Critical Review: Regulatory Incentives and Impediments for Onsite Graywater Reuse in the United States

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ABSTRACT: Graywater is a potential water source for reducing water demand. Accordingly, a review was undertaken of graywater reuse regulations and guidelines within the 50 United States. Major issues considered included acceptability for graywater segregation as a separate wastewater stream, allowable graywater storage, onsite treatment requirements, and permitted graywater use applications. Existing regulations and plumbing codes in the different states suggest that there are impediments to overcome but also potential incentives for graywater reuse. It is encouraging that regulations in 29 states promote safe graywater reuse, but there are also inconsistencies between plumbing codes and other regulations within and among the 50 states. Impediments to graywater reuse include disallowances of graywater segregation or collection, and restriction of graywater reuse to mostly subsurface irrigation with limited indoor use permission. Ease on restrictions and guidelines to promote development of low-cost and proven treatment technologies are needed to promote graywater reuse. *Water Environ. Res.*, **85,** 650 (2013).

KEYWORDS: graywater regulations, onsite graywater treatment, urban residential graywater reuse, storage, permit, impediments, incentives, nonpotable reuse.

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Introduction

In recent years, there has been a growing interest in the development of water sustainability through conservation, water use efficiency, generation of new supplies, as well as water reuse (NRC, 2007). Implementation of water sustainability strategies present a challenge especially in regions of rapid population growth and water scarcity (Asano et al., 2007). For example, centralized water utilities in a number of states (e.g., California, Florida, and Texas) have been developing alternative water sources (e.g., seawater and brackish water), reclaiming wastewater for groundwater recharge, engaging in large-scale evaporation retardation practices in water conveyance and storage, as well as implementing various water conservation measures (GWI, 2010a). Such centralized water management options, which often involve high capital and operational costs (Gikas and Tchobanoglous, 2009), are often financed at the municipal level with limited federal government support (U.S. EPA, 2002). Development of an expanded water portfolio is even more challenging given the high cost of maintenance and upgrade of existing aging and overloaded centralized wastewater conveyance and treatment infrastructures currently serving large metropolitan areas in the United States (U.S. EPA, 2009). It is estimated that water infrastructure maintenance/upgrade for the wastewater treatment sector alone would cost the United States more than $200 billion over approximately the next 20 years (U.S. EPA, 2008). Given the current massive federal budget deficit (estimated at approximately $15 trillion [U.S. Treasury, 2012]), it may be difficult if not unrealistic for municipal governments to expect significant federal assistance for major centralized water infrastructure projects.

Given the rising burden on centralized water conveyance and treatment systems, water reuse has emerged as a viable approach toward water sustainability. Treatment of wastewater for direct aquifer recharge and industrial reuse, as well as certain irrigation applications are now widely practiced in various states (Jiménez Cisneros and Asano, 2008). There has also been a major movement to augment local water portfolios through increasing aquifer recharge via better management of stormwater (Dillon, 2005; Pitt et al., 1999) as well as rainwater harvesting at the individual household level (Jones and Hunt, 2010). The practice of rainwater harvesting is growing in the United States (Kloss, 2008). Rainwater harvesting is seen as an approach (for individual households) to reduce dependence on potable water for nonpotable water applications such as landscape irrigation (U.S. EPA, 2012). Rainwater harvesting, however, is less likely to have a significant effect in much of the Southwestern United States, which has relatively low rainfall with sparse and often unpredictable rainfall patterns (NOAA, 2012). On the other hand, it has been argued that, at the household level, graywater reuse (given appropriate point-of-use treatment) can reduce overall water consumption for nonpotable applications (Christova-Boal et al., 1996; Jeppesen, 1996; Office of Water Reclamation, 1992).

Graywater is typically defined as domestic wastewater not originated from toilets or urinals (Christova-Boal et al., 1996; Eriksson et al., 2002; Friedler, 2004). Graywater constitutes up to approximately 70% (by volume) of the total indoor wastewater generation, but with only approximately 23% of the total mass of

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Table 1—Characteristics of individual graywater streams in the United States. (Data compiled from Casanova et al., 2001; Gerba et al., 1995; Mayer and DeOreo, 1999; Rose et al., 1991; Siegrist et al., 1976).

		Graywater streams							
					Laundry machine				
Contaminant	Mixed graywater	Garbage disposal	Kitchen sink	Dish-washer	Wash	Rinse	Bath/ Shower	Hand washing basin	Shower and laundry
Volume, L/capita-day	127–151	—	18–20	4	40–57	38–49	20	—	
pH	6.7–7.5	—	—	—	—	—	—	—	6.5
Temperature, °C		21.7	26.7	38.3	32.2	28.3	29.4	—	
Turbidity, NTU	64	—	—	—	39–296	14–29	28–96	—	76
TSS, mg/L	40–43	1490	720	440	280	120	120	—	—
TVSS, mg/L	—	1270	670	370	170	69	85	—	—
COD, mg/L	65	—	—	—	—	—	—	—	—
BOD_5, mg/L	35–120	1030	1460	1040	380	150	170	—	—
TOC, mg/L	—	690	880	600	280	100	100	—	—
TN, mg/L	—	60	74	40	21	6	17	—	1.7
NH_4-N, mg/L	—	0.9	6	4.5	0.7	0.4	2	—	0.7
NO_3-N, mg/L	1.8	0	0.3	0.3	0.6	0.4	0.4	—	1
TP, mg/L	—	12	74	68	57	21	2	—	9
PO_4-P, mg/L	—	8	31	32	15	4	1	—	—
Sulfate, mg/L	60	—	—	—	—	—	—	—	23
Chloride, mg/L	21	—	—	—	—	—	—	—	9
Fecal coliform, CFU/ 100 mL	5.6×10^5–$\times10^8$	—	—	—	1400–6300	25–320	220	—	—
Total coliform, CFU/ 100 mL	6.3×10^6–2.5×10^8	—	—	—	18 000	56–5300	1100–1.0×10^5	—	2.8×10^7
Fecal Streptococci, CFU/100 mL	240	—	—	—	210	75	44	—	1.8×10^4–7.9×10^6
Total bacterial, CFU/ 100 mL	8.0×10^7	—	—	—	1×10^7–1×10^8	1×10^7–1×10^8	1×10^7–1×10^8	—	6.1×10^8

generated suspended solids (Abu Ghunmi et al., 2011; Friedler, 2004). Therefore, one would expect that widespread practice of distributed (onsite) graywater treatment and reuse could potentially lead to significant reduction in potable water demand (for nonpotable uses) and volume of household wastewater delivered to centralized water resource recovery facilities (WRRFs) (Christova-Boal et al., 1996). Indeed, it is not surprising that water-stressed countries, such as Israel (GWI, 2010b) and Australia (NSW Health Dept., 2011), are promoting graywater treatment and reuse for nonpotable applications (e.g., landscape irrigation), such as for cold-water feed for washing machines and for toilet flushing (NSW Health Dept., 2011).

In the United States, the benefits of graywater reuse are becoming increasingly recognized by water agencies (LADWP, 2012) and among green enthusiasts (Little, 2000; Ludwig, 2009). Graywater policies and regulations at the state level, however, are key to widespread adoption of onsite domestic graywater treatment and reuse. Graywater policies and regulations vary widely among individual states with respect to allowable graywater reuse applications, acceptable reuse practices, and treatment requirements. Also, the often cumbersome permitting process for graywater reuse and the lack of public education resources have adversely affected the overall acceptance and adoption of onsite graywater treatment and reuse, as well as development of standardized technological approaches in the United States (Little, 2000; Office of Water Reclamation, 1992).

Graywater policies are essential to propelling the acceptance, economic viability, and adoption of graywater reuse as a key element of water sustainability and moving toward a paradigm shift in water reuse. Accordingly, this review focuses on graywater policies and relevant regulations/guidelines within the 50 states that may affect graywater reuse. The review addresses a number of major issues regarding graywater reuse that include the acceptability of graywater as a separate domestic wastewater source that can be harvested for reuse post-onsite treatment, types of allowable graywater uses, and treatment requirements before use and storage. The roles of these policies, which influence the economic viability of graywater, are highlighted throughout the review. In addition, the incentives and impediments for onsite graywater reuse and recycling in the United States are also discussed with the goal of identifying means of fostering growth of this emerging water reuse sector.

