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Graywater Assessment:

Final Report

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Prepared for the:

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EXECUTIVE SUMMARY

As the availability of fresh water continues to decrease from overpopulation, source water contamination, and increased water usage, engineers and scientists are seeking new ways to maintain the world's water resources. Two proposed methods of decreasing future impact on limited water resources are the reuse of moderately contaminate graywater and the harvesting of rainwater. Implementing these systems at the residential scale is plausible for many reasons. In instances where decentralized wastewater treatment and water distribution operations occur, graywater reuse and rainwater harvesting can to some extent substitute those services. In cases where wastewater treatment and water distribution are centralized, these practices could alleviate stress on both water and wastewater treatment infrastructure, reduce the need for vast collection and distribution piping networks, and allow homeowners to fully utilize water resources to the fullest extent. On a large scale, these systems appear to be the universal solution to water resource problems; however, there are significant small scale implications to these systems that must be considered.

Graywater constitutes a large portion of the daily indoor used water that is generated, thereby making it a consistent source for reuse. However, graywater is still a form of wastewater and may potentially contain pathogenic microorganisms and elevated concentrations of metals, suspended solids, surfactants and salts, and organic matter. Additionally, because it requires fairly substantial treatment for even nonpotable reuse applications, system design, installation and maintenance are typically cost-prohibitive for most homeowners. Conversely, rainwater itself is generally of very high quality. Once in contact with the intercepting surface during the harvesting of rainwater, contamination occurs. Though suitable for most nonpotable uses, it also must be treated to potable quality and its supply is variable.

The state of Wisconsin has been long known for its abundant freshwater resources. And though the state of those resources lies at the heart of the daily Wisconsin lifestyle, most residents in the state are not subject to withdrawal limitations, neither through high water use charges nor from lack of supply. Other states, namely those in the American West and Southwest, have experienced severe water shortages and have already pursued alternative means of maintaining their water resources. Essentially, as will be described within this report, the idea of reusing graywater or capturing rainwater dates back thousands of years but is just now being introduced to the residents of Wisconsin. The regulations for water reuse reflect this as well. For good reason, they maintain the century-old viewpoint on wastewater treatment – that conveyance away from the source (i.e. centralized wastewater treatment) is necessary to maintain public health and safety within the household. This philosophy, while proven greatly successful, must face future scrutiny in order for regulators to appropriately analyze, understand and accept comfortably a certain degree of risk in order to determine the feasibility of pursuing these reuse options on a widespread, residential scale.

This study was expanded to include rainwater harvesting in brief because of its close connection to graywater as a feasible reuse tool at the residential scale. The term "graywater" is written in the current literature in a variety of ways, including "graywater," "gray water," "greywater," and "grey water." For the remainder of this report, it will be referred to as "graywater." For congruence, unless included in the name of a product or publication, any citation that has it spelled otherwise has been modified to this form.

INTRODUCTION

Many regions around the globe are experiencing water shortages or are faced with contaminated water sources. These issues have resulted from a rise in the world population, the abuse of available water supplies, and the increased per capita consumption of potable water with upward changes in lifestyle (WASAL 2003). Deteriorating water and wastewater infrastructure and the unsustainable extraction from both groundwater and surface waters have exacerbated these problems. In response, water reuse has been brought to the forefront of water resource management and has driven the pursuit of innovative alternatives in water supply. Wastewater is now being viewed as a resource. In general, and as defined by Metcalf & Eddy (Asano, Burton et al. 2007), wastewater is *used* water discharged from homes, businesses, cities, industry and agriculture. Used wash water can be treated to meet specified water quality criteria for safe disposal or used beneficially. Among the reclaimed water options available to the typical homeowner are the reuse of household graywater and the harvesting of rainwater. Historically, reuse applications in industry have included industrial cooling and agricultural irrigation. Graywater reuse has been considered for toilet flushing, irrigation of cemetery lawns, golf courses, and college campuses, vehicle washing, fire protection, concrete production and wetland preservation (Jefferson, Palmer et al. 2004). It has also been applied to groundwater recharge and as a fertilizer substitute (Ottosson and Stenstrom 2003).

GRAYWATER

Graywater is a medium polluted used water that is collected from bathing and washing facilities, but excludes concentrated human wastes (i.e. flush water from toilets or urinals) and food wastes (i.e. kitchen sinks and food grinders). The most common sources are bath and shower water, hand wash water, and laundry wash water (Asano, Burton et al. 2007), as well as used water from laundry tubs (Sheikh 2010). The practice of reusing "gray" water is not a new concept. In rural and developing regions around the world, it is common for used water from bathing or washing to be immediately applied to gardens, used as rinse water, or to satisfy some other beneficial nonpotable application. In contrast, the extensive wastewater collection systems and potable water distribution systems in urban areas of developed countries, as well as the relatively cheap costs for such services, have made simple graywater collection and reuse uneconomical in many cases. A 1999 Soap and Drug Administration survey reported that 7% of U.S. households reuse graywater (based on 61,377 respondents). When data were normalized according to population density, it was revealed that a large portion of graywater reusers reside in the American West, Southwest, and Southeast ([The] NPD Group Custom Research Services 1999). Historically these regions have faced limited water availability and saltwater intrusion to groundwater aquifers, making water resources limited in both quantity and quality.

According to the 1999 *Residential End Uses of Water* study sponsored by the American Water Works Association Research Foundation, which considered 1,188 households (assumed to average 2.6 persons per household) representing 12 sites and 14 municipalities in the U.S. and Canada, the mean daily per capita indoor water use was 69.3 gallons (262 L) (Mayer, DeOreo et al. 1999). Graywater comprised about 40% of this volume (excluding faucet flows). The individual contributions provided by the various household appliances and fixtures are given in Figure 1.

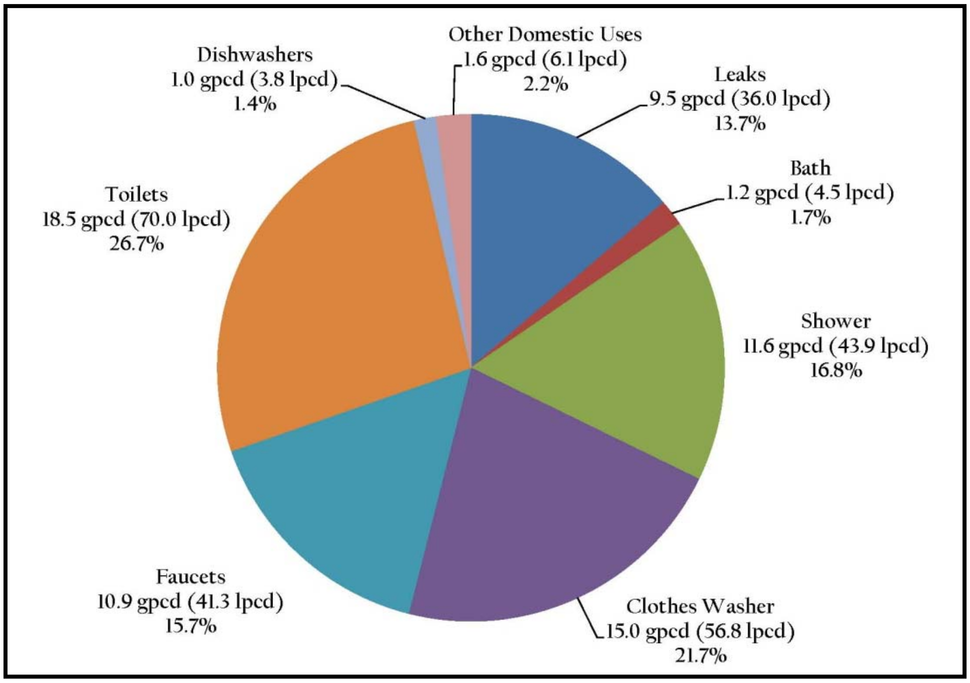


Figure 1: Average indoor water use
Adapted from Mayer, P.W., W.B. DeOreo, et al. (1999). Residential End Uses of Water. A.W.W.A. Research Foundation. Denver, Colorado.

Additionally, mean daily per capita outdoor water use was 100.8 gallons (381.6 L) (Mayer, DeOreo et al. 1999; Sheikh 2010). Proponents of graywater reuse believe that a large portion of water used outside of the household, whether for car washing rinse water, irrigation or other similar applications could be supplemented by treated graywater. The per capita water use figures provided by the 1999 *Residential End Uses of Water* study do appear to support this claim. Moreover, consideration of the numerous reuse applications indicates that there is sufficient opportunity for a household to beneficially reuse graywater that is adequately treated. Hence, both decreases potable water use and the associated cost savings have been major drivers in promoting graywater as a valuable resource. Additionally, other drivers have included:

- Reduction of loading to private septic or holding tank systems;
- Reduction of loading to public wastewater collection systems and treatment plants, as well as the reduction in the demand for potable water from public drinking water utilities, which are in some cases overburdened, outdated or in poor condition;
- Consistent production of adequately treated graywater makes it a reliable alternative water source;
- Alternative water source for landscape irrigation;
- Utilization of heat energy in fresh graywater;
- In limited instances, the desire to live a more environmentally-conscious and sustainable lifestyle.

In regions where phosphates in detergents are currently banned (e.g. most states in the Great Lakes region), graywater would likely have a low nutrient content and therefore have limited use as a fertilizer substitute.

Some members of the water recycling industry have expressed concerns with graywater reuse (Sheikh 2010):

- Public health concerns related to the potential for cross-contamination of either a potable or reclaimed water system;
- Fear of any health problems caused by the poor microbial quality of graywater becoming associated with high-quality water in the public's mind;
- Public, media, and elected officials' confusion of graywater and recycled water and their respective qualities;
- Reduction in the carrying capacity of sewers for solids as a result of reduced flow into the sewer; and
- Increase in the salinity of recycled water as a result of diversion of the lower-salinity bathwater, shower water, and lavatory wastewaters from the sewer.

The increase in salinity would likely not be an issue because the difference in salinity of the graywater and sewage fractions of household used water is minimal. Additionally, unauthorized modifications to residential systems and homeowner negligence or incompetence are also concerns. Collectively, these concerns are indicative of the overall apprehension of water reuse and the hesitation of public health agencies to permit such systems on a residential, single-family scale.

RAINWATER HARVESTING

Rainwater harvesting is the interception of stormwater runoff and subsequent utilization for another beneficial purpose. The act of harvesting rainwater dates back thousands of years. One of the earliest known examples of managed rainwater collection was in Crete during the Early Minoan period (ca. 3500-2150 B.C.). During this time, rainwater was harvested from gutters, open courts and flat rooftops and stored in cisterns or sedimentation tanks (Mays 2010). Even today rainwater harvesting remains a fairly simple and inexpensive practice. Materials generally include gutters, downspouts, storage containers, a method of distribution, and sometimes treatment. Rainwater collects in gutters and is conveyed to storage in barrels or cisterns for nonpotable use, or if treated appropriately, it can serve as an alternative potable water source. Rainwater has been used in evaporative coolers, toilet flushing, pet and car washing, indoor plant watering, pet and livestock watering, and for lawn and garden irrigation (Waskom and Kallenberger 2009). Rainwater is valued for a variety of reasons. According to the 2005 *Texas Manual on Rainwater Harvesting*, these include:

- The water is free; the only cost is for collection and use.
- The end use of harvested water is located close to the source, eliminating the need for complex and costly distribution systems.
- Rainwater provides a water source when groundwater is unacceptable or unavailable, or it can augment limited groundwater supplies.
- The zero hardness of rainwater helps prevent scale on appliances, extending their use; rainwater eliminates the need for a water softener and the salts added during the softening process.

