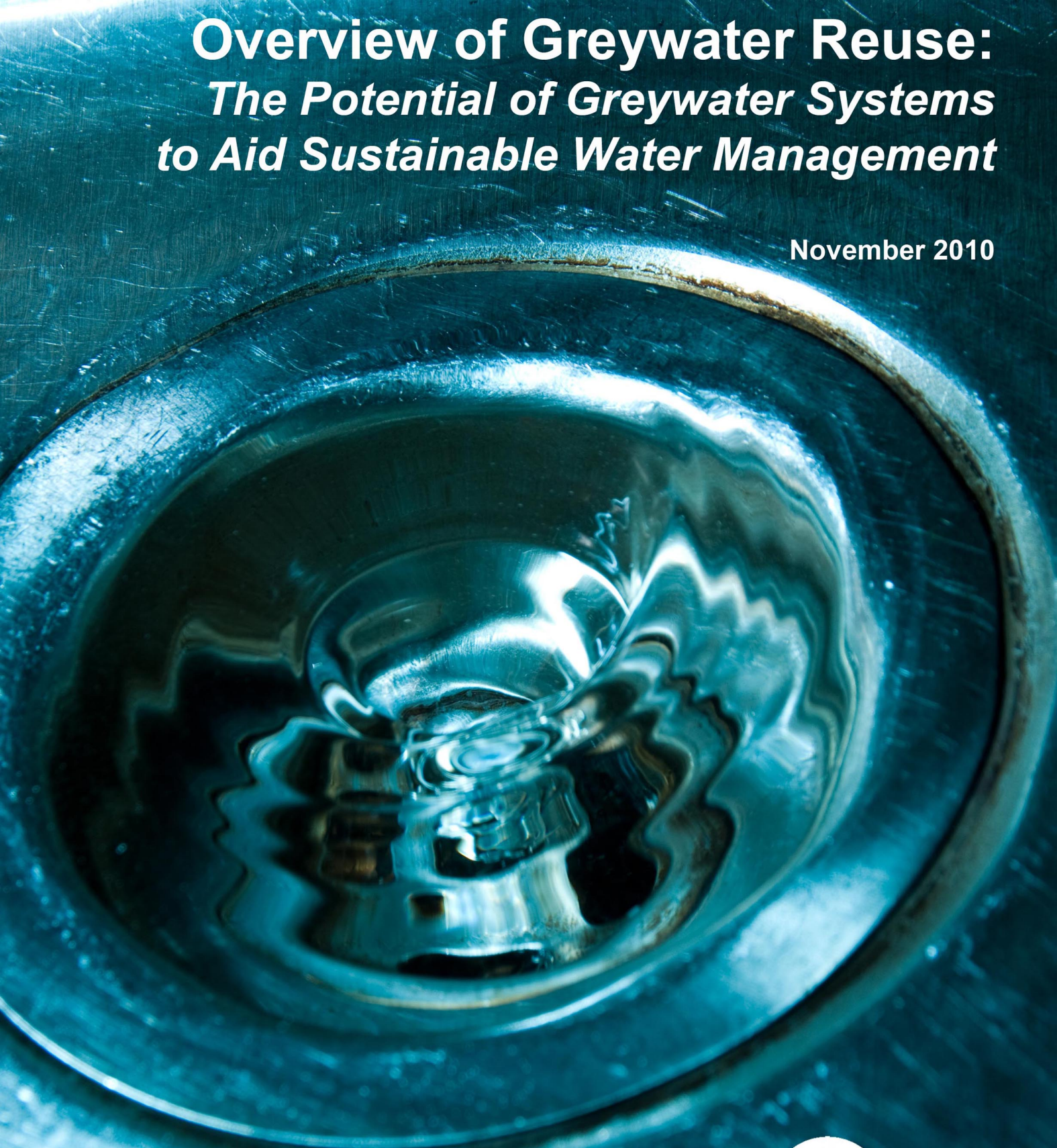
# Overview of Greywater Reuse:

## *The Potential of Greywater Systems to Aid Sustainable Water Management*

November 2010



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# Overview of Greywater Reuse: The Potential of Greywater Systems to Aid Sustainable Water Management

**November 2010**

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# Overview of Greywater Reuse: the Potential of Greywater Systems to Aid Sustainable Water Management

## Introduction

As pressures on freshwater resources grow around the world and as new sources of supply become increasingly scarce, expensive, or politically controversial, efforts are underway to identify new ways of meeting water needs. Of special note are efforts to reduce water demand by increasing the efficiency of water use and to expand the usefulness of alternative sources of water previously considered unusable. Among these potential new sources of supply is "greywater."

Greywater, defined slightly differently in different parts of the world, generally refers to the wastewater generated from household uses like bathing and washing clothes. This wastewater is distinguished from more heavily contaminated "black water" from toilets. In many utility systems around the world, greywater is combined with black water in a single domestic wastewater stream. Yet greywater can be of far higher quality than black water because of its low level of contamination and higher potential for reuse. When greywater is reused either on-site or nearby, it has the potential to reduce the demand for new water supply, reduce the energy and carbon footprint of water services, and meet a wide range of social and economic needs. In particular, the reuse of greywater can help reduce demand for more costly high-quality potable water.

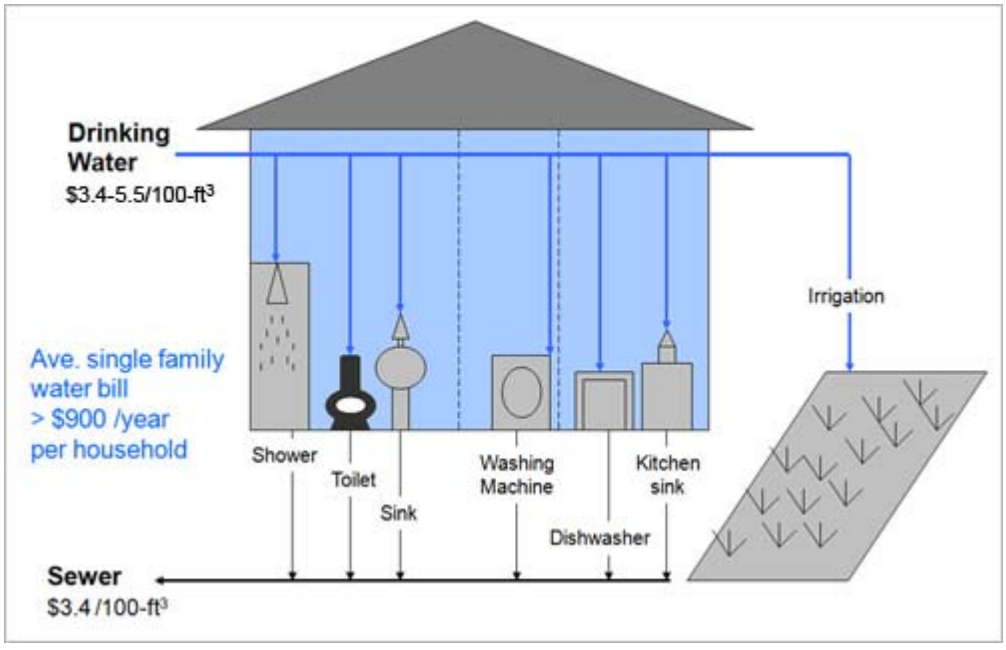


**Figure 1. Typical household water infrastructure; cost estimates are from Southern California, USA.**
Source: Cohen 2009

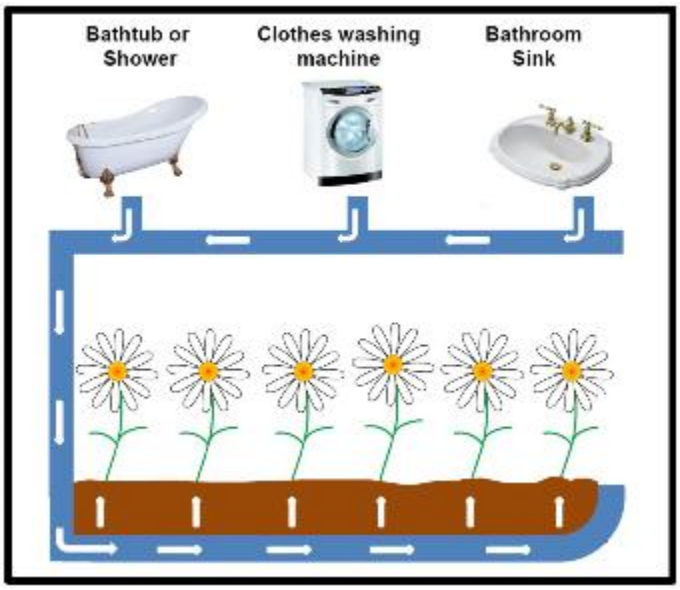


**Figure 2. Schematic of typical household sources of greywater, applied to a flower garden.**
Source: City of Santa Rosa 2010

By appropriately matching water quality to water need, the reuse of greywater can replace the use of potable water in non-potable applications like toilet flushing and landscaping. For instance, many homes have one set of pipes that bring drinking water in for multiple uses and another that takes water away. In this system, all devices that use water and all applications of water use a single quality of water: highly treated potable drinking water. This water is used once and then it enters a sewer system to be transported and treated again, in places where wastewater treatment occurs. In most modern wastewater systems treated wastewater is then disposed of into the ocean or other water bodies, voiding the reuse potential of this treated wastewater. In other places, once used wastewater may be disposed of directly in the environment. This system wastes water, energy, and money by not matching the quality of water to its use.

A greywater system, on the other hand, captures water that has been used for some purpose, but has not come into contact with high levels of contamination, e.g., sewage or food waste. This water can be reused in a variety of ways. For instance, water that has been used once in a shower, clothes washing machine, or bathroom sink can be diverted outdoors for irrigation (Figure 2). In this case, the demand for potable water for outdoor irrigation is reduced and the streams of wastewater produced both by the shower, washing machine, and sink are reduced. When the systems are designed and implemented properly, possible public health concerns with using different water qualities can be addressed. Attention to public health impacts of water reuse is also important in scaling up greywater solutions in areas where regulations around water reuse are not well enforced. Examples will be provided below of successful efforts to combine greywater systems, design, and regulation with health regulations.

In many places throughout the world, lower income communities live without access to a household water connection. In these communities, women and children often have to walk long distances or wait in line in order to access water which then needs to be carried home. In these households, the water that is brought to the home is highly valuable because of the amount of

labor invested and the cost relative to household income. These households often reuse water in the home and for household gardens or horticulture.

Greywater reuse can, therefore, also be a means of empowerment. Experiences in Lebanon, Palestine, and Jordan document that in many rural areas of the Middle East women are in charge of water management at the household level. For example, in Tannoura, Lebanon people suffer from severe water stress. The International Development Research Centre (IDRC) implemented a greywater reuse pilot project in the town.

"Its residents have never been connected to a municipal piped-water network and the only public water spring is heavily polluted from uncontrolled sewage disposal. Women often have to carry the filled water gallons back home, either on their shoulders or by using wheel-barrows or donkeys" (Haddad El-Hajj 2010). Women ended up being the main participants in building and maintaining greywater reuse systems, which reduced the amount of water they needed to transport. The women who participated in the greywater project perceived it as a way of both reducing their work load and increasing their involvement in community decision making (Haddad El-Hajj 2010).

