Residential Greywater Irrigation Systems in California:

An Evaluation of Soil and Water Quality, User Satisfaction, and Installation Costs

Greywater Action

in collaboration with
City of Santa Rosa and Ecology Action of Santa Cruz

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1

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All errors are our own.

Table of Contents

Appendices

Introduction

As water shortages become increasingly common, new and innovative ways to conserve and reuse water are critically important. Widespread reuse of household greywater has the potential to contribute significant water savings, up to 40% of residential consumption (Cohen, 2009), although how much water is actually saved depends on how people design and maintain their systems. Lack of scientific data on how greywater affects soils and plants has been a barrier for widespread implementation of greywater systems for residents and public agencies alike. Lack of data regarding the costs of installation, permitting and maintenance for greywater systems also present barriers for households that are considering greywater reuse. We seek to collect this data through a multi-faceted study of residential greywater systems in Central California.

In 2009 California rewrote its greywater code, making low-tech greywater systems legal for the first time, and excluding clothes washer systems from permit requirements (CBSC, 2010). The legalization of greywater reuse in California has stimulated many local governments and water utilities to invest in public education and incentive programs. The increase in public interest and installation of greywater systems has also generated concerns from some water districts, public agencies, and states about potential environmental problems resulting from using greywater. Despite these concerns, greywater systems have been legal and widely implemented in states like Arizona and New Mexico for many years with no reports of health or environmental problems.[2]

Few U.S. greywater studies have investigated residential greywater systems *in situ*, and those that have typically only evaluated a handful of systems (City of LA, 1992; Bennet et al., 1999; Little et al., 2000). Field studies of greywater systems in other countries have provided some information, however the results do not account for differences in local conditions, such as soaps used, water use patterns, soils, or types of plants grown (Al-Hamaiedeh and Bino 2010, Gross et al. 2005). This comprehensive study of 66 households, comprising a total of 83 residential greywater irrigation systems, seeks to fill critical scientific data gaps by evaluating indicators of soil and greywater irrigation water quality, plant health assessment, water consumption data, user satisfaction, and greywater system installation and permitting costs.

Background

Definition of Greywater

"Greywater", as we use the term, refers to water discharged from washing machines, showers, baths, and sinks. Greywater does not include water from toilets or wash water with fecal material (eg. soiled diapers). Kitchen sink water is often classified as "dark greywater", though currently some states in the United States, including California, classify it as "blackwater" and prohibit on-site reuse.

Reuse of greywater has many potential benefits; it can reduce overall potable water consumption, thus decreasing the demand for surface and groundwater. Greywater reuse can reduce energy consumption, as it offsets the need to treat water to potable quality for irrigation, and can protect water quality by reducing

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2

Allen, L. Personal communication with Charles Graf (ADEQ) and Val Little (Water CASA) on 7/2/09 and 7/16/09 flows on over-loaded septic systems.

However, greywater may contain pathogens due to fecal contamination or food handling. Greywater system design and safe management should prevent direct contact with greywater other than when performing system maintenance or repairs. Many systems distribute greywater subsurface, thus eliminating direct contact. Other systems deliver the water at the ground surface, where it quickly soaks in, thereby limiting opportunities for direct contact. Systems that allow for untreated greywater to pond or pool on the soil surface create a potential for direct contact with greywater.

Previous Greywater Studies

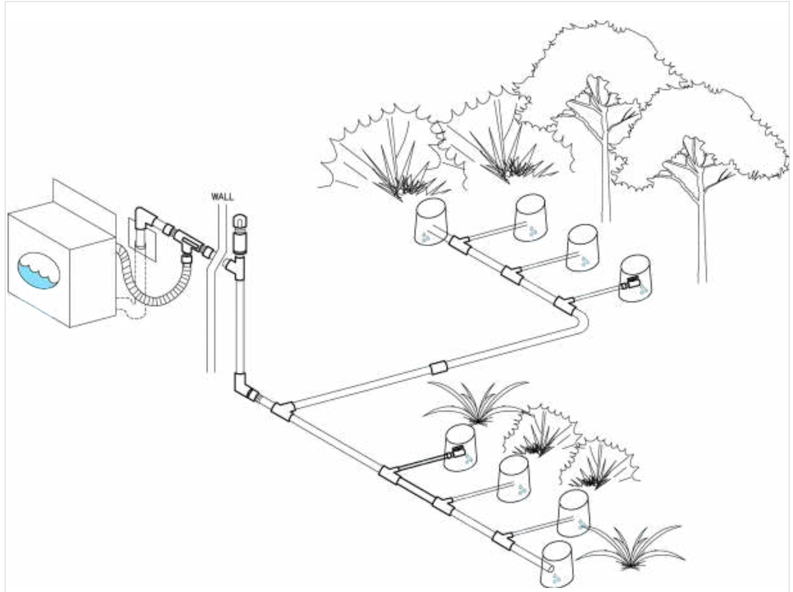
In an effort to understand the benefits and risks of greywater use, researchers have investigated the chemical and biological characteristics of greywater, the public health risks posed by different sources of water and different types of greywater systems, and the effect of different sources and distribution methods on soils and plants (Al-Hamaiedeh and Bino, 2010; Ottosson and Stenstrom, 2003; Pinto et al., 2009; Travis et al., 2010). A growing literature from Australia, the Middle East, and Europe documents the costs, water savings, maintenance requirements, effects on soil and plants, and social aspects of residential greywater systems.

A variety of studies look at the public health risks of greywater. Many have found fecal indicator bacteria present, (Casanova et al., 2001a; Ottoson and Stenstrom, 2003a; Friedler, 2004), demonstrating the potential for greywater to contain faecal transmitted pathogens. Nevertheless, few studies have found specific pathogens. Neither the City of Los Angeles nor the Water CASA study found disease causing organisms when they tested for salmonella, shigella, and entamoeba histolytica (City of LA, 1992) or *Cryptosporidium spp.* and *Giardia spp.* (Little, et al., 2000). However, *Cryptosporidium spp.* and *Giardia spp.* have been detected in greywater from other studies (Casanova et al., 2001b; Birks et al., 2004), as well as skin pathogens such as *Staphylcoccus aureus* (Kim, et. al 2008). Furthermore, there have been no documented cases of illness from greywater (Sheikh, 2010; Ludwig, 2009; Winward et al., 2007). In contrast, there are an estimated 3.5 million documented cases of illnesses in the United States each year caused by recreational contact with surface waters contaminated by sewage (American Rivers). Regardless, due to greywater's non-potable quality, care should be taken to avoid direct contact and irrigation of root vegetables should be avoided to prevent accidental ingestion of greywater.

In the United States a major focus of greywater educators is the use of “plant friendly” household products, those without salts and boron. Studies conducted internationally in places without availability of “plant-friendly” products found that, though it did not harm the soil or plants, the irrigation quality of greywater was lower than other sources of water. For instance, a study in Jordan found that the salinity and sodium adsorption ratio (SAR) of the soil increased over the one year study period, (Al-Hamaiedeh and Bino 2010) but that chemical properties of the crops were not changed. In another project study in Israel, researchers compared and analyzed soil and water quality on crops irrigated with freshwater, freshwater mixed with fertilizer (fertigation), and untreated greywater on crops over a three year period. They found that while water quality properties of the greywater can be lower than other sources of water with regard to contaminants of boron, surfactants, and SAR, the soil salinity in the greywater irrigated plot was similar to a site irrigated with fertilized water, and below concentrations harmful to plants (Gross et al. 2005). An Australian study on tomato plants irrigated with laundry greywater found that though the water was more saline, the tomato plants grew significantly more biomass than plants irrigated with tap water. The greywater irrigated tomato plants also contained significantly more nutrients than the plants irrigated with tapwater. The researchers concluded that “laundry greywater has a promising potential for reuse as irrigation water to grow tomatoes” (Misra et al., 2010).

Description of the Types of Greywater Systems in this Study

Greywater systems can be classified as those designed for outdoor irrigation and those for indoor non-potable use. In general, residential systems for outdoor irrigation are simpler and easier to maintain, while larger, mechanized systems for indoor non-potable use, such as toilet flushing, are more complicated. The systems surveyed in this study are residential systems, predominantly "laundry to landscape" and "branched drain" systems. These systems do not have tanks, pumps or filters, and irrigate landscape plants directly, though a few systems we studied did incorporate pumps. Figure 4 shows the breakdown of the types of systems studied.



igure 1: Laundry to landscape system. Credit: Cleanwater Components

In the "laundry to landscape" system, shown in figure 1, the washing machine pump sends greywater from the drain hose of the machine directly to the landscape (usually gravity based). The system does not alter the existing plumbing of the house and does not require a permit in the state of California or several other states, like Arizona, New Mexico, and Montana, if basic guidelines are followed.