Graywater Quality and Quantity

Domestic graywater is generated from bathtubs, showers, bathroom washbasins, clothes washing machines, laundry tubs, kitchen sinks, and dishwashers in households (Eriksson et al., 2002; Friedler, 2004). In the United States, approximately 127 to 151 L/day per person of graywater (Mayer and DeOreo, 1999) is generated on average, with laundry, baths, and shower graywater constituting the bulk of the graywater volume (Table 1). The daily generated volume of household graywater depends on personal habits and use of water-saving devices (Gregory and Leo, 2003).

Graywater is less contaminated than domestic wastewater with lower contents of total suspended solids (TSS), organic matter (e.g., BOD and COD), nutrients (e.g., nitrogen and phosphorous) and microorganisms, but with heavy metal

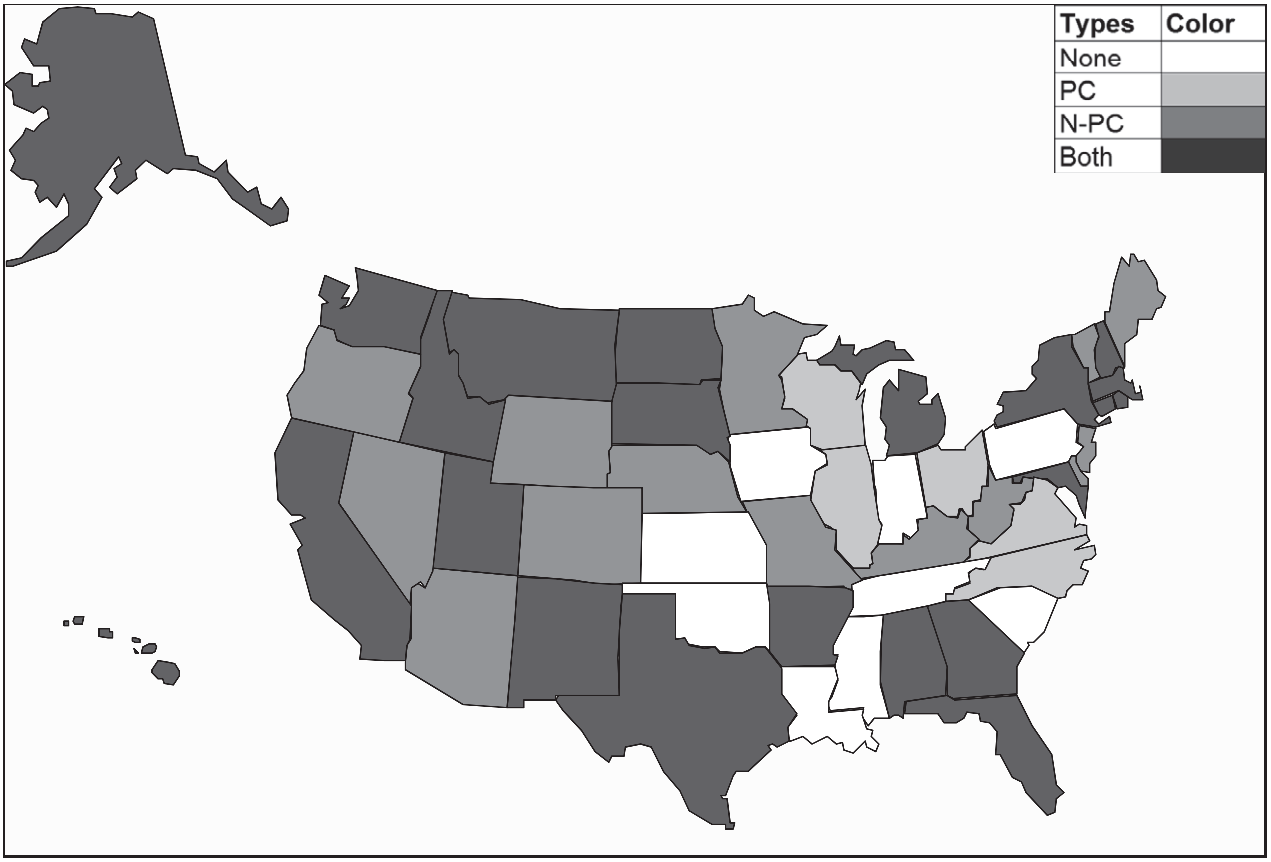

Figure 1—Provision of graywater definitions in state regulations and plumbing codesby states. (None = no regulations; PC = graywater regulations found in state plumbing codes only; N-PC = graywater regulations found in non-plumbing code regulations only; Both = graywater regulations found in both state plumbing codes and other regulations.)

concentrations similar to those in domestic wastewater (Eriksson et al., 2002). The quality of graywater can be affected by various factors including family structure (e.g., number of children and adults) (Rose et al., 1991) and the types of household cleaning and personal products used (Eriksson et al., 2002). It has been reported that graywater generated by families with young children contain higher concentration of indicator microorganisms (i.e., total and fecal coliforms) (Rose et al., 1991). Also, household and personal care products affect inorganic constituents and nutrients levels in graywater (Eriksson et al., 2002). For example, detergents can increase graywater salinity, chlorine can lead to zinc leaching from plumbing fixtures, and sunscreen and deodorant can elevate the concentration of zinc in graywater (Eriksson et al., 2002). It is noted that the content of phosphates in conventional dish detergents has been limited by 16 states (Koch, 2010) to a maximum of 0.5% (by weight), with such limit for laundry detergents mandated by 27 states (Litke, 1999).

Water quality of individual graywater streams vary depending on their origins. Kitchen graywater is the portion of graywater from dishwashers and kitchen sinks. These graywater streams are more contaminated compared to other nonkitchen graywater streams, containing more solids, oil, and grease; organics; microorganisms; and surfactant (Friedler, 2004). Kitchen graywater contributes approximately 22 to 24 L/capita-day to the total household generated wastewater volume and is a major source of solids, volatile organics, BOD, COD, nutrients (see Table 1), and microorganisms found in graywater (Casanova et al., 2001). Other sources of graywater, such as those that originate from hand-washing basins, bathtubs, showers, and laundry, contain less oil and grease, solids, and microorganisms than kitchen graywater (Casanova et al., 2001; Friedler, 2004). Nonkitchen graywater forms a major portion of domestic graywater with reported volumetric flow rate ranging from approximately 98 to 126 L/capita-day (Mayer and DeOreo, 1999). It has been reported that laundry graywater generated during wash cycles is the most contaminated of the various nonkitchen graywater sources (Friedler, 2004), whereas graywater from hand-washing basins is the least contaminated (Friedler, 2004). Microorganisms are also found in nonkitchen graywater with higher level of fecal coliforms detected in graywater from showers and the wash cycles of laundry machines (Friedler, 2004).

Graywater Regulations and Policies

Accepting and Defining Graywater. The acceptance of graywater as a separate wastewater source is a first step toward allowing its segregation, collection, treatment, and reuse. At present, 41 states provide regulatory definitions of graywater, whereas nine states are yet to include graywater in their state regulations (Figure 1). Of the 41 states that provide graywater definitions, five states define graywater only in their state

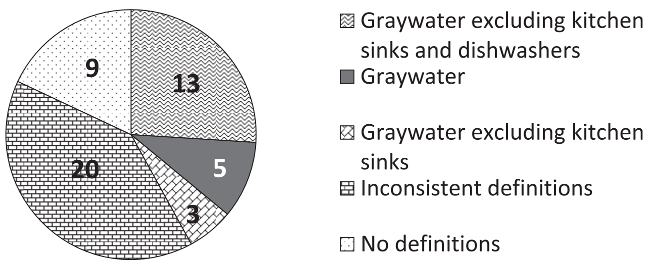

Figure 2—States with graywater definitions.

plumbing code, 14 states define graywater only in other state regulations (e.g., onsite sewage disposal regulations, water pollution control regulations, health and safety code, graywater reuse guidelines, environmental codes, House bills, water and wastewater regulations), and the remaining 22 states define graywater in plumbing codes and other state regulations (Figure 1).

Differences in regulatory definitions of graywater adopted by various states typically center on whether kitchen graywater should be included in the definition of graywater (Figure 1). In the plumbing codes of 26 states, only certain nonkitchen graywater sources are considered as graywater. The California plumbing code, for example, excludes laundry water that has been soiled by diapers from being considered as graywater (California Building Standards Commission, 2010). The Illinois and Wisconsin state plumbing codes, on the other hand, include kitchen and nonkitchen graywater as graywater (State of Illinois Adminstrative Code, 1996; Wisconsin Commerce Dept, 2011). Graywater definitions in nonplumbing code regulations of 36 states appear to emphasize either the inclusion or exclusion of kitchen graywater sources from the definition of graywater. At present, 14 of these 36 states consider only nonkitchen graywater to be graywater, 15 states include kitchen and nonkitchen graywater in their graywater definition, whereas four states include kitchen graywater from dishwashers but exclude water either from kitchen sinks or from kitchen sinks with garbage disposals. It is interesting to note that North Dakota provides guidelines for segregation of different household wastewater streams including water from kitchen sinks for the purpose of treatment and disposal (e.g., septic tanks), although it does not have an explicit regulatory definition for "graywater" (North Dakota Legislative Branch, 2000).

