes it unlikely to contract pathogens through flushing the toilet; this is further discussed in the effective treatment of water section. There are also many other negative perceptions about grey water, such as the odor it will create when used indoors.

There are plumbing codes and indoor water use requirements that need to be met for grey water, these requirements can be restrictive and thus a challenge to implementing grey water use. Restrictions for the use of grey water is due to the difficulty of segregating grey water for collection, limited use of watering landscapes and limited use for indoor uses; for grey water to be largely adopted there will need to be less restrictive policies and guidelines will have to be promoted (Sharma & Chhipa, 2014). Due to these restrictions, grey water adoption is slow, but is implemented by some countries while being researched by other countries.

Jordan is a semi-arid country with limited rainfall; their water availability is less than 1000 m^3 per capita per year, so it is pertinent that adoption of water saving technologies and water recycling is implemented (Jamrah, A., & Ayyash, S., 2008). Jamrah and Avyash (2008) conducted a survey in three cities in Jordan to determine the acceptance of grey water use, the following was found: the top reasons for opposing grey water use is for health concerns, the top reason to accept grey water use is to reduce the demand on water resources, the most acceptable use for grey water was to flush toilets, lastly many would agree to install separate grey water systems in their homes. This is an indication that education to the Jordanian public on the potential for health risks are low, in order for them to adopt and accept grey water fully.

Using untreated grey water for watering landscapes can save on treatment costs, yet there are some precautions. Untreated grey water that is used to water landscapes can affect the chemistry of the soil (increased salinity), and water infiltration (Yu et al, 2013). There is also an issue with using untreated grey water for watering landscapes if the water table is high, it can create contamination issues and is prohibited in California (California Building Standards Commission, 2010). It is less costly to use untreated grey water, but should be applied to specific instances and treated water can be more widely used.

Case Studies of Implementing Grey Water

Grey water thus far has been used in purple pipe systems to water public landscapes. Purple pipe systems were implemented to save using potable water to maintain public landscapes and landscapes of larger size. If one out of ten homes in

Southern California were to install grey water systems, the potable water savings would be equal to the desalination plant that is going to be built in San Diego County (Grey Water Corps, 2009). Worldwide, grey water has been implemented at various degrees and the implementation of grey water systems has been studied for consideration.

A. Countries Implementing and Researching Grey Water Use

Several countries have implemented grey water to different degrees and for different reasons: Japan has implemented grey water systems to accommodate the high population and limited land space for indoor and outdoor uses, the Unites States, Saudi Arabia, and Jordan have implemented grey water as a response to drought conditions for landscape irrigation, and Germany has implemented grey water use for flushing toilets and watering landscapes. Wastewater recycling has been implemented in Beijing since 1987, with more restrictive regulations being adopted in 2000; over 1,000 decentralized wastewater treatment systems have been constructed (Liang and Dijk, 2010).

In the United States, there are efforts to require grey water plumbing, but for the use of watering landscapes. Arizona requires that new residential construction install plumbing to promote grey water use. In California, only multifamily complexes and businesses are required to install plumbing for grey water recycling for watering landscapes. Among cities, water districts play a large part in local water initiatives and infrastructure. Irvine Ranch Water District (IRWD) began implementing the use of grey water systems in 1963, grey water uses over time has expanded to cover landscape irrigation, industrial processes, and toilet flushing in commercial buildings. IRWD conveys grey water to over 4,000 customers adding up to 23.5 million gallons of grey water (Irvine Ranch Water District, 2016). In California The Santa Clara Valley Water District (SCVWD) board of directors approved an advanced water purification center in 2010. The project was to be completed by 2014; the water from this advanced plant will produce up to 8 million gallons per day of highly purified water to be used for irrigation and industrial uses (Santa Clara Valley Water District, 2016).

Egypt is one country that is researching grey water use for future implementation. Nermin & Ali (2012) conducted an economic study in Egypt to implement grey water reuse. In Egypt the land consists mainly of desert and there is little rainfall, while water resources are restricted to the availability from the Nile River and ground water resources. Muslims in Egypt wash their hands five times a day for prayer thus; the grey water generated from ablution can be used for flushing toilets and other uses. As mentioned previously, the survey given by Jamrah and Avyash (2008) in Jordan was to estimate the amount of grey water created in Jordanian cities and to determine the public acceptance of grey water, the survey results were that most people oppose the use of grey water in Jordan, but if required, flushing toilets would be the most acceptable use. Jordan would benefit from grey water use, but will have to create an education and outreach campaign to gain public acceptance. A study completed by Dolnicar and Schafer (2009) in Australia was to determine the profiles for those that accept or reject grey water use, the results indicated that there are many misconceptions about grey water; they concluded that there is a need for policy makers and managers to gain the acceptance of grey water use.

B. Costs and Water Savings of Grey Water Systems in Multistory Buildings

Multistory buildings include: universities, apartment complexes and office buildings. The Public Utilities Commission (PUC) building in downtown San Francisco is a 13 story building that uses 60% less water compared to similar office buildings (San Francisco Water Power Sewer, 2015). The PUC building has onsite treatment for grey and black water, which meets the water needs to flush all the urinals and toilets in the building. The water recycling system has a capacity to treat up to 5,000 gallons of water and reduces water use per person by 59% (San Francisco Water Power Sewer, 2015). Another example of successful implementation of a grey water system in a office building is in Irvine, CA, which has used reclaimed water for flushing toilets for high-rise office buildings since 1991 (Leung, 2012). Irvine and San Francisco has been able to successfully implement centralized and decentralized grey water use.

Kohler completed a year long study in locker rooms using four grey water systems that use shower water to flush toilets, it was found that systems that are in the lower range of cost experience more maintenance issues compared to their pricey counterparts (Kohler, 2012): each system in the study had a different mechanism of disinfecting grey water for reuse, half of the systems did not pass onsite residential water reuse standards, half of the systems received complaints about odor or water appearance, and only one system showed the potential for payback based on operational costs and water rates. It was concluded from this study that the grey water systems tested well in a real life situation, and predicts that grey water technology advances will allow more cost effective systems in the near future (Kohler, 2012). Gyms use a great amount of water, especially those that have onsite laundry, thus implementing grey water systems such as the study by Kohler, has been proven it can be successful.

A study on the economic feasibility of installing a grey water system in a multi-story building was conducted by Imteaz & Shanableh (2012) in Melbourne, Australia. Imteaz & Shanableh (2012) found that the grey water generated from a multistory building generates more grey water than what can be used, due to the fact that there is little to no green areas surrounding complexes. Thus, in a multistory building the grey water generated from the top floors could supply the entire building with grey water. The following costs and payback period were determined for installing a membrane biological reactor for water treatment on the roof of a 20 story building: $163,00 for installation costs, $4,300 for maintenance costs and the payback period is 22 years (Imteaz & Shanableh 2012). Membrane biological reactor grey water systems incorporate a biological process to disinfect the grey water for indoor use. The payback period significantly decreases for a taller building, for a 30-story building the payback period is 8 years (Imteaz & Shanableh 2012).

A study completed by Friedler and Hadari (2005) on the economic feasibility of decentralized grey water recycling in multistory buildings took place in Israel. In urban areas the water use ranges from 100-180 L/day per capita, grey water used to flush toilets can decrease this water use by 40-60 L/day per capita resulting in a 10-

25% reduction of urban water use (Friedler and Hadari, 2005). The study was done on new construction, in which the grey water system was originally installed (no retrofits), only multistory buildings were considered where population density is high and there are great water savings potential.

