WHO-EM/CEH/125/E

Overview of greywater management
Health considerations

Discussed and approved at the regional consultation on national priorities and plans of action on management and reuse of wastewater, Amman, Jordan

World Health Organization
Regional Office for the Eastern Mediterranean
Centre For Environmental Health Activities
Amman, Jordan
2006

Printed by Eco Design Ideal

Document WHO-EM/CEH/125/E

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Preface

The adoption of non-conventional options for the conservation and reuse of water in countries of the Eastern Mediterranean Region is inevitable. With the growth in population and the subsequent additional demand for water, it has become apparent that new and innovative methods are needed to ensure the sustainable management of water resources. Interest in the separation and reuse of wastewater (grey and black water) has increased in recent years in an attempt to address the problem and as a result of economic and ecological considerations.

This guide has been prepared to assist government officers, homeowners, site and soil evaluators, designers, installers and service technicians with regard to the safe reuse of wastewater, and to act as a guide in the process of designing, installing and maintaining greywater systems in a manner which protects human health, plants, soil and the environment.

Greywater is the water collected separately from sewage flow that originates from clothes washers, bathtubs, showers and sinks, but it does not include wastewater from kitchen sinks, dishwashers or toilets. Shower, sink and laundry water comprises 50%–80% of residential wastewater, and if this greywater was to be collected, treated and reused, it would alleviate the demand on water resources and wastewater treatment plants.

As greywater is contaminated with faecal coliforms and some chemical pollutants from bathing and laundry, microbial and chemical contamination of greywater poses a potential risk to human health, and so it is important to recognize that greywater does have the potential to transmit disease. Accordingly, this guide was prepared by the WHO Regional Office for the Eastern Mediterranean and the Centre for Environmental Health Activities to act as a set of guidelines and procedures for the safe reuse of greywater.

1. Introduction

1.1 Wastewater reuse

Sustainable water resources are essential for socioeconomic development, and yet water is often misused and wasted in today's society [1]. The sound and sustainable management of water resources is crucial for arid and semi-arid regions.

In arid and semi-arid regions, water conservation and reuse are issues that receive a great deal of public attention. The responsible use and reuse of water is vital to the sustainability of the water supply and thus for the future of these areas. The treatment and reuse of wastewater is one of the best options for water conservation available to communities located in arid areas. Many large-scale reuse efforts have been developed, such as the watering of golf courses and the irrigation of landscapes with treated municipal effluent.

The potential for wastewater reuse is not only limited to large-scale projects supplied by community wastewater treatment facilities but is also available to individual homeowners [2]. Greywater recycling offers a way in which people can save and reuse the wastewater generated in their homes.

1.2 Greywater definition

Domestic wastewater, or "sewage", can be divided into two categories: blackwater which originates from toilets and kitchens has gross faecal coliform contamination and generally has high concentrations of organic matter; and greywater which originates from bathrooms and laundries and constitutes the largest flow of wastewater [3].

The term "greywater" refers to untreated household wastewater, which has not been contaminated by toilet waste. It includes the water from bathtubs, showers, hand basins, laundry tubs, floor wastes and washing machines. It does not include waste from kitchen sinks, garbage disposal units or dishwashers [4].

It is called greywater because if stored for even short periods of time, the water will often cloud and turn grey in colour [3]. The exact sources of greywater vary according to countries and organizations. Some definitions include the water sourced from the kitchen and dishwasher.

1.3 Quantity of greywater generated by households

The amount of wastewater generated by any household will vary greatly according to the dynamics of the household, and is influenced by such factors as the number of occupants, the age distribution of the occupants, their lifestyle characteristics, water-usage patterns, the cost of water and the climate [5]. Some water-usage surveys undertaken in capital cities of different countries have identified an average wastewater flow of 586 L per day for each household, as shown in Table 1.

Table 1: *Approximate percentage of generated wastewater/household [5]*

Wastewater type	Total wastewater		Total greywater	
	Total (%)	(L/day)	Total (%)	(L/day)
Toilet	32.0	186.0	–	–
Hand basin	5.0	28.0	8.0	28.0
Bath/shower	33.0	193.0	54.0	193.0
Kitchen	7.0	44.0	–	–
Laundry	23.0	135.0	38.0	135.0
Total	100.0	586.0	100.0	356.0

Table 1 shows that greywater represents about 61% of the total wastewater stream. This represents a significant water resource which can be managed in an environmentally responsible manner in accordance with ecologically sustainable development principles that do not pose a threat to human health and, at the same time, contribute to the sustainability of the water supply.