Among the states that have included graywater regulations in nonplumbing code regulations, three states (Hawaii, Minnesota, and Oregon) have included two different definitions of graywater in two separate regulations (Figure 2). All three states include, in the definition of graywater, light and kitchen graywater streams in one regulation. However, in a second definition of graywater in other regulations, Minnesota and Oregon exclude water from kitchen sinks with garbage disposal, whereas Hawaii excludes all water from kitchen sinks. More discrepancies regarding graywater definitions are found for states that have included graywater guidelines in plumbing codes and other state regulations. For example, it is interesting to note that 11 of the 20 states that exclude all kitchen graywater streams from graywater definitions in their plumbing codes, include kitchen graywater streams in their other state regulations.

The lack of consistent graywater definitions among the states (Figure 2) is problematic as it may complicate compliance and enforcement. Additionally, inconsistent or conflicting definitions can be perception of "legal barriers", which can reduce the level of productive cooperation (e.g., with respect to permitting) between the existing and potential future graywater reuse communities. Consistent regulatory graywater definitions are essential because these can have significant effects on the: (1) acceptance of graywater reuse, (2) the volume of graywater that can be collected and reused and/or recycled, and (3) required graywater treatment technology and the cost of such treatment. For residential onsite graywater reuse, consistent, simple and clear graywater definition is needed to enable practitioners to easily assess graywater treatment options and, accordingly, the most suitable practical treatment technology and permitted reuse applications. Inconsistent graywater definitions, within the regulations of certain states and even minor differences in graywater definitions among states, can be a hurdle that retards the widespread development of graywater treatment technology and its standardization.

The definition of graywater and allowable reuse policies may determine the economic viability of graywater systems in several ways. Most obviously, it can influence the cost of the technology needed for treatment. It may also determine the quantity of graywater available onsite, thereby influencing the minimum scale of production for an onsite system, which will determine the unit cost of treatment. At the industry level, fragmented state policies may prevent graywater technologies from reaching scales of production that would allow reduction in system costs to fall over time as has occurred for similar technologies. More inclusive graywater definitions and more consistent state policies could lead to declining graywater unit costs.

The definition of graywater and allowable reuse applications are key factors that determine the required level of graywater treatment and the technology that can be effectively implemented at the residential level. For example, homeowners may find it difficult to consistently control the reuse of laundry graywater when such water may intermittently include wastewater from washing of soiled diapers (currently excluded by graywater definitions in 12 states). Another example is the exclusion of kitchen sink graywater (with or without garbage disposals) from graywater definition. Graywater generated from kitchen sinks and dishwashers typically outflows to the same plumbing drain that is then conveyed to the main house drain. The exclusion of kitchen sink graywater from the definition of graywater (e.g., Texas, Minnesota and Oregon) means that residential graywater reuse would require additional costly plumbing connections for segregating this graywater source from dishwasher wastewater. Given the similarity in TOC, BOD, and total nitrogen levels between graywater from kitchen sinks or dishwashers (Table 1), one could argue that both water sources could be treated and reused, provided that suspended solids are effectively removed from kitchen sinks, especially those with garbage disposal systems.

Who Can Collect Graywater at Home? Establishing an unambiguous graywater definition is only an essential element of promoting onsite graywater reuse and recycling. However, having a graywater definition does not necessarily translate into the granting of permission for graywater collection, which is a necessary element of graywater reuse. For example, of the 41 states that define graywater, only 38 allow onsite graywater

Figure 3—Allowance of graywater collection.

collection, whereas 3 do not permit graywater collection. Among the 38 states that allow graywater collection, six ban graywater collection for households that have accessible sewer connections (Figure 3). The implication is that in the above states, households that are served by centralized treatment facilities cannot benefit from onsite graywater reuse. On the other hand, it is noted that 17 states allow graywater reuse irrespective of the availability of public sewer connections (Figure 3), whereas 15 states do not appear to have explicitly stated restrictions regarding graywater collection in areas served by centralized public sewer systems (Figure 3). It is reasonable to conclude that even in urban areas, onsite graywater reuse would relieve the treatment and water conveyance burden on already overloaded and aging centralized facilities. However, restriction on graywater collection, based on whether public sewers are available, would impede the growth of onsite graywater reuse because the majority of the U.S. population resides in urban areas or those served by public utilities.

Permits. The requirement of permits for onsite graywater reuse serves multiple purposes including, but not limited to, compilations of information regarding graywater reuse locations, treatment types and capacities, and oversight to ensure that installed systems meet treatment requirements for the intended/permitted water use applications. Unfortunately, the permitting process is often perceived as being tedious, time-consuming, and costly legal barrier for homeowners to cross (Little, 2000). Burdensome permitting procedures can increase the cost of deploying of graywater systems. In addition, it has been reported that lack of readily available user-friendly information concerning permit requirements and assistance, during the planning and permitting phases, can create "mental barriers" for homeowners who attempt to engage in graywater reuse (Little, 2000). However, permitting for onsite graywater collection and/or reuse is required in 30 states (Figure 4), two states (Maryland and North Carolina) do not specify if permits are required,

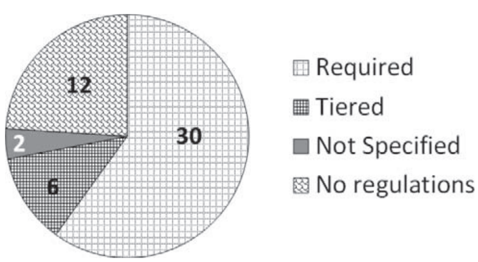

Figure 4—Permit requirements for onsite graywater reuse and/or disposal.

Table 2—Allowable daily quantity for graywater recycling systems to be operated without permits.

State	Allowable daily quantity without permits	Allowable applications without permits
Arizona	Less than 1514 L	Surface irrigation for nonedible crops without human contact
California	Volume generated by a single laundry machine serving up to two families	Subsurface irrigation of nonedible crops and subsurface irrigation
New Mexico	Less than 946 L	Discharge disposal; or nonfood crop and composting irrigation
Montana	Not specified	Toilet flushing
Texas	Less than 1514 L originating from a single-family dwelling	Nonsprayed garden or landscape irrigation, foundation stabilization, composting, disposal for a single-family dwelling
Wyoming	Less than 7571 L	Nonpotable water applications with minimal human contact

whereas six states (Arizona, California, New Mexico, Montana, Texas, and Wyoming) allow onsite graywater collection and reuse without permits subject to reuse volume thresholds (up to 7571 L in Wyoming) and reuse application (Table 2), with Montana only specifying that graywater reuse is restricted to toilet flushing without a reuse threshold volume. In California, only graywater from a single laundry machine serving up to two families can be used without permit for subsurface irrigation, which is perplexing because laundry graywater has been reported to be more contaminated than other nonkitchen graywater streams (Eriksson et al., 2002; Friedler, 2004; Siegrist et al., 1976) (Table 1). Clearly, there appears to be lack of uniformity with respect to the restrictions on allowable use or volume of graywater even among states that do not require permits for reuse.

There is a concern that permitting requirements are too restrictive and costly and permitting processes are too cumbersome and time-consuming. These may stifle the growth of graywater reuse and/or drive homeowners away seeking legitimate permitting of their graywater collection and treatment systems and reuse applications (Little, 2000; Ludwig, 2009). Graywater reuse permits, if established by regulators, can be an effective instrument that encourages compliance and promotes effective graywater reuse with the goal of fostering environmental protection. However, in order for the permitting process to be beneficial to homeowners, there should be sufficient public education resources and assistance, during the permitting process regarding graywater reuse systems planning and installation phases.