Two treatment options were considered Membrane bioreactor (MBR) and Rotating Biological Contractor (RBC). MBR utilizes an equalization basin in which, it regulates the flow and temperature of the untreated grey water, treatment is done by passing through membrane followed by disinfection. The RBC system also uses an equalization basin followed by sedimentation then disinfection. MBR is a newer technology compared to RBC, both have been able to consistently produce quality effluent (Friedler and Hadari, 2005). It as determined that the MBR system is about 3 times more expensive per flat compared to the RBC system. The payback period of MBR systems became reasonable when there was one system that served a cluster of 10 story buildings, the extra conveyance costs were negligible. The results may vary from city to city based on water rates, power rates, treatment systems and maintenance costs. In urban environments, such as cities that contain several apartment complexes could implement a grey water system, and have a reasonable payback period if the building is 20 stories or above.

Alum or Ferric are two chemicals that can be used to treat grey water for indoor use. In Egypt Nermin and Ali (2012) estimated the yearly savings using Alum or Ferric for treatment of grey water for reuse was determined to be LE 23652 and LE 29200 for up to 50 people including running costs and cost of equipment (LE is an abbreviation for livre égyptienne, which is a French or Egyptian pound) (Nermin &

Ali, 2012). Converting the yearly savings to U.S dollars amounts to: \$2663.81 and \$3288.66 approximately. Nermin and Ali (2012) recommended that grey water implementation should begin in buildings such as hotels or mosques.

A study completed in Beijing by Liang and van Dijk (2010) determined that grey water recycling is not financially feasible, but is economically feasible. The financial analysis takes the point-of-view of an individual (e.g. a project manager), when the economic analysis takes the societal costs into account. Using cost benefit analysis, a score of one signifies that the project should be implemented. The BNU project that was examined (serving a university population of approximately 30,000) resulted in the following: 1 = operation & maintenance (O&M) costs, economic scale and economic feasibility and 0 = total cost recovery and financial feasibility. These results mean that the operation costs can be sustained and the benefits to society are positive, but the payback on the initial investment will not be beneficial. For the economic analysis: economic, social and environmental costs were taken into account (See Figure 1) for reference. The implication for this study is that project costs are great, but society will benefit if the project is implemented, if grey water systems became more financially economical over time, then it could be widely adopted. The above cases resulted in different outcomes with respect to implementing grey water systems at a large scale. Irvine, San Francisco and Australia has successfully implemented grey water systems in multistory buildings, when Egypt is determining if it may be feasible, and Beijing has struggled with sustaining grey water systems.

C. Costs and Water Savings of Grey Water Systems in Single-Family Homes

There are several grey water systems that can be implemented into a single-family home. A grey water system costs for an individual home is approx. $3,350 to $6,695 and installation costs of approximately $1,100 on top (The Guardian, 2014), this does not include the permit costs and costs associated with retrofitting a home to install a system. According to Poplar Network (2014), there are currently four grey water recycling systems available: 1. Aqua2use, it takes water from the bathroom and treats it biologically and mechanical filters, followed by disinfecting through UV-C treatment. This treated water can be used to flush toilets, wash laundry and water landscapes. For a family of four, the estimated water savings are 30 gallons per person per day. 2. Sloan AQUS Water Reuse System, this system is used for bathrooms, the water from the sink is disinfected and stored in a tank under the sink, which is connected to the toilet, the stored water is to be used for flushing the toilet. 3. Clivus Multrum, offers a variety of grey water systems, some of them are custom made. One model takes water from all the fixtures in the home, aside from the toilet and delivers untreated water to an irrigation system. 4. Aquacell, offers systems that treats both grey and black water to use for flushing toilets, washing clothes and watering landscapes. Grey Water Action (2016) listed grey water systems on the market as well, Nexus E-water, which is a grey water system that can be used to irrigate a landscape of flush a toilet. Nexus E-water costs about $6,000 for the system (including installation), the filter and UV bulb will need annual replacement which amounts to $100. These various systems differ in costs and the process in which they disinfect water for indoor use, there is a variety available on the market to chose from.

A cost-benefit analysis was completed on implementing grey water systems in the residential areas of Los Angeles by Yu et al (2011). It was estimated that a grey water system could cost between $6,000 and $13,000 dollars, with yearly maintenance of $200 – 900 dollars, wetland grey water systems were determined to cost less and require lower maintenance compared to onsite piping system. Yu et al (2011), determined that in a single family home of at least three people will generate approximately 130 m^3/ yr. would offset the treatment costs of the grey water system and lower overall water bill costs. Grey water systems that serve single-family homes that have high maintenance and treatment costs can only be financially feasible for larger multi-family dwellings due to the amount of grey water generated in order to have water bill savings.

Referring to the study done by Imteaz & Shanableh (2012) in Australia they stated that grey water systems installed in a single-family home is not economically feasible due to high installation costs and low use of grey water. In Beijing it was determined by Liang and van Dijk (2010) that a decentralized grey water system serving a residential area of 2,500 people was economically feasible, but not financially feasible. Using cost benefit analysis, with a score of one signifying that the project should be accepted. The Qing project that was examined (residential area serving 2,500 people) resulted in the following: 1 = operation & maintenance (O&M) costs and economic feasibility and 0 = economic scale, total cost recovery and financial feasibility. These results mean that O&M costs are not a large hurdle, as well as the economic effects, what are the hurdles are the finances. The implication of this is most project managers would not recommend to move forward with this project, and in the case that it was constructed it would not be functional for long.

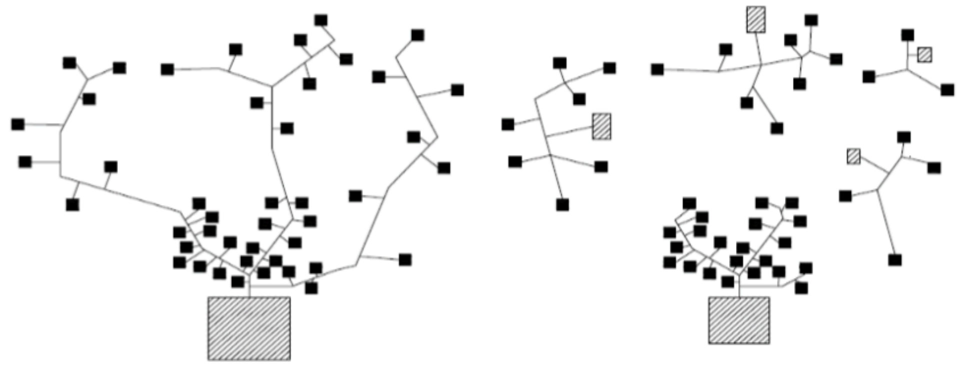
There are a variety of grey water systems on the market available, based on the homes needs and plumbing requirements, costs can vary widely. Australia and Chine has determined that grey water systems in homes were not economically feasible due to project costs and maintenance costs. Further, in China the system was centralized, which makes the project costs increase, due to the increase in infrastructure required for piping grey water to individual homes.

Future Implementation of Grey Water in California

A. Centralized versus decentralized

A centralized treatment plant would be a municipal facility, or a larger facility to treat and distribute larger amounts of water through a piping system. A decentralized facility will be at the individual building or small area level for treating and distributing grey water (Figure 5). A centralized treatment of water will be easier to regulate, although it will be more costly for operation and maintenance due to the complex sewer networks (Ahmed and Arora, 2012). Decentralized water will be more cost effective if it is done on an individual residential or business basis. Matos et al (2014) compared the energy requirements and thus, the carbon emissions from centralized and decentralized wastewater treatment and distribution.

Figure 5. Centralized treatment plant schematic (left) and Decentralized treatment plant (right). (Ahmed and Arora, 2012).



There are various forms of energy that are used when treating wastewater: electrical, manual, fuel and chemical (Matos et al, 2014). Total energy used for treatment of wastewater to the tertiary degree at a centralized facility is approximately 885.5 – 13,215.8 kWh/d, which translates to 329.6 – 4879.2 kg Co2/day (Matos et al, 2014). Total energy used for treatment of wastewater to the secondary degree, followed by UV disinfection at a decentralized facility is approximately 0.21 – 97 kWh/d, which translates to 0.08 – 0.36 kg Co2/day (Matos et al, 2014). With energy costs and carbon emissions taken into consideration, decentralized systems are more efficient in energy use and reducing environmental impacts from addition of carbon emissions.