1.4 Significance of greywater reuse

Much of the daily-generated wastewater is recognized as greywater. The total volume of greywater potentially generated each day from the average household (in different countries) is 356 L; this represents about 60% of the total generated wastewater [6]. Greywater can be used for different purposes, such as garden watering, ornamental uses in fountains and waterfalls, landscaping, lawn irrigation, car washing and toilet flushing [7]. Greywater reuse utilizes an on-site resource which would otherwise be wasted. As a result of reuse, fresh drinking-water supplies are conserved, which in turn enables the water to remain in natural ecosystems.

Greywater reuse succeeds in saving money spent by water authorities, reduces sewage flows and reduces the public demand on potable water supplies. By reusing greywater, the load on wastewater disposal systems is reduced, and therefore, the life of the wastewater disposal system is prolonged and capital expenditure required for the upgrading and expansion of systems is delayed. For example, the sewerage system in most of Australia's major cities is old and, in many areas, overloaded [8]. This problem is going to worsen as the country's population grows. Thus, alternatives to the traditional system, such as the reuse of greywater, need to be investigated [3].

2. Objectives

The purpose of this overview is to provide guidance for local government officers, homeowners, site and soil evaluators, designers, installers and service technicians on the impacts of greywater reuse on human health, plants, animals and the environment.

In addition, this overview will focus on the reuse of greywater for domestic purposes without compromising public health; and on how to maintain and enhance the quality of the environment by setting minimum standards for the design and installation of greywater reuse systems to achieve the following:

- protection of groundwater;
- protection of surface water;
- protection of land and vegetation;
- prevention of a public health risk;
- protection of the community against possible disease transmission arising from improper greywater reuse; and
- ensure that greywater installations do not harm the environment, or cause a nuisance, and are appropriately sited and maintained according to a regulatory standard.

3. Greywater quality

3.1 General quality

The quality of greywater between households, and even within households, varies daily depending on the activities of the household's occupants. In addition, the quality of greywater varies depending on the source of the water (Table 2). For most households greywater contains soap, shampoo, toothpaste, shaving cream, laundry detergents, hair, lint, body oils, dirt, grease, fats, chemicals (from soaps, shampoos, cosmetics) and urine[1]. The most significant pollutant of greywater is laundry detergent, particularly those high in sodium and phosphorus. Greywater also contains bacteria, parasites and viruses washed from the body and clothes [9].

[1] Some people (especially children) urinate in baths and showers. Urine is considered a sterile solution and, therefore, if it enters the greywater, will not contribute to health problems but only increase the nutrient load, which could be beneficial to plants if used appropriately [3].

Table 2: *Likely constituents of greywater from various household sources [10]*

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 [a]	Bacteria, organic matter and suspended solids (food particles), fat, oil and grease, soap and detergent residue

[a] In the case that kitchen water, which is not recommended in household reuse, is included in the definition of greywater.

3.2 Chemical quality

Greywater contains significant amounts of nutrients (Table 3), particularly nitrogen and phosphorus. An average volume of greywater (356 L per day) will produce approximately 45 g of nitrogen and 3 g of phosphorus per day [6]. If managed properly, these nutrients could be beneficial to the homeowner, reducing the amount of commercial fertilizer needed for gardens and lawns.

Chemical contamination found in bathroom greywater originates from shampoo, hair dyes, toothpaste and cleaning chemicals. Laundry water contains higher chemical concentrations from soap powders and soiled clothes (sodium, phosphate, boron, ammonia, nitrogen), and is high in suspended solids, lint, turbidity and oxygen demand and if applied to untreated land could lead to environmental damage, as well as posing a threat to public health [11].