Reuse Water Quality. Public and regulatory concerns regarding potential of human exposure to pathogens (Casanova et al., 2001; Noah, 2002; Rose et al., 1991) as a consequence of onsite graywater reuse has prompted the call for establishing protective guidelines/regulations. At present, 35 of the 38 states that allow graywater reuse do not have established graywater quality criteria for reuse, whereas three have specific water quality

Table 3—Water quality criteria for onsite graywater reuse.[a]

Standards	Type of reuse	Treatment level equivalent	Water quality criteria
Alabama	Drip irrigation	Secondary	Secondary with filtration
California	Subsurface irrigation	Primary	Not specified
	Aboveground nonpotable reuse	Disinfected tertiary (Title 22 Recycled Water quality)	Turbidity: 2 NTU (avg); 5 NTU (max) Total coliform: 2.2 MPN/100 mL (avg), 23/100 mL (max in 30 days)
Wisconsin	Subsurface irrigation	Secondary	$\leq$ 15 mg/L oil and grease; $\leq$ 30 mg/L BOD_5 $\leq$ 35 mg/L TSS; $<$ 200 fecal coliform cfu/100 mL
	Surface irrigation except food crops, vehicle washing, clothes washing, air conditioning, soil compaction, dust control, washing aggregate, and making concrete	Disinfected tertiary	pH 6–9; $\leq$ 10 mg/L BOD_5; $\leq$ 5 mg/L TSS Free chlorine residual 1.0–10 mg/L
	Toilet and urinal flushing	Disinfected primary with filtration	pH 6–9; 200 mg/L BOD_5; $\leq$ 5 mg/L TSS Free chlorine residual 0.1–4.0 mg/L

[a] States that provide specific water quality requirements for treated graywater.

requirements as listed in Table 3. The above 35 states have adopted one or more of the following guidelines for reducing human exposure to graywater: (1) allow only subsurface irrigation or disposal (16 states), (2) also allow above surface irrigation but disallow spray irrigation (four states), and (3) allow use of graywater for toilet flushing (seven states).

Graywater treatment standards (with respect to achievable treated water quality) have been established by the states of Alabama, California, and Wisconsin (Table 3). Alabama only reports graywater treatment for drip irrigation to secondary wastewater effluent standard with post-filtration prior to use in drip irrigation. However, treatment is not required of graywater bound for underground disposal in Alabama. Also, water quality criteria are not provided for graywater reuse for toilet flushing. California requires that graywater reused for nonpotable aboveground and indoor (e.g., toilet flushing) applications must be treated to achieve water quality equivalent (at the minimum) to that of disinfected tertiary wastewater effluent (see Table 3). It is noted that Wisconsin adopted separate water quality standard for subsurface irrigation, toilet flushing, and other aboveground nonpotable reuse applications (Table 3). Graywater reused for toilet and urinal flushing requires treatment to at least disinfected filtered primary wastewater effluent, subsurface irrigation requires graywater treatment to secondary wastewater effluent quality, whereas aboveground nonpotable reuse of graywater requires treatment to the quality level of disinfected tertiary wastewater effluent.

Although the above approaches are sincere attempts to reduce potential exposures to contaminants that may be present in graywater, certain requirements may be seen as either too restrictive or too lax, or there is lack of clarity regarding allowable reuse applications. For example, although allowance of direct reuse of graywater (i.e., without treatment) for subsurface in California and direct disposal in Alabama may be consistent with reduction of human exposure (to graywater), there remains the potential for soil subsurface and groundwater contamination. Allowed graywater reuse by 35 states without specification of treatment levels or water quality is also troubling from the viewpoint of public health and environmental protection. For example, it has been reported that use of untreated graywater for irrigation (i.e., primary effluent quality) can lead to reduced water infiltration and increase soil salinity and levels of various organic and inorganic contaminant in the vadose zone (Al-Hamaiedeh and Bino, 2010; Travis et al., 2008; Wiel-Shafran et al., 2006).

Graywater Reuse Applications. Graywater reuse can provide an alternative nonpotable water source to augment potable water use and reduce the overall discharge of wastewater into centralized water treatment facilities. Therefore, there are economic benefits of graywater with respect to quantity and value of portable water that it replaces as well as the wastewater treatment costs that it avoids. The size of both of these benefits could be determined by the range of acceptable graywater reuses that are permitted by policy. In the United States, 18 states allow outdoor nonpotable graywater reuse (whether treated or non-treated), seven states allow indoor reuse (e.g., toilet flushing) with various levels of treatment, and nine states only allow graywater disposal at various required treatment levels. The allowable water applications, as specified in various graywater regulations in the United States, include the following main categories (Figure 5): irrigation (landscape, compost, above-ground, and subsurface), toilet flushing, and other aboveground nonpotable uses (e.g., laundry machines water feed, dust control, and vehicle washing). Subsurface irrigation is allowed by the largest number of states (18), followed by surface irrigation by means other than spray irrigation (nine).

Graywater that undergoes appropriate treatment, is clearly identified by seven states as being allowed for indoor use (e.g., toilet flushing). Also, treatment of graywater for outdoor reuse (e.g., irrigation) may require different levels of treatment. Although irrigation is favored by a large number of states, water saving benefits can be limited in regions with abundant rainfall, winter temperature that drops below freezing (Washington State Legislature, 2011), and poor soil drainage (IAPMO, 2009; ICC, 2009). Furthermore, if the groundwater table is too shallow, discharging untreated graywater or partially treated graywater to the ground for irrigation is prohibited, such as in California (California Building Standards Commission, 2010) and Arkansas (Arkansas State Board of Health, 2012). Also, restrictions of subsurface as opposed to above surface irrigation increases the cost of graywater reuse for irrigation. In the United States, it appears that regulations advocate subsurface outdoor irrigation and subsurface disposal of graywater, whereas graywater for toilet flushing is the major permitted indoor reuse application (Figure 5). It is noted that, 11 of the 18 states that allow graywater reuse for toilet flushing appear to have

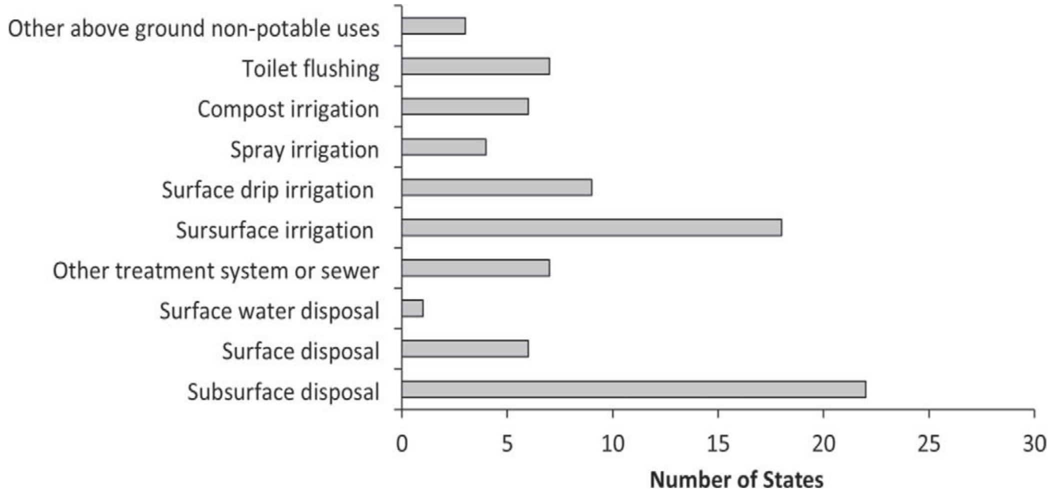

Figure 5—Beneficial graywater uses and disposal methods in the 38 states that allow graywater collection. Evaluation excluded 11 states under the "Toilet flushing" category, 10 under "Subsurface irrigation", and one under "Subsurface disposal" because of apparent inconsistencies in the above categories between their state plumbing codes and other state regulations.

inconsistent regulations regarding whether it is acceptable to reuse graywater for toilet flushing (Figure 5). California and Wisconsin specify the allowed use of treated graywater as feed water for washing machines and for car washing (see Table 3). The above range of graywater reuse applications is limited. In this regard, broadening the type of permitted indoor and outdoor uses of graywater would clearly expand the beneficial use of graywater and thus also more likely to improve the economics of graywater reuse.

Regulations and/or codes regarding beneficial graywater reuse, which have been indicated in 38 states, can serve to encourage and guide the development of the practice of graywater reuse. There are, however, conflicting regulations whereby a given state regulation or code may permit specific graywater management or reuse options, whereas the same options may be disallowed by another regulation in the same state (Figure 6). For example, although nonplumbing regulations for 11 states state that graywater can only be disposed of underground, these same states' plumbing codes permit toilet flushing with disinfected primary treated graywater. If state regulations regarding graywater by different agencies within the same state (e.g., building departments, public health, and environmental protection agencies) are confusing in the planning and permitting stage of graywater management, they may become a deterrent to the growth of this sector of water reuse.