- Rainwater is sodium-free, important for persons on low-sodium diets.
- Rainwater is superior for landscape irrigation.
- Rainwater harvesting reduces flow to stormwater drains and also reduces non-point source pollution.
- Rainwater harvesting helps utilities reduce summer demand peak and delay expansion of existing water treatment plants.
- Rainwater harvesting reduces consumers' utility bills.

Additionally, natural unpolluted rainwater has a pH of around 5.6 and is free from the disinfection byproducts and other anthropogenic contaminants found in surface waters (Novotny, Ahern et al. 2010).

GRAYWATER AND RAINWATER CHARACTERIZATION

The microbial, chemical, and physical constituents of untreated graywater and rainwater must be considered. Direct physical contact through the skin, oral ingestion, and inhalation are all paths of concern when dealing with untreated, nonpotable water sources.

MICROBIOLOGICAL QUALITY OF GRAYWATER

Graywater is often considered by water reuse grassroots organizations and "do-it-yourselfers" to be a relatively clean source of used water. However, studies have categorized graywater to be similar in composition to a medium-to-light strength wastewater and the quality highly variable. A study by Casanova et al. (2001) cited time of year, presence of children, inclusion of kitchen sink water in the graywater stream, and the use of in-ground storage as factors affecting quality. Additionally, the overall health of the contributing population (Dixon, Butler et al. 1999), lifestyles, customs, installations, product preferences and washing habits of a population are also common concerns (Jefferson, Palmer et al. 2004).

The microbiological quality of graywater is the most cited source of risk because of the possible presence of enteric pathogens causing gastrointestinal disease. Table 1 displays concentrations from various studies of the indicator organisms used to quantify the microbial quality of graywater. High levels of the coliform group of bacteria (defined as aerobic and facultatively anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria that produce gas upon lactose fermentation in prescribed culture media within 48 hours at 35°C), *E. coli*, fecal enterococci, and plate counts do not confirm that a wastewater is hazardous to human health; however, their presence does suggest the presence of enteric pathogens and caution is warranted. These pathogens can include certain bacteria, protozoa, viruses and parasites. In a study conducted by Birks and Hills (2007), untreated graywater from the baths, showers, and washbasins from 18 flats of a residence hall were tested for pathogenic organisms. The protozoan *Giardia* was identified in 63% of samples analyzed (though well below the harmful dose), and *Salmonella* was identified in only a single sample. Enterovirus was not identified (Birks and Hills 2007). The risk of viruses is especially troublesome due to their high excretion numbers, environmental persistence and low infectious doses (Ottosson and Stenstrom 2003).

Table 1. – Average Microbial Composition of Untreated Graywater from Various Sources

		(Ottosson and Stenstrom 2003)	(Birks, Colbourne et al. 2004) [2]	(Birks and Hills 2007)	(Laine 2001) [3]
Graywater Sources Included [1]		L, S, B, HB, KS	HB	S, B, HB	S, B, HB
Total Coliforms (CFU/100 mL)		$10^{8.1}$	6.5×10^5	2.2×10^7	$6.4 \times 10^3 - 9.4 \times 10^3$
E. coli (CFU/100 mL)		$10^{6.0}$	7.0×10^3	3.9×10^5	$10 - 1.5 \times 10^3$
Fecal Enterococci (CFU/100 mL)		$10^{4.4}$	$> 2.0 \times 10^2$	2.5×10^3	$40 - 2.1 \times 10^3$
Plate Counts (CFU/mL)	22°C	–	$> 3.0 \times 10^5$	8.0×10^6	–
	37°C	–	$> 3.0 \times 10^5$	6.3×10^6	–

– Indicates constituent was not reported in the given study.
[1] Laundry (L), shower (S), bathtub (B), hand basin (HB), kitchen sink (KS); various waters which can constitute a composite graywater sample.
[2] Median values are reported.
[3] Range of values are reported.

Dixon et al. (1999) provides a simple conceptual matrix of pathogenic risk in graywater reuse. This matrix identifies the key operating conditions of a reuse system. An optimized system would be designed in such a way so as to limit risk to individuals who may be exposed to the used water. Such a system would reuse graywater immediately after production to avoid proliferation of harmful pathogens and malodorous anaerobic conditions in storage, prohibit direct contact, and limit the contributing population.

	Lower Risk	**Intermediate Risk**	**Higher Risk**
Population	Small population (single family)		Large population (multi-occupancy)
Exposure	No body contact (sub-surface irrigation)	Some contact (water closet flushing, bathing)	Ingestion (Drinking)
Dose-Response	<1 Virus per sample, <1 Bacteria per sample		>1 Virus per sample $>10^6$ Bacteria per sample
Delay Before Reuse	Immediate reuse	Reused within hours	Reused within days

Used water from kitchen sinks and automatic dishwashers is typically excluded from graywater due to the high presence of organic food waste and the risk of food-borne bacterial contamination. The bacteria *Campylobacter* spp. and *Salmonella* spp. have a known presence in poultry products and have been shown to contaminate kitchen surfaces and utensils – including kitchen sinks – during food preparation (Cogan, Bloomfield et al. 1999). As a result, kitchen sink and dishwasher waste streams are commonly excluded from graywater collection. This recommendation was also supported by Casanova et al. (2001). Additional factors which may contribute to flourishing pathogenic populations are extended storage and the warm temperatures characteristic of newly generated graywater.

PHYSICOCHEMICAL QUALITY OF GRAYWATER

The physicochemical quality of graywater is also cause for concern if used in the untreated form. Use of untreated graywater is common, especially in unregulated household systems which directly apply graywater as irrigation water. Table 2 summarizes the physicochemical composition of graywater resulting from various studies. It should be noted that the following studies did not indicate whether phosphorus levels resulted from phosphate-containing or phosphate-free detergents.

Table 2. –Average Physicochemical Composition of Untreated Graywater from Various Sources [1]

	(Gross, Azulai et al. 2005)	(Leal, Zeeman et al. 2007) [5]	(Leal, Zeeman et al. 2007) [5]	(Finley, Barrington et al. 2009)	(Jefferson, Palmer et al. 2004)
Graywater Sources Included [2]	L, S, B, HB, KS	L, S, B, HB, KS	L, S, B, HB, KS	L, S, B	S, B, HB
TS	–	–	–	313-543	–
TSS	138	–	–	–	100
BOD_5	270	215	–	–	146
COD_{total}	686	425	1,583	278-435	451
COD_{ss}	–	115	605	–	–
COD_{diss}	–	175	576	–	–
TOC	–	114	254.5	–	72.6
Total P	17.7	5.7	9.86	0.24-1.02	1.37
PO_4^{3-}-P	–	2.3	2.25	–	0.35
Total N	14.0	17.2	47.78	–	5.00
NH_4-N	–	7.2	16.35	1.2-6.2	–
Boron	0.6	–	–	–	–
Anionic Surfactants	40	–	–	–	–
pH	6.7	7.12	–	7.15	7.47
EC (mS m^{-1}) [3]	140	7.52	–	–	–
SAR [4]	4.8	–	–	4.2-5.8	–
Turbidity (NTU)	–	–	–	–	100.6
Temp. (°C)	–	16.5	–	–	–
D.O.	–	8.9	–	–	–
K	–	11.2	23.28	2.2-2.5	5.79
Ca	–	60.79	65.53	30-44	47.9
Mg	–	6.15	30.55	8.0-9.9	5.29

Na	–	86.35	159.75	20-27	–
Fe	–	0.11	1.28	0.09	0.017
Cu	–	0.08	0.12	–	0.006
B	0.6	0.42	0.87	–	–
Si	–	11.97	21.43	–	–
Al	–	0.49	7.35	–	0.003
P	–	4.17	5.85	–	–
S	–	19.00	33.18	5.0-8.8	16..3
Zn	–	0	0.13	0.04-0.42	0.03

– Indicates constituent was not reported in the given study.
[1] In mg/L, unless otherwise stated.
[2] Laundry (L), shower (S), bathtub (B), hand basin (HB), and kitchen sink (KS)
[3] Electrical Conductivity
[4] Sodium Adsorption Ratio (calculated value)
[5] Results are from the same graywater study with different site/sampling locations.

An analysis done by Jefferson et al. (2004) revealed that raw graywater from baths, showers, and hand basins was deficient in trace metals, including Iron, Manganese, Copper, Aluminum, and Zinc and lacked Cobalt and Molybdenum. Caution must be practiced when considering metals concentrations in graywater, and the forms of the metals present should be understood. Measuring seemingly harmless metals concentrations may still be problematic under low alkalinity conditions. Carbonate alkalinity in water is capable of binding with metals, such as Copper, and precipitating them out of solution, thereby reducing their toxicity. Besides, graywater is often found to be deficient in phosphorus and nitrogen compared to typical domestic wastewater (Laine 2001), likely due to the absence of the blackwater fraction.

Concerns also arise with the implementation of a graywater system for landscape irrigation as a means of disposal. These concerns involve the pollution associated with high levels of salinity, boron, and surfactants. Concentrations of these contaminants in the graywater effluent stream result primarily from the use of household cleaning products and laundry detergents. Collectively these can upset soil conditions, damage plants, and contaminate groundwater (Gross, Azulai et al. 2005). Surfactants are organic chemicals that consist of both hydrophilic and hydrophobic groups. Due to their electrical charge from polarization, the hydrophilic groups form hydrogen bonds. As the distance between water molecules increases when surfactants are in aqueous solution, surface tension decreases. This has a direct effect on capillarity in soil. Capillarity is responsible for the upward movement of groundwater into the root zone of plants (Wiel-Shafran, Ronen et al. 2006). Decreased capillarity can inhibit plant growth by limiting root exposure to groundwater and lead to accumulated salt concentrations in upper soil layers (Wiel-Shafran, Ronen et al. 2006).

Boron and salts can also negatively affect soil composition and plant growth. A high sodium adsorption ratio (SAR) and high electrical conductivity (EC) are indicators of salt accumulation in soil. Boron salts are used in laundry detergents as a whitening agent and are beneficial to plants in very low concentrations (Wiel-Shafran, Ronen et al. 2006). Both salts and boron have been shown to accumulate in soils irrigated with raw graywater, though in concentrations not usually considered detrimental to plant growth (Gross, Azulai et al. 2005). Any visual evidence of plants being negatively affected by boron and salt concentrations is usually witnessed by chlorosis – the presence of brown patches on the tips of plant leaves (Wiel-Shafran, Ronen et al. 2006).