The "branched drain" greywater system (not shown) uses gravity to distribute greywater from showers, sinks, and baths. "Branched drain" systems typically divert greywater through the drainage plumbing of the house, which is then distributed to plants via a series of branching drainage-type pipes.

Both types of systems discharge greywater into "mulch basins", which are excavated trenches in the ground, usually 6 to 20 inches deep, 1 to 2 feet wide and 3 to 10 feet long, and filled with wood chips or other woody organic material (see figures 2 and 3). These basins require periodic maintenance to replace mulch and remove decomposed material. The frequency of maintenance depends on several factors, including the particle size of the mulch, the size of the mulch basin, soil texture type, and the quantity and source of greywater entering the basins. The experience of greywater installers and Greywater Action members is that basins need maintenance about once a year, although kitchen sink systems may need more frequent maintenance due to build up of organic matter and grease. Neglecting this maintenance can lead to

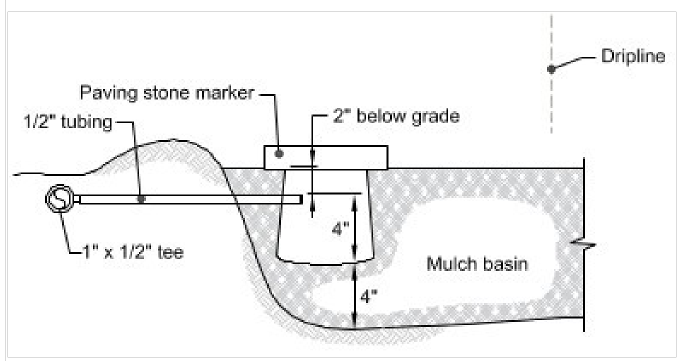
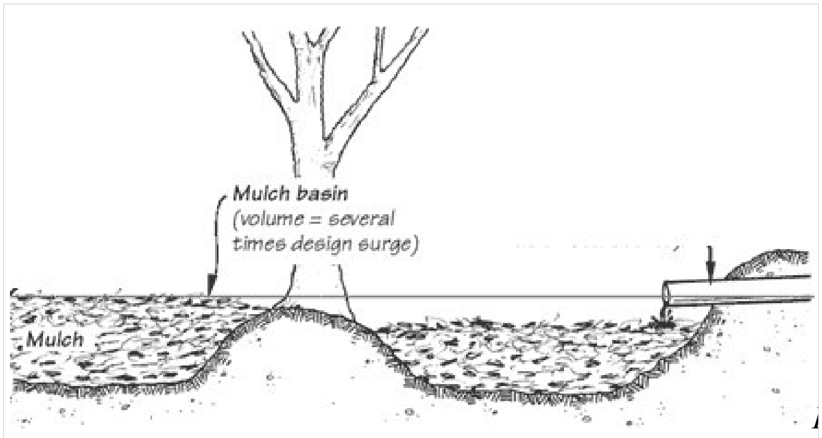


Figure 2: Subsurface irrigation. Credit: SFPUC

slower infiltration, pooling, or runoff of greywater.

The two types of pumped systems in the study, “pump no filter,” and “pump with filter,” both have a small surge tank to temporarily collect greywater. Inside the tank is a pump, which send the water to the landscape. The “pump no filter” system sends unfiltered greywater to the landscape, typically using 1” pipe or tubing, whereas the “pump with filter” first filters the greywater and sends it out through smaller tubing, typically 3/4” mainline with 1/2” irrigation lines with ¼” emitters.



igure 3: Mulch basin. Credit: Oasis Design

Study Group

The study group consisted of 66 households with one or more greywater systems located in the San Francisco Bay Area (Albany, Berkeley, El Cerrito, Oakland, Piedmont, Richmond, San Francisco, San Leandro, and San Pablo), the Monterey Bay area (Aptos, Monterey, Pacific Grove, Santa Cruz, Seaside, and Watsonville), and the Santa Rosa area (Cotati, Petaluma and Santa Rosa).

The San Francisco Bay Area is home to 1.6 million people, the Monterey Bay area to 732,708, and the Santa Rosa area to 234,000 people (US Census, 2010). Annual rainfall in the East Bay is approximately 24" and San Francisco 21”. Average annual rainfall in the Santa Rosa area is approximately 31”. Average annual rainfall in the Monterey Bay Area ranges from 42.8” in the Santa Cruz Mountains to 20” on the Monterey Peninsula The climate is “Mediterranean”, with mild, wet winters, and warm, dry summers. Average summertime high temperatures range from 66 to 83 , and winter lows from 37 to 47 degrees Fahrenheit. (The Western Regional Climate Center, 1919-2005, 1931-2005)

The participants for this survey were identified through the networks of the investigators (“snowball” sampling method). Greywater systems had been installed by homeowners, by independent professional installers, or through training programs led by local governments and NGOs.[3]

Methods

Structured Interview of Greywater System Users

We conducted a one-hour structured interview at each of the 66 households, representing a total of 83 greywater systems. Following the interview, w e collected greywater and soil samples and recorded qualitative plant health metrics for greywater-irrigated plants at each site. Interviews were conducted between May and July of 2012 by the principal investigators and trained enumerators.

Interview questions elicited demographic information, details about the greywater system(s) and other water

3 Greywater Action, Ecology Action of Santa Cruz, or the City of Santa Rosa

conservation practices (e.g rainwater harvesting), laundry and soap products used, and irrigation methods and frequencies. The interviews were recorded on a hand- held Android device using the program ODK (opendatakit.org) for data collection. See appendix IV for the survey questionnaire.

We interviewed the principal caretakers of the greywater system at each site. On sites where multiple people maintained the system we interviewed whoever was available at the time of the interview.

Greywater Testing

One sample of greywater was collected per system. For the “laundry to landscape” systems, we asked household members to wash a load of dirty laundry following their usual practice, then collected greywater at an accessible outlet in the landscape. The samples passed through the system before collection, and represent the typical irrigation water that plants receive. Shower, sink, and bath greywater from “branched drain” systems was either collected though a similar method (plugging the tub for a shower and collecting greywater from an outlet in the yard), or, in a few cases, were collected in the house by mixing a small quantity of products typically used in the system. Because this method of collection used less water than would be generated in typical usage, the concentration of constituents in greywater in the shower/sink samples may be higher than would be present in the actual greywater generated from these fixtures, and also did not pass through the greywater distribution pipes.

Greywater samples were tested on site for pH. Collected samples were refrigerated and sent to a laboratory [4] where they were tested for conductivity (an indicator of salt content), TDS (total dissolved solids), and boron. A subset of 57 samples were also tested for irrigation suitability at Soil Control Laboratory,including pH, total dissolved solids, conductivity, alkalinity (Carbonate and Bicarbonate reported as CO_3 & HCO_3), chloride, phosphate, boron, sodium, iron, potassium, nitrate (NO_3), phosphate (o-PO_4), sulfate (SO_4) and secondary nutrients (Calcium (Ca), Magnesium (Mg)).

The laboratories analyzed greywater samples following standard methods for examining irrigation water. Samples from the Santa Rosa area were tested in the city's water quality laboratory (ci.santa-rosa.ca.us) following standard methods.

Categorization of Greywater Quality and Soil Test Results

To summarize the results of the greywater and soil testing we categorized samples into “generally safe”, “slight to moderate”, and “severe” risk levels for soil and irrigation, following guidelines in “Abiodic Disorders of Landscape Plants” and “Water Quality for Agriculture”, based on the work of Pettygrove and Asano (1985). Long-term irrigation with water containing levels in the “generally safe” range should have no negative effects on most plants regardless of soil type. Levels in the “slight to moderate” risk may cause harm to sensitive plants and may be more problematic in clay or slow draining soils. Depending on the plant species, and other factors, long term irrigation with the level “slight to moderate” may have no negative affect, or it may reduce plant growth and productivity. Long term irrigation with water containing levels in the “severe” risk category will most likely cause plant growth problems, and reduce yields in most, but not all, plants.

4 Perry Laboratory, Watsonville, CA or Soil Control Laboratory, Watsonville, CA

Soil Quality and Texture

At the time of the site visit two soil samples were collected per greywater system. One sample was collected from soil underneath the greywater outlets, the area directly beneath where greywater entered the soil from the irrigation system. The other sample was collected from soil in the same area of the landscape that had no contact with greywater. Both samples were collected following standard soil sampling procedures. Investigators also conducted on-site soil texture tests following the soil ribbon and soil worm procedures (see Appendix III).