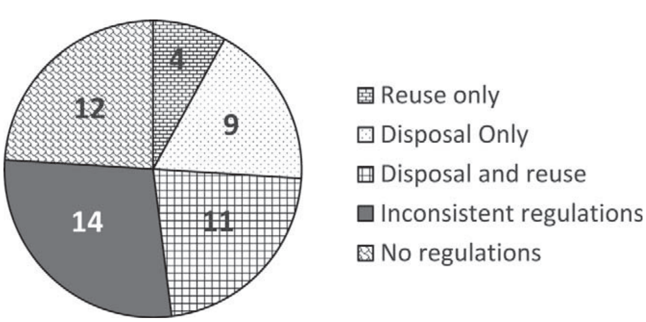

Figure 6—States allowing graywater reuse and/or disposal.

Graywater Treatment Requirements. Specification of the level of graywater treatment that is appropriate for the intended water reuse application is key to safeguarding public health and the environment. However, differences in treated graywater water quality requirements for a given reuse application, storage, or disposal, can differ from state to state (Figure 7). Gravitational settling of solids in storage tanks is the most common primary treatment method for subsurface irrigation and toilet flushing. Primary treatment is required for treating graywater reused for subsurface irrigation (20 states), aboveground irrigation that excludes spray irrigation (three states) and toilet flushing (13 states). Septic tanks are specified by New York and South Dakota as the required or acceptable graywater treatment method for subsurface and/or aboveground irrigation (except spray irrigation); whereas in South Dakota, septic tanks are specified as suitable for toilet flushing reuse of graywater (South Dakota Environment and Natural Resources Dept, 1996). It has been suggested that graywater that is used for irrigation after only primary treatment may have a negative effect on some plants as well as altering soil drainage and adsorption properties (Al-Hamaiedeh and Bino, 2010; Travis et al., 2010); these studies suggest that the suitability of only primary treatment for irrigation requires further evaluation. It is noted that secondary treatment (i.e., BOD removal) is required by three states (Alabama, Alaska, and Wisconsin) for subsurface and surface irrigation that excludes spray irrigation. The use of tertiary treatment with disinfection using chlorine or other proven disinfection technology is only required in the states of California (for all aboveground nonpotable graywater uses) and Wisconsin (for all aboveground except toilet flushing) (Table 3). It is noted that the provision regarding residual chlorine in treated effluent is only specified by Wisconsin. California specifies that the quality of treated graywater for aboveground nonpotable reuse must meet Title 22 Recycled Water quality (California Building Standards Commission, 2010).

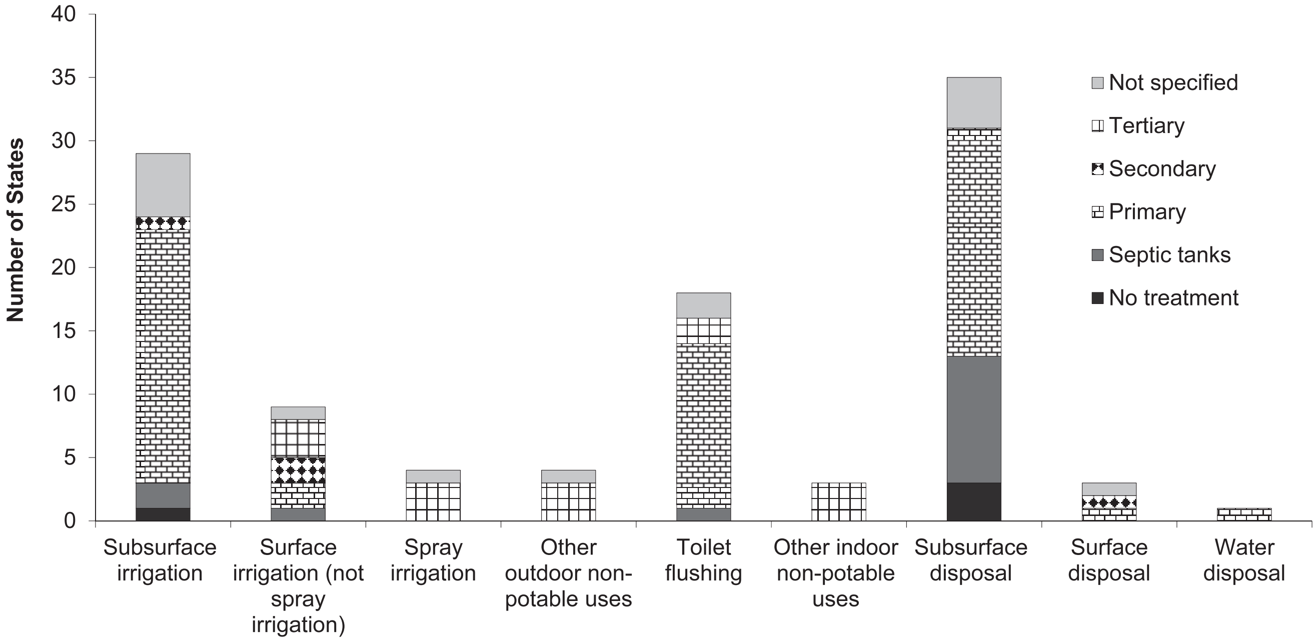

Figure 7—Treatment requirement for allowable graywater reuse applications and disposal in the United States. Evaluation includes acceptable alternatives stated in plumbing codes and other state regulations.

Detailed graywater treatment process specifications are available in two widely adopted standard plumbing codes: the International Plumbing Code (IPC) (10 states) and the Uniform Plumbing Code (UPC) (eight states). Treatment process specifications for primary treatment for subsurface irrigation or disposal are presented in both IPC and UPC (Figure 8). The main difference between the above specifications is that IPC specifies filtration of graywater before entering the storage tanks (Figure 8b), whereas UPC requires filtration when graywater is drawn from a storage tank before entering the subsurface irrigation or disposal systems (Figure 8a). Another primary treatment design specification is presented in IPC for graywater use for toilet/urinal flushing. Such a system is similar to the primary treatment system used for subsurface irrigation, except that it requires potable makeup water supply to the storage tank, and it also requires

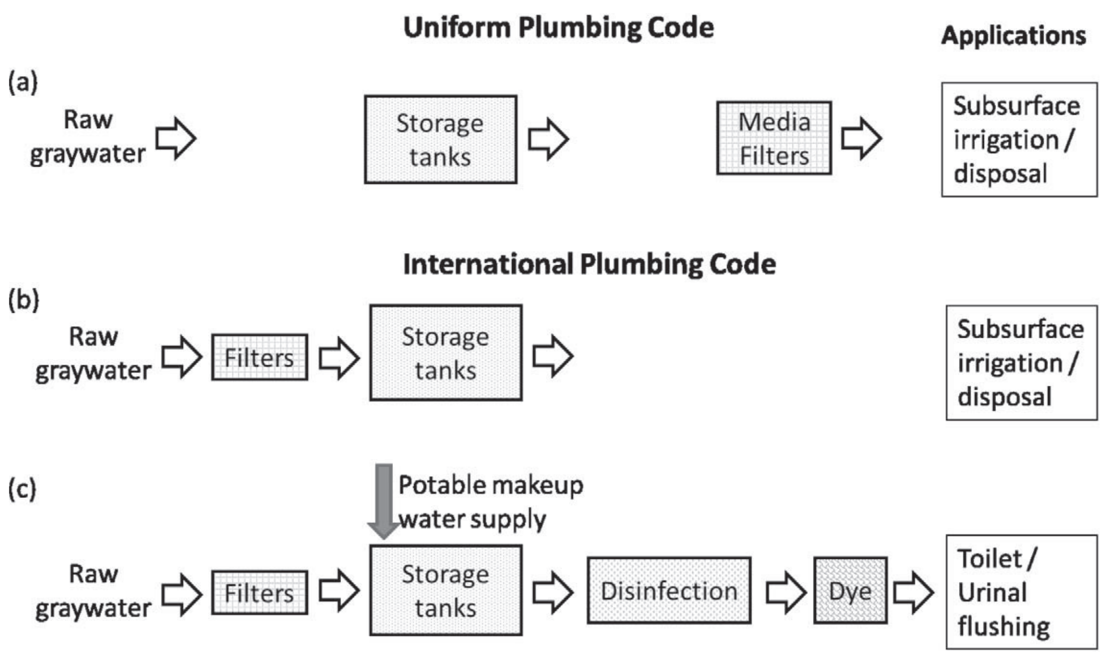

Figure 8—Graywater treatment processes specified in the Uniform Plumbing Code (UPC) for subsurface irrigation and the International Plumbing Code (IPC) for subsurface irrigation/disposal and toilet flushing.