Los Angeles could reduce the energy used to treat waste water by 4,300 MWh/yr (Yu et al., 2011) thus reducing the GHG emission associated with water treatment and conveyance, as well as reduce potable water consumption and load to centralized treatment plants. Brown (2007) discusses a 'water miles', which explains the energy used to convey water from it's various sources, water treatment and distribution, which can be lowered by decentralized grey water treatment systems. An economic benefit of a decentralized grey water system is the cost savings from reduced piping required to distribute the treated wastewater and water treatment done on site. The environmental benefit is reduced pressure on natural resources from depletion.

B. <u>Effective Treatment of Water</u>

Wastewater must be treated to the tertiary level in order to be used for flushing in toilets in California. There are several ways to treat grey water, which are: biological, physical and chemical, biological treatments are the best for residential use (Li et al., 2009). A basic two-stage treatment system is commonly used for grey water treatment in the UK, as described by Al-Jayyousi (2003): filtration is followed by chemical disinfection, the resulting water is of lower quality, depending on what filtration system is used the energy requirements will vary widely, the economic constraint on this system is the membrane maintenance that is required.

Biological treatment systems often contain both biological and physical components: A membrane bioreactor (MBR) is followed by a biological aerated filter (BAF) (Al-Jayyousi, 2003). BAFs are not as effective as MBRs in removal of suspended solids and disinfection. MBRs have been successfully implemented in Japan in commercial and residential buildings. MBR can be cost prohibitive due to the advanced technology of this system, a payback period of 5-10 years has been estimated for buildings such as schools and offices (Al-Jayyousi, 2003).

Concerns with grey water use have been focused on Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) and micronutrients balance.

Difficulties with maintaining a proper COD is due to quantity and types of detergent in the water, the types of detergents present in the water alters the chemical properties and balance in the grey water and can effect treatment (Al-Jayyousi, 2003). Biological Oxygen Demand is characterized by biodegradable organics, organics provide food for microorganisms, the increase in microorganisms growth can make disinfecting less effective and decrease oxygen in the water making the water quality decrease.

There are various detergents used in a home that cannot be accounted for in treatment and possible toxicity in recirculation. According to Sharma and Chhipa (2014), after conducting studies on water that has been used to wash clothes: grey water after treatment with effective microorganisms can be used to flush toilets.

According to Brown (2007), large scale recycled water systems are at risk for cross connection, which there was an incident in the Netherlands that caused an outbreak of gastroenteritis, which lead to community level water recycling getting banned. This incident was caused by improper maintenance to the system, which the connections were not disconnected afterwards, causing grey water to be mixed with potable water. Several studies about the safety of using grey water has covered concerns about pathogens in grey water, Brown (2007) stated that indicator microorganisms are present in grey water, but the pathogens themselves do not live outside their hosts, and viral pathogens in the case where someone in a home is ill, cannot replicate outside of their hosts.

Concerns with aerosols from grey water containing pathogens are unlikely, and in the case when pathogens can be contracted, it is from the rim of the toilet from contact with feces (Brown 2007). The Ministry of Health in New Zealand has written a report based on faulty research according to Brown (2007), indicating that presence if indicator organisms is an affirmation that pathogens are present. Misleading information such as this creates more stringent guidelines for grey water use and thus the associated treatment costs. At a decentralized level management of these systems can be more closely watched, and the risk of recycled water mixing with potable water is low.

Residence time of grey water storage has to be short due to the biological processes that create anaerobic bacteria that will decrease the quality of the water; water storage size is not necessarily more efficient if it is larger (Dixon et al, 1999). Having a landscaped area to use grey water on will assist with the payback period of the grey water system, although in an urban environment landscaping is not plentiful. The costs associated with treatment of grey water can be significantly lowered if the requirements for treatment for indoor uses weren't so high, requirements for flushing toilets can be treated to the bathing standards instead of drinking water standards (Brown, 2007). As this section explains, indoor use requirements are high for grey water and proper maintenance of grey water systems are essential to prevent accidental contamination and grey water treatment can be more affordable if the treatment requirements were lower.

C. Potential Future Government Involvement/ Mandates/ Advocacy

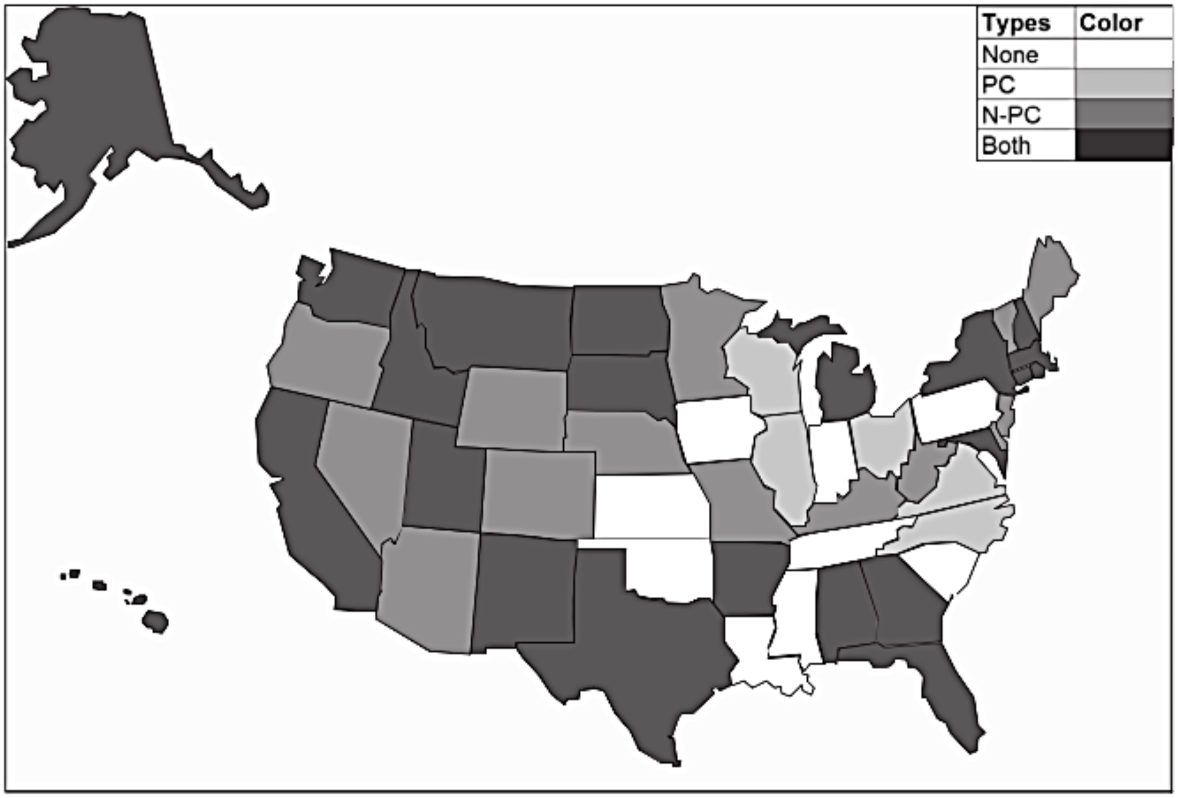
In the 1970s California offered tax credits to Californians who installed grey water systems, the incentive ended in 1982 (Huffpost Politics, 2015). During the most recent water mandates, no incentive program was offered, although the city and county of San Francisco does offer rebates and a manual for installing grey water systems. In Arizona, residents are reimbursed $1000 for installation costs, and grey water systems are required for new construction, except these systems are only used for watering landscapes (Huffpost Politics, 2015).

Grey water infrastructure can be costly to implement, but with many technologies, as adoption becomes greater, the cost will decrease. Perhaps cities on the individual level to incentivize installing grey water systems without the state taking the lead. There is a risk associated with water scarcity and managing these risks means securing water resources, there needs to be a bridge between science and policy disciplines to better manage water (Grey et al., 2016).