Greywater reuse offers a variety of opportunities and challenges. And greywater technologies, uses, and policies vary widely around the world. This paper provides a broad overview of the state of greywater implementation and policy, with a special emphasis on the Middle East. It examines the potential of greywater to reduce the water and energy intensity of water uses, and it analyzes key issues that must be addressed for greywater to be accepted, and implemented, at larger scales.

## Definitions, Terminology, and Characteristics

Greywater is spelled and defined differently in different parts of the world. Also commonly spelled graywater, grey water, or gray water, it refers to untreated household wastewater that has not come into contact with sewage (or "black water") (WHO-ROEM 2006). Common sources of greywater in the home include showers, baths, sinks, and clothes washers. Wastewater from kitchen sinks and automatic dishwashers tend to have high concentrations of organic matter that encourage the growth of bacteria. This water is sometimes referred to as "dark greywater." Many regions lack clear regulations or standards regarding greywater capture and reuse, but among regions that do have regulations, many do not allow wastewater from the kitchen to be reused. The Uniform Plumbing Code in the United States and greywater regulations in Queensland, Australia, for example, do not allow the reuse of kitchen wastewater (Alkhatib et al. 2006, MPMSAA 2008).

Rainwater, which can also be collected for use, is not considered to be greywater. Greywater is also distinct from reclaimed water, which is wastewater (including black water) that is treated by a centralized wastewater treatment plant for potable or non-potable reuse.

Table 1. Greywater definitions

| Term | Definition | Other terms in use |
|---|---|---|
| Greywater | Untreated household wastewater that has not come into contact with sewage | Graywater, gray water, or grey water |
| Black water | Wastewater from toilets, bidet, water used to wash diapers (and under some definitions, from kitchens (WHO-ROEM 2006)) | Sewage |
| Dark greywater | Untreated household wastewater that has not come into contact with sewage, but is from lower-quality sources such as kitchen sinks and dishwashers | (Sometimes considered to be part of black water) |

Greywater can be reused for purposes that don't require potable water – such as landscaping, agriculture, or for flushing toilets – thereby reducing potable water use. Greywater can also be allowed to seep into the ground to recharge aquifers and reduce the volume of wastewater needing to be treated. Greywater is often, but not always, treated before it is reused, and the degree of treatment can vary widely. Greywater may contain many of the same contaminants as raw sewage, but generally in lower concentrations. For example, greywater can contain fecal coliforms and nutrients including nitrogen and phosphorus (WHO-ROEM 2006, Maimon et al. 2010).

Table 2. Possible greywater contaminants by greywater source

| Greywater Source | Possible Contents |
|---|---|
| Automatic clothes washer | Suspended solids (dirt, lint), organic material, oil and grease, sodium, nitrates and phosphates (from detergent), increased salinity and pH, bleach |
| Automatic dishwasher | Organic material and suspended solids (from food), bacteria, increased salinity and pH, fat, oil and grease, detergent |
| Bathtub and shower | Bacteria, hair, organic material and suspended solids (skin, particles, lint), oil and grease, soap and detergent residue |
| Sinks, including kitchen | Bacteria, organic matter and suspended solids (food particles), fat, oil and grease, soap and detergent residue |

Source: WHO-ROEM 2006

## Greywater Technologies in Use in Worldwide

Greywater systems range from simple low-cost devices that divert greywater to direct reuse, such as in toilets or outdoor landscaping, to complex treatment processes incorporating sedimentation tanks, bioreactors, filters, pumps, and disinfection (NovaTec Consultants Inc. 2004). Some greywater systems are home-built, do-it-yourself piping and storage systems, but there are also a variety of commercial greywater systems available that filter water to remove hair, lint, and debris, and remove pollutants, bacteria, salts, pharmaceuticals, and even viruses from greywater.

**CASE STUDY: Greywater Use and Gender Equity – Experiences from Lebanon and Jordan**

*Tannoura is a remote, rural town located in the Bekaa Valley of Lebanon. Between 2006 and 2008, the Canadian-based International Development Research Centre implemented a household greywater reuse project in Tannoura. Though the project was initially conceived of as a means to address widespread poverty in the region where the average income is about US $2 per day, the project resulted in another, less expected, outcome. In particular, women were much more active in the project implementation than their male counterparts and perceived the project as a way to reduce their work load and increase their involvement in community decision making (Haddad El-Hajj 2010). The project, in many ways, became a tool for local women's empowerment.*

*In many areas of the Middle East, women are responsible for water collection. When water is scarce or contaminated, women may have to walk long distances and carry heavy containers to provide for their family's water needs. In Tannoura, 30% of the women interviewed reported suffering from back pain, which could be associated with water collection. In addition, many women are in charge of water management at the household level and are not employed outside the home. Therefore, they have an interest and availability that can make them critical to safe greywater reuse.*

*Rural women in many Middle Eastern countries share similar gender roles related to water management. In reviewing household greywater reuse projects in five communities in Jordan, women were found to play a vital role in the success of many greywater projects (Keogh et al. 2010). In Karak, Jordan, a monitoring survey demonstrated the key role women play in the successful operation and maintenance of the systems, and their role in the generation of economic benefits via enhanced household garden production. While women initially played a peripheral role in the project in Karak, a mandate to enhance equal gender participation in the projects facilitated the emergence of women as key players in the project. Thus, the success of greywater projects in many rural regions of the Middle East is linked to increased gender equity.*

*It has been suggested that future greywater project in the region consider women as the main stakeholders to ensure the uptake and sustainability of greywater reuse (Haddad El-Hajj 2010). Indeed, greywater reuse projects can be enhanced by the participation of women, who are often in charge of water collection, maintenance, and management activities. In addition, greywater reuse projects can be designed to reduce women's workload and enhance their participation in local decision-making. Keough et al. (2010) conclude that, "water management projects can and should be a catalyst for women's empowerment."*

The cost and energy requirements of these systems vary, usually increasing with higher levels of treatment.

"Various treatment processes are suggested in the literature, but since on-site greywater recycling is a relatively new practice, only a few off-the-shelf systems are commercially available, and even less were tested on full scale for long time periods. Most treatment units reported in the literature (and advertised commercially) are based on physical processes (filtration and disinfection), while the more current ones incorporate biological treatment as well" (Friedler et al. 2005).

Below, we categorize greywater treatment into three main categories: diversion systems, which do not store greywater (but may filter and disinfect it) before immediate reuse; physical greywater treatment systems, which allow greywater to be stored treated with filtration and disinfection processes; and finally, biological greywater treatment systems, which use biological water processing technologies and approaches. The following sections discuss the technologies, costs, and land requirements of each type of greywater system. Technologies that treat greywater to meet standards and regulations for reclaimed, or recycled, wastewater are not included in this survey of greywater reuse technologies.

## A. Diversion systems

*The reuse of greywater for toilet flushing and garden irrigation has an estimated potential to reduce domestic water consumption by up to 50%* (Maimon et al. 2010).

Many greywater codes do not allow greywater to be stored (e.g., Queensland, Australia; California, USA); thus, there are a variety of greywater systems that immediately re-use greywater rather than treating or storing it. These include systems that divert greywater into toilet tanks for toilet flushing, systems that divert greywater to outdoor irrigation, and systems that divert greywater to treatment wetlands. These systems typically involve some filtration to capture lint, hair, fats, grease, etc. The systems may also involve disinfection (e.g., chlorine tablets may be put in the toilet tank to kill bacteria). Currently, there are a variety of commercially available systems that divert water from shower and sink drains into toilet water tanks. These systems re-plumb drain water directly into a toilet tank for flushing or into a receptacle that is then pumped into a toilet tank. Systems that reuse sink water to fill toilet tanks can cost between $100 and $500, and are sold primarily in Japan, Australia, Europe, and North America by a variety of manufacturers. Figure 3 shows a toilet designed to re-use the greywater from the sink above it. These systems are relatively low cost and require no additional land area.

**Figure 3. Toilet that re-uses the greywater from the sink directly above it (manufactured by Caroma, Profile Smart model).** Source: Caroma

A second category of systems diverts drain water to outdoor irrigation, often requiring additional plumbing and irrigation tubing. An electrical pump may also be necessary to move the water outdoors, but simple systems can sometimes rely on gravity to move the water. These systems are also relatively inexpensive and require no additional land area, but are only useful on plots that have vegetation or are unpaved to allow infiltration as many greywater codes do not allow ponding of the greywater.

Finally, there are pilot greywater systems that divert greywater from showers and sinks into treatment wetlands or other plant- and soil-based filters. For example, in Berlin, Germany, a 60 square meter engineered wetland constructed in the courtyard of a housing settlement has been operating successfully for eight years (Nolde Grey Water Recycling). Greywater from bath tubs, showers, sinks, and washing machines enters the plant-covered soil filter where it undergoes biological treatment. Ultra violet disinfection has been included as a final safety measure before the use in toilet flushing (Deutsche BauBeCon, 1995, 1996). Extensive investigations over several years of operation have shown that within the soil filter, *E. coli* concentrations were reduced by

**Figure 5. Constructed wetlands used to treat greywater from a housing development in Berlin, Germany.**
Source: Nolde Grey Water Recycling

over 99% and all hygiene requirements have been achieved under the EU-Guidelines for Bathing Waters. The costs of this form of greywater treatment can vary widely and it is also land-intensive.

Currently, there are no uniform requirements for most greywater systems. Many of these basic diversion systems include two-way valves that can be set to an open or closed position. This allows greywater to either be routed to sewer pipes (as they normally would) or be routed to the greywater system. This option can help ensure that greywater systems are properly managed (e.g., can be turned off if someone does not understand how to use the greywater system or when there may have been black water contamination) and are never overwhelmed by a large volume of water.

**CASE STUDY: Greywater Tower Demonstration Project in Kitgum Town Council, Uganda**

*A greywater demonstration project in peri-urban settlements of Kitgum, Uganda, initiated by Resource-Oriented Sanitation Concepts for Peri-urban Areas in Africa (ROSA), built and trained families to use greywater-irrigated tower planters. According to a baseline study conducted by ROSA before implementing the project, greywater was most often disposed of in Kitgum by dumping the untreated wastewater onto the ground or into storm-drains, resulting in pools of water that developed a foul odor, facilitated mosquito breeding, and presented adverse community health outcomes. Despite water shortages in the area, this study indicated that greywater was not being reused (Kulabako et al. 2009).*

*Seven households were selected to participate in the demonstration project, representing households from low, middle and upper classes. At each household, three "greywater towers" were built. Greywater towers are columns of soil wrapped in a cloth and supported by stakes, with an inner core of stones. Plants grow sideways out of the tower through cuts in the cloth, and greywater is poured into the core of stones from top of the tower to irrigate the plants (Crosby 2005). This technology was selected because it could be constructed with local materials, is easy to operate and maintain, and can grow food on a small area of land (Kulabako et al. 2009).*

*Households were trained on how to use the greywater tower effectively, and how to maintain it. At one household a control tower was set up to determine if irrigation with greywater negatively impacted plant growth. This tower was built in the same way as the others, but was irrigated with groundwater rather than greywater. Greywater quality, the amount of greywater produced, and effects on plants were then studied for 6 months(Kulabako et al. 2009).*

*Overall, the demonstration projects worked well, and showed that plants irrigated with greywater generally performed comparably to those irrigated with groundwater (Kulabako et al. 2009). Interviews with community members indicated wide community awareness of, and interest in, the greywater towers. Furthermore, a walk-through of the area after 6 months revealed that 15 additional households had built and started using greywater towers, and additional households had set up other types of gardens irrigated by greywater (Kulabako et al. 2009).*

## B. Physical/ Chemical Greywater Treatment Systems

Greywater systems that involve storing greywater must treat the greywater to reduce the bacteria and other microorganisms that can multiply in stagnant water. Physical and chemical greywater treatment systems primarily utilize disinfection and filtration to remove contaminants while biological treatment uses aeration and membrane bioreactors (see section on next pages). Table 3 provides a list of common greywater treatment technologies and some of their respective advantages and disadvantages.