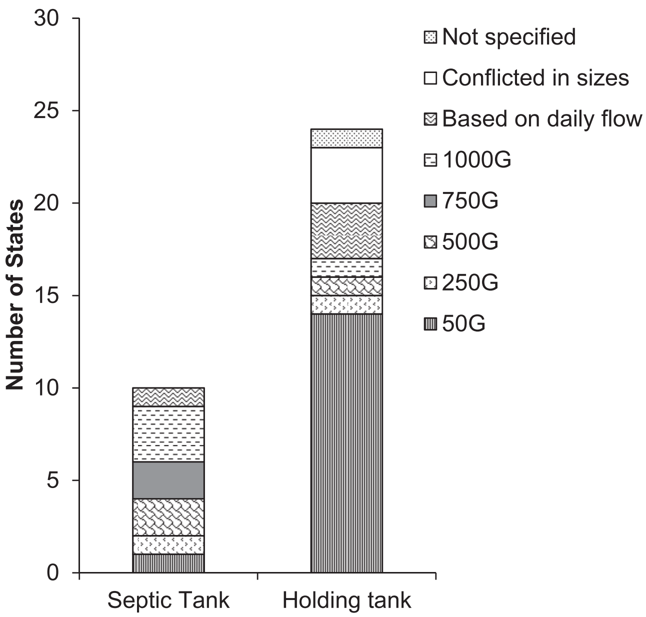

Figure 9—Minimum storage volume requirements.

disinfection and coloring of graywater just before reuse for toilet flushing (Figure 8c).

Graywater Disposal. Land disposal of primary treated graywater is practiced in 18 states, whereas septic tank effluent disposal/treatment is practiced in 10 states (Figure 7). California and Maine, however, permit subsurface disposal (or irrigation) of untreated laundry graywater, whereas disposal into a mini-dry well is allowed in New Hampshire. Ground surface and water discharge of secondary treated graywater is acceptable in Alaska. Onsite disposal (i.e., to subsurface, above surface, or natural waterbody) of graywater treated to various levels is allowed by 34 states (Figure 6) with nine of those states disallowing any reuses including subsurface irrigation. Allowing only onsite disposal but not subsurface irrigation is perplexing. Such a restriction on graywater management: (a) removes the local economic benefits of water reuse and (b) eliminates the benefit of reducing the burden on centralized WRRFs. It is not unreasonable to assert that onsite disposal would provide little incentive to homeowners unless such a practice would also reduce their sewer charges.

Storage. Graywater storage is an essential component of onsite graywater management because graywater generation is intermittent. Additionally, raw graywater storage tanks enable primary treatment through gravitational settling. Storage can be in either a holding tank (which can be either above or below ground) or via septic tanks, which by their nature are installed below the surface. It has been reported that TSS and COD are reduced when graywater is stored in holding tanks for approximately 24 hours; however, odor problem can arise if graywater is stored for more than approximately 48 hours (Dixon et al., 2000). On the other hand, when septic tanks are used, overall effluent quality improves with longer retention times (Ludwig, 2009).

The required storage volume depends on the household level of graywater generation, demand for graywater reuse capacity, and specific regulatory specifications. It is estimated that an average household of two to three people generates approximately 379 L of nonkitchen graywater per day (DeOreo and Hayden, 2008); thus, one would expect the need for storage of approximately the same volume or greater. Presently, 26 states specify the minimum onsite storage requirements in state regulations, with 189 L specified by 15 states, 946 L or above by eight states and 3785 L by four states (Figure 9 and Table 4). A few states (New York, Kentucky, New Mexico, and Wisconsin) specify graywater storage volume requirements on the basis of household size and daily volume of generated graywater. Also, six states do not provide requirements with respect to graywater storage. Inconsistencies between regulations in a given state regarding storage size and sizing requirements are found in six states (Table 4).

Storing untreated graywater (i.e., primary effluent) in holding tanks that are too large (larger than required household capacity) or storage times that are too long can create nuisance in residential homes (Dixon et al., 2000; Ludwig, 2009). It has been suggested that untreated graywater that is stored in holding tanks for up to a day should be drained daily to avoid septic conditions from developing by aged untreated graywater (Ludwig, 2009). Long storage times may be problematic, for example, when toilet flushing is the intended use, as it could create environmental nuisance for homeowners. To properly handle excess capacity of graywater via storage it has been suggested that: (1) graywater to be stored should receive at least secondary treatment; (2) untreated graywater could be stored in septic tanks, although this approach would make graywater unavailable for other reuse applications except for subsurface irrigation and disposal; and (3) storage tanks for raw graywater could be undersized so as to allow overflow to the sewer and thus minimize the risk of storing untreated graywater for prolonged periods.

Regulations Incentives and Impediments

Incentives. Although the graywater sector in the United States is still in its early development, there are encouraging signs that regulators are working to lower regulatory barriers, thereby encouraging onsite graywater reuse and recycling. Typical regulatory actions that represent positive movement toward expansion of the graywater sector include: (1) provision of regulatory definitions of graywater; (2) allowance of graywater collection in areas with sewer connections; (3) simplifying the process of permitting or registering residential graywater collection, treatment, and reuse systems; and (4) allowance of diversified graywater use applications.

The provision and inclusion of graywater definitions in the plumbing codes and other state regulations for 41 states (Figure 1) suggests that most states accept graywater as a separable stream of domestic wastewater having water quality characteristics different from domestic wastewater and black water. Although the provision of regulatory definitions does not always translate into granting homeowners permission for collecting and reusing graywater, it represents an important first step toward allowing graywater reuse. Additionally, allowance of graywater reuse by 29 states (Figure 6) demonstrates acceptance of graywater as an alternative water source for nonpotable applications. Approximately 75% of homes in the United States are served by public sewers (U.S. Census Bureau, 1990), hence allowing these homes to collect graywater is an important step toward point-of-use graywater recycling. Such a move would help relieve the burden on centralized WRRFs. The fact that 17

Table 4—Graywater storage requirements specified by 38 states that allow graywater segregation and collection (HT = holding tanks; ST = septic tanks; TF = toilet flushing; SI = subsurface irrigation; NS = not specified; NA = not applicable).

	Other state regulations			Plumbing code		
States	Tank type	Minimum volume, liter	Holding time, hours	Tank type	Minimum volume, liter	Holding time, hours
Alabama	HT	3785	48	HT	189	SI: 24; TF: 72
Alaska	HT	189	NS	HT	189	NS
Arizona	HT	NS	NS		NA	
Arkansas	HT	189	NS	HT	189	NS
California		NA	HT	NS	NS	
Colorado	ST	1893	30		NA	
Connecticut	ST	1893	24	HT	189 L	TF: 72
Florida	ST	946	NS	HT	189 L	SI: 24; TF: 72
Georgia	HT	1893	NS	HT	TF: daily use	TF: 24
Hawaii	HT	189	24	HT	NS	NS
	HT	2271	NS			
Idaho	HT	189	NS	HT	189 L	NS
Kentucky	HT	×2 design flow	NS		NA	
Maine[a]	ST	2839	NS		NA	
Maryland		NA	NS	NS	NS	
Massachusetts	ST	3785	NS	NS	NS	NS
Michigan	HT	189	NS	HT	TF: 189 L; SI: daily use	SI: 24; TF: 72
Minnesota[a]	ST	2839	NS			
Missouri[a]	HT	3785	NS		NA	
Montana	HT	189	NS	HT	189 L	NS
Nevada	HT	189	NS		NA	
New Hampshire	HT	189	NS	HT	TF: 189 L; SI: NS	SI: 24; TF: 72
New Jersey[a]	ST	946	NS		NA	
New Mexico	HT	Daily use	24		NA	
New York	ST	284/bedroom-day	NS	HT	TF: 189 L	TF: 72
North Carolina	HT	189	NS	HT	TF: 189 L; SI: NS	TF: 72; SI: 24
North Dakota	ST	189	NS	HT	189 L	NS
Ohio	NS	NS	NS	NS	NS	NS
Oregon[a]	NS	NS	NS		NA	
Rhode Island	HT	NS	NS	HT	NS	NS
South Dakota	HT	189	72	HT	TF: 189 L	TF: 72
Texas	HT	189	NS	HT	TF: 189 L; SI: daily use	TF: 72; SI: 24
Utah	HT	946	NS	HT	TF: 189 L	TF: 72
Vermont[a]	ST	3785	NS		NA	
Virginia		NA	NS	NS	NS	
Washington	HT	NS	24		NA	
West Virginia[a]	ST	1893	NS		NA	
Wisconsin		NA	HT	246/bedroom-day	NS	
Wyoming	HT	189	24		NA	

[a] State allows onsite disposal but not reuse.

states already allow graywater collection in areas with public sewer access (Figure 3), suggests that there is already national movement forward for graywater reuse in residential areas.