Friedler and Hadari (2005) compared water prices in German, Israeli and US to determine economic feasibility, amongst various countries, the US water rates were determined to be half of the Israeli rate, which makes grey water projects less likely to be economically feasible in the US. Friedler and Hadari (2005) recommended that grey water reuse should be subsidized, which would incentivize building owners to install them and the payback period would be significantly shorter.

Yu et al (2013) determined that twenty-nine out of fifty states in the Unites States (Figure 6) allow some form of grey water reuse, but there are inconsistencies between states in the regulations, plumbing codes, storage of grey water and limitations for indoor uses, this is a reflection that there is a need for consistent guidelines and regulations in order to have wide acceptance and implementation of grey water systems.

Figure 6. States that use Grey Water (Yu et al, 2013)



Forty-one states that do provide a definition for grey water define so in various respects: 14 define grey water in their state regulations, 5 define grey water only in their state plumbing code and 22 define them in plumbing codes and state regulations (Yu et al, 2013). Federal or State governments should subsidize grey water, incentivize grey water systems and create standard protocols for grey water treatment and use.

Radcliffe (2010) studied the evolution of water recycling in Australia; during a period of serious drought, the Commonwealth and all States of Australia signed an agreement called the National Water Initiative. This initiative called for innovate technology to treat water and develop water supplies, in 2003 there was an increase in water recycling projects due to initiatives. Each State committed to setting goals of amount of water use reductions, and amount of recycled water to be used. The strong government involvement and agreement amongst several states made grey water recycling implementation possible at a large scale.

Yu et al (2013) also describes incentives and impediments on implementing grey water systems. Incentives are; clearly define grey water regulations, allow individual homes to collect grey water, making the permitting process simplified, and expand the range of uses of grey water. Impediments are: various reuse restrictions on grey water reuse from different sources (e.g. plumbing codes and state regulations), because there is not a variety of grey water uses storage becomes an issue causing odors and decreased water quality, certification of grey water systems would be more easily implemented as opposed to meeting water quality standards, certification of grey water systems can lead to development of low-cost systems, best practices for treatment of grey water for a home should be developed, and lastly grey water producers and consumers should be credited on their water bills.

D. <u>Public expectance and education</u>

There is poor public understanding of grey water systems: there is confusion about the laws of installing these systems and there are concerns that contaminated water could spread disease. As mentioned under challenges of implementing grey water section, Little (2000) said the permitting process can create barriers to implementing grey water, as well as internal struggles with the process. There are concerns with disease caused by grey water consumption or contact; as mentioned previously Brown (2007) recalls a case if gastroenteritis in the Netherlands due to negligence by maintenance, the other concern with disease is when toilets are flushed, contaminated water could infect those through inhalation of aerosols (Brown, 2007), although pathogens are not able to live and replicate outside of their host. The research by Dolnicar and Schafer (2009) found that grey water is perceived by the public as the more environmentally preferred option when compared to desalinated water and there is a willingness to use grey water for flushing toilets and watering landscapes, positive and negative perceptions of grey water are displayed in Figures 7 and 8.

Figure 7. Positive Perceptions of Grey Water from the Public (Dolnicar and Schafer, 2009)

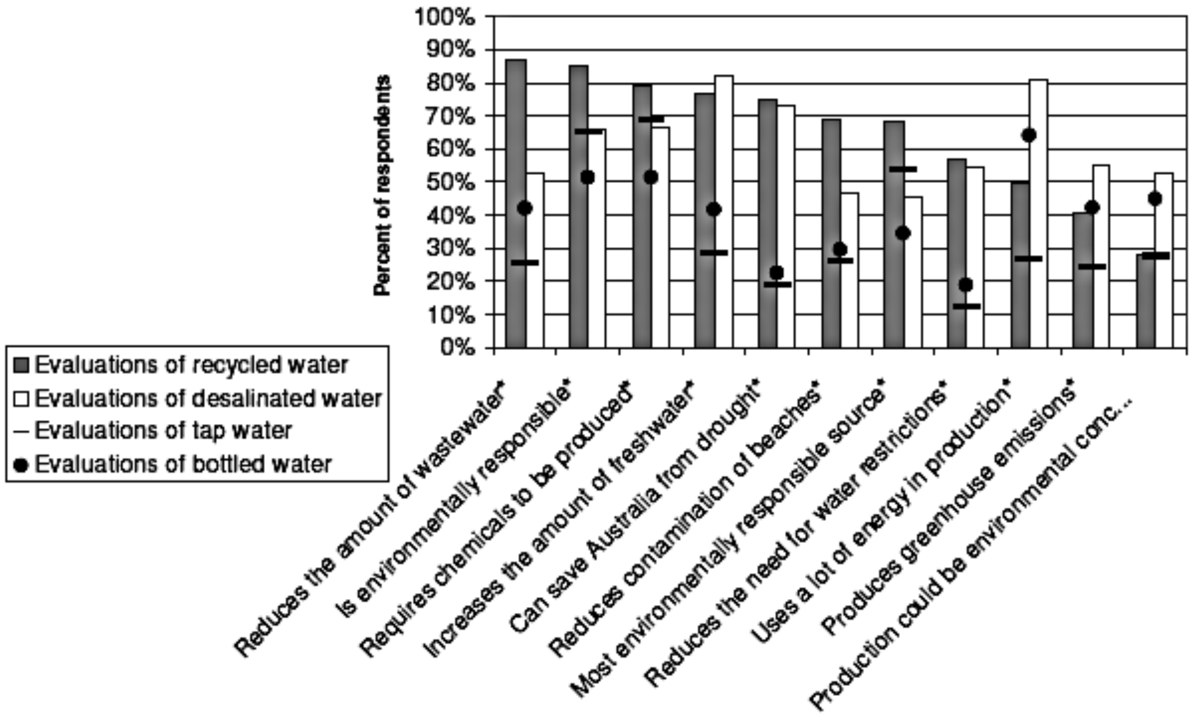
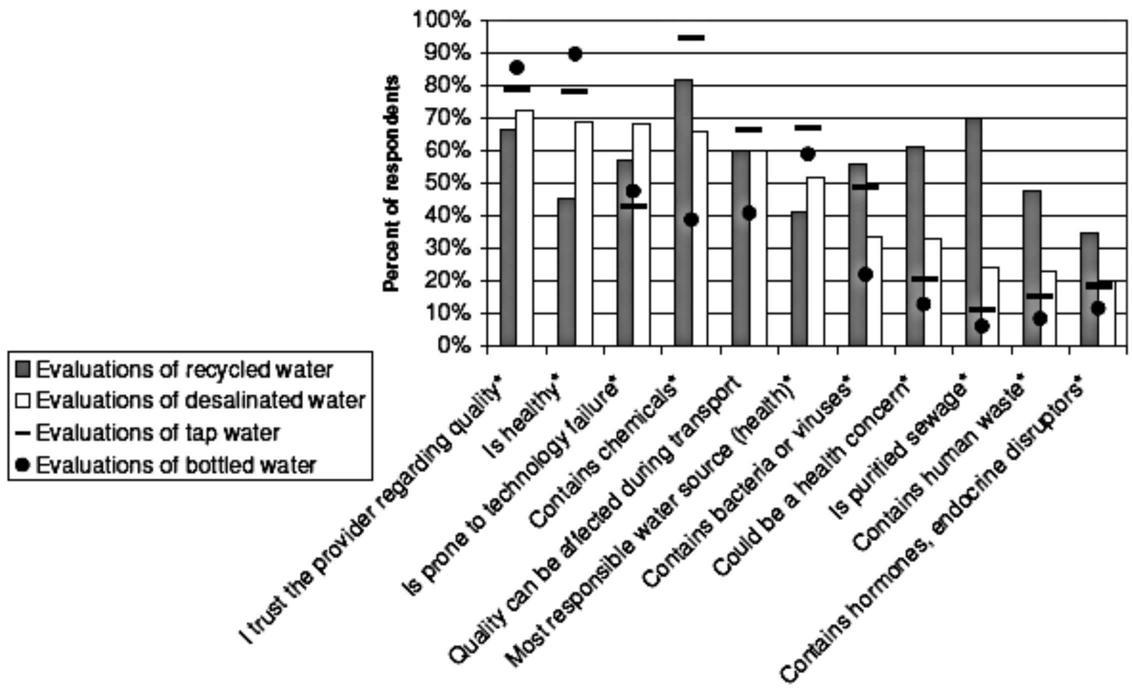