Soil samples were air dried and sent to the soil laboratory at the University of Massachusetts for standardized testing. Samples were tested for soluble salts, pH, extractable nutrients (P, K, Ca, Mg, Fe, Mn, Zn, Cu, B), extractable aluminum and cation exchange capacity. To test for an effect of greywater irrigation on these variables, at each site we subtracted the value for the non-greywater irrigated soil sample from the value for the greywater irrigated soil sample and tested whether the resulting differences were significantly positive (or negative). A positive difference would imply that greywater irrigated soil sample constituents were consistently larger than the non-greywater irrigated samples from the same site.

Plant Health Assessment

At each site several plants irrigated by greywater were visually analyzed for qualitative indicators of health. We observed 127 plants in detail, and briefly observed more than 1,000 greywater irrigated plants at the sites. Any plant that was identified by the respondent as having problems, or any plant that the investigator noticed as being unhealthy was observed in detail (one of the 127). We looked for leaf chlorosis, leaf necrosis, insect presence, other diseases (e.g. mildews, leaf curl, etc.) and abnormal growth. We rated each plant for the variables listed above with a numeric value (1,2, or 3). For example plants were rated for chlorosis by a “1”- signifying no sign of chlorosis, almost all leaves appear healthy, “2”- signifying some signs of chlorosis, multiple leaves show symptoms, or “3”- signifying severe chlorosis, most of the leaves show symptoms. We then categorized them as “fully healthy” (plant showed no symptoms, or one minor symptom, ie. minor insect presence), “mostly healthy” (plant showed two minor symptoms ie. minor insect presence and some chlorosis), or “unhealthy” (plant showed multiple symptoms or one severe symptom ie. disease, and severe chlorosis), depending on their symptoms.

Calculating Water Savings

We used two methods for calculating water savings. First, we looked at water consumption data for 34 sites (52% of study population) provided by one of the water utilities, East Bay Municipal Utility (EBMUD) and compared consumption before installation of the greywater system to consumption after installation. All water data ended in May of 2012. We analyzed average savings, as well as savings per subgroup. We classified study households into subgroups based on survey questions that explored other steps taken in the home that would influence water consumption, such as whether they made other water saving changes (eg. low-flow fixtures or rainwater harvesting systems) and whether they planted new plants at the time they installed the greywater system or irrigated existing plants.

Second, we estimated how much water would be required to irrigate the area at each site that is currently irrigated by greywater using local climate data and standard irrigation requirements. This method attempts to address the challenge of estimating savings for households that added additional plants to measure how much potable water their system potentially offset. Since we do not have information on whether the presence of greywater as an irrigation source affected a households decisions on what type of plants to grow (i.e. high water need plants vs. low water need plants), this estimate will not capture those variables.

Evaluation of Greywater System Costs

We conducted a separate survey of 20 professional greywater installers, mainly landscaping or plumbing contractors, to evaluate costs of greywater installation materials, labor and permitting. These greywater installers owned businesses in the San Francisco Bay area, Monterey Bay area, Sonoma and Marin counties, and Los Angeles county. Collectively, these installers reported that they had installed 259 greywater systems since 2009. 94% of these greywater systems were the same irrigation system types included in our general analysis (see figure 9). Interviews with greywater system installers were conducted over the phone and or using a web form between July and September 2012. See appendix V for the greywater installer survey questionnaire.

Statistical Methods

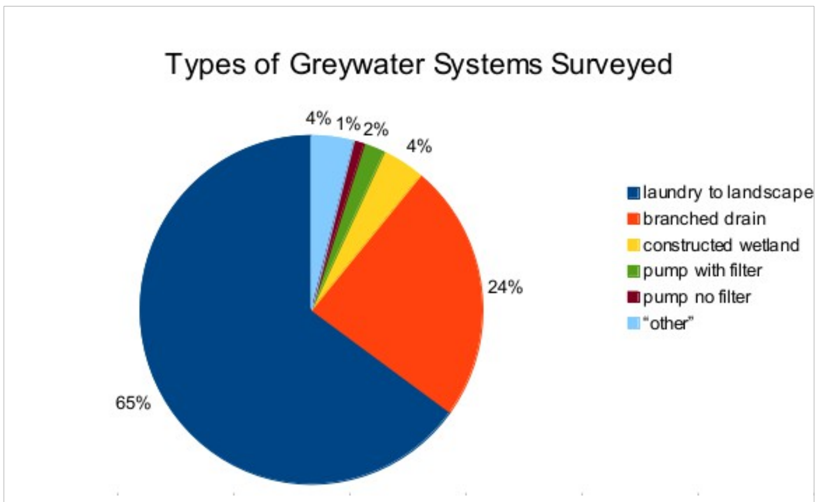
For the soil and greywater test results, many of the variables measured contained a few extreme outliers. To remove their influence and summarize typical values we use medians instead of means and discuss the outliers in detail in the Results.

In the water savings section, however, we used averages rather than medians because data was not influenced by large outliers. The average saving we found, therefore, reflects actual water savings a water district would see if more of their customers with similar water usage patterns as those in our study installed greywater systems.

Statistical analyses and plots were produced in R 2.7 (rproject.org).

Results

Here we report aspects of user experience, the results of the soil and water tests, plant health, water savings, and system costs.



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Greywater Users

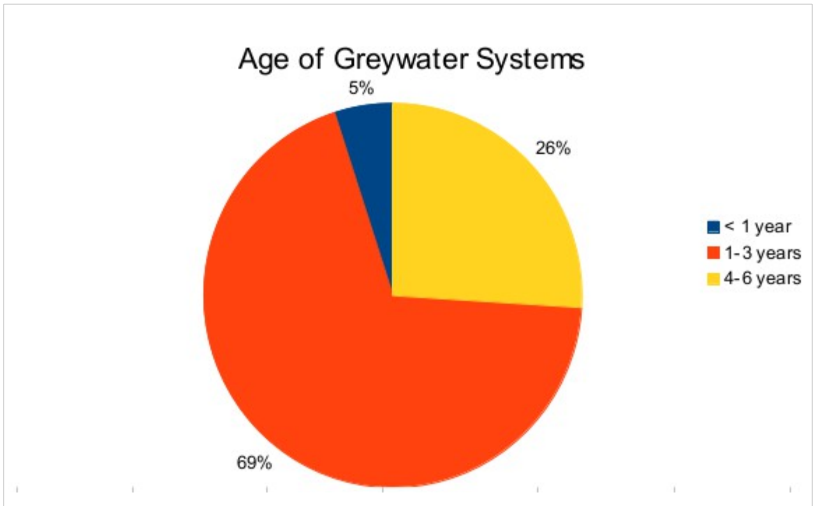
The vast majority, (95%), of participants were homeowners, the remainder rented their homes.

Participants in our study produced an estimated average of 11 gallons/person/day from shower/baths and 7 gallons/person/day from washing machines, (compared to the California code estimate of 25 gallon/person/day for showers/baths and 15 gallons/person/day for washing machines). These numbers were based upon testing the flow of the shower head nozzle, the make and model of washing machine, and reported usage of fixtures from the structured interview.

User Experience

We surveyed these aspects of the user experience:

- how people learned about greywater
- reactions to their system from the larger community
- motivations for installing a system
- perceived benefits
- problems
- user satisfaction
- maintenance and repair needs
- opinions on health risks



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Overall, respondents reported positive experiences with their greywater systems. Most people felt they had benefited from their systems, were satisfied with how the system worked.

We found that participants first learned about greywater reuse from multiple sources. The most common source was friends or colleagues, classes or workshops, and/or the media (eg. article or news coverage). 71% of respondents reported installing their system within three years of learning about greywater, with 35% of people installing the system within one.

We asked what kinds of comments people recalled hearing when they talked to friends, neighbors, and relatives about their greywater system. All respondents reported hearing positive comments of some sort, including "good idea", "excited", "want to do it too", and "interested". Only 6% of respondents heard some type of negative comment in addition to positive comments. 33% of respondents reported that a friend or family member installed a greywater system after learning about theirs.

Where People First Learned about Greywater*	
Friend or colleague	34%
Media	24%
Workshop	23%
Book	12%
Other	35%

*Multiple responses were recorded

able 1

Respondents were mainly motivated to install the system by a workshop, or a concern for saving and reusing water. Most households received no incentives or rebates for installations. Participants had a variety of goals for their greywater system, most commonly to save water or a general desire to make their home more ecologically sound . Most people, (68%), felt their system saved water, and almost half felt their plants benefited. People also reported their systems made them feel good about having a more ecological option for their greywater other than sending it down the drain with the rest of the sewage.