Because of these health and environmental concerns, treatment of graywater before discharge is required to prevent bioaccumulation of harmful contaminants. It is recommended that graywater systems are designed to reduce microbial contamination by considering both the contributing sources and minimizing human contact with untreated graywater and graywater-irrigated soils (Casanova, Little et al. 2001).

MICROBIOLOGICAL QUALITY OF RAINWATER

Rainwater is a desired resource over graywater because of its relative cleanliness. It is often the most cost-effective option for individuals residing in arid or remote regions where extensive piped distribution networks are either economically or technically infeasible (Sazakli, Alexopoulos et al. 2007). The quality of water that is collected in a rainwater harvesting system depends on the contaminants in the rainwater from ambient air pollution and on the catchment surface, as well as the catchment surface material. Most contaminants have been attributed to the rooftop. As summarized by Leggett and Shaffer (2002) and Sazakli et al. (2007), the main sources of contamination in rainwater are:

- Microbial pathogens from bird, mammal and reptile droppings;
- Leaves and other organic material that accumulate in gutters;
- Airborne chemical pollutants from traffic emissions and industrial activities near cities;
- Airborne agricultural pesticides and fertilizers in rural areas; and
- Where rainwater is collected from paved areas at ground level – contamination by dirt, silt, plant debris, animal feces and by hydrocarbons such as oil, petrol or diesel.

Also, additional sources of contamination in rainwater are:

- Elutriation of toxic chemicals (PAHs) from asphalt shingles; and
- Dissociated metal ions from gutters (e.g. Copper or Zinc) resulting from the effects of acid rainfall.

Table 3 summarizes the microbial composition of untreated rainwater from various studies.

Table 3. –Microbial Composition of Untreated Rainwater from Various Sources [1]

	(Birks, Colbourne et al. 2004)	(O'Hogain, McCarton et al. 2011) [2]	(O'Hogain, McCarton et al. 2011) [2]	(Sazakli, Alexopoulos et al. 2007)	(Simmons, Hope et al. 2001)
Rainwater Collection Surface	Rooftop	Rooftop	Rooftop	Ground level	Rooftop
Total Coliforms	1.8×10^4 (CFU/100 mL)	920.80 (MPN/100 mL)	8.55 (MPN/100 mL)	11 (CFU/100 mL)	27 (CFU/100 mL)

Fecal Coliforms		–	30.00 (CFU/100 mL)	1.0 (CFU/100 mL)	–	2 (CFU/100 mL)
E. coli		5.2 x 10 (CFU/100 mL)	48.20 (MPN/100 mL)	1.00 (MPN/100 mL)	0 (CFU/100 mL)	–
Fecal enterococci		> 2.0 x 10^2 (CFU/100 mL)	–	–	0 (CFU/100 mL)	15 (CFU/100 mL)
Plate Counts	22° C	6.7 x 10^4 (CFU/mL)	3684.00 (CFU/mL)	303.50 (CFU/mL)	1 (CFU/mL)	–
	37°C	6.4 x 10^3 (CFU/mL)	431.00 (CFU/mL)	39.00 (CFU/mL)	2 (CFU/mL)	–

– Indicates constituent was not reported in the given study.
1 Median values are reported.
2 Results are from the same study. Right column reflects microbial quality after system modified from original design. System modifications included installation of downpipe filters and replacement of tank manholes covers with gasket seals.

The microbial contamination of rainwater is due to contact with the catchment area and is not present in the rain itself. This has been confirmed in the comparative microbial analysis of runoff with non-intercepted rainfall (Sazakli, Alexopoulos et al. 2007). The presence of pathogenic microorganisms in rooftop collection systems has suggested that the microbiological quality of rainwater can be a potential source of illness if ingested. In an Auckland, New Zealand, study by Simmons et al. (2001), the bacterial pathogens of *Aeromonas* spp. and *Salmonella* spp. were identified in 16.0% and 0.9% percent of 115 samples, respectively, while *Legionella* spp. and *Campylobacter* spp. were not. Additionally, *Cryptosporidium* oocysts were detected in 4% of 50 samples and *Giardia* cysts were not. The inability to detect *Campylobacter* spp. (which is commonly carried in birds) in roof-collected samples was attributed to low sensitivity culture methods (Simmons, Hope et al. 2001). Contrasting this study, others have reported a much higher prevalence of protozoan pathogens in rainwater cisterns, with 45% and 23% of 44 samples being positive for *Giardia* cysts and *Cryptosporidium* oocysts, respectively (Crabtree, Ruskin et al. 1996; Ahmed, Gardner et al. 2011).

According to Ahmed et al. (2011), the microbial quality poses a more acute risk of illness than the physicochemical quality of rooftop-harvested rainwater. As a result, the presence of indicator organisms has suggested that some form of treatment be used – especially when rainwater is intended to be a supplementary source of potable water.

PHYSICOCHEMICAL QUALITY OF RAINWATER

The physicochemical quality of rainwater is also cause for concern if used in the untreated form. While rainwater is inherently less contaminated than graywater, some factors that can greatly affect the quality of roof-collected runoff include:

- the collection surface material,

- the presence of air pollution from regional industry and vehicular traffic,
- the contaminants present on the collection surface,
- the presence or absence of a first-flush diversion mechanism,
- rainfall acidity, and
- the conditions under which the collected rainwater is stored.

In cases where the collection surface is not maintained, pollution exists from local industry, and first-flush and treatment devices are not used, rainwater can be characterized by a variable pH, high concentrations of particulate matter, and may contain chemical compounds which adversely affect human health.

Table 4 provides a summary of the physicochemical composition of untreated rainwater from four studies monitoring the operation of rainwater harvesting systems.

Table 4. – Physicochemical Composition of Untreated Rainwater from Various Sources [1, 2]

	(O'Hogain, McCarton et al. 2011) [4]	(O'Hogain, McCarton et al. 2011) [4]	(Sazakli, Alexopoulos et al. 2007)	(Simmons, Hope et al. 2001)
Graywater Sources Included [1]	Rooftop	Rooftop	Ground level	Rooftop
TSS	3.00	3.50	–	–
TDS	49.00	55.00	–	–
PO_4^{3-}-P	–	–	0.09	–
NO_3^--N	1.20	3.98	7.04	–
NO_2^--N	0.03	0.02	0.013	–
NH_4-N	0.56	1.11	0.01	–
SO_4^{2-}	0.30	2.65	8	–
S^{2-}		–	–	–
Cl^-	1.49	4.51	7	–
Hardness (mg/L as $CaCO_3$)	–	–	40	–
Alkalinity (mg/L as $CaCO_3$)	–	–	42.5	–
pH	6.98	6.32	8.31	7.3
Ca	1.40	7.40	15.2	–
Mg	–	–	0.6	–
Na	1.50	4.03	6	–
K	–	–	2.4	–
F	–	–	< 0.01	–
Fe (µg/L)	57.75	56.59	11	–
Mn (µg/L)	–	–	1.0	–
Cd (µg/L)	< 0.01	0.30	0.05	–
Pb (µg/L)	2.21	5.24	< 2.0	< 10

Cu (µg/L)	–	–	‹ 2.5	60
Cr (µg/L)	–	–	‹ 1.3	–
Ni (µg/L)	–	–	‹ 10.0	–
Zn (µg/L)	–	–	10.0	400
As (µg/L)	–	–	–	‹ 5
EC (µS cm^{-1}) [3]	–	–	103	–
Turbidity (NTU)	0.40	1.31	–	0.56

– Indicates constituent was not reported in the given study.
[1] In mg/L, unless otherwise stated.
[2] Median values are reported.
[3] Electrical Conductivity
[4] Results are from same study. Right column reflects physicochemical quality after system modified from original design. System modifications included installation of downpipe filters and replacement of tank manholes covers with gasket seals.

When using intercepted rainfall from a catchment surface, the material of the catchment surface is an important consideration. Catchment surface materials can include metal, clay or concrete tile, composite or asphalt shingles, wood and slate. Each option possesses its own benefits and drawbacks based on the material cost, roughness and absorption capacity, and the possible presence of toxins from sealants or resins. In general, most roofing materials are suitable for the harvesting of rainwater for nonpotable uses, but special considerations must be made when rainwater is to supplement drinking water supplies. Methods of coarse debris removal are often encouraged within the collection systems. These include leaf guards along gutters, funnel-type downspout filters, strainer baskets, cylindrically-rolled wire screens, and other filtering mechanisms (Texas Manual on Rainwater Harvesting, 2005). When catchment surfaces and these coarse filter mechanisms are cleaned and well-maintained, their performance is optimized and less strain is placed on treatment and distribution devices. Because periods of sparse rain can lead to the accumulation of dust, debris, bird droppings and chemical contaminants on rooftops, it is suggested that a first-flush device is also incorporated into the collection system prior to any required treatment (Texas Manual on Rainwater Harvesting, 2005). A first-flush device diverts a specified amount of runoff from entering the storage container. In doing so, contaminants initially present on the catchment surface before a rain event are largely prevented from entering the system. Maintenance also contributes to the microbial and physicochemical condition of the water, and periodic cleaning of system components is an encouraged practice.

Storage tank material options are numerous – ranging from fiberglass, polypropylene and wood to concrete and ferrocement. The material of the storage tank will depend on the strength required to contain the volume of water but even more so will be decided based on tank sizing and the ensuing cost to the owner. It is often the most expensive system component. Its size depends on rainwater supply, water demand, the projected length of dry spells without rain, the catchment surface area, aesthetics, personal preference, and budget. According to the *Texas Manual on Rainwater Harvesting* (2005), storage tank requirements are few but important to maintaining a high quality of water when stored.

- Storage tanks must be opaque, either upon purchase or painted later, to inhibit algae growth.
- For potable systems, storage tanks must never have been used to store toxic materials.
- Tanks must be covered and vents screened to discourage mosquito breeding.

- Tanks used for potable systems must be accessible for cleaning.

Rainfall in a low pH range promotes the deterioration of many catchment surface materials. Highly acidic rainfall that has been affected by regional air pollution can promote the leaching of metals from metal roofing. This increases the metals concentrations already potentially present from industrial air pollution (Sazakli, Alexopoulos et al. 2007). In cases, where a concrete storage tank is used the concrete imparts some alkalinity to the water.

WISCONSIN WATER REUSE REGULATIONS

Wisconsin's water reuse policy is currently regulated under Chapter Comm 82 of the Wisconsin Uniform Plumbing Code within the Wisconsin Administrative Code. The Wisconsin Uniform Plumbing Code encompasses Chapters Comm 81 through 87. Chapter Comm 82 of the Wisconsin Uniform Plumbing Code is the primary code utilized for water reuse system compliance, and it describes the treatment standards for plumbing systems. Additionally, some provisions of Comm 84, NR 811, NR 812, and DHS 172 also apply in some circumstances. Table 5 provides a brief description of each code number.