Table 3: *Typical composition of greywater*

Parameter	Unit	Greywater range
Suspended solids	mg/L	45–330
Turbidity	NTU	22–200
BOD_5	mg/L	90–290
Nitrite	mg/L	< 0.1–0.8
Ammonia	mg/L	< 0.1–25.4
Total Kjeldahl nitrogen	mg/L	2.1–31.5
Total phosphorus	mg/L	0.6–27.3
Sulfate	mg/L	7.9–110
pH	–	6.6–8.7
Conductivity	mS/cm	325–1140
Sodium	mg/L	29–230

Source: Jeppersen and Solley (1994) [12]

3.3 Microbial quality

3.3.1 General

The microbial quality of greywater is dependent on the presence of faecal contamination. The main hazard from greywater emanates from faecal cross-contamination [13]. However, as toilet waste is not included in the definition of greywater, faecal contamination is limited to activities such as washing faecally-contaminated laundry (i.e. diapers), childcare and showering. Faecal contamination is measured by the use of common indicator organisms, such as coliforms and enterococci [14]. Some studies have reported high numbers of these organism groups, which indicate substantial faecal contamination of greywater as shown in Table 4.

Wastewater generated from bathtubs, showers and hand basins is considered to be the least contaminated type of greywater. Thermotolerant coliform concentrations have been assessed in shower and bath water to be in the range of 10^2 to 10^5 cfu/100 mL.

Greywater from the laundry is improved in quality from wash water to first-rinse water to second-rinse water. Thermotolerant coliform loads varied from 10^7cfu/100mL when nappies were washed, to 25 cfu/100 mL for second-rinse water [11]. Where greywater used for the washing of diapers is included, the coliform count is greatly increased. Many studies recommend not reusing water used for the rinsing or washing of nappies because of the high faecal coliform count and the potential for disease [15].

***Table 4**: Faecal coliforms numbers in greywater*

Reference	Source of water	**Number of faecal coliforms** (cfu/100 mL)
Nolde (1999) [4]	Bath, shower and washing machine with baby diapers	10^4–10^6
Jepperson and Solly [12]	Bathing and shower	6 x 10^3
Water CASA (2003) [15]	Washing machine, bathroom sink, shower and kitchen sink	3.44 x 10^6
Water CASA (2003) [15]	Washing machine (with children)	2.6 x 10^4–8.45 x 10^5
Water CASA (2003) [15]	Washing machine (without children)	7 x 10^1–2.9 x 10^4
Christova-Boal et al (1996) [18]	Shower and hand basin	1.5^2 x 10^2–3.5 x 10^4
Feachem et al (1983) [19]	Shower and bath	10^1–5 x 10^3

Viruses can also be found in greywater [16]. The number of viruses found in greywater is dependent upon the health of the population generating the liquid as infected individuals may excrete a virus [17].

The numbers of faecal coliforms shown in Table 4 are well above the accepted safety level. These data demonstrate that greywater could pose a potential health risk to people coming into contact with it.

3.3.2 Indicators of faecal pollution in greywater

The most widely used indicators are members of the coliform group, but enterococci, bacteriophages and spores of sulfite-reducing anaerobic bacteria are becoming more frequently used [13].

Coliform bacteria

Coliform bacteria are the most widely used faecal indicators and play an important role in water management. Thermotolerant coliform bacteria have a direct correlation to sewage pollution. *Escherichia coli* (*E. coli*) are almost exclusively of faecal origin and thus are a more reliable faecal indicator than the other coliform groups [20].

Enterococci

Enterococci (faecal streptococci) are present in faeces in densities between 10^5 to 10^7 cfu [20]. They are more tolerant to environmental stress and have also been suggested as an indicator of the presence of enteric viruses.

Bacteriophages
Bacteriophages are viruses that infect bacterial host cells and are harmless to humans. Many enteric viruses are more resistant in the environment, as well as to different treatments, than bacteria. Therefore, bacteriophages have been suggested as indicator organisms to predict the presence and behaviour of enteric viruses in the environment [21].

Spores of sulfite-reducing anaerobic bacteria
These are dominated by *Clostridium perfringens* spores, which are present in human and animal faecal matter. The spores survive for long periods in water and may give an indication of intermittent faecal pollution [13].

3.3.3 Hazard identification

The presence of faecal pollution in greywater will give an indication that greywater contains etiological agents that can cause infection to humans [14].

Bacteria
A range of bacteria can cause infection, but *Salmonella* and *Campylobacter* were chosen as index organisms for the bacteria group.

Campylobacter are harboured in the intestines of a wide range of domestic and wild animals and have been found in almost all bird species [22].