User Satisfaction Findings

Overall, greywater users felt overwhelmingly positively about their greywater systems. All respondents but one were either “very satisfied” or “satisfied” ; only one felt “neutral” about their greywater system. They also felt positively about their system's reliability or need for maintenance: 92% reported they were either “very satisfied” or “satisfied”. People felt slightly less satisfied regarding how well their greywater systems waters the plants, with 90% of users reported they felt either “very satisfied” or “satisfied”.

User Satisfaction with Greywater System					
	% Very satisfied	**% Satisfied**	% Neutral	% Dissatisfied	% Very dissatisfied
Overall satisfaction	**75**	**24**	1	0	0
Reliability (need for maintenance)	**69**	**23**	7	1	0
Irrigation performance	**55**	**40**	5	0	0

able 2

86% of system users said they would recommend their systems to others, and 13% said they would recommend the system with modifications. Only one person said they were “not sure” if they would recommend their system, and no one said they would not recommend it.

Maintenance, Repairs, and System Use

The majority of households reported no operations problems with their systems. 12% reported clogging problems, mostly at the greywater outlet (see figure 2), and for most it was a single occurrence that they fixed themselves. The single household that had the most frequent clogging issues had a pump with filter system and reported that the filter clogged every 1-2 months. 8% reported that the system was not irrigating properly, due to a clog, or a valve that had come detached. Pests occasionally disturbed the systems. At one site, slugs congregated inside of the greywater outlets, while at another gophers dug up the mulch basins.

84% of households reported no broken parts up to the date of the interviews with their greywater systems. Of the eleven households that reported a broken part, the tubing caused a problem for nine, one the filter, and one a valve. The typical reason for the tubing to break was through damage during gardening, for example, by accidentally putting a shovel through it. Though not technically part of the greywater system, the “mulch shield” which protects the greywater outlet from root intrusion, was often damaged when it had been made out of a plastic polyethylene nursery pot (instead of using a rigid irrigation valve box or hard plastic container).

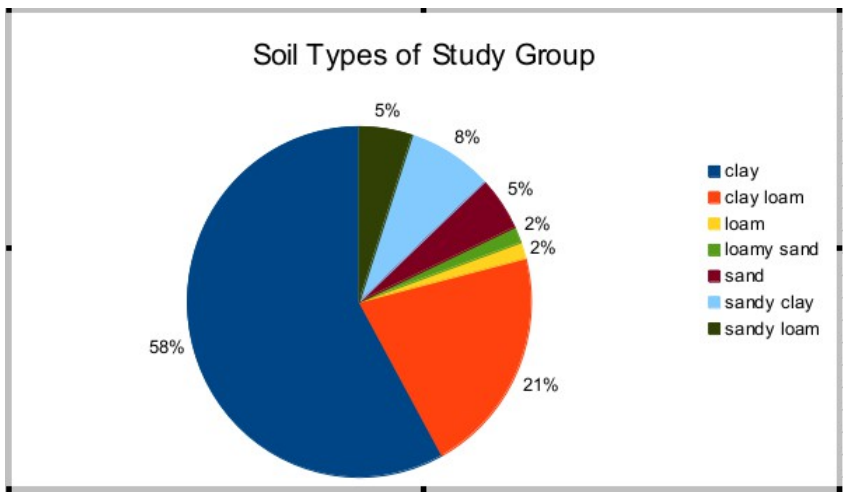
Most households did very little general maintenance on their systems. Of the 89% of households with mulch basins, about half had done nothing to the basin, and the other half had dug out the area under the outlet and replaced the mulch. Through most respondents indicated they did not notice greywater pooling or running off the soil surface, continued lack of maintenance could lead to this problem. Participants did not believe that system clogs had exposed residents to pooled greywater (97%). Only two participants reported that possible direct contact with greywater had occurred (not including maintenance), both incidents were from greywater runoff onto a path. Though most respondents in the survey were not public health professionals, we asked about their perception on safety, specifically if they thought anyone could get sick from their greywater system. From their personal experience no one believed their system could cause illness.

Even though few people reported pooling or runoff, investigators noticed several additional sites that had some pooling when water was run through the system, indicating these people were not checking the outlets frequently enough to notice the problem. In fact, 25% of people reported they never checked the outlets. After the interview several participants asked questions about maintenance, indicating there was not a good understanding of maintenance needs, even though most people reported they had a good understanding of how the system functioned in general.

Soil Testing Results

Our soil test results suggest that irrigation with greywater did not affect soil salinity, boron, or other nutrient levels. We can be quite confident that if there is an effect it is quite small, since we compared soils irrigated with greywater to soils not irrigated with greywater at each site, thus controlling for most other sources of variation.

We compared the difference between greywater and non-greywater irrigated soils for the variables of soil pH, soluble salts, boron, as well as other nutrients (P, K, Mg, Ca, S) and micronutrients (Zn, Mn, Cu, Fe, Cd, Pb, Al, Cr, Ni). We analyzed the differences between variables at each site (See figure 7). We also compared differences by soil type to see if some soils could be more impacted by greywater irrigation, since heavy clay soils are known to be more susceptible to accumulation of salts and other ions, whereas sandy soils are more easily leached. However, we saw no significant differences between greywater and non-greywater irrigated soils for any of the soil types (Wilcoxon signed-rank tests). Most of our sites were in clay, clay loam, or sandy clay soils, so these results are more informative than the soil types of loam, loamy sand, sand, and sandy loam that had few samples.



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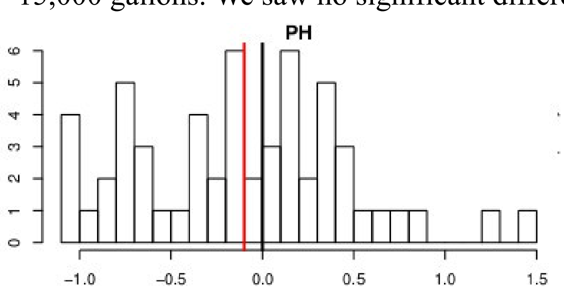
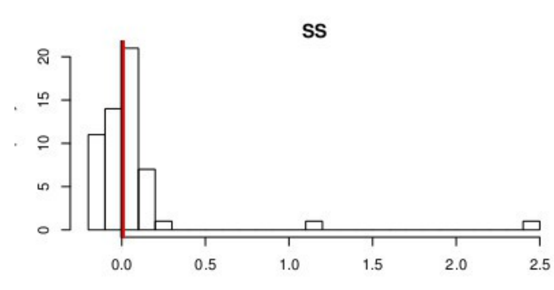
Additionally, we looked for correlations between the age of the system and the difference between greywater and non-greywater irrigated soils, as well as quantity of greywater produced, since older systems might have had more time to accumulate salts or boron. Systems were grouped into less than 1 year old, 1-3 years old, 4-6 years, and more than 6 years. The only variable we found to be significantly different (Wilcoxon signed-rank test) between age categories was a lower pH (relative to the paired non-greywater irrigated soil sample from the same site) in systems older than four years. Since the greywater samples in our study were typically more acidic than the average pH of the municipal water, the reduction of pH could be due to the long term irrigation of a more acidic water. (Note that the pH range of the soils was still with in the safe range for soil pH). Systems were also grouped according to how much estimated greywater had been discharged: less than 5,000 gallons, 5,000 -10,000 gallons, 10,000 -15,000 gallons; or greater than 15,000 gallons. We saw no significant difference for any variable between these groupings.





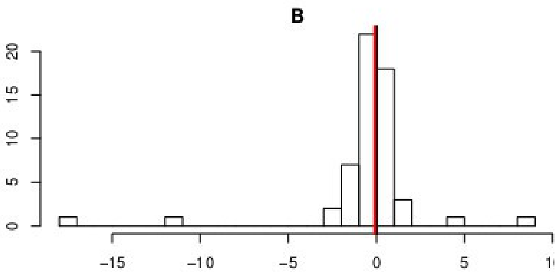


Figure 7

Difference between GW and non-GW

soil tests for pH, suspended salts (SS),

and boron (B) at the same site. Gray

Salts and boron are two constituents commonly found in greywater of most concern for plant health. We found no significant difference between the greywater irrigated soils, and the non-greywater irrigated soils in their level of salts (the EC), or boron levels. Additionally, the difference between greywater and non-greywater soil variables (soluble salts and boron) wasn't correlated with the amount of the salts or boron found in the greywater samples from the same site (EC, B, Na, and Cl).