**Table 3. Common greywater treatment technologies (adapted from NovaTec Consultants Inc. 2004).**

| Treatment technique | Description | Pros | Cons |
|---|---|---|---|
| Disinfection | Chlorine, ozone, or ultraviolet light can all be used to disinfect greywater. | Highly effective in killing bacteria if properly designed and operated, low operator skill requirement. | Chlorine and ozone can create toxic byproducts, ozone and ultraviolet can be adversely affected by variations in organic content of greywater. |
| Activated carbon filter | Activated carbon has been treated with oxygen to open up millions of tiny pores between the carbon atoms. This results in highly porous surfaces with areas of 300-2,000 square meters per gram. These filters thus are widely used to adsorb odorous or colored substances from gases or liquids. | Simple operation, activated carbon is particularly good at trapping organic chemicals, as well as inorganic compounds like chlorine. | High capital cost, many other chemicals are not attracted to carbon at all -- sodium, nitrates, etc. This means that an activated carbon filter will only remove certain impurities. It also means that, once all of the bonding sites are filled, an activated carbon filter stops working. |
| Sand filter | Beds of sand or in some cases coarse bark or mulch which trap and adsorb contaminants as greywater flows through. | Simple operation, low maintenance, low operation costs. | High capital cost, reduces pathogens but does not eliminate them, subject to clogging and flooding if overloaded. |
| Aerobic biological treatment | Air is bubbled to transfer oxygen from the air into the greywater. Bacteria present consume the dissolved oxygen and digest the organic contaminants, reducing the concentration of contaminants. | High degree of operations flexibility to accommodate greywater of varying qualities and quantities, allows treated water to be stored indefinitely. | High capital cost, high operating cost, complex operational requirements, does not remove all pathogens. |
| Membrane bioreactor | Uses aerobic biological treatment and filtration together to encourage consumption of organic contaminants and filtration of all pathogens. | Highly effective if designed and operated properly, high degree of operations flexibility to accommodate greywater of varying qualities and quantities, allows treated water to be stored indefinitely. | High capital cost, high operating cost, complex operational requirements. |

Physical and chemical treatment systems usually involve holding tanks, filters, and pumps. For example, the major components of the ReWater greywater treatment system (Figure 6) are a surge tank, sand media filtration tank, and piping to an outdoor irrigation system. Many basic greywater treatment and storage systems also incorporate activated carbon and/or clay filters and disinfection (e.g., chlorination, purification with ultraviolet radiation). These systems can cost between $1,000 and $5,000 for a single family home and can be fairly land-intensive, requiring space for holding tanks and filtration units.

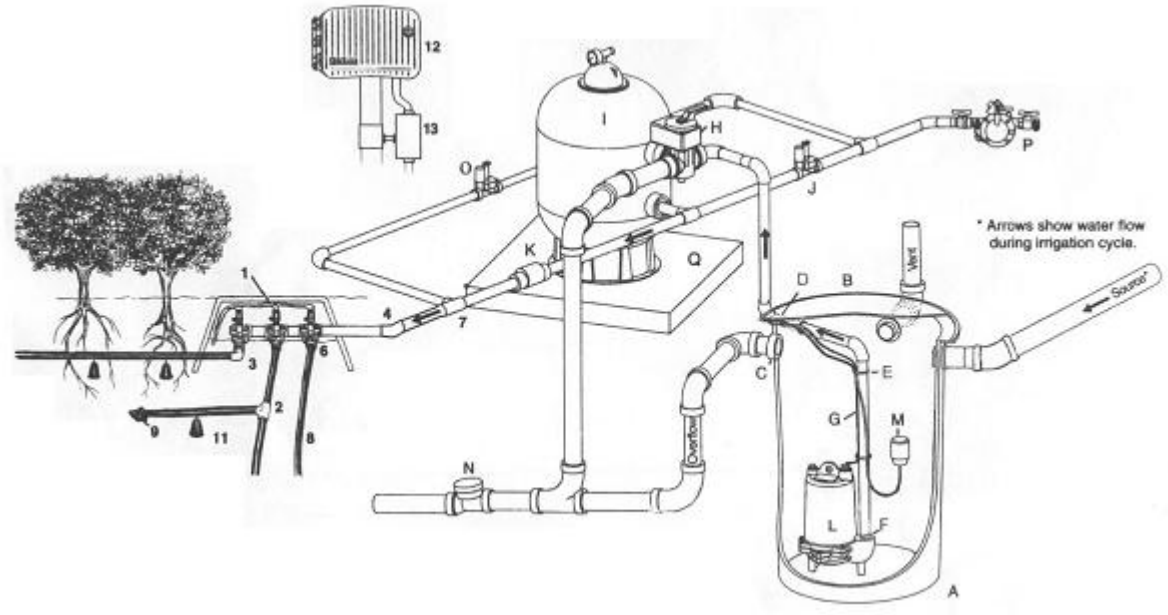


**Figure 6. ReWater's greywater treatment system for outdoor irrigation.**
*Source: ReWater 2010*

In Qebia village, Palestine, the IDRC set up a physical greywater treatment system to meet household greywater treatment needs (Figure 7). The system was comprised of a gravel filter medium, mostly crushed, hard limestone. The tanks were made of concrete and/or bricks, and were divided into four compartments.

> "The first compartment is a septic tank and grease trap and receives the GW [greywater]– from the shower, kitchen, sinks and washing machine – through a 5 or 7.5 cm diameter PVC pipe, via a screened manhole, by means of a T-shaped outlet. One end of this outlet is directed upward and open to atmospheric pressure and the other is at a level of about 30 cm from the bottom of the tank. The second and third tanks act as up-flow graduated gravel filters. The fourth compartment acts as a balancing tank for the treated GW, with a submersible pump installed to lift the water to a multilayered aerobic filter. Through a controlled flow from the top tank, the GW passes through the filter layers (sand, coal, and gravel) to a storage tank from where it can then be supplied to the irrigation network" (Burnat and Eshtayah 2010).

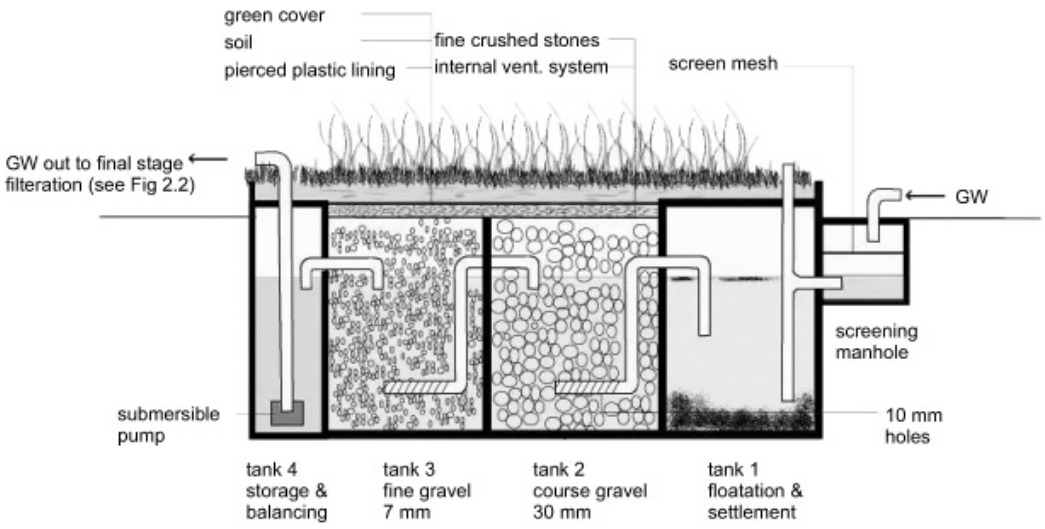


**Figure 7. Physical greywater treatment system used in Qebia Village, Palestine.**
*Source: Burnat and Eshtayah 2010*

### CASE STUDY: The Palestinian Hydrology Group's Experience with Greywater in Rural Palestine

*Water supply and wastewater disposal are both serious concerns in Palestine. Around 70% of the population is not served by centralized wastewater infrastructure (Mahmoud and Mimi 2008), and as a result, management of household wastewater can be a major expense for families, with some spending up to 20% of their monthly income on wastewater management (Tamimi et al). Additionally, wastewater is a significant source of pollution, with negative impacts on both environmental and human health. Greywater reuse in Palestine, therefore, has the multiple benefits of providing additional water supply, reducing wastewater disposal costs, and reducing pollution. Furthermore, greywater forms around 80% of household wastewater in Palestine – a higher percentage than in many other regions due to differences in how households use water – and around 60% of this can be recovered for reuse (Tamimi et al).*

*Recognizing the great potential for greywater reuse in Palestine, the Palestinian Hydrology Group (PHG), an NGO, has installed 161 greywater treatment and reuse systems in the West Bank and Gaza Strip that serve a total of about 215 families and 27 schools (Tamimi et al). One of these projects, implemented in the northern part of the West Bank, includes a centralized greywater treatment plant that serves more than 70 families and reuses the water for agricultural irrigation.*

*Through its decade of experience installing greywater treatment systems in Palestine, the PHG has found that reuse of greywater for irrigation is limited by lack of public acceptance and lack of knowledge about its economic and other benefits (Tamimi et al). However, it has also seen that installing greywater treatment systems can provide significant water for irrigation, and help to improve poor families' socioeconomic conditions by greatly reducing the cost of wastewater disposal and improving food security. Additionally, greywater reuse makes sense in light of political and cultural conditions, because reuse of greywater is more culturally acceptable than other types of water reuse, and because much of Palestine lacks central wastewater infrastructure.*

## C. Biological Greywater Treatment Systems

Some greywater systems use aerobic biological treatment. These systems can often be scaled up or down, depending on the quantity of greywater produced. See Table 4 for a list of several of the major manufacturers and treatment details. For example, Nubian Oasis, a company based in Australia, has developed a modular greywater treatment system that can treat from 1,000 to 50,000 liters of greywater per day (the average per capita water use is around 200 liters per day in Australia). The treatment technologies include membrane filters to remove contaminants, bacteria, and viruses along with aerobic biological treatment. Aerobic biological treatment involves aeration to increase dissolved oxygen and activate bacteria

present in the greywater to consume the oxygen and digest the organic contaminants. Some aerobic treatment systems include corrugated plastic sheets or other media for bacteria to attach to and grow on. One common method of aerobic biological treatment uses a rotating biological contactor (RBC) that cycles discs in and out of greywater tanks.