Salmonella spp. are Gram-negative, aerobic, rod-shaped and have the potential to infect people, birds and other animals [22].

Viruses
Several gastrointestinal viruses are of public health concern. As viruses are usually excreted in high numbers, are persistent in the environment and have low infectious doses, they are important waterborne agents. It is believed that many waterborne outbreaks with unknown etiological agents are viral [22].

Protozoa
Protozoa are single or unicellular, eukaryotic organisms divided into four main groups: flagellated, amoeboid, ciliated and sporozoids. All four groups contain intestinal parasites, of which many are zoonotic, i.e. can be transmitted directly from animals to humans, such as *Giardia* and *Cryptosporidium* [22].

Giardia is considered to be the most common intestinal parasite in the world [23]. The infectious life stage of *Giardia* is the cyst, which can survive and remain infectious for several months in water. In addition, the infectious dose can be low; the median infectious dose for *Giardia* is between 10 and 100 cysts.

Cryptosporidium is present in the environment as an (oo) cyst. In aqueous solutions (oo) cysts remain infectious for up to 6 months and are viable for 9 months [22]. The infectious dose in *Cryptosporidium* is between 30 and 1000 (oo) cysts [24].

3.3.4 Risk characterization

To characterize this risk of greywater reuse, Ottosson (2003) identified treatment required for different organisms at different exposure points to be within an acceptable level of risk as shown in Table 5 (expressed as log reduction) [13].

Groundwater exposure

If greywater is used for groundwater recharge, drinking-water from the tap will be the primary transmission route. The largest risk emanates from rotavirus and a mean 3.7 log reduction is needed. The treatment requirement would be about the same for adenovirus and calicivirus. The other pathogens of concern are *Campylobacter*, *Salmonella, Giardia* and *Cryptosprodium* for which a 2.2, –0.3, –1.4, –0.4 log reduction, respectively, is required.

Direct contact with treated greywater

If treated greywater is released locally into a pond, a mean 3.0 log reduction is desired for rotavirus and 0.9 for *Campylobacter* (Table 5). For the other pathogens, the concentration before treatment was low enough not to signify risks over the accepted level.

Exposure via irrigation of sports fields and gardens

Irrigation is suggested in several studies as a means of reusing greywater [25]. This can lead to health risks as a result of contact with the irrigated area or ingestion of irrigated crops, as well as ingestion/inhalation of aerosols during irrigation. Treatment required to reduce the pathogens to be within an acceptable level of risk is shown in Table 5.

Table 5: *Treatment required for different organisms at different exposure points to be within an acceptable level of risk [13]*

Exposure	Rotavirus	Campylob-acter	Salmonella	Giardia	Cryptospor-idium
Groundwater	3.7	2.2	–0.3	–1.4	–0.4
Direct contact	3.0	0.9	–1.6	–1.4	–2.2
Sports field	3.0	0.9	–1.6	–1.4	–2.2
Aerosol	0.7	–1.3	–3.8	–3.7	–4.4

Source: Jepperson and Solley (1994) [12]

4. Effect of storage on greywater quality

All forms of wastewater when stored will turn septic unless the wastewater is treated. Similarly, when greywater is stored, it will also turn septic, giving rise to offensive odours and providing suitable conditions for microorganisms to multiply [15]. Thermotolerant coliforms have been found to be multiplied by between 10 and 100 times during the first 24 to 48 hours of storage. Therefore, greywater must only be stored temporarily in a surge tank, unless it is adequately treated [26].

5. Greywater systems

5.1 Greywater treatment

Greywater is not malodorous immediately after discharge. However, if it is collected in a tank, it will consume the oxygen very quickly and become anaerobic. Once it reaches the septic state, greywater forms sludge that either sinks or floats depending on its gas content and density. Septic greywater can be as foul smelling as any sewage and will also contain anaerobic bacteria, some of which could include human pathogens. Consequently, the key to successful greywater treatment lies in its immediate processing and reuse before reaching the anaerobic state. The simplest, most appropriate treatment consists of directly introducing freshly generated greywater [27].

There are four reasons why greywater may need to be treated [10]:

1. To remove substances that may be harmful to human health.
2. To remove substances that may be harmful to plants and soil.
3. To remove substances that may be harmful to the environment.
4. To remove substances that may clog the irrigation system.