Guidelines for Interpreting Soil Test Results

	Generally safe	Slight to moderate risk	Severe risk
Soluble salts (EC) mmhos/cm	0.5-2.0	2.0-4.0	>4.0
Boron (ppm)	0.1-0.5	1 – 5	>5

able 3

We found large variation in the non-greywater irrigated soil samples for the variables we tested, much larger than the typical differences between greywater and non-greywater irrigated soils due to variability in original soils, imported soils, use of fertilizers, etc. Table 4 below illustrates these variations for soluble salts, pH, and boron.

We found the median pH of the greywater irrigated soils to be 6.5 with a range of 5.3 to 7.5, whereas the non-greywater irrigated soils also had a median of 6.5 , with a range of 5.2 to 7.6. The median pH difference between greywater irrigated and non-greywater irrigated soils was -0.1. These results indicate that the greywater irrigated soils were slightly more acidic than the non-greywater irrigated soils, although the difference is not statistically significant and much smaller than the natural range of variation. Range in pH common for arid region mineral soils are 6.5-9. Range in pH common for humid region soils is 5-7 (Brady, Weil, 1999).

The median soluble salts in the greywater irrigated soil was 0.17 mmhos/cm (dS/m), with a range of 0.05 mmhos/cm to 2.6 mmhos/cm. The median for non-greywater irrigated soils was 0.16 mmhos/cm with a range of 0.05 mmhos/cm to 1.85 mmhos/cm. The median difference between greywater and non-greywater irrigated soils was 0.01. All but two of the greywater irrigated samples were in the "generally safe" range, and 3% were in the "slight to moderate" risk range for soluble salts, whereas 100% of non-greywater irrigated samples were in the "generally safe" range.

Greywater and Non-greywater Irrigated Soil Testing Results								
		Median	Min	Max	Samples in **"generally safe"** range	Samples in **"slight to medium"** risk range	Samples in **"severe"** risk range	median difference btw. GW and non-GW samples
Soluble salts (mmhos/cm) or dS/m	greywater	0.17	0.05	2.6	97%	3%	0%	0.01
	non-GW	0.16	0.05	1.85	100%	0%	0%	
pH	greywater	6.5	5.3	7.5				
	non-GW	6.5	5.2	7.6				-0.1
Boron (ppm)	greywater	1	0.2	9.3	55%	42%	3%	
	non-GW	0.8	0.2	19.3	65%	32%	3%	0

able 4

The two greywater soil samples with salt levels outside of the "generally safe" range (2.03 and 2.6 mmhos/cm) did not have high salt levels in the greywater we tested. Greywater from the first site tested low in salts (EC 0.31 mmhos/cm and TDS 198 ppm) and greywater from the second site had salt levels slightly above the "generally safe" range. (EC of 0.78 mmhos/cm, TDS of 504 ppm, and SAR of 5.4). Soap used at this second site listed no sodium products in its ingredients list, and other sites that used the same detergent did not have levels of salts out of the "generally safe" range. Since this was a one time sampling, it is possible the higher level of salts could have come from the clothing, or residue from other detergents. This site also reported that manure had been added within the month, possibly another source of salts to the soil since manures have been found to have salts ranging from 12.0 to 23.0 mmhos/cm (Costello et. al 2003). We did not see any problems with plants at either site.

The median level of boron in the greywater irrigated soils was 1.0 ppm, with a range of 0.2 to 9.3 ppm; while the median for non-greywater irrigated soils was 0.8 with a range of 0.2 to 19.3. The greywater from the site with the highest levels of boron in the greywater irrigated soil (9.3 ppm) had very low levels of boron in the greywater, 0.18 ppm, indicating the source of boron in the soil was from elsewhere. Even though the greywater irrigated soils had a higher median boron level, the difference is not attributed to greywater. The median difference between boron levels in greywater and non-greywater irrigated soil samples from the same site was 0.00 and the distribution was not significantly positive (wilcoxon signed-rank test).

Guidelines for Interpreting Greywater Test Results			
	Generally safe	**Slight to moderate risk**	**Severe risk**
EC (mmhos/cm)	<0.7	0.7-3.0	>3.0
TDS (ppm)	<450	450-2,000	>2,000
SAR	<3	3 – 9	>9
Boron (ppm)	<0.5	0.5-1.0	>1.0
Chloride (ppm)	<140	140-300	>300
Sodium (ppm)	<70	70-200	>200

Table 5

Greywater Testing Results

In this section, we report our findings for each variable we tested for, where we found most samples to be in the generally safe range for irrigation water, and provide details on outlier samples. Only one site used powdered detergent and was the source for many of the outliers results. A few sites occasionally used powdered cleaning products.

Municipal water contains some amounts of salts and bo ron, Table 6 s hows ranges found in tap water from the municipalities of the study area. Note that the reported maximum levels of salts (EC, TDS, Na, and Cl) found in tap water from some municipalities in our study area are in the “slight to moderate” risk category for irrigation, hence, results from those districts will most likely have higher salt content than from municipalities with lower salt content in the tap water. Although we lack data on the specific salt levels of tap water in our greywater samples, we suspect some of our samples were influenced by this, particularly the samples that tested on the low-end of the “slight to moderate” risk category for EC, TDS, SAR, chloride, and sodium, came from sites using products that tested “generally safe” at other sites, and did not contain any salt compounds in their ingredients.

See appendix I for information about each variable and its effect on soils and plants and table 5 (above) for the ranges for each category of “generally safe”, “slight to moderate”, and “severe” risk for long term irrigation.

The median pH was 6.5, with a range of 5.5 to 9.7[5].

The median EC was 0.31mmhos/cm, with a range of 0.07 to 4.82 mmhos/cm. 85% were in the “generally safe” range for irrigation water, 14% were on the low end of the “slight to moderate risk” (0.704, 0.74, 0.78, 0.79, 0.91, 0.92, 1.15, 1.21, 1.3, 1.35 mmhos/cm), and one sample was in the “severe” risk range- 4.82 mmhos/cm. This site used powdered laundry detergent.

We found the median TDS to be 198 ppm, with a range of 47 to 3133 ppm. 84% were in the “generally safe” range, 15% in the “slight to moderate” risk range, and only one in the “severe” risk range. This site used powdered laundry detergent.

The median sodium absorption ratio (SAR) (adjusted Rna) level was 1.8 with a range of 0.35 to 64. 80% of the samples had a SAR rating in the “generally safe” range, 18% in the low range of the “slight to moderate” risk, and two samples in the “severe” risk category (SAR 14 and SAR 64). The sample with the highest SAR rating, SAR 64, used powdered laundry detergent, and the sample with the second highest rating, SAR 14, used many different commercial brands (like Suave).

We found the median boron level to be 0.05 ppm, with a range of 0.003 to 4.55 ppm. 92% of the samples were in the “generally safe” range, 5% were in the “slight to moderate risk” range, and two samples were in the “severe” risk range, with levels of 2.81 and 4.55 ppm. The site with the highest boron levels in the water used a detergent that lists itself as “greywater safe”, though boron is an ingredient (7th Generation). The second site used Arm and Hammer Oxy Clean Power Gel, which does not list all ingredients.

We evaluated the boron levels in the soil at the sites with high boron levels in the greywater. It was not obvious that boron levels were increasing, though they could over more time. The soil from the two sites with highest levels of boron in the greywater did have more boron in the greywater irrigated soil than in the non-greywater irrigated soil. However, soil from the three greywater samples that showed a “slight to moderate” risk had only one site with an increase in boron levels and two sites with no increase compared to the non-greywater irrigated soil sample. Since most of the greywater samples did not contain elevated levels of boron, we do not have many sites that could experience a build up of

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5 There was some discrepancy between the on-site pH tests and the laboratory, we used the average between the two results.

boron.

The median chloride level was 24 ppm, with a range of 4 to 210 ppm. 94% of samples had levels in the "generally safe" range, with most samples lower than 50ppm. Six percent of samples had levels in the "slight to moderate" risk range. No sites had chloride levels in the severe risk range.

The median sodium level was 32 ppm, with a range of 7 to 1024ppm. 85% of samples were in the "generally safe" range, 13% were in the "slight to moderate" risk range. One sample was in the "severe" risk range, with a level of 1024 ppm. This site used powdered detergent.