Figure 8. Negative Perceptions of Grey Water from the Public (Dolnicar and Schafer, 2009)



Environmental issues have been widely reported to the public, increasing the awareness of the public has decreased the willingness to accept environmental impacts to acquire resources, and the desire to protect resources has increased (Gleick, 2000). With several countries in the world with dire need for water and many countries experiencing sever drought: the public at large should embrace use of grey water for watering landscapes and flushing toilets. Educating people about the benefits of implementing grey water systems in a home will help increase the acceptance of using grey water. Increased supporters of grey water will place pressure on local governments to support water reuse and develop water reuse guidelines (Nermin & Ali, 2012).

Methods

Information was gathered from the literature about grey water systems including systems costs, installation, and maintenance to determine the payback period and Net Present Value (NPV) when possible. Payback period is the amount of time that it takes to receive positive return on the original investment, basically when savings or profit outweigh costs. The payback period is calculated using a model I built in MS Excel, with the following formula: (Initial investment - Annual operation and maintenance costs) + (Annual water saving* Annual water rate increase) = Ending Balance. The year that the ending balance is positive is the payback period. NPV assists to determine the project profitability; NPV takes present cash inflows and outflows into consideration. A positive NPV means that the projects profits will outweigh the costs and it is worth investing in a particular project. NPV was calculated using a formula that exists in MS Excel, which is NPV. The inputs for the NPV formula are the Ending balance for a number of years and the discount rate.

The payback period and NPV was calculated by making a few assumptions from literature given and from information that appeared to be standard throughout several articles. I assumed that the discount rate was 4% (Ballard and Malcolm, 2003), water price increased 3.4% per year (Stevens and Morin, 2015), and all other factors were gained from each case. Payback period on the original investment should be before the useful life of the system is over, this has not been determined since many of the early systems installed in New Zealand have been in use for over 20 years and have not required replacement or major fixes (Brown, 2007), which is based on the grey water systems in New Zealand that have lasted for over a decade without major system repairs or defects, I used this to determine when to cut off the payback period, as some projects will eventually payback in 100 years or more. Memon et al (2005) estimates that the useful life of a grey water system that is well maintained is 15 years. Table 1 shows the results form this exercise. Various international monetary conversions were completed using an online converter found on Google.com, Table 2 shows the conversion rates used.

Table 1. Payback Period and Net Present Value

City/ Country	Scale	Project Cost Information	Initial Investment	Payback Period	NPV	Source
Maidenhead, UK	New 5 bedroom home with 3 adults and 3 children	$2,340 for a grey water system	$2,340	No payback*	(-$38,913.54)*	Memon et al, 2005
Australia	Single family home	Cost of system, cost of permits and installation $6,188	$6,188	2 occupants <15 years, 4 occupants <7 years, 6 occupants <5 years	(-$3,567), (-$372), $2,824	Brown, 2007
New Zealand	Single family home	$2,029 for installation, permits and system cost	$2,029	2 occupants >25 years, 4 occupants <22 years, 6 occupants <14 years	$754, $3,949 and $7,145	Brown, 2007
Los Angeles, California	Single family home	$6,000-$13,000 grey water system cost for a single family home. $200- 900 for maintenance annually. (tx capacity of 1.2-1.6 m^3/day)	$9,500	No payback*	(-$136,188)*	Yu et al., 2011
Los Angeles, California	Vertical wetland grey water recycling for a single family home	$1,500-2,500 for grey water system. $150 biannual maintenance costs.	$2,000	11 years *	(-$885)*	Yu et al., 2011
Beijing, China	Qing project:Residential area serving approximately 2,500 people	$447,289 for the grey water system and $12,339 for operation and maintenance	$447,289	16 years *	(-$3,075,219)*	Liang and van Dijk, 2010
Melbourne, Australia	A 20 story building	$119,210 for installation costs, $3,145 for maintenance costs	$119,210	22 years	N/A	Imteaz & Shanableh, 2012
Melbourne, Australia	A 20 story building (includes a grey water system coupled with water saving technologies**)	N/A	N/A	4.1 years	N/A	Imteaz & Shanableh, 2012
Melbourne, Australia	30 story building	N/A	N/A	8 years	N/A	Imteaz & Shanableh, 2012
Israel	MBR grey water system for a multistory building that is less than 80 flats	$1,000 per flat when # flats < 80 (20 Storeys)	N/A	Positive income for a 7 story building. Only economically feasible for a 38 story building (which is not a typical building height.	N/A	Friedler and Hadari, 2005
Loughborough, UK	Residence hall of a university, serving 40 people.	$4,817 for a grey water system	$4,817	12 year *	(-$14,423)*	Memon et al, 2005
Beijing, China	BNU project:A university campus serving approximately 30,000 people	$570,679 for the grey water system and $30,847 for operation and maintenance	$570,679	2 years *	$44,498,818 *	Liang and van Dijk, 2010
Israel	RBC grey water system for a multistory building with less than 10 flats	$1,000 per flat in a multistory building when # flats <10 (20 flats = 5 storeys) (about 3 storeys)	N/A	Positive income for a 3 story building. Payback period of <15 yrs for a 7 story building	N/A	Friedler and Hadari, 2005
Israel	Cluster of four 10 story buildings	N/A	N/A	13.5 years	N/A	Friedler and Hadari, 2005
Israel	Cluster of ten 10 story buildings	N/A	N/A	4.9 years	N/A	Friedler and Hadari, 2005

*Calculated by Natalie Muñoz

** Water saving technologies: dual flush toilets, water efficient clothes and dishwashers, and flow restrictors for faucets

Table 2. International Monetary Conversion to USD

	USD
$1 AUD	$0.73
$1NZD	$0.68
$1 GBP	$1.44
$ Chinese Yuan	$0.15
$1 LE	$0.11

In order to apply these financial calculations, I have considered the number of single-family homes high rises in a city such as San Francisco. According to the Bay Area Census (2010), there are 345,811 total households. According to Emporis (2016), there are 698 low-rise buildings and 426 high-rise buildings in San Francisco. From my previous cases that I calculated NPV and payback period from, I grouped them into 3 categories: single-family homes, high-rise buildings and low-rise buildings, I then multiplied the number of buildings by the average project costs to determine the total cost to implement at a citywide scale, table 3 displays this summary.

Table 3. Estimated costs to implement grey water systems at a citywide scale

	Average cost per single family home for a grey water system	Average cost per multistory building for a grey water system HIGH = 20-30 stories	Average cost per multistory building for a grey water system LOW less than 20 stories (includes schools and dorms)
Avg. project costs	$4,411.00	$119,210	$287,748
Avg. payback period (years)	14	11	9.48
Avg NPV	-$18,362.00	N/A	$22,242,197.50
Households in SF:			
345,811	$1,525,372,321.00		
High-rise buildings in SF:			
426	$50,783,460		
Low-rise buildings in SF:			
698	$200,848,104		
Total:	$1,777,003,885.00		

San Francisco's budget for fiscal year 2016-2017 will be $8.96 billion; this is close to the budget for Nevada, which has three times the residents of San Francisco (San Francisco Chronicle, 2015). San Francisco will increase the budgets to the Department of Public Health, Muni, and Police Department (San Francisco Chronicle, 2015). The budget also includes a port at the Hetch Hetchy water system, which is also funded by users, augmenting the water system, could reduce the supply needed from the Hetch Hetchy water supply. According to the San Francisco budget report for fiscal year 2015-2016 the revenue for water and wastewater has reduced by $4.8 million for water sales and $12.4 million for sewer service, these reductions have been attributed to the drought, more revenue could be saved further if grey water systems were implemented. Many cities in California were mandated to reduce water use by 25% (State Water Resources Control Board, 2016) each home or building could save approximately 30-50% using grey water systems (The Guardian, 2014) (Grey Water Corps, 2009). As displayed in table 3, the approximate cost to install grey water systems in San Francisco would be approximately $1.8 billion, which could be a worthy investment to incentivize.