It has been suggested that when the graywater reuse permitting processes is time-consuming and costly, homeowners can be led to either abandon the idea of graywater reuse, or may opt for unpermitted reuse activities (Little, 2000; Ludwig, 2009). It is interesting to note that six states do not require permits for reuse of untreated graywater, but place restrictions on the maximum reuse quantity and specific reuse applications (Table 3). Given various concerns regarding potential health effects associated with graywater reuse (Casanova et al., 2001; Noah, 2002; Rose et al., 1991), it is imperative that the permitting process addresses the need for identifying homes and other residential/commercial facilities in which graywater reuse is practiced. Moreover, the permitting process should not be imposing. Instead, it should be useful in promoting responsible graywater reuse.

Although graywater reuse applications for outdoor irrigation and toilet flushing are permitted in 18 and seven states, respectively (Figure 5), available graywater capacity may be higher than the volume demand in most urban centers (DeOreo and Hayden, 2008). Therefore, broadening the permitted graywater nonpotable reuse applications beyond outdoor irrigation and including toilet flushing would provide homeowners greater flexibility over graywater reuse particularly in areas in which irrigation needs can vary considerably over the course of the year. Broadening the range of permitted outdoor (e.g., car washing and dust control) and indoor (e.g., irrigation and laundry) nonpotable reuse would increase the available capacity for reuse, with minimal plumbing retrofit, and thus increase the economic value of graywater reuse.

Impediments. Inconsistent graywater definitions and reuse regulations between state plumbing codes and other state regulations (Figures 2 and 6 and Table 4), for the same state, can lead to confusion regarding agency jurisdiction for enforcement, graywater storage and treatment requirements and allowable graywater reuse applications. It is also noted that whereas nine states only allow graywater disposal but not reuse, 12 states do not provide graywater reuse regulations. The term *graywater systems* often does not clearly differentiate between graywater collection, storage, and treatment systems. Moreover, state graywater regulations do not specify the required effluent water quality produced by such a system. In contrast, the IPC and UPC provide specific details regarding graywater system components, plumbing connections, treatment processes, and reuse applications (Figure 9). However, the entirety of the IPC and UPC are not followed by most states because the states typically include various amendments/additional restrictive regulations to their own plumbing codes and/or other state regulations. The full benefit of graywater reuse is limited in most states, primarily as a result of restriction on graywater storage volume and limitations of outdoor reuse to mostly irrigation (18 states, see Figure 5). Requirements for installation of large raw graywater storage tanks (Figure 9 and Table 4) may be infeasible in most urban areas, whereas nuisance (e.g., odor) created by prolonged storage of raw graywater could discourage residential graywater reuse. Clearly, lower storage capacity would be appropriate by increasing the allowed range of graywater reuse applications beyond simply outdoor irrigation (Figure 5). Irrigation opportunities are particularly limited in densely populated areas (small outdoor areas), and requirements of subsurface irrigation adds to the cost of graywater reuse, especially when the graywater volume demand for irrigation is below the generated graywater capacity. The restriction of outdoor nonpotable graywater reuse to irrigation is suggestive of a conservative regulatory approach to public health protection. Although reuse of untreated or primary treated graywater for subsurface irrigation is likely to minimize direct human contact, contaminants in graywater, which are introduced to the soil subsurface, may be of environmental concern. Therefore, to broaden the range of nonpotable graywater reuse applications (e.g., laundry feed water, vehicle washing, and dust control), while alleviating public health concerns, use of adequate treatment could be suggested in graywater regulations. Moreover, certification of graywater systems that meet regulatory standards could be more beneficial to homeowners than specific requirements of water quality standards. For example, the Australian New South Wales Department of Health provides certificates for accreditation of graywater treatment systems for irrigation, toilet flushing, and cold-water supply to washing machines (NSW Health Dept, 2011). Also, the National Sanitation Foundation (NSF) published *NSF/ANSI Standard 350: On-site Residential and Commercial Water Reuse Treatment Systems* for certification of graywater treatment systems that produce treated effluent suitable for nonpotable applications (Bruursema, 2011). Certification of graywater systems and/or technologies could encourage the development of low-cost graywater systems, which will then expand this water reuse sector.

Residential homeowners should not be expected to have the capability of conducting detailed monitoring of treated graywater quality and treatment system performance as would be expected in centralized WRRFs. For example, meeting strict requirements of water quality as set forth by California and Wisconsin (Table 2), for nonpotable reuse application in residential homes would be extremely demanding for homeowners. Moreover, enforcement and monitoring of graywater reuse based on water quality criteria stipulated by California and Wisconsin will be a challenge. In this regard, homeowners would benefit from graywater reuse regulations or guidelines that provide guidance with respect to use of best treatment practices, as well as acceptable low-cost water quality testing methods that could be carried out by homeowners.

Finally, to the authors' knowledge, no state policies require wastewater utilities to credit graywater producers/consumers for reducing the quantity of wastewater that must be treated by the sewerage system. Such a credit system may appear at first glance difficult to accomplish administratively. Most wastewater charges are calculated as multipliers on the quantity of water sold to a homeowner or business. However, the graywater permitting process represents an opportunity to calculate the quantity or percentage of wastewater diverted into the graywater system. The utility would then need only adjusts the household's wastewater multiplier to credit them on their bill for the cost savings that the household provides the wastewater utility.

Closure

Review of graywater reuse regulations with respect to restrictions, definitions, reuse water quality criteria, types of reuse applications, treatment, and storage requirements concerning onsite graywater collection, treatment, and reuse in the United States suggests the existence of a number of impediments to overcome and possible key incentives for growth of this important water sector. Although regulations for promoting safe graywater reuse are provided by 29 states, inconsistencies between state plumbing codes and other state regulations (22 states) make implementation of graywater reuse a challenge and unnecessarily costly. Whereas graywater is accepted as a separate wastewater stream by 41 states (three explicitly do not allow graywater segregation or collection), some disallow collection for areas serviced by centralized sewer systems, disallow segregation and/or collection, exclude kitchen graywater (5 to 10% of total indoor water use) or disallow a host of nonpotable reuse applications (even with treatment). Graywater reuse is typically permitted for irrigation but is mostly restricted to outdoor subsurface irrigation (18 states) and/or indoor toilet flushing (seven states) with primary treatment. Graywater reuse applications for aboveground irrigation and other nonpotable outdoor or indoor reuse applications are typically disallowed. Restrictions on graywater reuse applications reduce the usable graywater reuse capacity and thus the size of the derived economic benefits.

Graywater reuse has been practiced over the centuries and will continue to be practiced (in many areas in the United States and around the world) whether regulated or not. In these times of increasing water scarcity and need to establish sustainable water use practices, it is imperative that the development of well-designed graywater reuse regulations and technologies are encouraged to ensure safe and responsible graywater reuse.

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References

Abu Ghunmi, L.; Zeeman, G.; Fayyad, M.; van Lier, J. B. (2011) Grey Water Treatment Systems: A Review. *Crit. Rev. Environ. Sci. Technol*, **41,** 657–698.

Al-Hamaiedeh, H.; Bino, M. (2010) Effect of Treated Grey Water Reuse in Irrigation on Soil and Plants. *Desalination*, **256,** 115–119.

Arkansas State Board of Health (2012) *Rules and Regulations Pertaining to Onsite Wastewater Systems, Designated Representatives and Installers*; Arkansas State Board of Health, Department of Health and Human Services: Little Rock, Arkansas; p 63.

Asano, T.; Burton, F. L.; Leverenz, H. L.; Tsuchihashi, R.; Tchobanoglous, G. (2007) *Water Reuse : Issues, Technology, and Applications*. McGraw-Hill: New York.

Bruursema, T. (2011) The New NSF 350 and 350-1. *Plumbing Systems & Design Magazine*.