Greywater Testing Results

		Median	Min	Max	Samples in "generally safe" range	Samples in "slight to medium" risk range	Samples in "severe" risk range
EC (mmhos/cm)	greywater	0.31	0.07	4.82	85%	14%[2]	1%
	municipal water[1]	0.38	0.04	1.64			
TDS (ppm)	greywater	193	47	3133	84%	15%[2]	1%
	municipal water[1]	240	29	846			
SAR[3]	greywater	1.8	0.35	64	80%	18%[2]	2%
	municipal water[1]	no data available					
pH	greywater	6.5	5.5	9.7			
	municipal water[1]	8.3	6.7	9.7			
Boron (ppm)	greywater	0.04	0.003	4.55	92%	5%[2]	3%
	municipal water[1]	0.31	ND	0.88			
Chlorine (ppm)	greywater	24	4	210	94%	6%[2]	0%
	municipal water[1]	24	3	394			
Sodium (ppm)	greywater	32	7	1024	85%	13%[2]	2%
	municipal water[1]	23	3	140			

1- We averaged the quality of municipal water for the seven water districts of the study area. Since there was not an even distribution of sites in each water district, the averages show above do not reflect an accurate estimate of constituents preexisting in the water, rather they shows levels that can be found in municipal water.

2- Most samples were at the low end of range, see results section for details

3- SAR- We used the adjusted Rna calculation

able 6

Plant Health Results

Our detailed observations of greywater irrigated plants found 95% to be fully healthy. We found seven cases of disease, none of which appeared to be attributed to greywater. Of the plants identified as unhealthy, half had been identified by the household as unhealthy prior to greywater irrigation, while the remaining unhealthy plants showed

Health of Greywater Irrigated Plants

	No signs	Some signs	Severe signs
Leaf necrosis	95%	5%	0%
Leaf chlorosis	94%	5%	1%
	Fully healthy	**Mostly healthy**	**Unhealthy[1]**
Overall health	95%	2%	3%

1- Of the unhealthy plants, half were identified to be unhealthy before greywater irrigation began.

able 7

symptoms of common diseases that did not appear to be directly related to greywater (such as peach leaf curl).

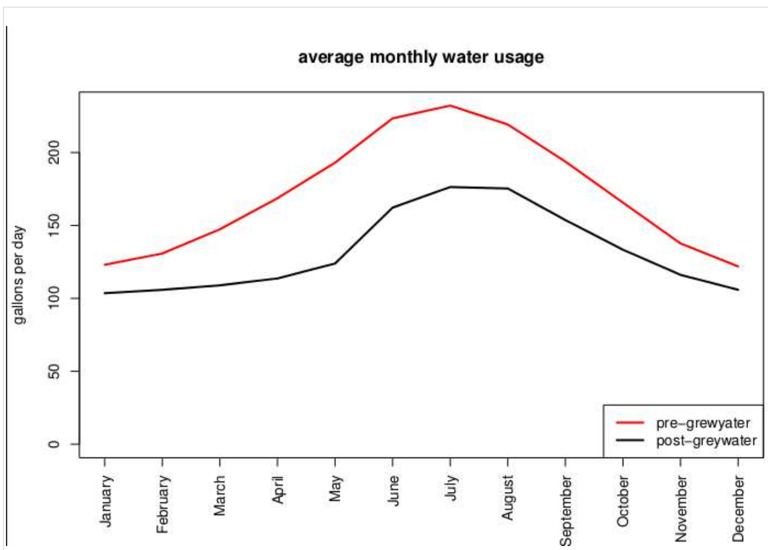
Leaf chlorosis and necrosis are common symptoms of salt and boron toxicity, but can also indicate nutrient limitations and other stresses. 95% of the plants observed showed no signs of necrosis, 5% of plants showed minimal signs of necrosis, and no plants showed severe signs of necrosis. 94% of plants showed no signs of chlorosis, 5% showed minimal signs of chlorosis, and two plants showed extreme signs of chlorosis. Of the two plants with severe chlorosis, one was grossly over-watered (all greywater was being directed to one tree) with poor drainage, and the other was a lemon tree, which often suffer from chlorosis due to nutrient deficiencies.

We observed plants in good health under a large range of irrigation regimes. For each household, we estimated weekly greywater production and plant water requirements. We found that some plants were being under-watered, some appropriately watered, and some over-watered. This demonstrates that the common landscape plants included in this study can tolerate and thrive under many different soil moisture conditions.

Water Savings Results

In this section we provide results for estimating water savings, as well as water consumption findings for various subgroups of households, for example, separating results from households that planted new plants with their greywater system vs. those that did not.

From the water consumption data we found an average water savings of 17 gallons per person per day after installation of the greywater system and people used 48 gpd (down from 65 gpd before greywater system installation).



igure 8

Average annual household water savings was 14,565 gallons each year after installation of the system. Average savings varied by season, with higher savings in spring and summer, (nearly 10,000 gallons), and lower in fall and winter, (close to 5,000 gallons). Since these systems were used for outdoor irrigation we would expect to see higher savings during the irrigation season.

Average Water Usage and Savings Pre and Post Greywater System				
Month	**Pre-greywater gpd**	**Post-greywater gpd**	**Daily savings**	**Monthly savings**
January	123	104	19	589
February	131	106	25	700
March	147	109	38	1178
April	169	114	55	1650
May	193	124	69	2139
June	223	162	61	1830
July	232	176	56	1736
August	219	175	44	1364
September	194	154	40	1200
October	166	133	33	1023
November	138	116	22	660
December	122	106	16	496
		Annual average household savings (gal)=		**14 565**

able 8

Though the average per capita daily savings was 17 gallons per day (gpcd), (68 gallon/day for a family of four), some households actually used more water after installing greywater, (up to 32 gallons/day), while others saved much more than this (up to 122 gallons/day). For households that reported they had adopted other water-saving practices in addition to their greywater system the average savings was 23 gpcd. Of the households that did not make any water saving changes, those that planted new plants when they installed their greywater system used an average of 4 more gallons per person per day, while households that did not plant new plants saved an average of 11gpcd. Some households had a change in the number of people living in the house before and after installing the greywater system. We will discuss the implications of this and affects on our results in the Discussion.

Per Capita Savings Per Category (GPCD)			
	Average	Minimum	Maximum
Per capita	**17**	-32	122
GW + other water saving changes in home	**23**	-18	81
Planted new plants with GW, no other changes	**-4**	-19	8
No new plants, no other changes	**11**	-32	122

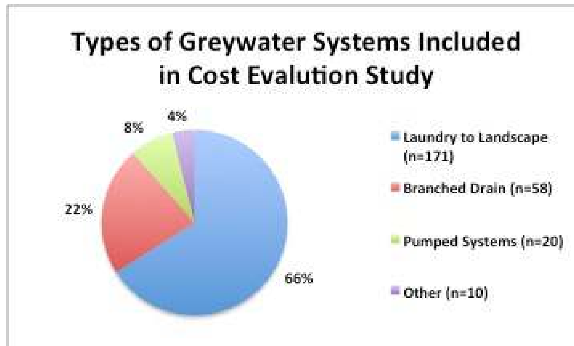
able 9

To account for the amount of water potentially offset by a greywater system that was installed with new landscaping, we looked at the total area irrigated with greywater at each site and then estimated how much irrigation water it would require during an eight month irrigation season. We found that on average 325 square feet was irrigated with greywater at each study site, offsetting an estimated 5,200 gallons of potable water a year per site. Landscaped areas irrigated with greywater ranged from 36 to

1,380 square feet, offsetting an estimated 576 to 22,080 gallons a year. These calculation assume that all new landscape area irrigated by greywater would have been irrigated with municipal water [6]. The estimated savings found with this method were significantly lower than the actual savings we observed from water consumption data, suggesting that actual savings associated with greywater systems may be influenced by factors other than just landscape irrigation needs.