**Figure 8. Nubian Oasis's physical greywater treatment systems, at a smaller household scale and a larger industrial scale.**
Source: Nubian Oasis 2010

Biological greywater treatment also includes membrane bioreactors (MBR), which have become commonplace in wastewater treatment since the 1990s. The breakthrough for the MBR came in the early 1990s when the separation membrane was directly immersed into the bioreactor. Until then, MBRs required a great deal of pressure (and therefore energy) to maintain filtration. The submerged membrane relies on bubble aeration to mix the effluent and limit clogging of the membrane pores. The energy demand of the submerged system can be up to 2 orders of magnitude lower than previous bioreactors (Judd 2006). Aeration is considered as one of the major parameters on process performances both hydraulic and biological.

The lower operating cost obtained with the submerged membrane along with the steady decrease in the membrane cost encouraged an exponential increase in MBR in wastewater plants from the mid 1990s. There are now a range of MBR systems commercially available, most of which use submerged membranes, although some external modules are available. Membranes typically consist of hollow fibers and flat sheets (Le-Clech et al. 2006). For instance, the Copa MBR Technology is an aerobic biological treatment process that incorporates Kubota flat sheet membranes. The membrane panels have a pore size of 0.1 to 0.4 microns, thus filtering out particulates, spores like giardia and cryptosporidia, bacteria, and even viruses.

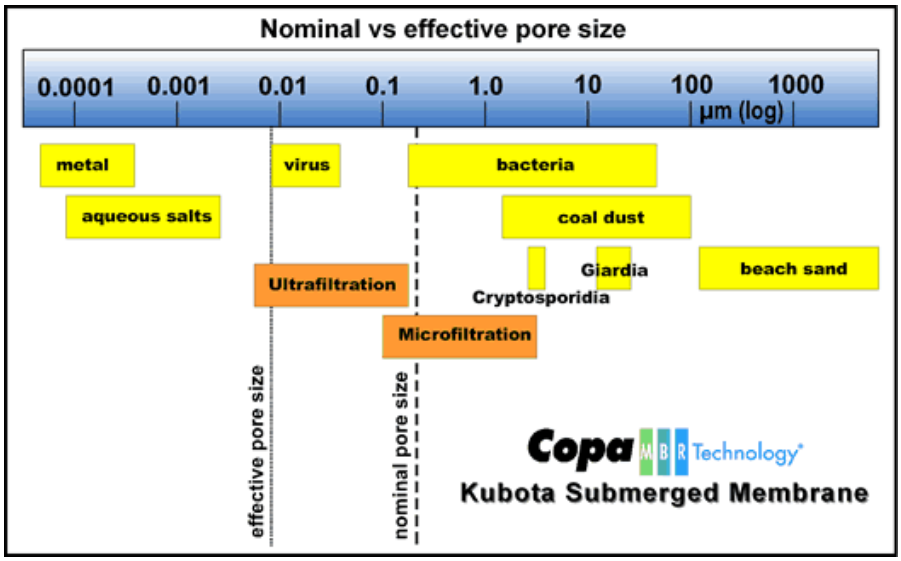


**Figure 9. Membrane pore size and filtration abilities.**
Source: Ovivo 2010.

Pontos, a greywater system manufacturer based in Germany, has created AquaCycle. The AquaCycle system filters out coarse particles, then the water enters the holding tanks where it is aerated, undergoes biological treatment, and then is disinfected using ultraviolet radiation. These types of systems tend to be the most expensive, costing as much as $10,000 for a single family home, and also require space for multiple treatment tanks.

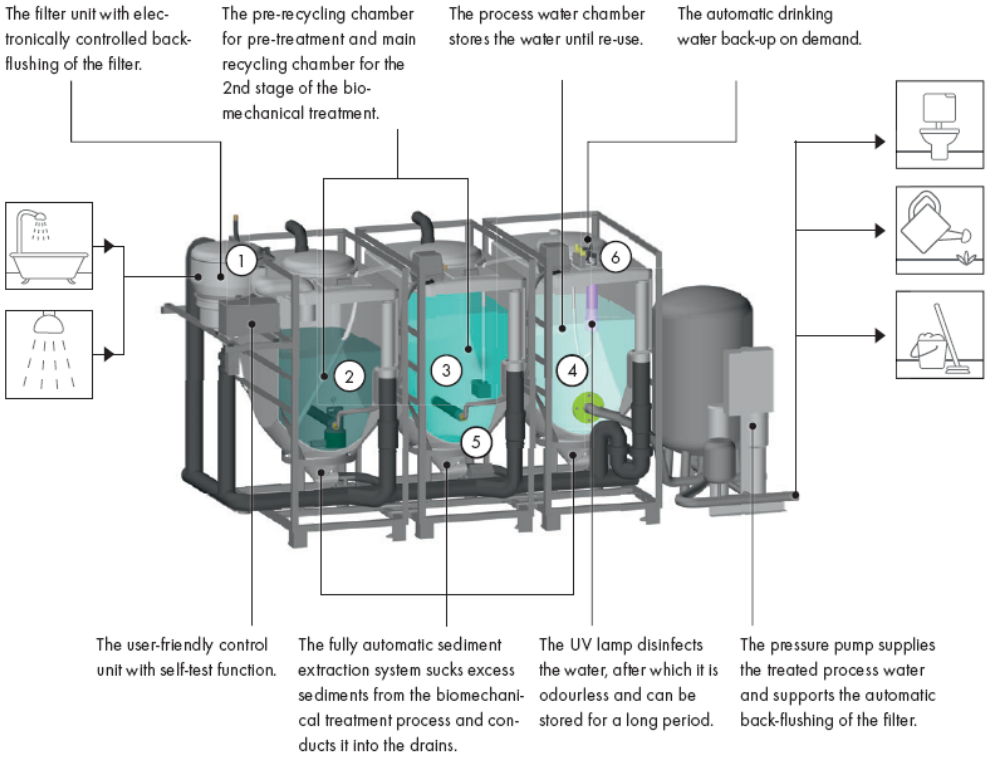


**Figure 10. The AquaCycle**
Source: Pontos 2010

Currently, there are few uniform treatment technologies or quality standards for greywater. In many cases, the treatment technologies provided by different companies are unclear, as they are proprietary. Many greywater users need better information about key chemical components of treated water, e.g., turbidity, conductivity, pH, levels of organic matter, etc. For instance, the salinity of the treated greywater may be extremely important in some cases (e.g., if the water is being used on crops). It is critical that comprehensive information be provided to greywater users about treatment options, and the quality of the output water.

Table 4. Matrix of greywater system characteristics adapted from NovaTec Consultants Inc. 2004

| Manufacturer | Filtration | Secondary Treatment | Disinfection |
|---|---|---|---|
| Clivis Multrum | - | - | - |
| Envirosink | - | - | - |
| Greywater Saver | X | - | - |
| Aquacarius | X | - | - |
| Nature Loo | X | - | - |
| Biolytix | X | - | - |
| Equarius | - | X (biological) | - |
| Clearwater | - | X (biological) | - |
| CopaMBR | X | X (biological) | X (ultraviolet) |
| Wasser | X | X (biological) | X (ultraviolet) |
| Electropure | - | X (physical) | - |
| WaterSaver Technologies (AQUS) | X | - | X (chlorine) |
| ReWater | X | - | - |
| Pontos AquaCycle | X | X (biological) | X (ultraviolet) |

# Policies and Regulation

## A. Overview of Greywater Policies, Regulations, and Laws around the World

Internationally, there is diversity in the approaches to and stringency of greywater regulations, from being legal with few restrictions, to being prohibited in all circumstances (Prathapar et al., CSBE 2003). In other cases, there are not clear policies on greywater and its use may instead be indirectly regulated by building, plumbing, or health codes written without consideration of greywater reuse. For example, a country may have wastewater regulations that do not distinguish between black and greywater, e.g. Oman, Jordan (Maimon et al. 2010), or have a plumbing code that prohibits discharge of nonpotable water through outlets such as faucets, such as in Canada's National Plumbing Code (CMHC 1998).

Greywater reuse is illegal in some Middle Eastern countries, and regarding greywater regulation in Oman, Prathapar et al. (2005) note,

> "At present, Omani wastewater reuse standards do not distinguish between greywater and blackwater and require that greywater be treated to the standards of potable water. However, there are many households and mosques in Oman (and many parts of the world) that use untreated greywater for home irrigation. In principle such uses are illegal, but the bottom line is that unrealistic laws have poor participation rates."

Nevertheless, greywater use is growing, even in regions with laws restricting greywater use and those with no explicit policies regarding greywater. For example, Sheikh estimates that only about 0.01% of greywater systems in California are permitted (2010). It has also been documented that greywater reuse occurs in households in the Middle East regardless of its legality (McIlwaine 2010). Similarly, recognizing that using wastewater for irrigation is a reality in many middle- and low-income countries, the World Health Organization has established guidelines to help ensure the safety of wastewater reuse, including greywater reuse, for irrigation (WHO 2006).

Further, in his work on greywater use in the Middle East, McIlwaine notes that no country in the Middle East and North African region has "developed a clear approach to its use that clearly states the responsibilities of the users and the regulatory requirements" (McIlwaine 2010). Jordan passed a standard in 2006 regarding greywater reuse in rural areas, however the code does not fully clarify what households must to do be permitted to reuse greywater (McIlwaine 2010). Israeli is expected to soon pass a law that would legalize greywater reuse from showers, bathroom sinks, and washing machines outdoors for landscaping and indoors for toilet flushing (Global Water Intelligence 2010).

Australia is often considered to be a leader with respect to greywater policies. Specific regulations and requirements vary by state. For example in New South Wales, untreated greywater can be used for subsurface irrigation (NSW Office of Water 2010), while in Tasmania, all greywater must be treated before reuse (Tasmanian Environment Centre Inc. 2009). At the national level, Australia has developed guidelines for greywater reuse, "*Australian Guidelines for Water Recycling: Managing Health and Environmental Risks,"* and reuse is encouraged through a program that offers $500 rebates for the installation of a greywater system (Australian Government). Several other countries also have incentive programs for installation of greywater systems, including Korea and Cyprus (CWWA 2002, CSBE 2003). In Tokyo, Japan, not only are there incentives for installing greywater systems, but they are mandatory for buildings with an area of over 30,000 square meters, or with a potential to reuse 100 cubic meters per day (CSBE 2003). Several municipalities of Spain, including Sant Cugat del Vallès near Barcelona and several other municipalities in Catalonia, have passed regulations to promote greywater reuse in multistory buildings (Domenech and Sauri 2010).