Discussion

A. Findings

In general grey water systems are more economically feasible in large buildings with multiple stories, and it is not economically feasible in single-family homes. The cost of water can change the payback period, being if water rates are subsidized or the water rate is low the payback period will take longer. NPV is affected by water prices, since it will change the amount saved from toilet flushing, NPV decreases with increasing water prices (Memom et al, 2005). The payback period may increase due to implementation of water saving fixtures, a similar trend with increase in NPV occurs with low flushing volumes.

B. Limitations

There are several barriers that are preventing implementation of grey water systems from being a regular structure of every building or widely accepted. One being the economic costs of systems, the initial investment to purchase a system can costs several thousand dollars, can be costly to have them installed by a contractor and annual maintenance can outweigh the costs savings on the water bill. The second being regulatory guidelines and permitting process required to be in compliance when installing a system, permit costs can be confusing and costly to obtain and may cause interested persons to give up. Third, there are public concerns about the potential health impacts that using grey water indoors can cause, such as contact with pathogens causing illness and outbreaks, a concern such as this is likely to become reality if a system is mismanaged and crossing of pipelines occurs. The public perception will have to be changed in a positive light through extensive education of the need to augment the potable water resource, the benefits of water recycling to the environment and the safety of using grey water. Per Sharma and Chhipa (2014) the possible road blocks to the adoption of grey water is not being allowed to separately collect grey water for reuse, and restriction of use on certain landscapes. Nermin & Ali (2012) recommends that installing grey water systems is best done when preparing design plans for a home, as opposed to during construction or retrofitting a home.

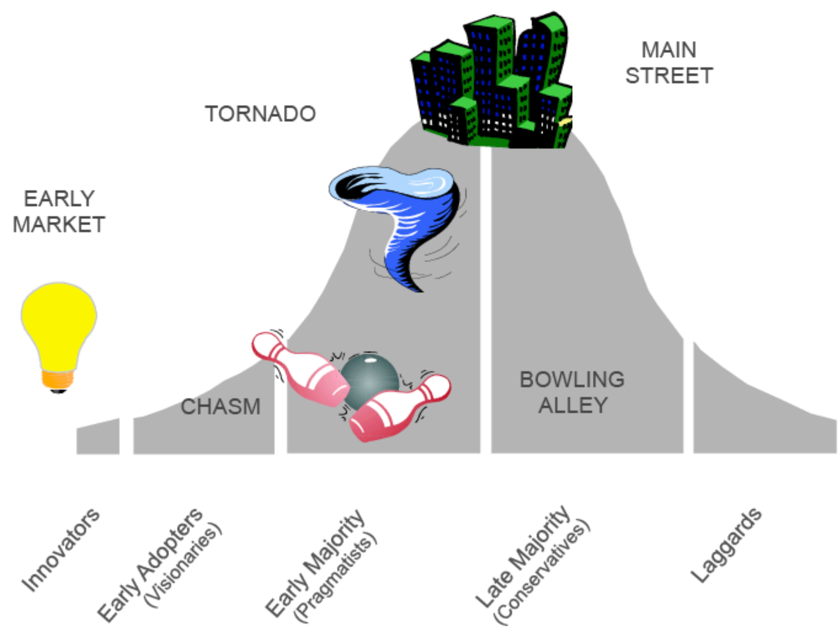
C. Implications and Outlook

Plumbing codes and government may require some form of grey water use in the future. There may be some initial cost and infrastructure barriers until cities, counties or the state adopts grey water systems as a required policy for building upgrades and new buildings and offer incentives for installation. Grey water systems could save a great deal of water if installed in residents and businesses. Since incentives are being offered and cities in the U.S are beginning to adopt installation of grey water systems, it is only a matter of time before this becomes a regular practice. As water resources become further exploited, it is inevitable that water rates will increase. In Los Angeles water rates increased annual by 3-5%, based on this rate water prices could reach \$2/m^3 by 2013 (Yu et al, 2011), and according to Stevens and Morin (2015), the average water rate increase in California will be 3.4% for the next five years until 2020. Increasing water rates will make grey water recycling systems more economically feasible, especially if the technology of grey water systems lower in cost. A third-party ownership model can be used to install grey water systems; developers could finance retrofitting and installation requirements. The third-party owner could maintain the system and ensure that treatment standards meet local requirements for non-potable uses. Implementing grey water can save on water bills and can save energy from transporting water, Nermin & Ali (2012) determined that the amount of savings will depend on: the volume of water that is saved, cost of installation, maintenance costs, operation costs and cost to replace any water mains.

Conclusions and Recommendations

I recommend that cities with the available resources offer incentive programs to residents to install grey water systems, low and high rise buildings should be able to afford implementing grey water systems on their own. If rebates are offered, they need to cover a majority of the cost of the system in order to make the rebate appealing to prospective buyers. Cities may have to pursue the county or state to ask for policy in making it mandatory for new building structures and updates. Once residents of single-family homes have adopted installing grey water systems, the next step could be installation of centralized treatment for complexes and businesses. Large buildings and new construction should install grey water systems since it is more economically feasible than upgrading an existing home. As grey water systems are increasingly adopted the cost of technology will decrease and will be available to the mass market, as displayed in the Technology Adoption Lifecycle Figure 9.

Figure 9. The Technology Adoption Lifecycle (Moore, 2014)



The Technology Adoption Lifecycle is used in marketing to gain market share in the early market of a product, which is composed of several segments: early market, chasm, tornado, main street and bowling alley. The chasm in the Technology Adoption Life cycle is the barrier to widespread adoption to reach the mass market or main street, this barrier is composed of several items: public acceptance, water policy and prices, plumbing codes, permitting process, and lack of incentives. Barriers to implementing grey water at a large scale, which would allow the cost of technology to fall, further more consistent state water policies can lead to a decrease in grey water costs (Yu et al, 2013).

Reduced property taxes can be rewarded to buildings that use grey water systems. Subsidized water rates make implementation of decentralized grey water less financially feasible, and not subsidizing grey water rates does not promote an incentive to install grey water systems (Ling and van Dijk, 2010), states or cities should consider changing water rates to promote grey water systems. The city can provide a low interest-financing program to allow property owners to repay or the grey water system through their utility bill (Yu et al, 2011). These are a few examples of how grey water systems can be incentivized aside from offering discounts on a system.

Grey water systems should be implemented in new construction of all building sizes, as seen by my analysis multistory buildings can economically benefit from installing a grey water system. Grey water use requirements and installation of grey water systems should be streamlined, and the permit costs should be low and easy. Contractors that install grey water systems should be properly trained on maintaining these systems to prevent contamination, as well as the building occupants. When all new construction has grey water systems, system costs could be lower and then should be implemented in all building sizes of older construction. Grey water systems offer a clear solution to decreasing potable water use, and potable water should not be used to flush toilets when there is a serious drought.