Greywater System Cost Results

Results show that homeowners that hire a professional plumber or landscaper to install a greywater irrigation system can expect to pay a range of costs depending on the system type, size and complexity of the system installed. Table 10 documents the low, average, and high range of system costs including materials, labor, and permitting fees for systems installed by the 20 professional installers in the study group. Table 11 reports the low, average, and high range of costs for homeowners who install their own greywater systems.



igure 9

Professional-Installed Greywater System Cost Range

MATERIALS + LABOR + PERMIT	L2L (no permit)	Branched Drain	Pumped Systems
Low	$350.00	$500.00	$1,800.00
Average	$750.00	$1,740.00	$3,790.00
High	$2,000.00	$4,250.00	$5,750.00

Table 10

Homeowner Installed Greywater System Cost Range

MATERIALS + PERMIT ONLY	L2L (no permit)	Branched Drain	Pumped Systems
Low	$100.00	$250.00	$800.00
Average	$250.00	$715.00	$1,790.00
High	$500.00	$1,750.00	$2,750.00

Table 11

<u>Materials Costs</u>

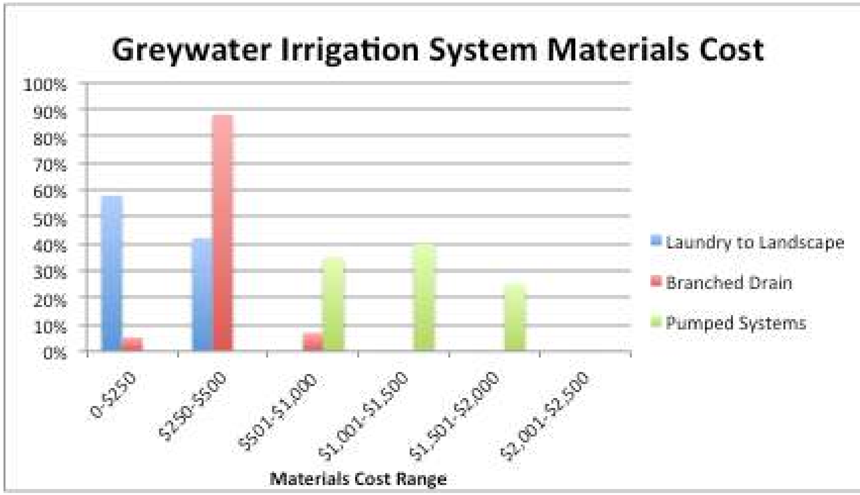
Laundry-to Landscape

58% of laundry to landscape systems had material costs between $0-$250. 42% these installations had material costs between $250-$500.

6 We used the estimate of 0.5 gallons/square foot of planted area per week for irrigation need

Branched Drain
88% of branched drain systems had material costs between $250-$500.

Pumped Systems
Contractors reported the widest range of costs for pumped systems, with a total of 75% of installations costing between $500 and $1,500.

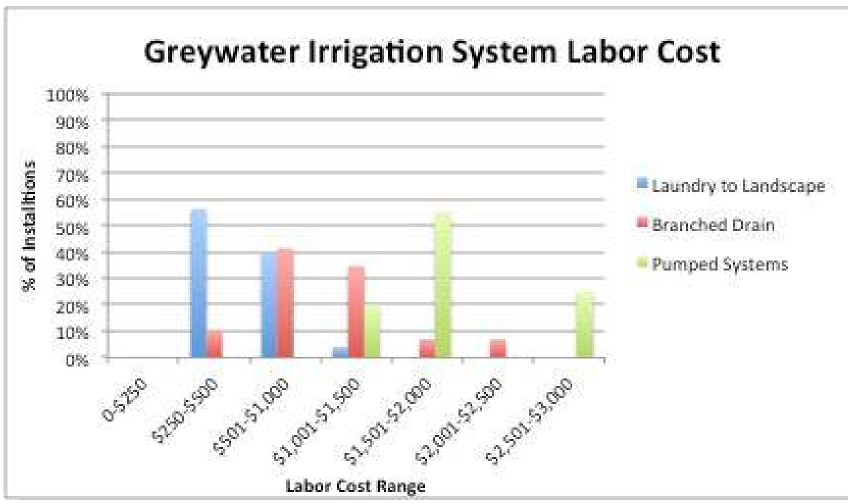


igure 10

Labor Costs

Laundry-to Landscape
56% of laundry to landscape systems had installation labor costs between $250-$500. Another 40% of these systems had labor costs in the $501-$1,000 range.

Branched Drain
41% of branched drain systems had installation labor costs between $501-$1,000. 34% of these systems had labor cost between $1001-$1,500. 10% of systems had lower labor costs in the range of $250-$500, while 14% of systems had labor costs over $1,501.



igure 11

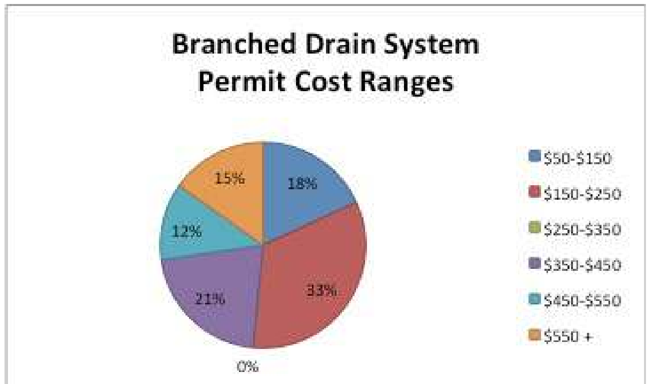
Pumped Systems
A total of 75% of pumped system had labor costs between $1,001-$2,000. The remaining 25% of installations had labor costs in the range of $2,501-$3,000. Pumped systems often combine flows from more than one greywater fixture. Higher labor costs reflect the increased complexity of designing pumped systems, which involves sizing, selecting, and siting an appropriate pump, preparing more complex permit applications and drawings, as well as installing additional electrical outlets and other site specific overflow requirements.

Permitting Costs
Installers who reported the lowest permit fees ($50-$150 range) were from the Monterey Peninsula and the San Francisco Bay area. Higher permit fees were defined as >$550. Installers from the Los Angeles area reported the highest permit fees of the study group.

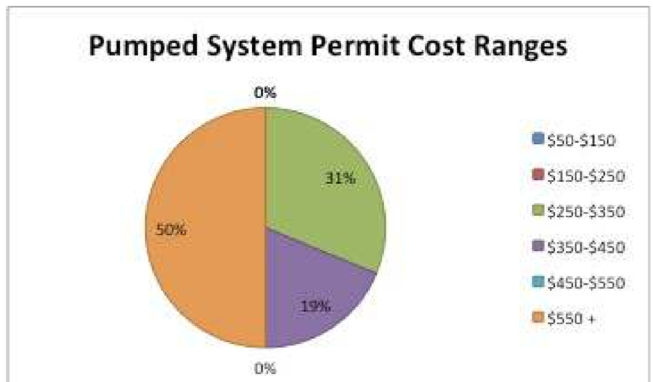
The average permit fee for a branched drain system was $340, although the most common permit fee reported (33% of systems) was between $150-$250.

The average permit fee for a pumped system was $540, although the most common permit fee reported (50% of systems) was greater than $550.

When installed by a professional installer, average greywater system permitting costs were 20% and 14% of the total installation cost for branched drain and pumped systems respectively. Homeowners who have the training and skills necessary to install their own greywater irrigation systems will experience lower overall average costs because they are contributing their own labor: $250 for a laundry-to landscape system, $715 for a branched drain system, and $1790 for a pumped system. For homeowners who act as their own contractors, average permitting costs are 48% and 30% of the total installation cost for branched drain and pumped systems respectively.



igure 12



igure 13

<u>Total Average Costs for Three Most Common Types of Greywater Irrigation Systems</u>

igure 14

igure 15

Average materials and labor costs were lowest for laundry to landscape systems. Pumped system had the highest average materials, labor, and permitting costs.

igure 16

Discussion

Overall, the greywater systems in our study saved water and had few problems. Key findings include:

- Per capita water consumption decreased by an average of 17 gallons per day after greywater system installation, at least half of which is directly attributable to water savings from greywater reuse.
- Greywater did not negatively affect soil or plant health.
- Quality of greywater was typically suitable for long-term irrigation of plants, so long as households used products without sodium or boron compounds.
- System users were overwhelmingly satisfied with their systems.
- Though people did very little maintenance on their system, no major problems developed. However, more education and a few changes in design can improve greywater systems to avoid potential problems.

Relationship to Other Studies

Other studies have found the quality of greywater for irrigation to be much lower than ours (Al-Hamaidedeh and Bino, 2010; Alifya, et al., 2012; Misra and Sivongxay 2009). We believe this difference is due to the fact that most of the households in our study changed their products after installing their greywater system, or were already using plant friendly soaps and detergents prior to irrigation with greywater. For example, an Australian a study found the average EC value three times higher than our results, SAR seven times higher, sodium five times higher, and pH 2.7 units higher (Howard, et al., 2005).

It is clear that we cannot form conclusions about the quality of greywater as a source of irrigation without considering the types of products used in the systems, since the quality of greywater is dependent upon what products are used in the home. For example, many people and organizations (Greenplumbers, Duttle for New Mexico State University) report that greywater is alkaline or basic, when, as seen in our study, greywater can actually be acidic depending on what products are used.

Water Savings

Overall water usage decreased after households installed greywater systems by an average of 17 gallons per capita per day (gpcd), which represents an average reduction of 26% (48 gpcd down from 65 gpcd). It is interesting to note that the average reduction of 26% that we found is higher than the target reduction of 20% in the 2020 plan for the state of California.