Table 5. – Codes relating to water reuse applications

Code Number	Title	General Description
Comm 82	Design, Construction, Installation, Supervision, Maintenance, and Inspection of Plumbing	Ensures that plumbing of sanitary and storm drainage, water supplies, wastewater treatment, and dispersal or discharge for buildings, except for POWTS systems, in the state are safe, sanitary and protect the health of the public and state waters.
Comm 84	Plumbing Products	Dictates the quality and installation of materials, fixtures, appliances, appurtenances, and equipment required to meet Plumbing Treatment Standards.
NR 811	Requirements for the Operation and Design of Community Water Systems	Governs the minimum standards for the general operation, design and construction of community water systems and the construction of any water system serving 7 or more single family homes, 10 or more duplex living units, 10 or more mobile homes, 10 or more condominium units or 10 or more apartment units.
NR 812	Well Construction and Pump Installation	Establishes uniform minimum standards and methods for obtaining/extracting groundwater, protecting groundwater and aquifers from contamination through proper (re)construction of water systems, as well as governs the locations, (re)construction/maintenance of water systems, the abandonment of wells/drillholes and the

		installation/maintenance of pumping and treatment equipment.
DHS 172	Safety, Maintenance and Operation of Public Pools and Water Attractions	A health and safety based policy which regulates the maintenance and operation of public pools and water attractions in the interests of the public.

WATER DESIGNATIONS

The Wisconsin Uniform Plumbing Code was last updated on January 1, 2011. Previously, the various flow streams were not mentioned explicitly within Comm 82. Comm 82.34(3)(a)1 now states, "…graywater, storm water, clear water, blackwater and other wastewaters as approved by the department may be reused in conformance with s. Comm 82.70 [Plumbing Treatment Standards]." These various flow streams – and others not stated which may be considered during the approval process – are defined below (Novotny, Ahern et al. 2010):

- *Graywater* – Medium polluted water from laundries, bathrooms (shower and bathtub), and wash basins that is often emulsified with soap and detergent; it may have significant concentrations of biodegradable and nonbiodegradable organics and may also contain pathogens.
- *Blackwater* – Highly polluted wastewater from toilets and urinals containing urine and excreta and at times drain water from kitchen sink disposal units.
- *Brown water* – Blackwater after the removal of urine (yellow water).
- *Yellow water* – Separated urine (about 1% of the total flow).
- *Blue water* – Water that is naturally well-suited for potable use that originates from springs and wells, high-quality surface water bodies, and unpolluted rainwater, or water that has been treated to potable water quality. It is also known as clear water.
- *Green water* – Water used in irrigation.
- *White water* – Mildly polluted surface runoff (also known as stormwater).

COMM 82.70 TREATMENT STANDARDS

The recent written inclusion of alternative water sources into Chapter Comm 82 is intended to promote water reuse in the state of Wisconsin while still observing the original principles of Comm 82: (1) to ensure that public health is not compromised, and (2) to protect the waters of Wisconsin from environmental degradation. Comm 82 treatment standards specify limits based on the intended use of the treated water. The Wisconsin Plumbing Treatment Standards are shown in Appendix A, as adapted from Table 82.70-1 of Comm 82.70 of the Wisconsin Uniform Plumbing Code.

MOTIVATIONS FOR IMPLEMENTATION IN WISCONSIN

Over the last century, public health and sanitation have been held paramount in the civil engineering and health professions. Conventional urban wastewater treatment systems convey wastewater away from the source for centralized treatment as a means of providing safe and sanitary living conditions. As a result, there is much apprehension for implementing graywater reuse and rainwater harvesting at a residence and possibly exposing the public to the microbiological contaminants in untreated graywater – unless strict quality standards are imposed. Chemical constituents of raw graywater in the form of surfactants, salts, BOD_5, TSS, phosphorus and nitrogen can be especially detrimental to soils and natural water bodies.

The philosophy behind the water reuse paradigm shift is based on a number of factors. First, the health and environmental concerns prompted Wisconsin regulators to mold Comm 82.70 into a performance-based code. Therefore, a specific technology or treatment scheme is not suggested within the code, so long as those treatment standards listed in Table 82.70-1 are met for the intended use during operation. This philosophy is congruent with the conclusive recommendation of the 2001 study by Casanova et al., which stated that "the quality of graywater and its intended use determine the appropriate guidelines to reduce health risks associated with reuse."

Second, a performance-based code encourages product development and promotes market competition, as well as allows the owner the flexibility and creative capacity to dictate system components. While the Comm 82 Appendix does detail many system requirements, the methods and technologies that achieve a quality limit are unstated. Still water reuse systems, whether consisting of a single device or multiple devices in series, must be approved through a Safety and Buildings Plumbing Plan Review by the Department of Commerce to ensure product and process reliability. Additionally, local municipality requirements independent of the Department of Commerce must also be met.

Third, it became difficult for the State to mandate that all household water fixtures provide potable water, especially in areas of the state where contaminated or limited groundwater resources may be an issue. Additionally, because potable water may not be required for all household activities, water reuse and alternative water sources have become more viable options for some Wisconsin residents and industries.

DETERRENTS FOR HOMEOWNERS

Aspects of the Wisconsin Uniform Plumbing Code which have been identified as deterrents to homeowners considering the installation of a water reuse system are:

- Exact treatment schemes or technologies are not dictated by the Code. This requires greater know-how and understanding of system components.
- Residential permits and supplementary submittal materials are essentially the same as those for commercial reuse systems.
- Costs continue after installation with maintenance and periodic testing by a licensed plumber.
- The language of the treatment standards listed in Table 82.70-1 (e.g. pH, BOD_5, TSS, fecal coliform, and residual chlorine) is uncommon to laypersons.
- The homeowner must be responsible for system maintenance.

Additionally, a plumbing plan must be submitted and approved prior to any installation. This plumbing plan is a 12-point list of requirements ranging from scaled plan details and isometric drawings to approval letters for system components and a written description of all aspects of the system. To acquire this compliance information requires a homeowner to consult a Wisconsin registered Architect, Designer, Engineer, or licensed Master Plumber. The costs associated with consulting – especially for more advanced treatment systems – are likely prohibitive for the average homeowner and result in an extensive payback period. However, these requirements are typically well-suited for two reasons. First, most homeowners are not qualified to correctly design a graywater reuse or rainwater harvesting system of moderate complexity due to lack of knowledge or understanding. Second, engineers and designers are obligated to abide by strict codes of conduct relating to public health and safety and environmental quality. According to the American Society of Civil Engineers Code of Ethics (ASCE 2009), Fundamental Principle (a), "Engineers uphold and advance the integrity, honor and dignity of the engineering profession by using their knowledge and skill for the enhancement of human welfare and the environment." Furthermore the First Fundamental Canon states, "Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties." Engineers and designers, therefore, are held liable for the ability of their designed systems to minimize risks to human health and the environment.

In reference to the 2007 State-of-the-Art of Water Supply Practices report issued by the Southeastern Wisconsin Regional Planning Commission (SEWRPC), principal costs of water reuse systems for residential applications are for conservation devices, attendant installation, renovation or retrofitted plumbing costs, appliances and treatment technologies, and required service connections, as well as any energy requirements or maintenance costs over the life of the system. Initial costs may outweigh any long-terms savings at some single-family dwellings, since costs typically range between several hundred to several thousand dollars; and as expected capital costs increase with increasing scale of operation. For areas that face high water usage rates, the capital investment may be practical and water use costs for the graywater reuser would likely be reduced. Additionally, reduced water use by the consumer may lead to reduced revenue for the water utility, and hence diminished support for conservation measures by the water utility. Because municipal water utilities rely on water service charges to fund treatment and supply, rates would necessarily increase as a result. Utilities in Southeastern Wisconsin – consisting of Milwaukee, Waukesha, Walworth, Washington, Ozaukee, Racine and Kenosha counties – typically use a decreasing block rate structure whereby rates decrease as water use increases. This rate structure is not supportive of conservation practices. An increasing block rate structure would be more conducive to water conservation. In Southeastern Wisconsin, it is noteworthy that even in neighboring counties, such as Milwaukee and Waukesha, there exist differences in water rates and the availability of quality water.

COMPARISON OF REGULATIONS WITH OTHER STATES

The movement toward increased water reuse and rainwater harvesting in Wisconsin can be considered relatively unhurried compared to other states – namely California, Florida, Arizona, and Texas – which have experienced severe water shortages. Within the United States, these four account for nearly 90% of reclaimed water use (Crook 2010). Currently, approximately 30 states have adopted graywater regulations that vary greatly in their comprehensiveness (Sheikh 2010).

Wisconsin's Comm 82 is a general code written broadly for water reuse and, as such, specifies only the required treated water quality for an intended use, regardless of the source of water. The Comm 82 Appendix illustrates in detail many design requirements, including sizing, setback and separation distances, appliance connection and venting requirements, and stormwater collection calculations. It is written for architects, engineers and plumbers. This differs significantly from the more progressive states that are forthright proponents of either or both graywater reuse and rainwater harvesting.

A fundamental difference between Wisconsin's Comm 82 and the regulations of the more progressive states is that these states also provide educational materials in addition to the regulations. These materials guide and encourage homeowners in the design and implementation of a water reuse system. Both Texas and Arizona provide comprehensive manuals for state residents that describe the concept of rainwater harvesting, necessary system components, water quality requirements, calculations for sizing and water demand, as well as Best Management Practices for users to consider. Wisconsin's requirements for these systems are not easily identifiable within the code, as evidenced by the wide dispersal of applicable information throughout the entirety of the 63 pages of Comm 82. Another difference is the language in which the regulations are written. Arizona regulations for landscape irrigation, for example, do not require a graywater system to meet water quality standards in terms of pH, BOD_5, TSS, fecal coliform, or chlorine residual, as is required by the Wisconsin Plumbing Code. Instead, Arizona's regulations are presented as Best Management Practices (BMPs), which provide qualitative rules-of-thumb that will typically have no apparent or measurable negative effects on the environment. While this makes monitoring the performance of a system difficult, it makes implementation for the homeowner more feasible. In the continuing sections, descriptions of graywater regulations from the states of Arizona, California, Florida, and Texas are provided. References are also made to rainwater harvesting materials provided by these states but are not described in detail.

ARIZONA WATER REUSE REGULATIONS

In Arizona, reclaimed water issues and water reuse are regulated under the Arizona Department of Environmental Quality (ADEQ). Arizona defines graywater as used water from clothes washers, bathtubs, showers and bathroom sinks. Contrary to the state of Wisconsin, graywater brochures are provided to the public to encourage graywater reuse within homes. Household requirements for water reuse are found in Title 18, Chapter 9, Article 7 of the Arizona Administrative Code. According to an informational brochure distributed by ADEQ and provided on the department's public website, residents must adhere to a Reclaimed Water Type I General Permit, which requires no notification to ADEQ, no approval of plan reviews or system design, and provides exemption from public notice, reporting or renewal. Instead, a homeowner is expected to design a system so as to abide by a list of 13 Best Management Practices (BMPs) given by ADEQ, which are meant to preserve both human and environmental health. This Reclaimed Water Type I General Permit only applies to water that is generated by a single residence or small multi-family residence and is used onsite for the sole purpose of subsurface drip or surface flood irrigation where the graywater flow is less than 400 gallons (1,514 L) per day. Specifically excluded from the Type I General Permit is the use of spray irrigation and non-irrigation uses. The 13 Best Management Practices are provided in Appendix B.