References:

1. Accuweather.com. 2015. Will a 'Godzilla El Nino' Help Bust the California Drought?. <http://www.accuweather.com/en/weather-news/will-gozilla-el-nino-end-bust-california-drought/51757922 > Accessed: April 16, 2016.
2. Agudelo-Vera, C. M., Leduc, W. R. W. A., Mels, A. R., & Rijnaarts, H. H. M. (2012). Harvesting urban resources towards more resilient cities. *Elsevier*, *64*, 3–12. http://doi.org/10.1016/j.resconrec.2012.01.014
3. Ahmed, M., & Arora, M. (2012). Suitability of Grey Water Recycling as decentralized alternative water supply option for Integrated Urban Water Management. *IOSR Journal of Engineering*, *2*(9), 31–35. Retrieved from www.iosrjen.org
4. Al-jayyousi, O. R. (2003). Greywater reuse : towards sustainable water management. *Elsevier*, *156*, 181–192.
5. Association of California Water Agencies. 2016. California's water: facts on "water efficiency gardens in full bloom". <http://www.acwa.com/content/conservation/californias-water-facts-water-efficency-gardens-full-bloom> Accessed: April 16, 2016.
6. Ballard B. W. and Malcolm M. Whole life costing for sustainable drainage schemes. Proceedings of the 2nd National Conference on Sustainable Drainage, Coventry University, 23–24 June 2003.
7. Bay Area Census. 2010. San Francisco City and County. <http://www.bayareacensus.ca.gov/counties/SanFranciscoCounty.htm> Accessed: February 6, 2016.
8. Bay Area Water Supply and Conservation Agency. 2016. Rebates. <http://bawsca.org/conserve/rebates> Accessed: April 16, 2016.
9. Brown, C. A. (2007). *Greywater recycling-Risks, Benefits, Costs and Policy*.
10. California Building Standards Commission (2010). *California Plumbing Code,* Title 24, Part 5; California Building Standards Commission: Sacramento, California; International Association of Plumbing and Mechanical Officials.
11. Caltrans Division of Engineering Services Water and Wastewater branch. (2015). Waterless Urinals at Caltrans Safety Roadside Rest Areas.
12. Department of Water Resources. 2008. California State Water project milestones. <http://www.water.ca.gov/swp/milestones.cfm> Accessed: April 9, 2016.
13. Department of Water Resources. 2010. California State Water Project Overview. <http://www.water.ca.gov/swp/ > Accessed: April 9, 2016.
14. Dixon, A., Butler, D., & Fewkes, A. (1999). Water Savings Potential of Domestic Water Reuse Systems using Greywater and Rainwater in combination.
15. Dixon, A., Butler, D., Fewkes, A., & Robinson, M. (2000). Measurement and modeling of quality changes in stored untreated grey water. *Urban Water,* 1, 293-306.
16. Dolnicar, S. and Schafer A. (2009). Desalinated versus recycled water — public perceptions and profiles of the accepters. *Journal of Environmental Management*, *90*, 888–900.

17. East Bay Municipal Utility District. 2016. Toilet rebates. <http://www.ebmud.com/water-and-drought/conservation-and-rebates/residential/rebates/toilet-rebates/ > Accessed: April 16, 2016.
18. Ehrlich, P.R, Holdren, J. . (1971). Impact of Population Growth. *Science*, *171*(3977), 1212–1217.
19. Emporis. 2016. San Francisco. <http://www.emporis.com/city/101040/san-francisco-ca-usa > Accessed: April 22, 2016.
20. Eriksson, E., Auffarth, K., Henze, M., & Ledin, A. (2002). Characteristics of grey wastewater. *Elsevier*, *4*, 85–104.
21. l, K., Marsalek, J., & Schaefer, K. (2004). A Review of Water Reuse and Recycling , with Reference to Canadian Practice and Potential : 1 . Incentives and Implementation. *CAWQ*, *39*(1), 1–12.
22. Facilities Net. 2014. Low-Flow Fittings Proven Way to Conserve Water: <http://www.facilitiesnet.com/plumbingrestrooms/article/Low-Flow-Fittings-Proven-Way-to-Conserve-Water-Facility-Management-Plumbing-Restrooms-Feature--14890> Accessed: April 16, 2016.
23. Friedler E. (2004). Quality of Individual Domestic Greywater Streams and Its Implications for On-site Treatment and Reuse Possibilities. Environ. Technol., 25, 997–1008.
24. Friedler, E., & Hadari, M. (2006). Economic feasibility of on-site greywater reuse in multi-storey buildings. *Elsevier*, *190*, 221–234. http://doi.org/10.1016/j.desal.2005.10.007
25. Gleick, P. H. (1998). WATER IN CRISIS : PATHS TO SUSTAINABLE WATER USE. *Ecological Applications*, *8*(August), 571–579.
26. Gauley, B., & Koeller, J. (2010). *Sensor-Operated Plumbing Fixture Do They Save Water ?*
27. Gleick, P. H. (2000). The Changing Water Paradigm: A look at Twenty-first Century Water Resources Development. *Water International*, *25*(1), 127–138.
28. Grey, D., Garrick, D., Blackmore, D., Kelman, J., Muller, M., & Sadoff, C. (2016). Water security in one blue planet: twenty-first century policy challenges for science. *Philosophical Transactions of The Royal Society*, 1–10. http://doi.org/10.1098/rsta.2012.0406
29. Grey Water Action, for a sustainable water culture. 2016. Manufactured greywater systems. <http://greywateraction.org/contentmanufactured-greywater-systems/ > Accessed: February 13, 2016.
30. Grey Water Corps. 2009. FAQs. <http://greywatercorps.com/faqs01.html> Accessed: February 6, 2016.
31. Hamburg, R. O., Freiburg, U. B., & Lübeck, M. O. (2002). Innovative Technologies for Decentralised Wastewater Management in Urban and Peri-Urban Areas. *Keynote Presentation at IWA Small2002, Istanbul, Sept 2002*.
32. Hanemann, W. . (2005). Title: The economic conception of water. *Department of Agriculture and Resource Economics UC Berkeley*, 1–30. Retrieved from http://escholarship.org/uc/item/08n4410n
33. Hoekstra, A. Y., & Mekonnen, M. M. (2012). The water footprint of humanity. *PNAS*, *109*(9), 3232–3237. http://doi.org/10.1073/pnas.1109936109

34. Home Water Works. 2016. Clothes Washers. <http://www.home-water-works.org/indoor-use/clothes-washer > Accessed: April 16, 2016.
35. Huffpost Politics. 2015. There's A Simple Way To Make A Big Dent In California's Drought. Why Aren't Government Officials Promoting It?: <http://www.huffingtonpost.com/2015/04/08/greywater-california-drought_n_7026350.html > Accessed: February 6, 2016.
36. Imteaz, M., & Shanableh, A. (2012). Feasibility of Recycling Grey-water in Multi-Storey Buildings in Melbourne.
37. Irvine Ranch Water District. 2016. Recycled water. <http://www.irwd.com/services/recycled-water > Accessed: March 12, 2016.
38. Jamrah, A., & Ayyash, S. (2008). Greywater Generation and Characterization in Major Cities in Jordan. *Jordan Journal of Civil Engineering*, *2*(4), 376–390.
39. Kohler. 2012. Is gray-water reuse ready for prime time? <http://www.us.kohler.com/webassets/kpna/pressreleases/2012/KOHLER-GRAYWATER_111412.pdf > Accessed: April 22, 2016.
40. KQED News. 2014. How Much Water Do Californians Use and What Does A 20 Percent Cut Look Like?: <http://ww2.kqed.org/lowdown/2014/01/23/how-much-water-do-californians-use-each-day-and-what-does-a-20-reduction-look-like/> Accessed: March 13, 2016.
41. Lattemann, S., & Höpner, T. (2008). Environmental impact and impact assessment of seawater desalination. *Elsevier*, *220*, 1–15. http://doi.org/10.1016/j.desal.0000.00.000
42. Little, V.L. (2000). Residential Greywater Reuse: The Good, the Bad, the Healthy in Pima County, Arizona: A survey of current residential greywater reuse. Water Resources Research Center, University of Arizona: Tucson, Arizona.
43. Leung, R. W. K., Li, D. C. H., Yu, W. K., Chui, H. K., Lee, T. O., Loosdrecht, M. C. M. Van, & Chen, G. H. (2012). Integration of seawater and grey water reuse to maximize alternative water resource for coastal areas : the case of the Hong Kong International Airport. *Water Science and Technology*, 410–417. http://doi.org/10.2166/wst.2012.768
44. Li, F., Wichmann, K., & Otterpohl, R. (2009). Science of the Total Environment Review of the technological approaches for grey water treatment and reuses. *Science of the Total Environment, The*, *407*, 3439–3449. http://doi.org/10.1016/j.scitotenv.2009.02.004
45. Liang, Xiao and Van Dijk, P. (2010). Financial and economic feasability of decentralized wastwater reuse systems in Beijing. *Water Science and Technology*, 1965–1973. http://doi.org/10.2166/wst.2010.105
46. Libralato, G., Ghirardini, A. V., & Avezzù, F. (2012). To centralise or to decentralise : An overview of the most recent trends in wastewater treatment management. *Journal of Environmental Management*, *94*(1), 61–68. http://doi.org/10.1016/j.jenvman.2011.07.010
47. Los Angeles Times. 2016. In California, water use is all over the map: <http://www.latimes.com/local/california/la-me-1105-california-water-20141106-story.html> Accessed: March 13, 2016.
48. Market Place. 2015. One California drought winner? The local car wash. <http://www.marketplace.org/2015/06/09/sustainability/one-california-drought-winner-local-car-wash > Accessed: April 16, 2016.