The European Council Directive 91/271/EEC states that "treated wastewater shall be reused whenever appropriate," however, how to determine if it is appropriate is left ambiguous (Somogyi et al. 2009). Greywater standards are currently under development through the European and International standards committees (Anglian Water). Germany has been a leader in Europe in the use of greywater (Nolde, Regulatory Framework and Standards). Domestic greywater reuse systems are legal in Germany, but must be registered with the Health Office

**CASE STUDY: Effective Greywater Regulation in Arizona, U.S.**

*The state of Arizona has one of the most greywater-supportive policies, which has effectively balanced public health concerns with the reality that policies that are too restrictive or burdensome often result in the use of illegal greywater reuse. Arizona's current greywater policy was passed in 2001 and implemented a tiered approach that has different requirements for systems of different sizes. The three tiers are:*

> *Tier 1: systems with a flow of less than 400 gallons per day that meet 13 best management practices (BMPs);*
>
> *Tier 2: systems with a flow of less than 400 gallons that do not meet all 13 BMPs or with a flow rate of 400-3000 gallons per day; and*
>
> *Tier 3: systems with a flow rate of over 3000 gallons per day (Ludwig 2002).*

*Tier 1 systems are regulated under a general permit which does not require that users obtain permission or provide notification for their system. Instead, users must simply comply with the 13 BMPs contained in the general permit. These BMPs are meant to protect public and environmental health, for example by limiting human contact with greywater, prohibiting spray irrigation, and requiring that any storage tanks are covered (ADEQ). Tier 2 systems must submit their plans to the Department of Environmental Quality and apply for a permit before using the system. Additionally, all Tier 2 permits must be renewed every 5 years. Tier 3 systems must also apply for a permit, and these systems are considered on a case-by-case basis; only Tier 3 systems require written verification from the permitting department before operating (Ludwig 2002).*

*Under previous Arizona law, all greywater reuse required an individual permit. In a survey conducted in the city of Tucson, Arizona, 13% of respondents indicated that they reused greywater (Water CASA 1999). However, the greywater permitting agency had never issued a permit (DEQ 2001); thus, all systems were operating illegally. In making the new regulation, the Department of Environmental Quality acknowledged that, "the current reuse permitting program is unwieldy, duplicative, and costly to the permittee"(DEQ 2001).*

*To guide the new greywater regulations, a study was conducted to assess the number of households already using greywater systems and the public and environmental health implications of greywater reuse (Water CASA 1999). The study concluded that reusing kitchen sink water presents the greatest public health risk and recommended that kitchen sink water be excluded from the state's definition of greywater (Water CASA 1999).Overall, however, it determined that the types of systems that were already being used had few long-term public health risks (Noah 2002).*

(Nolde 2005). The United Kingdom has conducted research into greywater reuse, particularly for toilet reuse, noting a number of problems with maintenance, reliability and costs of these more complex systems (CSBE 2003), and greywater systems are not in wide usage (UK Environment Agency 2008). However, it is legal, provided that it complies with certain building codes and the British Standards Greywater Systems Code of Practice. Sweden and Norway have also done research into greywater and have implemented systems in some student dormitories and apartment buildings (Jenssen 2008). Much of this research has been situated in research into ecological sanitation more broadly, including urine separation (Esrey et al. 1998).

With regard to greywater policy in North America, a 2002 report by the Canadian Water Works Association concluded: "traditional regulatory practices prohibiting rainwater harvesting or greywater reuse as substitutes for potable water supply are changing…However, there is a marked reluctance on the part of most jurisdictions in North America to consider these options (CWWA 2002)."

The United States does not have a national greywater policy, leaving regulation of greywater to the states. About 30 of the 50 states have greywater regulations of some kind (Sheikh 2010). These regulations vary widely. North Carolina has stringent greywater regulations and only allows reuse of water if it is treated to the same standards that are required for treating sewage water (Sheikh 2010). The state of Arizona has a more flexible greywater policy than many states, and is often seen as a leader in terms of promotion of greywater reuse in the United States (see Case Study on following page).

## B. Existing Infrastructure

Reuse of greywater requires separating greywater from sewage water, which is not standard plumbing practice in many countries, and therefore requires plumbing retrofits. The difficulty and expense of this retrofit varies widely, depending on the building and complexity of the system (e.g., how many collection points the system will have). For example, in Jordan most houses are constructed of reinforced concrete with pipes cast into floor slabs, making greywater plumbing retrofits difficult and expensive (CSBE 2003).

On a larger scale, widespread diversion of greywater could potentially be disruptive to wastewater collection and treatment, as a lower volume of wastewater would be diverted for treatment, and it would contain a higher concentration of contaminants and solids. In pipes with low slopes, this could potentially lead to insufficient flows in sewers to carry waste to the treatment plant (CSBE 2003). Sheikh notes that "as graywater reuse becomes more widespread, it may interfere enough with the operation of sewers and water reclamation facilities to engender legal or legislative action" (Sheikh 2010). On the other hand, some conventional sewers, particularly those that combine storm runoff and municipal sewage, are prone to overflowing. In these cases, greywater reuse can reduce the risk of sewage overflows (Bertrand et al. 2008).

Because of these conflicts with existing infrastructure, large scale (i.e., community-wide) greywater reuse may be most feasible in rural

### CASE STUDY: Shomera's Greywater Recycling Initiative

*Shomera for a Better Environment, an Israeli NGO, has launched The Greywater Recycling Initiative – a pilot project to promote greywater recycling in Israel. Israel is very experienced in regulating blackwater reclamation, where water quality can be centrally monitored. Monitoring and regulating decentralized greywater systems, however, poses a challenge to regulatory authorities, including public health agencies at the national and regional levels.*

*The initiative is the outgrowth of a project originally envisioned by Shomera nearly a decade ago in 2001. At that time, Shomera proposed that water from a mikveh (ritual bath facility) could be used to irrigate land nearby to create parks and public spaces, when it was informed that approval from the Israel Ministry of Health would be required. Due to a lack of clearly defined guidelines and standards for greywater reuse, the Ministry of Health and Shomera began a dialogue to determine the technology and monitoring systems necessary to attain the desired quality of the recycled greywater. These requirements substantially increased the costs of the technology and eventually the project was disbanded because it was no longer economically viable.*

*As the demand for greywater recycling in Israel grew, Shomera realized that the obstacles it encountered in trying to receive authorization of the project were common to other attempts at greywater reuse and could be addressed. Moreover, there was a need for local experience in greywater reuse in order to pave the way for additional projects to follow. In 2007, under the leadership of Miriam Garmaise, Shomera began reviving the greywater recycling project. The goal this time was to achieve the first authorized urban greywater recycling facility in Israel as a method to jumpstart additional greywater recycling projects. Appreciating the complexity of the undertaking, Shomera forged partnerships with experts and key stakeholders in greywater reuse, including academics, the private sector, and the Ministry of Health. It was the first time the Ministry had joined in a collaborative effort of this nature to assess the viability of greywater reuse.*

*The revived initiative entails several key changes in its approach: first and foremost is the relationship with the Ministry of Health. As a result of the Ministry of Health's involvement from the outset in the project's design and decision of technologies to be used, the pilot was more likely to meet the key health related standards of the Ministry. Second, though the mikveh remains the pilot application, the greywater which will be treated will be used in showers rather than ritual bath water, so that the model can serve as a precedent for a broad range of facilities that use large amounts of shower water such as hotels, country clubs, sports clubs, dormitories etc.*

*Currently, the project is in the final phase of securing a building permit and raising the funds necessary to implement the initiative. In the next phase, the technologies will be installed and the treated greywater tested and monitored regularly. Once water quality levels are approved, the Ministry of Health will provide authorization for the greywater to be used for irrigation and toilet flushing. Until then, the treated greywater will be disposed of in the sewer system. In the subsequent planned initiative, the pilot site will become a demonstration site where decision makers, practitioners, end users, and others can see the technologies in action. This will be accompanied by a broad-scale greywater recycling educational campaign and joint initiatives with additional partners. Involving all key stakeholders from the beginning of the project is perceived to be the key to the success of the second phase of the grey-water reuse project and serves as an important model for future work.*

areas or other areas without extensive existing water and wastewater infrastructure. While it does not specifically address sanitation, and thus would always need to be implemented in conjunction with sanitation systems, it can reduce loads on septic systems and other decentralized sewage treatment techniques.

## C. Planning and Plumbing Codes

In addition, greater use of greywater can conflict with established planning and plumbing codes. For instance, the International Association of Plumbing and Mechanical Officials (IAPMO) is an industry group that creates uniform code that plumbers and planners refer to around the world. The most recent 2006 Uniform Code manual has a section on greywater (Chapter 16, Part 1). The chapter states clearly that a permit is necessary for any greywater system to be installed and it only describes greywater systems that collect and store greywater for outdoor, subsurface irrigation. It does not address diversion systems, a more common and less costly option. In the American Southwest, states and municipalities are increasingly amending their codes to allow small greywater systems (including diversion systems) to be installed without a permit (e.g., Arizona's greywater code and California's new greywater code).

On the other hand, some new green building standards provide incentives for greywater reuse. The LEED (Leadership in Energy and Environment Design) Green Building Rating System was devised as a voluntary standard for developing high-performance, sustainable buildings. LEED was initially created by the U.S. Green Building Council to establish a common measurement to define "green building." Since its inception in 1998, LEED has grown to encompass more than 14,000 projects in the United States and 30 other countries (citation LEED for existing buildings v2.0 reference guide page pg 11). On average, a LEED™ certified building uses 30% less water than a conventional building.

Projects receive points for each "green" practice that they implement. In LEED 2009, there are 100 possible base points. Buildings can qualify for four levels of certification: LEED Certified - 40 - 49 points; Silver - 50 - 59 points; Gold - 60 - 79 points; and Platinum - 80 points and above. Greywater reuse can earn a significant number of LEED points across several categories:

- Water Use Reduction: 20% Reduction - 1 point.
    - 20% reduction in water use for building using alternative on-site sources of water such as rainwater, stormwater, and greywater
- Water Efficient Landscaping, No Potable Water Use or No Irrigation - 2 points
    - Use only captured rainwater, recycled wastewater, or recycled greywater for site irrigation.
- Innovative Wastewater Technologies – 2 points
    - Reduce generation of wastewater and potable water demand, while increasing the local aquifer recharge – use captured rainwater or recycled greywater to flush toilets and urinals or treat 50% of wastewater on-site to tertiary standards.
- Water Use Reduction, 30% - 40% reduction – 2-4 points
    - Maximize water efficiency within building to reduce the burden on municipal water supply and wastewater systems. Use alternative on-site sources of water such as rainwater, stormwater, and greywater for non-potable applications such as toilet flushing and urinal flushing.

# Challenges and Opportunities for Greywater Reuse Internationally and in the Middle East

## A. Public Health Concerns

Greywater contains many of the same contaminants as sewage water, and while generally present in lower concentrations than in sewage water, they can be well above international drinking, bathing, and irrigation water standards (Sheikh 2010). Greywater can contain pathogens derived from fecal contamination, food handling, and opportunistic pathogens such as those found on the skin (Maimon et al. 2010). While there have not been any documented cases of public health impacts of greywater reuse, this is by no means definitive proof that greywater reuse has never caused any public health impacts, as it is often difficult to trace illness back to a source.