If these general conditions are met on a continuous basis, the Type I General Permit does not expire. If graywater flows exceed 400 gpd (1,514 lpd) but are not more than 3,000 gpd (11,356 lpd), one must obtain a Type III General Water Reclamation Permit for Gray Water, which has more stringent administrative and technical requirements. This is beyond the household scale.

Arizona also provides guidelines and supplementary materials for rainwater harvesting. Two comprehensive references are the 2005 City *of Tucson Water Harvesting Guidance Manual* (Phillips 2005) and the 2006 *Harvesting Rainwater for Landscape Use* manual (Bickelmann 2006).

CALIFORNIA WATER REUSE REGULATIONS

In California, graywater reuse is regulated under Chapter 16A of the 2010 California Plumbing Code. California is hailed as the most progressive of the graywater-reusing states, and the California Plumbing Code reflects this. Chapter 16A is dedicated to nonpotable water reuse systems, and the intentions listed in the code openly promote the use of approved systems. These intentions read (California Plumbing Code, 2010):

1. Conserve water by facilitating greater reuse of laundry, shower, lavatory, and similar sources of discharge for irrigation and/or indoor use.
2. Reduce the number of noncompliant graywater systems by making legal compliance easily achievable.
3. Provide guidance for avoiding potentially unhealthful conditions.
4. Provide an alternative way to relieve stress on a private sewage disposal system by diverting the graywater.

Unlike the graywater regulations of some other states, Chapter 16A of the California Plumbing Code is user-friendly to engineers, architects, plumbers, and designers, as well as laypersons. Within the Code is provided definitions, general system requirements, design requirements (including site specifications), example demand and capacity calculations, and other design parameters necessary for installing a water reuse system that is standardized, well-documented, and safe for operation.

The Code defines various graywater systems as they relate to system complexity in Section 1602A.0. These systems are the: (1) Clothes Washer System, (2) Simple System, and (3) Complex System. A Clothes Washer System utilizes the effluent water from a single domestic clothes washing machine for a one- or two-family dwelling. A Simple System applies to one- or two-family dwellings that discharge 250 gallons (946 L) per day or less. A Complex System is one that discharges over 250 gallons (946 L), regardless of the dwelling size. The Clothes Washer system is the only system that does not require a construction permit, so long as the provisions of 1603A.1.1 are met.

Section 1603A.1 provides the general graywater reuse system requirements for Clothes Washer, Simple and Complex Systems; these are listed in Appendix C. It should be noted that these general conditions, in no way, summarize the entirety of Chapter 16A. Chapter 16A of the California Plumbing Code is an extensive document that should be consulted in its entirety for additional reuse information.

According to the City of San Diego's Water Conservation Program website, there are no known laws in California that restrict the harvesting of rainwater, but there are also no laws which regulate the act. The American Rainwater Catchment Systems Association (ARCSA) has developed a rainwater harvesting guide which will be presented to the International Association of Plumbing and Mechanical Officials (IAPMO). Publications provided to residents by the City of San Diego include the 2005 *Texas Manual on Rainwater Harvesting*, the guidebook *Harvesting Rainwater for Landscape Use* by Christina Bickelman, and *Rainwater Harvesting: Supply from the Sky*, a publication from the City of Albuquerque.

TEXAS WATER REUSE REGULATIONS

Texas graywater regulations are covered under Title 30, Part 1, Chapters 210 and 285 in the Texas Administrative Code. Texas defines graywater as used water from clothes washers, bathtubs, showers and bathroom sinks, and specifically excludes any sink that is used to dispose of hazardous or toxic materials. It also prohibits the washing of diapers or other materials containing human excreta in these fixtures. Like some other states, it is unclear from the regulations how noncompliant graywater reusers who choose to wash contaminated materials are discovered and prevented from doing so again in the future. On-site sewage facilities are regulated under Section 285.81 of Subchapter H of Chapter 285 and specify the Criteria for Disposal of Graywater. It was adopted in June 2001 and amended in January 2005. These criteria are listed in Appendix D.

Additionally, Chapter 210, Subchapter F, also applies. Chapter 210 regulates the use of reclaimed water; Subchapter F regulates graywater systems specifically. Subchapter F applies to graywater that is used for irrigation or other agricultural purposes on the domestic, commercial, industrial, and institutional levels. Applicable sections to a household graywater reuse system are Sections 210.83 and 210.85. These sections were also adopted in January 2005. Section 210.83 lists the Criteria for the Domestic Use of Graywater; Section 210.85 lists the Criteria for Use of Graywater for Irrigation and for Other Agricultural Purposes. These criteria for 210.83 and 210.85 are both provided in Appendix D.

Texas also provides guidelines and supplementary materials for rainwater harvesting, including the 2005 *Texas Manual on Rainwater Harvesting*, and the 2006 *Rainwater Harvesting Potential and Guidelines for Texas*, which establishes treatment standards required for the potable use of rainwater. This report was presented to the 80th Legislature by the Texas Rainwater Harvesting Evaluation Committee and published by the Texas Water Development Board.

FLORIDA WATER REUSE REGULATIONS

In Florida, graywater for residential applications is regulated under Appendix C: Gray Water Recycling Systems of the Florida Plumbing Code, Sections C101.1 to C101.12. Graywater is defined as used water from bathtubs, showers, lavatories, clothes washers, and laundry trays. The 2007 Florida Building Code allowed for the reuse of graywater for the flushing of toilets and urinals and for subsurface landscape irrigation. However, the code was amended in March 2009 to eliminate Appendix Section C103 – Subsurface Landscape Irrigation Systems; therefore, graywater may not be used for landscape irrigation. Currently the requirements for graywater systems are fairly basic:

- The maximum retention time is 72 hours for graywater used for flushing water closets and urinals.
- The holding capacity of the storage tank must be a minimum of twice the volume of water required to meet the daily flushing requirements of the applicable graywater fixtures, but not less than 50 gallons (189 L).
- Graywater must pass through an approved filter before entering storage. This filter may be a media, sand, or diatomaceous earth filter.
- The graywater must be disinfected by one or more approved disinfectants. These disinfectants may include chlorine, iodine, and ozone.
- Graywater that is supplied to graywater fixtures must be dyed blue or green with a food-grade vegetable dye beforehand.
- Distribution piping and storage tanks carrying and holding graywater must be color-coded or have metal tags indicating the contents as such.
- Potable water is required as system makeup water when graywater supply is inadequate to meet needs.

Section 373.619 of the 2010 Florida Statutes considers individual graywater disposal systems as water and sewer-saving disposal systems. Publicly-owned or investor-owned water and sewerage treatment works are encouraged to reduce connection and service charges to those residents who implement graywater reuse systems.

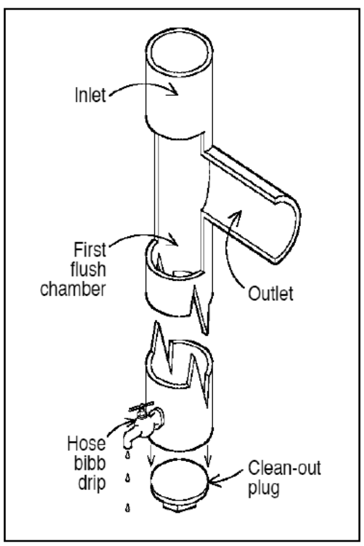
Currently, graywater reuse in Florida is not as widely used as it is in the western states. Officials receive more requests for rainwater harvesting systems than they do for graywater systems. In retrospect, Florida receives frequent rainfall, and currently provides reclaimed water service to more than 250,000 households (Sheikh 2010). Florida provides guidelines for rainwater harvesting in the *Rainwater Harvesting with Cisterns for Landscape Irrigation Workshop Presentation/Manual* (Hernandez, Yeh et al. October 2009).

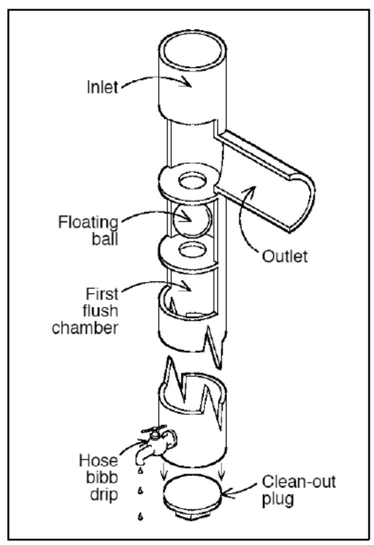
THE STATE OF RESIDENTIAL WATER REUSE TECHNOLOGIES

CURRENT TECHNOLOGIES

The processes used for treatment and disinfection depend on the intended use of the reclaimed water. The Soap and Drug Administration's 1999 survey ([The] NPD Group Custom Research Services 1999) found that 93% of graywater reusers do not have treatment systems (n = 443). Additionally, 95% of respondents (n =482) apply graywater for irrigating plants and vegetation, while 46% of the same respondent population applies graywater directly to edible vegetable and fruit gardens. This suggests that a large portion of graywater reusers are unaware of the hygienic implications of directly applying contaminated graywater to edible plants. Storage and distribution systems are also typically above ground because most graywater reusers apply graywater by hand or use a hose extending from the source. As a result, frequent direct exposure to the graywater necessitates its treatment before reuse. A comprehensive list containing an arbitrary selection of available graywater treatment package systems for residential use is available in Appendix E. Systems vary greatly in complexity, size and price.

Rainwater technologies are typically simpler than those used to treat graywater. An integral component of a rainwater harvesting system is a first-flush mechanism. Because they often do not require power, the first-flush mechanism is an economically favorable way to improve the quality of collected rainwater and reduce stress on subsequent treatment devices. Of the existing technologies, two of them are especially simple and can be easily retrofitted by a homeowner. The first is a PVC standpipe extension to a downspout. After the standpipe fills with runoff, excess is diverted to the application or to storage and an open hose bib slowly drains the standpipe. This is well-suited for a small collection system. Because the volume diverted to the standpipe depends on its length, space and practicality are design considerations. The second simple design is a standpipe with a floating ball valve. The floating ball valve allows the standpipe to fill with runoff until the ball valve seals the seat, at which point the water is diverted to the application or to storage. Similarly an open hose bib drains the standpipe (Texas Manual on Rainwater Harvesting, 2005).





Standpipe first-flush diverter (left) and Standpipe with ball valve (from the 2005 *Texas Manual on Rainwater Harvesting*)

Among the many treatment options provided by the *Texas Manual on Rainwater Harvesting* are ultraviolet (UV) radiation, cartridge filters, ozonation, nanofiltration, reverse osmosis and chlorination. According to Sazakli *et al.* disinfection should be applied, and the simplest method is chlorination. Chlorination may be appropriate for larger-scale systems; however, on the household or small cluster housing level care should be exercised when using a chemical disinfectant. If high concentrations of organic matter are present and an inexperienced homeowner provides too great a dosage of chlorine to a graywater stream, reaction of organic matter with chlorine can result in the formation of harmful disinfection byproducts (DBPs). This is a concern when disinfecting rainwater that is to be used as a potable water source. The protozoa *Cryptosporidium* and *Giardia*, which have been found in intercepted rainwater, do show resistance to chlorination.