Greywater reuse methods can range from low-cost methods, such as primary treatment methods that coarsely screen oils/grease and solids from the greywater before irrigation, to more expensive secondary treatment systems that treat and disinfect the greywater to a high standard before using it for irrigation via micro-drip or spray systems, or for toilet flushing. The choice of system depends on a number of factors including [28]:

- The owners’ willingness to operate and maintain the facility;
- The source of greywater to be recycled; and
- The purpose of the greywater reuse (whether for subsurface irrigation or sprinkler irrigation or for toilet flushing or waterfalls).

5.2 Primary diversion systems

Primary diversion methods use coarse screen filters or sedimentation to remove oils/grease and solids prior to discharge to the land application areas. These systems are likely to be considered the most economically attractive for greywater use because maintenance can usually be carried out by the homeowner, and they generally do not rely heavily on electricity or chemicals to operate. These include the gravity diversion system and the pump diversion system.

a) Gravity diversion system

A gravity diversion device incorporates a tank-activated valve, switch or tap which is fitted to the outlet of the waste pipe of the plumbing fixtures, such as the laundry tub. The plumbing diversion device can be switched by the householder to divert greywater from the laundry tub by gravity directly to the diversion line and the proposed land application area. The greywater must not be stored. The types of gravity diversion systems are shown in Figures 1 and 2.

b) Pump diversion system

The pump diversion system directly recycles untreated domestic greywater for lawn and ornamental garden watering. This system does not allow storage or treatment. The system incorporates a surge tank to temporarily hold large drain flows from washing machines and bathtubs before distribution by a pump to a land application area. The surge tank does not operate as a storage tank. The greywater may be screened as it enters the surge tank and immediately distributed for reuse by a pump [11].

5.3 Secondary treatment systems

Secondary treatment systems further treat the greywater to remove more of the oils/ grease, solids and organic material. This allows secondary treated greywater to be irrigated via micro-drip or surface irrigation methods. These systems are generally more expensive due to the initial establishment costs associated with the continuing treatment needs and ongoing maintenance costs. However, the treatment level enables a much more conventional surface irrigation system and presents less of a health risk in case of human contact [11]. There are many types of secondary treatment systems, including: slow sand filter, activated sludge, constructed wetland, trickling filter and rotating biological contactor.

a) Active sludge treatment

In active sludge treatment, bacteria digest organic material in the wastewater, significantly reducing the organic material, which is measured as biological oxygen demand (BOD) and chemical oxygen demand (COD). In the process, nitrogen, phosphorus, inorganic substances and pathogens are also reduced. Pathogen reduction is due to competition, digestion and sedimentation. In Swedish greywater treatment plants, a 53%–98% reduction in different microorganisms was observed in the active sludge treatment process [13].

b) Constructed wetland

Constructed wetland performance was efficient in the removal of BOD, COD, turbidity, total coliforms, faecal coliforms, *E-coli*, Kjeldahl nitrogen, ammonia, aluminum, potassium and phosphate from greywater, however wetland was inefficient in heavy metals and total dissolved solid removal [13].

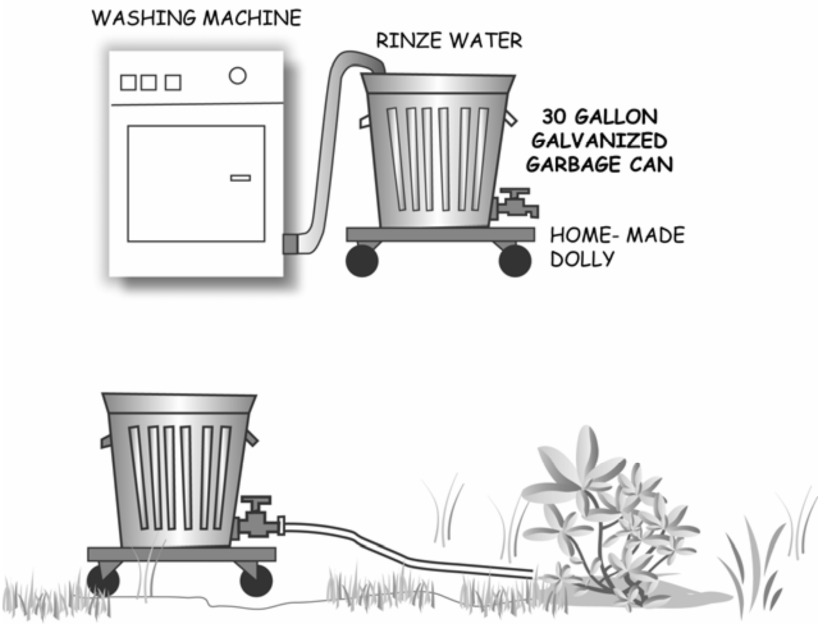

Figure 1. Gravity system with potable tanks [29]