**Table 5. Comparison of total coliform in various water types and selected drinking water standards**

| **Source of water** | **Total coliform bacteria MPN/100 mL** | **Source** |
|---|---|---|
| Disinfected Tertiary Recycled Water | <2.2 | Sheikh 2010 |
| Disinfected Secondary Reclaimed Water | <23 | Sheikh 2010 |
| Greywater | 100 to 100 million | Sheikh 2010 |
| Raw wastewater | Millions to billions | Sheikh 2010 |
| **Use of water** | **Value** | |
| U.S. EPA Drinking Water Standard | Coliform detected in no more than 5.0 percent samples in a month.* | EPA 2010 |
| WHO Drinking Water Guideline | *E. coli* or thermotolerant coliform bacteria must not be detectable in any 100mL sample | WHO 2006 |

*For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.

On the other hand, when managed properly, greywater reuse can be quite safe for public health. Two primary ways of managing risk are (CSBE 2003):

1) treating greywater before reusing it, and

2) eliminating physical contact with the greywater.

Greywater treatment can take many different forms with varying levels of complexity and treatment (see section on technologies). The quality and characteristics of greywater can vary greatly – between different households as well as within one household. One study on greywater characteristics concluded that concentrations of $BOD_5$ (Biological Oxygen Demand, the amount of dissolved oxygen consumed in five days by biological processes breaking down organic matter) ranged from "concentrations equivalent to a medium strength influent municipal sewage at one end to a final effluent at the other" (Jefferson et al. 2004). Greywater in areas with very low consumption such as Jordan tend to have particularly low greywater quality, as contaminants

are concentrated in the small quantities of water used (Halalsheh et al. 2008). Because of this, treatment technology should be chosen on an individual basis taking into account the quality of the raw greywater and the quality needed for the end use to ensure that greywater is being treated adequately. Another exposure route risk is through groundwater that becomes contaminated by greywater.

There are other design considerations that contribute to the safety of a system as well. Storage of greywater can allow bacteria to multiply, so it should only be stored if it has first been thoroughly treated.

**Table 6: Comparison of greywater fecal coliform measured in various studies**

| **Source of water** | **Number of fecal coliforms** (cfu/100 mL) | **Study** |
|---|---|---|
| Bath, shower, and washing machine with baby diapers | $10^4$–$10^6$ | Nolde (1999) |
| Bathing and shower | $6 \times 10^3$ | Jepperson and Solly |
| Washing machine, bathroom sink, shower, and kitchen sink | $3.44 \times 10^6$ | Water CASA (2003) |
| Washing machine (with children) | $2.6 \times 10^4$–$8.45 \times 10^5$ | Water CASA (2003) |
| Washing machine (without children) | $7 \times 10^1$–$2.9 \times 10^4$ | Water CASA (2003) |
| Shower and hand basin | $1.5^2 \times 10^2$–$3.5 \times 10^4$ | Christova-Boal et al (1996) |
| Shower and bath | $10^1$–$5 \times 10^3$ | Feachem et al (1983) |

Source: WHO Organization 2006.

Many systems are set up to intentionally reduce or eliminate human contact with the greywater. For systems reusing greywater for irrigation, for example, an underground irrigation system may be used (and is required in some jurisdictions).

## B. Public Perception

A major hurdle for implementation of greywater reuse is public perception that it is unsafe or unhealthy, or a more general aversion to the idea of reusing wastewater. However, some studies have revealed that public acceptance of greywater reuse for certain activities can be quite high. In one study on community receptivity to greywater reuse in northern Sydney, Australia, 95% of respondents indicated that they were receptive to watering a garden with greywater. Positive perceptions were directly the inverse of the level of physical contact with the water – for example there was higher receptivity of using water for toilet flushing than washing a car or washing clothes with it (Brown and Davies 2007).

Concerns about health, water pricing signals, and a belief that using recycled water represented a decrease in the standard of living were key reasons for the lack of acceptance of greywater reuse in this study (Brown and Davies 2007). A study in Barcelona, Spain found that factors determining level of public acceptance of greywater reuse include: perceived health risk, perceived cost, operation regime, and environmental awareness (Domenech and Sauri 2010). This study found that greywater reuse was seen as relatively safe, with 84% of those surveyed perceiving health threats to be low or very low. A study on a hotel that used greywater to flush toilets concluded: “Data led to the conclusion that with adequate information, social acceptance can be obtained” (March et al., 2003).

In his work on local acceptance of greywater, Laban identified four important questions people may raise regarding greywater reuse: acceptability with regard to religious and cultural values; affordability and financial benefits; difficulty; and ability to improve access to sufficient quality and quantity of water (Laban 2010). This highlights the need for a participatory approach to the development of greywater reuse technologies, so that the needs and concerns of the user are addressed. There has also been some perception that greywater reuse is not compatible with Islamic religious beliefs, although in 1978 the Council of Leading Islamic Scholars (CLIS) in Saudi Arabia found that treated wastewater can be reused as long as it does not present a health risk (Al-Jayyousi 2010 citing CLIS 1978).

## CASE STUDY: Improving Public Perception of Greywater

*Public perception is an important barrier to the widescale uptake of greywater reuse solutions. Several studies have assessed the current state of public acceptance in regions in the Middle East. Examples from studies in Oman and Qebia, Palestine are provided below.*

***Oman***
*In a greywater reuse survey conducted in Oman, a majority (76%) of respondents indicated acceptance of greywater reuse for irrigation (Jamrah et al. 2008). The most common reason respondents indicated they were opposed to grey water reuse was concern that it was unsafe (88% of those opposed), followed by religious concerns (60% of those opposed) and concerns that it would harm the environment (53% of those opposed) (Jamrah et al 2008).*

***Qebia, Palestine***
*In Qebia, Palestine, a survey of public perception was conducted among families that participated in a project implemented by Qebia Women's Cooperative (QWC) that installed greywater treatment systems (Burnat and Eshtayah 2010). Greywater was reused to irrigate household gardens. A survey taken before the treatment units were installed found that 89% of households used untreated greywater to irrigate their gardens, but a majority (53%) believed that this practice adversely affected soil and plants. Only 36% of households surveyed believed that using untreated wastewater affected health, indicating a need for better public information about safe use of greywater (Burnat and Eshtayah 2010).*

***Strategies to Improve Public Perception of Greywater***
*Proponents of greywater reuse would be well served to look at successful water sector projects that changed behavior, policy, or public acceptance. Strategies to change public perception include campaigns that educate the public, engage the community, and activate the media. Examples of these strategies are provided below.*

***Education and Awareness-Building Campaigns***
*Education and awareness-building campaigns play a critical role in building public knowledge and support for new water solutions. An important example of the role that these campaigns can play in transforming the water sector is the birth of the public health movement in the late 19$^{th}$ century in England. Poor water quality in many cities of the time began to negatively impact productivity due to illness, social and societal decay, and declines in public order. Increasing media attention, community pressure, and education on the impacts of poor water quality resulted in millions of dollars worth of capital investments to protect public health and water quality through the construction of sewerage.*

***Community Engagement***
*A key strategy to building public acceptance is working directly with affected communities in designing, developing, and implementing solutions. For example, a greywater management project in Badia, Jordan included community members, NGOs, government officials, and researchers from universities and research institutions in its design and implementation. A study on this project concluded that, "combining the strengths of different stakeholders made up for the scarce learning resources and human and financial resources that are needed to develop greywater treatment technology for the Badia region" (Dalahmeh et al 2010). In addition, gender perspective needs to be deliberately integrated into community engagement campaigns to recognize the key role that women play as the primary water managers at the household level. Recent studies have found that projects designed and run with the involvement of women were more sustainable and effective than those that did not have women's participation (UN-Water 2008).*

***Working with the Media***
*Using the media as a venue to carry messages about the importance of greywater reuse can be an effective way to move education and awareness efforts at larger scales. The news focuses public attention, and has the ear of policy makers and elected officials. When working with the media, it is important to provide interesting visuals, and key statistics developed from research, and to present success stories. For example, the Ethiopia WASH movement has had success in raising public awareness among the most vulnerable groups, in part because of their partnerships with media. Each year, the movement chooses a slogan, such as "Your Health is in Your Hands," or "Let Us Use Latrines for our Health and Dignity," around which to raise awareness (GWP 2008).*

## C. Greywater as Percentage of Total Water Use

The percentage of household water that is greywater varies regionally and between households, depending on the primary uses of water in a home and how efficiently water is used, but is generally between 50% and 80%. In Palestine, greywater makes up about 80% of household water, and projects have demonstrated that at least 60% of this water can be captured and reused (Burnat and Eshtayah 2010). In the United States, greywater comprises up to 50% of single-family household use (Sheikh 2010); a study on schools in rural Western Madyha Pradesh, India found that greywater comprised about 50% of their total water use (NEERI and UNICEF 2007). However, the total volume of indoor residential water used in India (11-16 gals/capita/day) is much lower than that in the U.S. (38.7 gals/capita/day).

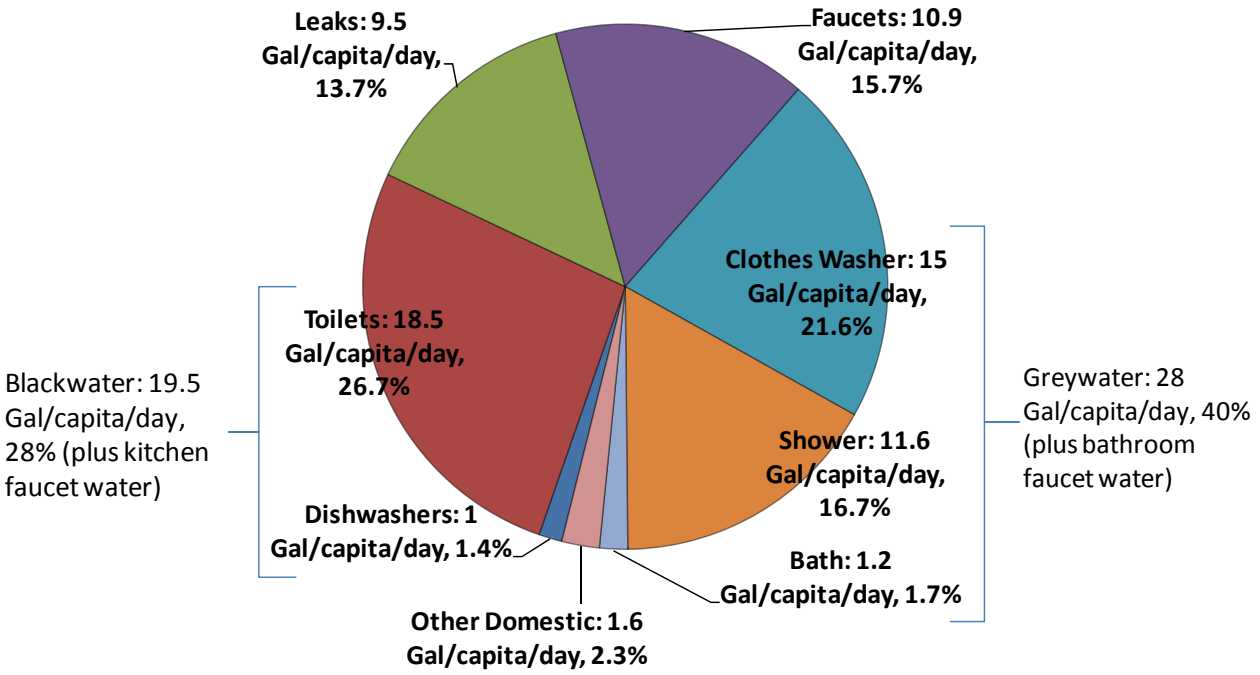


**Figure 11. Average indoor residential water usage for 12 North American cities.**

Source: Data from AWWA 1999.