SOUTHEASTERN WISCONSIN WATER REUSE SURVEY RESULTS

In February of 2011, Marquette University conducted a survey of water and wastewater professionals to gather regional perspective on the issues of graywater reuse and rainwater harvesting, as well as the future outlook for such applications in southeastern Wisconsin. The responding individuals represented governmental, consultancy, educational, manufacturing and utility establishments. This 13-question survey consisted of short response and Likert scale questions, and focused on current roadblocks, technology gaps, and the existing presence of these systems in Wisconsin. According to a respondent population of 21 individuals (55% response rate), the majority of respondents (71%) had never worked on a graywater reuse system. Additionally, 57% of respondents had never worked on a rainwater harvesting system. From this information it was determined that there is an overall lack of familiarity with graywater reuse and rainwater harvesting in Wisconsin by working professionals, though there was more familiarity with rainwater harvesting. There was also an overwhelming lack of awareness of the Wisconsin Plumbing Code's Chapter Comm 82.70 for water reuse – especially as it applied specifically to graywater and rainwater.

The greater familiarity with rainwater harvesting was attributed to the fact that they are generally simpler systems and more manageable for the average homeowner. Also, the Milwaukee Metropolitan Sewerage District (MMSD), the state-chartered regional government agency that provides water reclamation and flood management services to more than one million customers in the Greater Milwaukee Watersheds, has influenced the understanding of rainwater harvesting through its "Every Drop Counts" campaign, which was established in 2005 (M.M.S.D.). Through the promotion of water conservation efforts and sustainable water infrastructure using pamphlets and other publications, the use of rain barrels has recently become a moderately common occurrence at residences in southeastern Wisconsin.

One respondent, who was identified as a plumbing consultant for the Department of Commerce, indicated that he had consulted on approximately 50 approved graywater reuse systems and 30 approved rainwater harvesting systems in the state of Wisconsin. This indicates that both graywater reuse and rainwater harvesting systems are being implemented in Wisconsin, though it is not a common practice.

TECHNOLOGY GAPS

Survey free response questions indicated that existing technologies for water reuse and recycling at the residential scale generally do not inhibit system implementation. Rather, current technologies are more than adequate to meet treatment needs. Instead, inhibitory factors stated included the cost and footprint of such systems, regulations, required owner maintenance, system complexity and an overall lack of education on reuse and recycling options for homeowners.

CONCLUSIONS

According to Novotny et al. (2010), the drive toward implementing more sustainable water and wastewater infrastructure is "because rainwater and wastewater will be considered as a resource and not waste" and significant economic benefits will materialize from the conversion of urban sewage to energy.

The use of rainwater and graywater has been slow to gain acceptance in Wisconsin. Presumably, this is because water is an abundant resource within the state. With access to both Great Lakes Superior and Michigan (the first- and fifth-largest largest freshwater lakes on Earth, respectively), upwards of 15,000 inland lakes, more than 32,000 miles of perennial rivers and streams, and high-capacity groundwater aquifers (WASAL 2003), quality and quantity of water are generally not considered limiting factors in the Wisconsin lifestyle. Water service rates are also relatively cheap for residents who are provided water from Lake Michigan. Therefore, both graywater reuse and rainwater harvesting may be more attractive to the rural resident who relies on municipal or private wells for potable water or on-site septic system treatment of wastewater. In this case, effluent from a graywater drainfield would return to the local groundwater table. Contributing to the lack of outright promotion of water reuse is the considerable improvement of public health and sanitation since the early 20th century. As stated in Chapter Comm 82.10, "environmental sanitation and safety" are held paramount in the design, installation, and maintenance of plumbing systems in order to "protect the health, safety and welfare of the public or occupants and the waters of the state." Since water resource quantity and quality are not a constant worries for the citizens of the state of Wisconsin, there has been an absence of drive towards more innovative, sustainable uses of water. However, sustainable use of water resources is becoming a global goal and the use of graywater and rainwater are intimately intertwined with the efforts to reach a more adequate state of environmental consciousness. It is important for Wisconsin to join this movement, aligned with other states. However, as shown, the physicochemical and microbiological concerns with these alternative water sources prove that this must not be done hastily. Appropriate analyses that recognize, understand, and accept comfortably the degree of risk associated with graywater and rainwater reuse must be determined when considering the feasibility of pursuing these reuse options on a widespread, residential scale. Survey responses have indicated that the required technologies are readily available; however, it is not uncommon for these treatment technologies to be cost-prohibitive. To most homeowners, affordability – more so than environmental responsibility – will justify pursuing alternative means of handling used water.

Though in-depth cost comparisons have not been prepared within this report, two important factors for implementing a reuse system are:

- The seasonal weather patterns affecting rainwater volumes versus the consistent production of household graywater, and
- The increased capital costs to treat a medium-light strength "gray" wastewater versus the lower capital costs to treat natural rainwater, which is nearly free of contaminants.

These concerns were illustrated in the first two years of the long-term study by the University of Arizona of a residential water conservation facility in arid suburban Tucson, Arizona, known as Casa del Agua. During this period, it was reported that lower than average recorded rainfall required one of the designed rainwater storage tanks with a volume of 4,800 gallons (18,170 L) to be converted to a graywater holding tank, which was concurrently operating in excess of design capacity (900 gallons or 3,406 L) and was discharging to the municipal sewer (Karpiscak, France et al. 2001). Graywater provided about 19% of the water budget of Casa del Agua during its operation, while harvested rainwater provided about 11% (Karpiscak, France et al. 2001). The relationship between these two factors makes it difficult for an industry to manufacture a universal, non-site-specific product that can be mass produced.

The current regulations are not written to encourage homeowners to install water reuse technologies. Instead they are written for architects, engineers, designers and plumbers. Therefore, the task of designing and installing a water reuse system to the average homeowner is a daunting task. Homeowners must consult engineers and rely on professional plumbers for virtually all system design and installation. This leads to much higher capital costs for system implementation. More progressive graywater and rainwater states provide educational materials which may absolve some of the design costs to the homeowners. As stated by Leggett and Shaffer (2002), installation, operation, maintenance, time and cost are all practicalities which must be considered for both rainwater harvesting and graywater reuse systems. These practicalities may prove to be prohibitive when compared to the benefits provided by mains water use. If this is the case, conservation by limiting water usage is likely the most appropriate concern.

APPENDIX A

Table 82.70-1
Plumbing Treatment Standards

Intended Use	Plumbing Treatment Standards [f]
Drinking, cooking , food processing, preparation and cleaning, pharmaceutical processing and medical uses	NR 811 and 812 approved sources
Personal hygiene, bathing and showering	NR 811 and 812 approved sources
Automatic fire protection systems	As acceptable by local authority
Swimming pool makeup water	NR 811 and 812 approved sources
Swimming pool fill water	DHS 172 requirements
Cooling water [b]	pH 6 – 9 [b] ≤ 50 mg/L BOD_5 ≤ 30 mg/L TSS Free chlorine residual 1.0 – 10.0 mg/L [b]
Subsurface infiltration and irrigation, using reuse as the source [c]	≤ 15 mg/L oil and grease ≤ 30 mg/L BOD_5 ≤ 35 mg/L TSS < 200 fecal coliform cfu/100 mL [d]
Subsurface infiltration and irrigation, using stormwater as the source [c]	< 15 mg/L oil and grease < 60 mg/L TSS
Surface or spray irrigation using stormwater and clearwater as the source [c]	≤ 10 mg/L BOD_5 ≤ 5 mg/L TSS
Surface irrigation except food crops, vehicle washing, clothes washing, air conditioning, soil compaction, dust control, washing aggregate, and making concrete [a, c]	pH 6 – 9 [b] ≤ 10 mg/L BOD_5 ≤ 5 mg/L TSS Free chlorine residual 1.0 – 10.0 mg/L [b]
Toilet and urinal flushing	pH 6 – 9 [b] 200 mg/L BOD_5 ≤ 5 mg/L TSS Free chlorine residual 0.1 mg/L – 4.0 mg/L [b]
Uses not specifically listed above	Contact department for standards

[a] Refer to the department of agriculture, trade and consumer protection for commercial use.
[b] Applies only to wastewater treatment devices for reuse systems. Other equivalent disinfection methods may be approved by the department.
[c] These requirements do not apply to the treatment of industrial wastewater or other wastewater discharges that are subject to a WPDES permit issued by the department of natural resources.
[d] A 12-inch minimum separation of medium sand or finer material above high groundwater or bedrock.
[f] For stormwater, the plumbing treatment standards are based on an annual average. Evaluation of research to prove compliance with this table is based on the geometric mean of the data acceptable to the department or an equivalent method.

APPENDIX B

The 13 Best Management Practices provided by the Arizona Department of Environmental Quality; as adapted from the Arizona Administrative Code:

1. Human contact with gray water and soil irrigated by gray water is avoided;
2. Gray water originating from the residence is used and contained within the property boundary for household gardening, composting, lawn watering, or landscape irrigation.
3. Surface application of gray water is not used for irrigation of food plants, except for citrus and nut trees;
4. The gray water does not contain hazardous chemicals derived from activities such as cleaning car parts, washing greasy or oily rags, or disposing of waste solutions from home photo labs or similar hobbyist or home occupational activities;
5. The application of gray water is managed to minimize standing water on the surface;
6. The gray water system is constructed so that if blockage, plugging, or backup of the system occurs, gray water can be directed into the sewage collection system or on-site wastewater treatment and disposal system, as applicable. The gray water system may include a means of filtration to reduce plugging and extend system lifetime;
7. Any gray water storage tank is covered to restrict access and to eliminate habitat for mosquitoes or other vectors;
8. The gray water system is sited outside of a floodway;
9. The gray water system is operated to maintain a minimum vertical separation distance of at least five feet from the point of gray water application to the top of the seasonally high groundwater table;
10. For residences using an on-site wastewater treatment facility for black water treatment and disposal, the use of a gray water system does not change the design, capacity, or reserve area requirements for the on-site wastewater treatment facility at the residence, and ensures that the facility can handle the combined black water and gray water flow if the gray water system fails or is not fully used;
11. Any pressure piping used in a gray water system that may be susceptible to cross connection with a potable water system clearly indicates that the piping does not carry potable water;
12. Gray water applied by surface irrigation does not contain water used to wash diapers or similarly soiled or infectious garments unless the gray water is disinfected before irrigation; and
13. Surface irrigation by gray water is only by flood or drip irrigation.

APPENDIX C

The general provisions in California for the Clothes Washer, Simple, and Complex graywater reuse systems are described below. Sections that apply include: 1603A.1.1 (Clothes Washer System), 1603A.1.2 (Simple System), and 1603A.1.3 (Complex System). These general provisions are adapted directly from Chapter 16A of the California Plumbing Code, though not in their entirety.