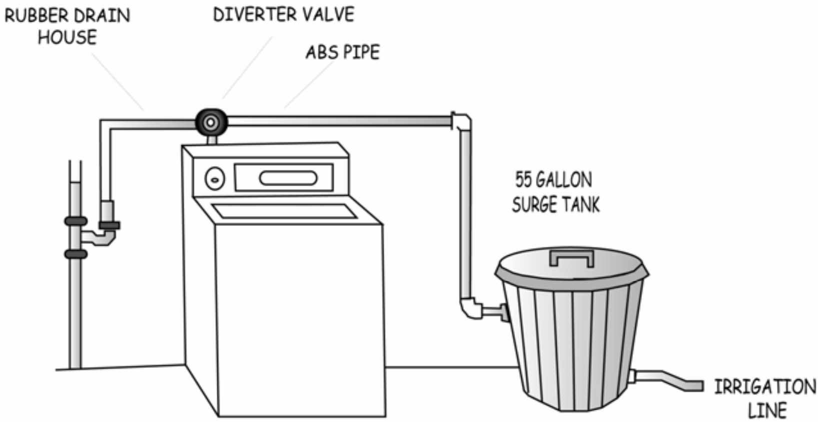

Figure 2. Gravity system with surge tank [29]

5.4 Disinfection

Disinfection is the process of inactivation of pathogenic microorganisms in greywater. Disinfection provides the opportunity for homeowners to use treated greywater for domestic purposes, such as toilet flushing and car washing (Figure 3). There are many methods of disinfection: chlorine, bromine chloride, calcium hypochlorite, ozone and ultraviolet radiation [30]. It is important to look at the available techniques for treatment and their efficiency in the treatment of greywater. Treatment efficiency and reliability need to be inside an acceptable level of risk as shown in Table 6. There are varying recommendations for the planning of greywater treatment units depending on specific on-site conditions, such as topography, type of soil and height of the water table. There are many factors that influence viral movement in soil, and that are thus important to evaluate when preparing a treatment unit. Factors are listed in Table 7.

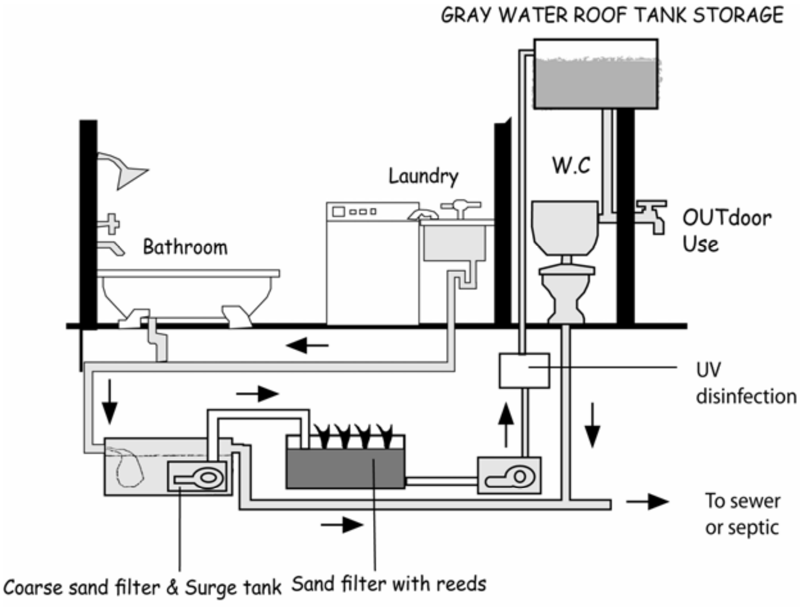

Figure 3. Greywater collection, treatment and reuse for toilet flushing and outdoors [31]