California Building Standards Commission (2010) *2010 California Plumbing Code,* Title 24, Part 5; California Building Standards Commission: Sacramento, California; International Association of Plumbing and Mechanical Officials: .

Casanova, L. M.; Little, V.; Frye, R. J.; Gerba, C. P. (2001) A Survey of the Microbial Quality of Recycled Household Graywater. *J. Am. Water Resour. Assoc*., **37,** 1313–1319.

Christova-Boal, D.; Eden, R. E.; McFarlane, S. (1996) An Investigation into Greywater Reuse for Urban Residential Properties. *Desalination*, **106,** 391–397.

DeOreo, W. B.; Hayden, M. (2008) *Analysis of Water Use Patterns in Multifamily Residences*; Final Report; Aquacraft, Inc. Water Engineering and Management: Boulder, Colorado.

Dillon, P. (2005) Future Management of Aquifer Recharge. *Hydrogeol. J.*, **13,** 313–316.

Dixon, A.; Butler, D.; Fewkes, A.; Robinson, M. (2000) Measurement and Modelling of Quality Changes in Stored Untreated Grey Water. *Urban Water*, **1,** 293–306.

Eriksson, E.; Auffarth, K.; Henze, M.; Ledin, A. (2002) Characteristics of Grey Wastewater. *Urban Water*, **4,** 85–104.

Friedler, E. (2004) Quality of Individual Domestic Greywater Streams and Its Implication for On-site Treatment and Reuse Possibilities. *Environ. Technol*., **25,** 997–1008.

Gerba, C. P.; Straub, T. M.; Rose, J. B.; Karpiscak, M. M.; Foster, K. E.; Brittain, R. G. (1995) Water-Quality Study of Graywater Treatment Systems. *Water Resour. Bull*., **31,** 109–116.

Gikas, P.; Tchobanoglous, G. (2009) The Role of Satellite and Decentralized Strategies in Water Resources Management. *J. Environ. Manage.,* **90,** 144–152.

Gregory, G. D.; Leo, M. D. (2003) Repeated Behavior and Environmental Psychology: The Role of Personal Involvement and Habit Formation in Explaining Water Consumption. *J. Appl. Soc. Psychol*., **33,** 1261–1296.

GWI (2010a) *Municipal Water Reuse Markets 2010*; Media Analytics: Oxford, U.K.

GWI (2010b) New Bill Allows for Grey Water Reuse. *Global Water Intell.,* **11** (7).

International Association of Plumbing & Mechanical Officials (IAMPO) (2009) *2009 Uniform Plumbing Code*; International Association of Plumbing & Mechanical Officials: Ontario, California.

International Code Council (ICC) (2009) *2009 International Plumbing Code*; International Code Council: Country Club Hills, Illinois.

Jeppesen, B. (1996) Domestic Greywater Re-Use: Australia's Challenge for the Future. *Desalination*, **106,** 311–315.

Jiménez Cisneros, B. E.; Asano, T. (2008) *Water Reuse: An International Survey of Current Practice, Issues and Needs*; IWA Publishers: London.

Jones, M. P.; Hunt, W. F. (2010) Performance of Rainwater Harvesting Systems in the Southeastern United States. *Resour. Conserv. Recycl*., **54,** 623–629.

Kloss, C. (2008) *Managing Wet Weather with Green Infrastructure Municipal Handbook Rainwater Harvesting Policies;* U.S. Environmental Protection Agency: Washington, D.C.

Koch, W. (2010) 16 States Ban Phosphate-Laden Dishwasher Soap. *USA Today* (June 30).

Los Angeles Department of Water and Power (LADWP) (2012) *Go Green: Graywater;* Los Angeles Department of Water and Power: Los Angeles, California.

Litke, D. W. (1999) *Review of Phosphorus Control Measures in the United States and Their Effects on Water Quality;* Water Resources Investigations Report 99–4007; U.S. Geological Survey, Geological Survey Information Services: Denver, Colorado.

Little, V. L. (2000) *Residential Graywater Reuse : The Good, the Bad, the Healthy in Pima County, Arizona: A Survey of Current Residential Graywater Reuse*. Water Resources Research Center, University of Arizona: Tucson, Arizona.

Ludwig, A. (2009) *The New Create an Oasis with Greywater: Choosing, Building and Using Greywater Systems; Includes Branched Drains*; Oasis Design: Santa Barbara, California.

Mayer, P. W.; DeOreo, W. B. (1999) *Residential End Uses of Water*; Report No. 1583210164; American Water Works Association: Denver, Colorado.

National Oceanic and Atmospheric Administration (2012) *National Temperature and Precipitation Maps;* National Climatic Data Center, National Oceanic and Atmospheric Administration Satellite and Information Service: Washington, D.C.

National Research Council (NRC) (2007) *Improving the Nation's Water Security: Opportunities for Research*; Committee on Water System Security Research, National Research Council; The National Academies Press: Washington, D.C.

Noah, M. (2002) Graywater Use Still a Gray Area. *J. Environ. Health*, **64,** 22–25.

North Dakota Legislative Branch (2000) *Private Sewage Disposal Systems;* Chapter 62-03.1–03; State of North Dakota: Bismarck, North Dakota.

NSW Health Dept. (2011) *Greywater Treatment Systems: Register — Certificates of Accreditation;* New South Wales Department of Health: Sydney, Australia.

Office of Water Reclamation (1992) *Gray Water Pilot Project;* Final Project Report; Office of Water Reclamation, City of Los Angeles: Los Angeles, California.

Pitt, R.; Clark, S.; Field, R. (1999) Groundwater Contamination Potential from Stormwater Infiltration Practices. *Urban Water*, **1,** 217–236.

Rose, J. B.; Sun, G.-S.; Gerba, C. P.; Sinclair, N. A. (1991) Microbial Quality and Persistence of Enteric Pathogens in Graywater from Various Household Sources. *Water Res.,* **25,** 37–42.

Siegrist, R.; Witt, M.; Boyle, W. C. (1976) Characteristics of Rural Household Wastewater. *J. Environ. Eng. Div. (Am. Soc. Civ. Eng.)*, **102,** 533–548.

South Dakota Environment and Natural Resources Dept. (1996) *Individual and Small On-site Wastewater Systems*; South Dakota Legislature Administrative Rules: Pierre, South Dakota.

State of Illinois Adminstrative Code (1996) *Private Sewage Disposal Code,* Title 77; Illinois Department of Public Health: Springfield, Illinois.

Travis, M. J.; Weisbrod, N.; Gross, A. (2008) Accumulation of Oil and Grease in Soils Irrigated with Greywater and Their Potential Role in Soil Water Repellency. *Sci. Total Environ*., **394,** 68–74.

Travis, M. J.; Wiel-Shafran, A.; Weisbrod, N.; Adar, E.; Gross, A. (2010) Greywater Reuse for Irrigation: Effect on Soil Properties. *Sci. Total Environ.*, **408,** 2501–2508.

U.S. Census Bureau (1990) *U.S. Census Data on Small Community Housing and Wastewater Disposal and Plumbing Practices;* U.S. Environmental Protection Agency, Office of Water: Washington, D.C.

U.S. Treasury (2012) *The Debt to the Penny;* U.S. Department of the Treasury: Washington, D.C.

U.S. Environmental Protection Agency (2002) *The Clean Water and Drinking Water Infrastructure Gap Analysis*; U.S. Environmental Protection Agency, Office of Water; Washington, D.C.

U.S. Environmental Protection Agency (2008) *Clean Watersheds Needs Survey 2004 Report to Congress*; U.S. Environmental Protection Agency: Washington, D.C.

U.S. Environmental Protection Agency (2009) *Drinking Water Infrastructure Needs Survey and Assessment: Fourth Report to Congress*; U.S. Environmental Protection Agency, Office of Water, Office of Ground Water and Drinking Water, Drinking Water Protection Division: Washington, D.C.

U.S. Environmental Protection Agency (2012) *What Is Green Infrastructure?;* U.S. Environmental Protection Agency: Washington, D.C.

Washington State Legislature (2011) *Greywater Reuse for Subsurface Irrigation;* WAC Section 246–274; State of Washington Department of Health, Office of Drinking Water: Olympia, Washington.

Wiel-Shafran, A.; Ronen, Z.; Weisbrod, N.; Adar, E.; Gross, A. (2006) Potential Changes in Soil Properties Following Irrigation with Surfactant-Rich Greywater. *Ecol. Eng.*, **26,** 348–354.

Wisconsin Commerce Dept. (2011) *Plumbing*; Wisconsin Department of Commerce: Madison, Wisconsin.