1603A.1.1 Clothes Washer System. A clothes washer system in compliance with all of the following is exempt from the construction permit specified in Section 1.8.4.1 and may be installed or altered without a construction permit:

1. If required, notification has been provided to the Enforcing Agency regarding the proposed location and installation of a graywater irrigation or disposal system.
2. The design shall allow the user to direct the flow to the irrigation or disposal field or the building sewer. The direction control of the graywater shall be clearly labeled and readily accessible to the user.
3. The installation, change, alteration, or repair of the system does not include a potable water connection or a pump and does not affect other building, plumbing, electrical, or mechanical components including structural features, egress, fire-life safety, sanitation, potable water supply piping, or accessibility.
4. The graywater shall be contained on the site where it is generated.
5. Graywater shall be directed to and contained within an irrigation or disposal field.
6. Ponding or runoff is prohibited and shall be considered a nuisance.
7. Graywater may be released above the ground surface provided at least two (2) inches (51 mm) of mulch, rock, or soil, or a solid shield covers the release point. Other methods which provide equivalent separation are also acceptable.
8. Graywater systems shall be designed to minimize contact with humans and domestic pets.
9. Water used to wash diapers or similarly soiled or infectious garments shall not be used and shall be diverted to the building sewer.
10. Graywater shall not contain hazardous chemicals derived from activities such as cleaning car parts, washing greasy or oily rags, or disposing of waste solutions from home photo labs or similar hobbyist or home occupational activities.
11. Exemption from construction permit requirements of this code shall not be deemed to grant authorization for any graywater system to be installed in a manner that violates other provisions of this code or any other laws or ordinances of the Enforcing Agency.
12. An operation and maintenance manual shall be provided. Directions shall indicate the manual is to remain with the building throughout the life of the system and indicate that upon change of ownership or occupancy, the new owner or tenant shall be notified the structure contains a graywater system.

1603A.1.2 Simple System. Simple systems exceed a clothes washer system and shall comply with the following:

1. The discharge capacity of a graywater system shall be determined by Section 1606A.0. Simple systems have a discharge capacity of 250 gallons (947 L) per day or less.

2. Simple systems shall require a construction permit, unless exempted from a construction permit by the Enforcing Agency. The Enforcing Agency shall consult with any public water system(as defined in Health and Safety Code, Section 116275) providing drinking water to the dwelling before allowing an exemption from a construction permit.
3. The design of simple systems shall be acceptable to the Enforcing Agency and shall meet generally accepted graywater system design criteria.

1603A.1.3 Complex System. Any graywater system that is not a clothes washer system or simple system shall comply with the following:

1. The discharge capacity of a graywater system shall be determined by Section 1606A.0. Complex systems have a discharge capacity over 250 gallons (947 L) per day
2. Complex systems shall require a construction permit, unless exempted from a construction permit by the Enforcing Agency. The Enforcing Agency shall consult with any public water system(as defined in Health and Safety Code, Section 116275) providing drinking water to the dwelling before allowing an exemption from a construction permit.
3. A complex system shall be designed by a person who can demonstrate competence to the satisfaction of the Enforcing Agency.

APPENDIX D

The Texas Criteria for Disposal of Graywater, as adapted from the Section 285.81 of Subchapter H of Chapter 285:

a) Permits and inspections are not required for the domestic use of less than 400 gallons of graywater each day if:
   1) the graywater originates from a single family dwelling;
   2) the graywater system is designed so that 100% of the graywater can be diverted to the owner's on-site sewage facility (OSSF) system during periods of non-use of the graywater system. A graywater system may only be connected to the OSSF system if the following requirements are met.
      A) The connection must be in the line between the house stub-out for the OSSF and the OSSF treatment tank.
      B) The discharge from the graywater system must enter the OSSF system through two backwater valves or backwater preventers;
   3) the graywater is stored in tanks and the tanks:
      A) are clearly labeled as nonpotable water;
      B) restrict access, especially to children;
      C) eliminate habitat for mosquitoes and other vectors;
      D) are able to be cleaned; and
      E) meet the structural requirements of the 2004 American Water Works Association standards;
   4) the graywater system uses piping clearly identified as a nonpotable water conduit, including identification through the use of painted purple pipe, purple pipe, pipe taped with purple metallic tape, or other methods approved by the commission;
   5) the graywater is applied at a rate that will not result in ponding or pooling or will not cause runoff across the property lines or onto any paved surface; and
   6) the graywater is not disposed of using a spray distribution system.
b) No reduction in the size of the OSSF system will be allowed when using a graywater system.
c) Builders of single family dwellings are encouraged to:
   1) install plumbing in new housing to collect graywater from all allowable sources; and
   2) design and install a subsurface graywater system around the foundation of new housing to minimize foundation movement or cracking.
d) Graywater from a graywater system as described in subsection (a) of this section may only be used:
   1) around the foundation of new housing to minimize foundation movement or cracking;
   2) for gardening;
   3) for composting; or
   4) for landscaping at a single family dwelling.
e) All aspects of the permitting, planning, construction, operation, and maintenance for any proposed graywater system that does not meet the requirements of subsection (a) of this section must meet the requirements of the remainder of this chapter.
f) The installer of the graywater system must advise the owner of basic operating and maintenance procedures including any effects on the OSSF system.
g) Graywater use must not create a nuisance or damage the quality of surface water or groundwater. If graywater use creates a nuisance or damages the quality of surface water or groundwater, the

permitting authority may take action under §285.71 of this title (relating to Authorized Agent Enforcement of OSSFs).

h) Homeowners who have been discharging wastewater from residential clothes-washing machines, otherwise known as laundry graywater, directly onto the ground prior to the effective date of this rule, may continue this discharge under the following conditions.
   1) The disposal area shall not create a public health nuisance.
   2) Surface ponding shall not occur in the disposal area.
   3) The disposal area shall support plant growth or be sodded with vegetative cover.
   4) The disposal area shall have limited access and use by residents and pets.
   5) Laundry graywater that has been in contact with human or animal waste shall not be discharged on the ground surface and shall be treated and disposed of according to §285.32 and §285.33 of this title (relating to Criteria for Sewage Treatment Systems and Criteria for Effluent Disposal Systems, respectively).
   6) Laundry graywater shall not be discharged to an area where the soil is wet.
   7) The use of detergents that contain a significant amount of phosphorus, sodium, or boron should be avoided.
   8) A lint trap shall be required at the end of the discharge line.

i) Graywater systems that are altered, create a nuisance, or discharge graywater from any source other than clothes-washing machines are not authorized to discharge graywater under subsection (h) of this section.

The Texas Criteria for the Domestic Use of Graywater are provided below, as adapted from Section 210.83:

a) An authorization is not required for the domestic use of less than 400 gallons of graywater each day if:
   1) the graywater originates from a private residence;
   2) the graywater system is designed so that 100% of the graywater can be diverted to an organized wastewater collection system during periods of non-use of the graywater system and the discharge from the graywater system must enter the organized wastewater system through two backwater valves or backwater preventers;
   3) the graywater is stored in tanks and the tanks:
      A) are clearly labeled as nonpotable water;
      B) must restrict access, especially to children;
      C) eliminate habitat for mosquitoes and other vectors;
      D) are able to be cleaned; and
      E) meet the structural requirements of §210.25(i) of this title (relating to Special Design Criteria for Reclaimed Water Systems);
   4) the graywater system uses piping that meets the piping requirement of §210.25 of this title;
   5) the graywater is applied at a rate that:
      A) will not result in ponding or pooling; or
      B) will not cause runoff across the property lines or onto any paved surface; and
   6) the graywater is not disposed of using a spray distribution system.

b) Builders of private residences are encouraged to:
   1) install plumbing in new housing to collect graywater from all allowable sources; and

2) design and install a subsurface graywater system around the foundation of new housing to minimize foundation movement or cracking.

c) A graywater system as described in subsection (a) of this section may only be used:
   1) around the foundation of new housing to minimize foundation movement or cracking;
   2) for gardening;
   3) for composting; or
   4) for landscaping at the private residence.

d) The graywater system must not create a nuisance or damage the quality of surface water or groundwater.

e) Homeowners who have been disposing wastewater from residential clothes-washing machines, otherwise known as laundry graywater, directly onto the ground before the effective date of this rule may continue disposing under the following conditions.
   1) The disposal area must not create a public health nuisance.
   2) Surface ponding must not occur in the disposal area.
   3) The disposal area must support plant growth or be sodded with vegetative cover.
   4) The disposal area must have limited access and use by residents and pets.
   5) Laundry graywater that has been in contact with human or animal waste must not be disposed onto the ground surface.
   6) Laundry graywater must not be disposed to an area where the soil is wet.
   7) A lint trap must be affixed to the end of the discharge line.

f) Graywater systems that are altered, create a nuisance, or discharge graywater from any source other than clothes-washing machines are not authorized to discharge graywater under subsection (e) of this section.

The Texas Criteria for Use of Graywater for Irrigation and for Other Agricultural Purposes are shown below, as well, as adapted from Section 210.85:

a) If used in accordance with this subchapter, graywater used for irrigation and other agricultural purposes does not require authorization from the commission.

b) Graywater systems used for irrigation and other agricultural purposes must be designed so that 100% of the graywater can be diverted to an organized wastewater collection system during periods of non-use of the graywater system. The discharge from the graywater system must enter the organized wastewater system through two backwater valves or backwater preventers.

c) Graywater, as defined in §210.82(a) of this title (relating to General Requirements), may be used for the following activities.
   1) Process water.
      A) Graywater used for irrigation and other agricultural purposes may be treated to a standard that allows the graywater to be used in operational processes.
      B) Treatment described in subparagraph (A) of this paragraph does not require an authorization from the commission.
   2) Landscape maintenance. If graywater is used for landscape maintenance, the graywater must meet the following standards.
      A) If the graywater will be applied in areas where the public may come into contact with the graywater, the graywater must meet the following standards:
         (i) Fecal coliform, 20 colony forming units (CFU)/100 milliliters (ml), geometric mean; or
         (ii) Fecal coliform (not to exceed), 75 CFU/100 ml, single grab sample.

B) If the graywater will be applied in areas where the public is not present during the time when irrigation activities occur or disposed of for other uses where the public would not come into contact with the graywater, the graywater must meet the following standards:
   (i) Fecal coliform, 200 CFU/100 ml, geometric mean; or
   (ii) Fecal coliform, 800 CFU/100 ml, single grab sample.

3) Dust control. If graywater is used for dust control, the graywater must meet the standards in paragraph (2)(B) of this subsection.
4) Irrigation of fields. If graywater is used to irrigate fields where edible crops are grown or fields that are pastures for milking animals, the graywater must meet the standards in paragraph (2)(A) of this subsection.
5) Other uses. If graywater is used for other similar activities where the potential for unintentional human exposure may occur, the graywater must meet the fecal coliform limits in paragraph (2)(A) of this subsection.

d) Graywater used for irrigation and for other agricultural purposes must be monitored for fecal coliform at least monthly in areas where the public may come into contact with graywater and the records must be maintained at the site. These records must be readily available for inspection by the commission for a minimum period of five years.