49. Matos, C., Pereira, S., Amorim, E. V, Bentes, I., & Briga-sá, A. (2014). Science of the Total Environment Wastewater and greywater reuse on irrigation in centralized and decentralized systems — An integrated approach on water quality , energy consumption and CO 2 emissions. *Science of the Total Environment, The*, *493*, 463–471. http://doi.org/10.1016/j.scitotenv.2014.05.129
50. Mckee, T. B., Doesken, N. J., & Kleist, J. (1993). *The relationship of drought frequency and duration to time scales*.
51. Memon, F. ., Butler, D., Han, W., Liu, S., Makropoulos, C., Avery, L. M., & Pidou, M. (2005). Economic assessment tool for greywater recycling systems. *Engineering Sustainability*, *158*(ES3), 155–161.
52. Moore, G. 2014. Crossing the Chasm: Marketing and selling disruptive products to mainstream customers. 3rd edition. *Harper Collins Publishers*.
53. Nermin, M., Ali, S. S. (2012). Economic Study For Greywater Reuse To Achieve The Sustainability In Egypt. *Australian Journal of Basic and Applied Science*, *6*(3), 655–665.
54. NOAA. 2016. National Centers for Environmental Information- Climate at a Glance. < http://www.ncdc.noaa.gov/cag/time-series/us/4/0/pdsi/12/4/1895-2016?base_prd=true&firstbaseyear=1901&lastbaseyear=2000> Accessed: May 12, 2016.
55. Office of Governor Edmund G. Brown Jr. 2014. Governor Brown declares drought state emergency. <https://www.gov.ca.gov/news.php?id=18368 > Accessed: January 30, 2016.
56. Pacific Gas & Electric Company. 2016. High-Efficiency Clothes Washer Rebate. <http://www.pge.com/includes/docs/pdfs/shared/saveenergymoney/rebates/clotheswasher_application.pdf > Accessed: April 16, 2016.
57. Pope, J., Annandale, D., & Saunders-Morrison, A. (2004). Conceptualising Sustainability Assessment. *Elsevier*, *24*, 595–616.
58. Networks. 2014. Graywater recycling systems: <http://www.poplarnetwork.com/topics/graywater-recycling-system> Accessed: February 6, 2016.
59. Regional Water Providers Consortium. 2016. Conserve H20, Toilet: <http://www.conserveh2o.org/toilet-water-use > Accessed: March 13, 2016.
60. Regional Water Providers Consortium. 2016. Conserve H20, Faucet: < http://www.conserveh2o.org/faucet-water-use> Accessed: March 13, 2016.
61. San Francisco Chronicle. 2015. A city with an $8.96 billion budget should be able to…. <http://www.sfchronicle.com/bayarea/article/A-city-with-an-8-96-billion-budget-should-be-6311442.php> Accessed: April 22, 2016.
62. San Francisco Water Power Sewer. 2015. Sfwater.org
63. San Jose Mercury News. 2015. California drought: How San Jose's mandatory water rationing will work: <http://www.mercurynews.com/drought/ci_28102311/california-drought-new-details-emerge-about-san-joses > Accessed: February 26, 2016.
64. Santa Clara Valley Water District. 2016. Recycled Water. < http://www.valleywater.org/EkContent.aspx?id=184&terms=grey+water> Accessed: March 12, 2016.
65. Schwartz, P., & Randall, D. (2003). *An Abrupt Climate Change Scenario and Its Implications for United States National Security*. 1-22.

66. Sharma, H., & Chhipa, R. C. (2014). An opportunity for water conservation : A Grey water (cloth washings) and its application. *International Journal of Research Aspects of Engineering and Management*, *1*(2), 2348–6627.
67. Sjovold A., and Krieger C. (2016). *Fixing the State Water Project.* News Depply, Water Deeply. <https://www.newsdeeply.com/water/op-eds/2016/03/17/fixing-the-state-water-project/> Accessed: April 2, 2016.
68. State Water Resources Control Board, California Environmental Protection Agency. 2016. Media Release: Californians save 1.1 million acre-feet of water, urged to stay focused on conservation. < <http://www.waterboards.ca.gov/water_issues/programs/conservation_portal/docs/2016feb/pr22516_jan_conservation_pr.pdf> Accessed: February 6, 2016.
69. Stevens M. and Morin M. 2015. L.A., pushing big water rate increases, seeks 18% more from typical users. Los Angeles Times. < http://www.latimes.com/local/lanow/la-me-ln-dwp-rates-20150708-story.html> Accessed: April 29, 2016.
70. The Guardian. 2012. How will climate change impact on fresh water security?: <http://www.theguardian.com/environment/2012/nov/30/climate-change-water> Accessed: March 13, 2016
71. The Guardian. 2014. Greywater systems: can they really reduce your bills?: <http://www.theguardian.com/lifeandstyle/2014/jul/21/greywater-systems-can-they-really-reduce-your-bills > Accessed: February 6, 2016.
72. The Sacramento Bee. 2015. Southern California desalination plant will help ease water crunch, but price is steep. <http://www.sacbee.com/news/state/california/water-and-drought/article49468770.html> Accessed: April 22, 2016.
73. Unites States Census Bureau. 2014. 2014 National Population Projections: Summary Tables <http://www.census.gov/population/projections/data/national/2014/summarytables.html> Accessed: March 13, 2016.
74. Unites States Census Bureau. 2014. 2015 Population Estimate: <http://www.census.gov/search-results.html?page=1&stateGeo=none&searchtype=web&cssp=SERP&q=population+projections&search.x=0&search.y=0&search=submit > Accessed: March 13, 2016.
75. US Drought Monitor. 2016. US Drought Monitor California. <http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA> Accessed: February 4, 2016.
76. Wilson, Kathleen. *Low-flow toilets required in California for all home renovations*. Huffpost Los Angeles. 2013. <http://www.huffingtonpost.com/2013/08/23/low-flow-toilets-required_n_3800061.html > Accessed: March 13, 2016.
77. Yu, Z. L. T., Deshazo, J. R., Stenstrom, M. K., & Cohen, Y. (2011). *Cost-Benefit Analysis of Onsite Residential Graywater Recycling – A Case Study : the City of Los Angeles*.
78. Yu, Z. L. T., Rahardianto, A., Deshazo, J. R., Stenstrom, M. K., & Cohen, Y. (2013). Critical Review : Regulatory Incentives and Impediments for Onsite Graywater Reuse in the United States. *Water Environment Research*, *85*(7), 650–662. http://doi.org/10.2175/106143013X13698672321580