## D. Greywater and Energy

The impact of expanded greywater use on energy consumption has not yet been comprehensively assessed. Though much of the literature lists decreased energy requirements as a benefit of greywater use, there are many factors that must be considered, at various scales, to determine if greywater use would increase or decrease energy consumption. These factors include: the energy intensity of current water supply and wastewater treatment (how is drinking water and wastewater currently treated?); future infrastructure needs (is new infrastructure required to deal with increased demand for water or increased volumes of wastewater?); and the energy intensity of the greywater system (how much energy is required to treat and move the greywater?).

If local water sources are highly energy intensive, for instance if water is produced through desalination or has to be pumped long distances, then greywater use will likely decrease energy requirements. Also, if local wastewater must be treated to high levels using greywater will likely decrease energy requirements. On the other hand, if local water sources and wastewater treatment processes are not energy intensive, e.g., if wastewater is treated via a septic system or is not currently treated then greywater reuse may slightly increase household energy requirements.

However, this ignores the impact of greywater use on collective water demand and thus on infrastructure needs. Large-scale infrastructure can be extremely costly and energy-intensive due to building materials and energy for continued operation and maintenance. For instance, if half of households in a community begin reusing greywater, both the community's water demand and wastewater production would decrease and this may mean that the community would not need to build larger pipelines to supply increased demand or upgrade their sewage treatment plant to accommodate increased volumes of wastewater. Thus, even if greywater use results in a significant increase in household energy consumption, its impact on lowering system-wide water demand and wastewater production could mean that it actually results in a net energy savings.

## E. Greywater and Agriculture

Greywater is often applied to outdoor uses, particularly landscape and crop irrigation. However, the impact of greywater on soils and the sanitary implications of reusing greywater on edible crops remain of concern. "Water quality issues that can create real or perceived problems in agriculture include nutrient and sodium concentrations, heavy metals, and the presence of contaminants such as human and animal pathogens, pharmaceuticals, and endocrine disruptors" (Toze 2006).

In many cases, the potential long-term agronomic impacts of using greywater for irrigation depend on the chemical constituents of the local greywater sources. For instance, if local greywater is somewhat saline, salts can slowly accumulate and reduce crop productivity. Yet, it remains to be documented whether or not these constituents will accumulate in the soil in sufficient quantities to harm plants or people, or perhaps be transported into groundwater (Roesner et al. 2006). Though literature on the subject is scant, there have been several recent studies of greywater use for irrigation that have not documented soil or health problems associated with greywater irrigation.

A study of greywater use for irrigation in the Middle East took place in southern Jordan between February 2004 and October 2007. According to the study, "Two simple and low-cost GW [greywater] treatment units – the four barrel and the confined trench type – were installed in 110 low-income households not served by a sewerage network. The resulting GW was used to irrigate crops that are not eaten raw. The quality of treated GW obtained by these units was shown to be in accordance with both Jordanian and WHO [World Health Organization] guidelines for the use of treated wastewater" (Bino et al. 2010).

A study of greywater use for irrigation in Canada used a paired study design to record water quality and plant productivity in three plots, two of which were irrigated with greywater (untreated and sand filtered), and one that was irrigated with tap water. "The key result in this study was the similarity in the distributions of bacteria on plant surfaces following irrigation with tap and domestic greywater. Both showed very high variation. This suggests that bacterial

contamination may not be a significant risk factor for edible crop irrigation" (Finley et al. 2009). In addition, plant productivity was unaffected by the use of tap water or greywater for irrigation in the study.

**CASE STUDY: Environmental Health Implications of Irrigating with Greywater**

*While greywater is generally of significantly higher quality than wastewater (black and greywater combined), irrigating with greywater nevertheless poses some public health concerns. These concerns include illness associated with direct exposure to greywater, consumption of heavy metals or other toxins taken up by plants irrigated with greywater, and broader concerns about the effects of greywater irrigation on the environment. Of particular concern is evidence that long-term irrigation with greywater may affect soil fertility. While there is little documentation of greywater irrigation causing illness, recent studies document its potentially harmful effects on soil and plants.*

*One study in the Al-Amer villages in Jordan used treated greywater to irrigate olive trees and vegetables and analyzed the quality of the greywater and its effects on the soils and plants to which it was applied. Greywater was treated in 4-barrel and confined trench treatment systems, both of which were developed by the Inter-Islamic Network on Water Resource Development and Management and used to irrigate home gardens in Jordan (Bino et al. 2010). The study found that the salinity and the sodium adsorption ratio (SAR) of the soil increased over the year-long study period (Al-Hamaiedeh and Bino 2010). Chemical properties of the crops were not changed, and because of the high salt tolerance of olive-trees, they are a good candidate for greywater irrigation. However, some of the vegetable samples taken contained high concentrations of total and fecal coliform bacteria.*

*Another research effort on a small farm in Israel irrigated plots with either freshwater, fertilized water, or untreated greywater over a three-year period and analyzed soil and water quality properties. Water-quality analyses found that greywater can be of worse quality than wastewater with regard to particular contaminants, particularly boron and surfactant concentrations. Irrigation with greywater resulted in increased levels of salts, surfactants, and boron in the soil. The increased salinity in the plot irrigated with greywater was not greater than that of the plot irrigated with fertilized water, and was not at a concentration that affected plants. However, the source of the salinity in the plots differed. In the greywater-irrigated plot, boron (a component of some detergents) contributed to the salinity. Boron can be toxic to plants, making it more of a concern than some other sources of salinity (Gross et al. 2005).*

*Yet another study used both treated and untreated artificial greywater to irrigate lettuce plants in containers of different soil types over a period of 40 days. Soil irrigated with untreated greywater had significantly more oil and grease, surfactants, and bacteria than those irrigated with treated greywater, and some soil types irrigated with untreated greywater had increased hydrophobicity (Travis et al 2010).*

*While some of these studies recommend treating greywater before reusing it for irrigation to reduce contaminants that can accumulate in soils (Gross et al 2005, Travis et al 2010), Al-Hamaiedeh and Bino 2010 found adverse impacts on soil irrigated with treated greywater. Additional studies are needed to better understand the impact of greywater on soils, and the level and type of treatment needed to avoid or reduce these impacts.*

## F. Financing

A key issue that limits the wide scale uptake of greywater technologies is that their initial capital cost can be high relative to the cost of water. Because water is inappropriately priced in many parts of the world, there is little incentive to conserve water use. For example, many communities lack volumetric pricing for water. Since households only pay a fixed monthly fee, and not are not billed based on the quantity of water they use, there is no financial incentive to reuse greywater on site. In other cases, the total cost of water to the household is so low that the payback time on the installation of a greywater system can be over 20 years. Private companies, including both large corporations that are developing greywater treatment technologies and venture capital firms, have expressed this barrier to marketing and selling greywater reuse technologies.

## G. Greywater as an Adaptation Strategy for Water Scarcity, Insecurity, and Climate Change

Climate change has profound implications for water resource supplies. At the same time, social change greatly affects and will continue to affect water resource demand, quality, and supply. The combination of these two processes has the potential to seriously disrupt water availability. As climate change begins affecting water resources, individuals and communities will take actions to respond to and cope with perceived changes. Some of these actions will be adaptive and resilient to a variety of climate and social changes. Other actions will be maladaptive, making individuals and communities more vulnerable to changes, even while appearing to improve resilience. There are two principal paths toward adapting water supply systems to climate change: expand water supply in a way that reduces climate vulnerability, or address water use and demand to reduce exposure to climatic variability and extremes. For the former, we must modify the design, construction, and operation of centralized water collection, treatment, and delivery systems; for the latter we must change patterns and practices of water use by end-users.

In the past, water planning and management decisions relied on the assumption that future climatic conditions would have the same characteristics and variability as past conditions. Dams are sized and built using available information on existing flows in rivers and the size and frequency of expected floods and droughts based on previous trends. Reservoirs are operated for multiple purposes using the past hydrologic record to guide decisions. Irrigation systems are designed using historical information on temperature, water availability, and soil water requirements. With climate change, the patterns of the past do not provide as reliable measures for the future, and we will need to adapt to new challenges on water systems.

As a key strategy that reduces demand, greywater reuse is an important strategy in improving the resilience of water systems to the impacts of climate change. In addition, greywater reuse can also be considered a relatively secure or drought resistant source of water supply because presumably greywater generated from showers and washing machines will continue, if at a reduced rate, in the future. Reuse of greywater can help displace demand for water, thus reducing conflicts over water and reducing the demand for new water supply projects. Increasing greywater reuse can help provide more resilience to the insecurity of water supply as a result of climate change.

### CASE STUDY: Review of Potential Greywater Financing Strategies

*In identifying appropriate strategies for financing large-scale greywater reuse projects, or developing a financing strategy that has the potential to scale greywater reuse, it is useful to look to other sectors that face similar constraints. Solar energy for rooftops presents a similar decentralized technology that has a high upfront cost relative to monthly costs. To promote solar energy numerous strategies have been put in place in many areas worldwide which can serve as a set of options to consider in moving forward greywater reuse technologies and projects. In addition, new financing approaches have begun being used in the water sector that may also be useful for greywater technology financing. A few examples are provided below.*

***Microfinance***
*Microfinance has been used as a tool in development for many decades. More recently, some groups, including Water.org have begun an initiative to use microfinance in the water, sanitation, and hygiene sector. Their WaterCredit initiative has promoted loans to households, community based organizations, and other groups to build toilets, obtain a household connection, and other high capital cost needs. As discussed in the Tafila, Jordan case study (Case Study 5), the Ain El Baida Voluntary Society also used microfinance to provide loans to low income people to develop small scale greywater reuse systems.*

***Leasing Arrangements***
*Another strategy that has been used for promotion of high capital cost, decentralized infrastructure is a leasing program. In the energy sector, private companies such as Sungevity and SunEdison have developed solar systems where the private company (Sungevity or SunEdison) is the owner of the system on the home or business rooftop, and the energy user (the homeowner or business owner) pays a monthly fee to the leasing company. This is a potential model to explore for funding greywater technologies.*

***Government Rebates***
*In Australia, the government of Australia has developed a National Rainwater and Greywater Initiative as part of their Water for the Future Initiative. Household rebates of $500 for new greywater systems purchased after January 2009 have been offered. Purchasing and installing a grey water system, which is installed by a licensed plumber, qualifies users for a rebate from the Department of the Environment, Water, Heritage and the Arts. It is not clear whether these rebates provide enough funding to displace the high capital costs for greywater systems, nor if they provide enough incentive.*

***Property Tax Based Financing***
*The City of Berkeley started a solar financing program to allow property owners to borrow money from the City's Sustainable Energy Financing District to install solar PV. The cost for the solar system is then paid for through a special tax on the property, spread over 20 years. This provides financing similar to a traditional equity line or mortgage. If the property is sold or transferred, the system and the additional tax obligation are also transferred.*

***Government Programs to Target the Poor***
*Another key issue is ensuring equitable outcomes in the use of greywater technologies. Solar incentive programs developed by governments (state and federal) have often benefited the wealthy, who are able to finance the remaining (unsubsidized) portion of the up-front costs. In California, to support equitable distribution of solar funding, the state government adopted the California Solar Initiative Incentive Program (making up 10% of the entire Solar Initiative's funding). The program provides incentives for solar installations on single-family, owner-occupied homes, as well as for multi-family residences. The incentives subsidize roughly 50 to 75 percent of the photovoltaic system for about 5,000 qualifying homeowners, and the state's program manager will help recipients find loans and grants to cover the remaining cost of the system.*

## H. Greywater in the Context of New Water Solutions

The world is in the midst of a major transition in water management and use. Over the past century, the construction of massive infrastructure in the form of dams, aqueducts, pipelines, and complex centralized treatment plants, funded with a limited set of financial tools and approaches, dominated the water agenda. This "hard path" approach focused on expanding water supply brought tremendous benefits to billions of people, reduced the incidence of water-related

diseases, expanded the generation of hydropower and irrigated agriculture, and moderated the risks of devastating floods and droughts. But the hard path also had substantial, often unanticipated social, economic, and environmental costs.