APPENDIX E

The following is a list of graywater treatment package systems and was adapted from Tampa Bay Water's *Research of Graywater for Use in Residential Application* publication (Vallee and Sanchez 2010). Some information provided within this Appendix, including system components, prices and hyperlinks, are subject to change. This list is a random survey of some of the products available for graywater treatment and, in no way, endorses the use of a specific product or brand.

Graywater Systems Available in North America

- **AQUS®** system by WaterSaver Technologies is U.S.-based and can reduce metered water usage in a two-person household by about 10-20 gallons (38-76 L) a day, or approximately 5,000 gallons (18,927 L) a year. The AQUS conserves water and helps save money on water consumption charges and wastewater treatment or sewer fees. This system costs $295.00 plus shipping. According to the WaterSaver Technologies website, the AQUS® system has received a Product Listing in the Uniform Plumbing Code by IAPMO; therefore, it does not violate current UPC codes. It is also promoted as a green technology that can contribute to LEED compliance. For more information: www.watersavertech.com
- The **Brac Greywater Recycling System** was designed in Canada and is built for residential use. By reusing graywater this system decreases home water consumption by approximately one third. It can be purchased in the U.S. from private retailers. Costs range from $2000.00 to $3000.00 plus shipping. The system is covered by a two year warranty. According to the Brac Systems website, the Brac Greywater Recycling Systems for residential use are IAPMO-certified. For more information: www.bracsystems.com/home.html

The Brac Systems RGW-150

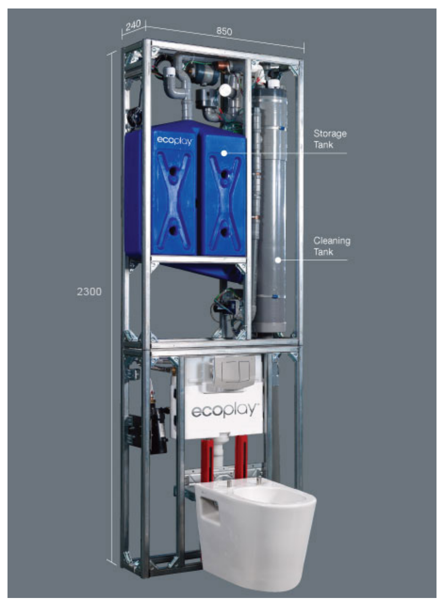
The Brac Systems LB-300

- The **ReWater® System** captures, filters, and reuses shower, tub, bathroom sink, and laundry water. This equates to about 50% of all water use inside a residence. ReWater systems are available in the U.S. and have been used in the West for a while. ReWater Systems, Inc. warrantees all parts of the ReWater System to be free of manufacturing defects for a period of two years from the date of purchase, with a ten year warranty on the filter vessel and collection tank. According to the ReWater Systems website, this system complies specifically with Chapter 16A of the California Plumbing Code and the regulations of less restrictive states as well. It is promoted as a viable option for LEED certification. For more information: http://www.rewater.com/
- The **Nutricycle System, LLC** is a U.S. based system. This is a fully automated system utilizes graywater to irrigate flower beds and requires no maintenance or handling of residuals. The system is designed to facilitate nutrient recycling for any sized facility, by accepting water from sinks, showers, baths, and laundry. Nutricycle Systems can provide graywater treatment systems to residential locations, as well as commercial and public facilities. Prices depend on specifications of each location (i.e. number of bedrooms, number of toilets, the floor plan, maximum daily use, etc.). Residential prices are $6,000 and $12,000. The Nutricycle Systems website listed this system as a contributor to green building credits. It also states that the system purveyor offers installation and maintenance services in Maryland and Virginia, though no information was found concerning compliance with any state, national, or international codes. For more information: http://nutricyclesystems.com/
- The **Natural Home** graywater recycling kit is a non-electric irrigation reuse kit. Graywater from the home is piped to a buried vault that settles out debris and grease, and then empties the clarified graywater to planter beds or irrigation systems. The system is $795, with free shipping and consultation. This system is only offered in the lower 48 states, and does not ship to Canada or Mexico. A similar product is also available on their website for graywater disposal for $695. No regulatory compliance information was available on the product website. For more information: http://www.thenaturalhome.com/graywater.html
- The **Aqua2use** graywater diversion device is an easy to install filtration system that uses a multi-chamber plug flow concept with four filters to trap high volumes of impurities without clogging the system. According to company documents this system can be installed above ground, half-submerged in ground, or underground, for convenience. It reuses treated graywater for lawns and gardens. The system cost is $770 and it is estimated to save a family of four 38,000 gallons (143,846 L) annually. The company is U.S. based and offers Arizona residents a 25% tax credit for installing their system. The product is shipped internationally. **Aqua2use** also offers the **Water legacy Greywater System WL55**, that uses graywater to flush toilets. It consists of a water filter, 55 gallon (208 L) storage tank, and a UV and hydrogen peroxide disinfection system. This system prides itself on requiring almost no owner intervention or monitoring. It retails for $3,000 and excludes shipping. Implications of regulatory compliance were found on each products' website, though not specifically stated. For more information: http://www.graywater-systems.com/aqua2use.htm or http://waterlegacy.com/grey-water-recycling-systems/grey-water-products.htm

Graywater Systems Available in Europe

- **AquaCycle of PONTOS** provides safe water treatment to a constantly high quality. It works using a refined, four-phase water treatment process that includes pre-filtration, two-stage biological treatment, sedimentation, and UV disinfection. Systems vary in size; the smallest can recycle up to 2,000 L (528 gallons) per day, while the largest can recycle up to 22,500 L (5,944 gallons) per day. As shown in the product brochure, the AquaCycle system is well-suited for large-scale developments, such as residence halls and hotels, but is also advertised to meet the needs of residential homes. The recycled water conforms to the European Union Bathing Water Directive 76/160/EEC. This product is offered by Hansgrohe in Germany. For more information: http://pro.hansgrohe-int.com/4253.htm
- **Ecoplay** is a water management system provided by Macdee which collects and cleans bath and shower water so it can be treated and reused for flushing the toilet. Water from the bath and shower is collected in a 100-L storage tank where a skimmer removes foam, hair and soap. Heavier particles sink to the bottom of the tank and are removed with flushing. This system offers compliance with the United Kingdom's Code for Sustainable Homes. Ecoplay systems are based out of the United Kingdom, with a distributorship in Spain. For more information: http://www.ecoplay-systems.com/

Pontos AquaCycle 2500 by Hansgrohe



Ecoplay system by Macdee

Graywater Systems Available in Australia

- The **Aqua Reviva** is a graywater treatment and recycling system. According to the most recent version of the systems technical data sheet found through an internet search, the Aqua Reviva is approved by the New South Wales Health Department, the Victorian EPA, and in the Australian Capital Territory. The Aqua Reviva System consists of a collection cell with a minimum holding capacity of 1000 L (264 gallons), a treatment cell which utilizes fixed-growth reactor technology with bromine disinfection, and storage. The system is built so that if it malfunctions, it will divert water directly to the sewer. The technical sheet was found at the web address: www.savewater.com.au/library/Aqua_Reviva/Aqua%20Reviva%20Tech%20Sheet_final.pdf

- The **Nylex Greywater Diverta** captures graywater for immediate reuse of shower, bathroom sinks, laundry sinks, and washing machines. This product helps in reducing demand for main water supply. It costs ~$187.00 plus shipping and taxes. No regulatory compliance information was provided. For more information: http://www.enviro-friendly.com/nylex-graywater-diverta.shtml
- The **Home Water Bowser Graywater Wheelie Bin** allows you to capture water from your washing machine or it can be used for rainwater collection. Its cost ranges from $449.00 to $499.00. This system comes with a four meter inlet hose for the washing machine and a twenty meter outlet hose for watering the garden. It ships to Metro Brisbane, Sydney, Melbourne, and Adelaide. No regulatory compliance information was provided. For more information: http://www.enviro-friendly.com/grey-water-bowser.shtml
- The **NETA H2grO Graywater Diverter System** is designed to collect shower and laundry water for garden irrigation. The unit can be installed outside the home and underground. It was manufactured for Australian conditions and plumbing regulations and has watermark approval to Australian Technical Specification ATS 5200.460-2005, License No 21211. Price ranges from ~$2090.00 for the manual system to $3300.00 for the electric diverter system. For more information: http://www.enviro-friendly.com/neta-h2gro-grey-water.shtml
- The **Gator Pro Greywater Diverter System** diverts graywater into the system, activating a pump that dispenses water only where it is needed. The system uses Matala® 3D Progressive multi-stage filtration that can clean thousands of gallons of graywater before the filters need cleaning. The Gator Pro costs $895-$1,044 depending on upgrades and excludes shipping cost. Its purchase reportedly qualifies Victoria residents for a $500 government rebate. For more information: http://www.enviro-friendly.com/gator-pro-grey-water.shtml
- The **Greywater Gardener 230** is an automatic water reuse system hooked up to the plumbing in the shower and sink or laundry machine. It transfers the water to a compact surge capsule outside the house. Once the water is in the capsule it slowly releases the graywater directly into the soil. The **Gardener 230** has a tank capacity of about 30.5 gallons (115 L) or 61 gallons (230 L) and provides service for over 30 years. The standard **Greywater Gardener 230 Garden 80 kit** is $3,695 and requires assembly. An installed **Gardner 230** starts from $5,995. The price includes installation by a licensed plumber. Five-hundred-dollar rebates are available in Victoria, Queensland and New South Wales. New South Wales also offer another $500 rebate for eligible participants through the NSW Government's Water Savings Fund. For more information: http://www.waterwisesystems.com/products/greywater-gardener-230/
- The **Nubian GT600 Greywater Treatment System** is an aboveground, continuous treatment unit. It requires little or no owner intervention and is capable of recycling from 500 L (132 gallons) to 100,000 L (26,420 gallons) each day, depending on the scale of the system. The Nubian GT600 Greywater Treatment System operates at the residential scale on the principles of solids separation, media filtration/adsorption and biological treatment, and UV disinfection. For commercial uses, the system is upgraded to include ultrafiltration (UF) and chlorination steps. It is recognized as an accredited graywater technology in most territories of Australia, though must be approved by local authority before installation. For more information: http://www.nubian.com.au/Residential-Greywater-Treatment-System.asp

- **Ozzi Kleen** provides both graywater treatment and rainwater harvesting products. The **GTS10 – Greywater Treatment System** was designed for the urban environment and treats graywater to standards suitable for watering gardens, laundry use or for flushing toilets. The storage tank is made of polyethylene. Ozzi Kleen meets Australian Standard AS/NZS 1546.1, License No SMKB20032. For more information: http://www.ozzikleen.com/domestic-sewerage-treatment-systems/gts10-greywater-treatment-system

Nubian GT600 Greywater Treatment System

GTS10 Greywater Treatment System by Ozzi Kleen

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