The range in water savings was large, with maximum savings reaching 122 gpcd. Measuring water savings is not as straight forward as simply looking at water consumption data. Increased water use associated with new landscaping or young children in the home are important considerations when assessing actual savings from a greywater system. Also, behavior factors, such as continued irrigation of plants that are also irrigated with greywater, can negatively affect potential water savings. In our study group most homes (27 households) decreased their total usage. Ten of our study sites increased, with four of the increases explained by an increase in landscaped area, and two by an increase in water use associated with a new baby in the home. We observed some additional trends with water savings:

- Households that used more water to begin with were more likely to see reductions than households that used less water to start with.
- Many households implemented additional water saving techniques after installing their greywater system; these homes saved more water than those that reported they made no other changes in water use, 23 gpcd vs. 11 gpcd.
- There was a wide range of savings, as some households saw reductions seven times higher than the average, and in contrast, some used more water after installing their system then before.

These trends suggest that while greywater systems can save water on their own, they can be effectively incorporated into a wider suite of water saving techniques.

Cost of Greywater Systems

The installation and maintenance of greywater irrigation systems has the potential to create quality green jobs in the water sector. Early adopters of greywater reuse (such as those included in this study) reported investing in a greywater system because of a general concern for saving and reusing water. However, many consumers may be genuinely interested in greywater reuse but will be motivated to actually install a system if there are economic savings over a reasonable period of time.

Our evaluation of average system costs and corresponding payback period under a range of residential water rate scenarios shows that for professionally-installed systems, the payback period for the greywater irrigation system may exceed the period of time the homeowner actually owns the home. As conservation water rates increase, the return on investment of a greywater system becomes more attractive. The calculation does not include other potential benefits of the greywater system that are more difficult to quantify economically, such as “drought insurance” for landscapes during water restrictions, extending the life of septic systems, delaying the need to drill deeper wells, time savings on watering, or increasing a home’s resale value.

Average permitting fees that amount to between 20-48% of the total cost of the system may negatively impact a homeowner’s decision to move forward with a greywater irrigation system installation. Regions with higher permit fees and/or time-consuming permit processes may experience an increase in unpermitted installations by uneducated homeowners and unlicensed contractors. Regions who use inexpensive, over-the-counter permits and streamlined inspections for simple greywater systems will have more opportunities to educate residents about best practices at the permit counter.

To overcome these types of financial barriers, the energy efficiency industry employs a multitude of federal, state, and local financing mechanisms and rebates to incentivize residential energy efficiency and alternative energy installations and upgrades (DOE, Database of State Incentives for Renewables & Efficiency, 2012). Expedited permits or reduced permit fees, state and municipal utility rebate programs, tax credits, PACE programs[7], and other low interest financing should all play an important role in lowering economic barriers to investing in greywater systems for the average consumer. Public agency-sponsored hands-on installation workshops for lower cost laundry to landscape systems are an important strategy for increasing adoption of greywater systems, especially in disadvantaged and lower income communities. Increasing water rates throughout the state, combined with financial incentives and peer-to-peer sharing of greywater system satisfaction will help to drive market demand for greywater irrigation systems in the future.

Use and Maintenance

A large number of our respondents did not maintain their greywater systems adequately. Maintenance for the majority of systems in our study would only require annual replacing of decomposed mulch. This is a simple task, in most situations should take approximately one hour or less. This leads us to conclude that greywater promoters, educators and installers should do more to educate people about how to maintain their systems, and installers should create maintenance contracts with their clients who are unwilling or unable to do this work**.**

Furthermore, we believe that a strong emphasis on appropriate choice of soaps, detergents, and cleaning products is important to improve the quality irrigation water from greywater systems. Most people in our study group used products with little or no salts or boron, resulting in a better quality irrigation water. The few samples that were not safe for irrigation came from households that used either powdered detergents, known to be high in salts, or commercial brands not typically considered “greywater friendly” nor listed all ingredients.

System Performance and Design Recommendations

We observed a few minor problems that could be avoided by better design or more frequent maintenance. A few sites had pooling or runoff of greywater, and a few others experienced uneven distribution of greywater to plants. Locating greywater outlets away from pathways can prevent any pooling that results from lack of maintenance or other causes, from creating a route of exposure to the public. In systems where greywater outlets are located near hardscape, such as the cement paths of the two sites with runoff in our study, any of three simple design changes would have prevented runoff and subsequent potential for public exposure:

- Ensure sufficiently large basin sizes.

7 PACE: Property Assessed Clean Energy, formerly known as Special Energy Financing District

- Move the basin farther from the path.
- Create a mound of soil (a “berm”) next to the path to prevent greywater from overflowing onto the path.

Irrigation problems are another potential problem related to system design. We observed two system designs resulting in over-irrigation.

- One system had shut-off valves on all greywater outlets. Someone shut off all but one valve, so all greywater was directed to one tree, resulting in massive over-watering. Poor soil drainage and excess water caused the tree to exhibit signs of stress, so the homeowner watered it more, unaware that the problem was too much water.

- One site had an existing irrigation system that the homeowner did not disconnect or turn off, so the plants were being irrigated twice (greywater and drip system). In this situation there was good drainage and the plants were not harmed, but the system design did not result in water savings.

For the most part, plants grew healthily with greywater with no obvious changes from when they received freshwater irrigation. Several sites reported plants that had been unhealthy becoming healthy after greywater irrigation. One bougainvillea vine didn't flower much until it received greywater, a fig tree began to “thrive”, and a lime tree that the homeowner thought was going to die began to flower and produce fruit.

Conclusion and Policy Recommendations

Greywater irrigation is an important component of reducing total residential water consumption. Residential greywater systems can work synergistically with other water conservation strategies, such as lawn removal, conversion of non-greywater irrigated landscapes to xeriscaping or native plantings, rainwater harvesting and rain gardens, and installation of water-efficient fixtures and appliances. In preparation for drought-related water shortages and mandates for reduced water withdrawals to help restore our aquatic ecosystems, water districts can encourage deep savings by promoting a suite of options to reduce water demand by increasing incentives to the homeowner as they incorporate all the strategies.

Our findings suggest five policy approaches that can help agencies and other organizations realize residential greywater systems’ water savings potential at scale:

- Simple laundry-to-landscape and branched drain systems should be promoted, as these types of systems are more economical, have few problems, and result in high user satisfaction.
- Education programs should also include support for implementation, since most people installed their systems within a year of learning about greywater. For example, installation workshops, subsidized installations, or referrals to local installers could enable people to follow through with their ideas for a home greywater systems.
- Use of plant-friendly products (without salt and boron) should be emphasized, to ensure good

quality greywater for irrigation.

- To increase water savings, greywater systems should be designed to replace other irrigation methods. Drip irrigation should be removed from greywater-irrigated areas, and supplemental hand watering should be discouraged.
- Thoughtful integration of greywater irrigation with rainwater harvesting, rain gardens, and climate-adapted plantings can maximize outdoor water savings by replacing municipal water as an irrigation water source. Such landscapes will be resilient in the face of future water shortages, and should be promoted as a strategy to increase resilience to droughts and adapt to climate change.

Our study should allay concerns about long-term effects on soils and plants, so long as greywater system owners have proper education about the importance of "plant friendly" products, but key questions about the mechanisms to maximize water savings and economic barriers to widespread adoption and sustained use of greywater irrigation systems remain. Most of our respondents are classic "early adopters", who were motivated by environmental concerns and desires for a more "eco-friendly" landscape, and who invested a few hundred or thousands of dollars in their greywater systems. Understanding how to recruit other potential adopters is a key area for future research.

We found significant average water savings in households that installed greywater irrigation systems (17 gpcd), but there was significant variation between households, given that many concurrently adopted other water saving practices, while others increased the amount of landscaped area, and others had changes in household size or composition. (Despite these confounding factors, we estimated that at least half of the 17 gpcd was due directly to greywater.) The adoption of multiple conservation measures is encouraging for scale up, but the variability in water savings suggests that how people use systems, and behavioral practices related to irrigation, are also important.

Follow-up studies can be designed to evaluate the long-term effect (more then 3 years) of greywater irrigation on soil and plant health over the growing season. Such a study conducted in a phased matter (over irrigation seasons, e.g. Spring, Summer and Fall), especially in productive urban gardens, along with documentation of plant species irrigated, yields obtained over the growing season, and detergents used will strengthen the evidence for greywater reuse in residential irrigation. Such studies will also make a case for productivity of greywater irrigation, strengthening the socio economic angle for greywater reuse.

Finally, follow-up studies should be conducted to investigate the lifetime and long-term maintenance needs of these systems. These studies should assess the lifetime of system components, the effects of different maintenance regimes, whether new owners and residents understand and choose to maintain the systems, and how systems fare when new residents undertake major changes to the landscape.

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