A new way of thinking is emerging, called the "soft path" by some analysts (Gleick 2003, Brooks et al. 2009). The soft path continues to rely on carefully planned and managed centralized infrastructure but complements it with small-scale decentralized facilities. It delivers water services and qualities matched to users' needs, rather than just delivering quantities of water. It applies economic tools such as markets and pricing, but with the goal of encouraging efficient use, equitable distribution of the resource, and sustainable system operation over time. It includes local communities in decisions about water management, allocation, and use. And it uses the tool of back-casting (defining a desirable future and working backward to identify key policies and efforts), as a way to help communities and water users think about long-term objectives, rather than short-term expediencies. The industrial dynamics of this approach are very different, the technical risks are smaller, and the dollars risked are potentially far fewer than those of the hard path.

The soft path is about increasing the productivity of one unit of water. Greywater reuse can be a key soft path solution, in certain contexts. The soft path for water includes numerous technologies and approaches to undertake more systematic planning for both supply and demand:

1. *Demand Management:* Demand management refers to the focus on conservation of water and efficiency in water use. Water efficiency improvements in many parts of the United States have greatly reduced per-capita water use and eliminated the need for a wide range of new supply investments.

2. *Soft Supply Options:* The soft path for water also incorporates "soft supply" options (non-centralized options) that encompass a *decentralized, end-user* approach to achieving water supply. It also matches water quality with water demand. Soft supply options include strategies like rainwater harvesting, greywater reuse, and dual plumbing solutions, and can offer advantages for reducing exposure to climatic risks.

Rainwater harvesting allows individual homeowners, institutions, and end users to collect and store rainwater on site for use in landscaping and for other non-potable uses.

Dual plumbing allows industrial and commercial buildings to use highly treated water utility wastewater for toilet flushing and other non-potable purposes.

Greywater reuse allows individual homeowners, institutions, end users, and industrial and commercial buildings to collect and store greywater on site for use in landscaping and for other non-potable uses.

**CASE STUDY: Cost-Effectiveness of Greywater Reuse in Tafila, Jordan**

*Micro-financing of simple household greywater irrigation systems in Tafila, Jordan, demonstrated that greywater reuse can be cost-effective and provide a number of socio-economic benefits. After a successful pilot project implemented by CARE Australia and Ain El Baida Voluntary Society in which greywater from a school in Tafila was used to irrigate vegetables and fruit trees, the Ain El Baida Voluntary Society provided small loans to 50 local, poor families for permaculture activities. Most of the loan recipients (87%) used the money to make plumbing modifications to allow greywater to be reused to irrigate food gardens. A majority of these (74%) implemented very simple systems that collect wastewater in a bucket under the kitchen sink, then run this water to the garden through a hose or carry the bucket of water outside and irrigate manually. Most were happy with the benefits of irrigating with greywater, and were interested in upgrading to a system that piped water to the garden or collected greywater from more household uses for reuse. All loans were fully repaid (Faruqui and Al-Jayyousi 2002).*

*A survey of a sample of program participants was done to assess the costs and benefits of the greywater systems that were implemented. Overall economic benefits were significant, with an average benefit to cost ratio of 5.3 to 1. Some cost-savings were the result of lower water costs; on average, families lowered their total water use by 15%. Additionally, the greywater systems allowed families to grow more food than they previously were able to, because of constraints on how much water they could afford. The greywater systems gave them a more steady source of irrigation water, and they were therefore able to grow more food for their own consumption, to sell, or both. The average annual value of crops consumed or sold was US$308 dollars per household. For the poorest family in the study, the value of food consumed or grown was equal to 44% of their annual income. In addition to these economic benefits, the greywater systems allowed households, particularly women, to develop gardening, irrigation and food preservation skills (Faruqui and Al-Jayyousi 2002).*

*While the costs of these very simple systems are low, the benefits are also low relative to more complex systems because they collect water only from the kitchen sink, and therefore the volume of water displaced is relatively small. A larger follow-up project in the same region used more complex greywater systems that treated and stored greywater from multiple household sources and distributed it to the garden. These systems decreased domestic water consumption by about 30%, and increased household income by US$50 to US$150 per month (Al-Beiruti 2010). However, it is not yet clear whether these economic benefits make the systems cost-effective to install (Keough et al. 2010).*

## Moving Forward

In many places around the world, increasing demands on freshwater and the impacts of climate change on water availability are reducing the security of water access. Globally, many regions have reached a point at which existing water resources are already being over-used, as evidenced by the depletion of groundwater aquifers and rivers which no longer reach the sea. Many new water sources will require that societies go further and pay more to access water. But limitations in water availability can also lead to the more efficient use of water, better management of existing resources, and increases in the resource productivity of a single unit of water.

Greywater reuse is a promising strategy in terms of the significant local water, energy, and cost savings that it can produce. Small demonstration projects and new, more flexible, greywater policies have demonstrated the successful use of greywater at multiple scales. However, there are also a variety of challenges to the increased use of greywater in homes, farms, and businesses. Currently, these challenges have hampered broad implementation of greywater reuse. Below, we outline several strategies for overcoming some of the most critical challenges to wider use of greywater internationally.

**Develop supportive policy instruments**

A supportive policy environment that protects public health, yet is not unduly burdensome, will be necessary for the responsible expansion of greywater reuse. Current water reuse policies in many countries are very restrictive of responsible on-site greywater reuse. Few states and countries have in place supportive policies, particularly in the Middle East. Policy and regulatory frameworks that provide consistent rules and regulations regarding greywater reuse are needed in the region. These policies should balance the public health and environmental risks of greywater reuse with the economic and water saving benefits particularly in regions with inadequate access to freshwater. Appropriate policies should differentiate between different scales, e.g., household greywater use versus institutional greywater use, and should be tailored to local or regional conditions, e.g., existing plumbing and infrastructure. Finally, greywater policy should be harmonized with World Health Organization standards and local plumbing and building codes in order to avoid contradiction and complication.

**Match technology to end-use**

There are a wide variety of greywater technologies from diversion systems to biological treatment. A clear and consistent categorization of different technologies, matched to appropriate end-uses, is needed. Technologies that treat greywater more extensively often require more complex infrastructure and operation, more frequent maintenance, and normally have higher costs and energy requirements. Appropriate technology means choosing a greywater treatment system that follows local greywater codes and matches the quantity and quality of water to its intended use. For instance, when greywater is reused in the toilets of large buildings this requires treatment and storage of large volumes of water before reuse, and appropriate technologies include physical, chemical, or biological treatment and large scale storage systems. On the other hand, small scale systems that provide water for subsurface irrigation are well suited for simple diversion systems that filter but do not treat greywater before reuse.

**Develop consistent industry standards**

There is a clear need for industry standards in the realm of greywater treatment technologies. A wide array of commercially available greywater treatment technologies exist that have varying degrees of complexity and effectiveness. When comparing greywater treatment options, manufacturer-provided information can be confusing and relatively limited. In many cases, there is little information to help a consumer determine which type of treatment would be the most appropriate for a particular quantity and quality of source water. Industry standards are necessary to compare greywater treatment technologies and provide useful information to consumers. Standards could provide information to a consumer regarding the ability of different systems to treat particular contaminants that may be present in source water, the length of time that the treatment process takes, the amount of energy required, etc.

**Support long-term research on health and environment**

Much of the public concern around greywater reuse is related to a lack of information about the long-term health and environmental impacts of greywater. Multi-year studies with controls are needed to examine the long-term impacts of greywater on human health and soil chemistry. While some long-term studies are currently being completed by the Water Environment Research Foundation, more work is needed, particularly on the long-term impacts of different qualities of greywater on soil and plant health for agricultural applications. Studies conducted by respected academic organizations and international research organizations would be especially useful.

**Promote appropriate financing approaches**
Financing efforts would benefit from a variety of approaches, at different scales and across various sectors. Given the multiple scales of greywater reuse from the household to larger-scale institutions, financing options may vary. Micro finance and public sector incentives should be considered alongside private sector investment and large-scale international aid and development funding. In addition, while greywater reuse is often considered primarily as a benefit in terms of water conservation, it also conserves energy, reduces waste water, and the water savings may, in some cases, be allocated to other uses. Therefore, financing efforts should consider the co-benefits that could be provided to (and could also be paid for by) water suppliers, energy suppliers, wastewater utilities, and additional water users.

**Create an international "Greywater Organization"**
While there are a variety of international institutions exploring the expanded use of desalination technologies and recycled water, there is no organization that brings together utilities, communities, aid organizations, technology manufacturers, non-profits, and academic institutions that are interested in greywater. Such an organization could greatly enhance information exchange and learning between stakeholders and countries. It could also work to improve public perception of greywater, for instance by developing voluntary standards for greywater treatment technologies.

**Expand greywater education and outreach**
Better public information and awareness of the opportunities, benefits and risks associated with greywater will be necessary to expand greywater reuse. Public perception of greywater as unsafe for reuse, or uncertainty around how to safely reuse greywater, is a major challenge for its increased use. Additionally, greater awareness of the potential water benefits and its cost effectiveness will all aid in the expansion of responsible greywater use. This type of public outreach should accompany new policies and can be done by governments and other organizations interested in promoting greywater, including a new international greywater organization (as noted above).

**Create Learning Exchanges**
A key building block to get institutions, policymakers, city planners, engineers, public health professionals, and developers familiar with greywater reuse technologies is direct interaction in learning exchanges with professional colleagues. Learning exchanges have been important in numerous areas to promote new policy instruments, strategies, or technologies. For example, delegations of policymakers from one country could visit another to see first-hand how supportive greywater reuse policies have led to impacts on the ground. In the case of public health professionals, learning directly from a colleague about the impacts of greywater reuse on public health in that region, and the role the public health agency can play in promoting responsible greywater reuse can be a useful model. Practitioners, including architects, plumbers, and engineers, could benefit from touring greywater reuse projects in other countries to identify opportunities to replicate these technologies in their countries.

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