Table 6*: Treatment efficiency and reliability need to be inside an acceptable level of risk*

Treatment	Total coli-forms	Thermo-tolerant coli-forms	*E. coli*	Enterococci	Bacteriophages	References
UV / Swedish	–	1.2	1.1	–	–	Lindgren and Grette (1998) [32].
Constructed wetland / Swedish	–	–	1.5	–	–	Lindgren and Grette (1998) [32].
Settling tank, active sludge / Swedish	0.86	–	1.0	0.66	0.24	Ottosson and Stenstrom (2002) [33].
Constructed wetland / Kenya	–	3.5	–	1.7	–	Emanuelsson and Linderholm (2001) [34].

***Table 7**: Factors that influence the movement of viruses in soil [13]*

Factor	Remark
Rainfall	Viruses retained near the soil surface may be eluted after heavy rainfall because of the establishment of ionic gradients within the soil column.
pH	Low pH favors virus adsorption; high pH results in elution of adsorbed virus.
Soil composition	Viruses are readily adsorbed to clays under appropriate conditions and the higher the clay content of the soil, the greater the expected removal of the virus. Sandy loam soils and other soils containing organic matter are also favorable for virus removal.
Flow rate	As the flow rate increases, virus removal declines.
Soluble organics	Soluble organic matter competes with viruses for adsorption sites on the soil particles, resulting in decreased virus adsorption.
Cautions	The presence of cautions usually enhances the retention of viruses by soil.

6. Health considerations

6.1 Effects of greywater reuse on human health

Greywater is contaminated with human excretions from bathing and laundry. Microbial and chemical contamination of greywater poses a potential risk to human health, a risk that is likely to be increased if microbial contamination is increased [16]. It is important to recognize that greywater does have the potential to transmit disease.

The environmental transmission of pathogens occurs through several different routes [28]. These may be:

- directly through contact with greywater;
- directly through contaminated drinking-water;
- directly through vegetables, shellfish or other food products exposed to contaminated water or soil;
- by accidental ingestion of contaminated water during recreational activities;
- by inhalation of aerosols or dust due to irrigation with greywater;
- vector-borne transmission where the vector or the intermediate host breeds in water; and
- by secondary transmission through contact with infected individuals.

Disease transmission is determined by several pathogen-related factors including:

- an organism's ability to survive or multiply in the environment (some pathogens require the presence of specific intermediate hosts to complete their life-cycles);
- latent periods (many pathogens are immediately infectious; others may require a period of time before they become infectious); and
- an organism's ability to infect the host (some pathogens can cause infections when present in small numbers, such as *Ascaris*, others may require a million or more organisms to cause infection).

However, there are no recorded incidents of serious effects on human health from the reuse of greywater [10].

To minimize the risk to human health and to prevent a nuisance from greywater reuse, the following considerations are important:

- Greywater systems must dispose of the greywater below ground surface unless treated and disinfected to meet an appropriate standard [35].
- The system must be designed and operated to prevent human contact with greywater [29].
- There must be no cross connection with a potable water supply [11].
- Greywater must not be allowed to enter any stormwater drainage system [28].
- Greywater should not be used in a manner that may result in direct contact with vegetables or other edible plants. It may be used to irrigate fruit plants where the fruit does not make contact with greywater [28].
- The opportunity for the breeding of mosquitoes must not be permitted in any part of the greywater system [in conveyance, treatment, storage, or soil application] [3].
- Greywater must not be allowed to pond on the surface or to run off the property.
- Disinfection and other advanced treatment systems must be applied to reach the required standard for use in toilet flushing and for car washing [3].
- The land application system must be signposted to advise that greywater is being reused and that contact with the water must be avoided.
- Greywater should not be stored, unless it has been treated and disinfected [31].
- Sprinkler irrigation must be avoided [10].

6.2 Effects of greywater reuse on plants

Most greywater is used to irrigate plants, and so the most immediate risks of pollutant constituents in the greywater are related to plant health. Greywater may be beneficial for plants because it contains nutrients, mainly nitrogen and phosphorus, but it may also contain sodium and chloride, which can be harmful to some plant species. It is assumed that users will avoid the disposal of inappropriate substances [paints, antifreeze, solvents, mothballs, wastewater from oily rags, chemicals from photographic laboratories, etc.) into greywater. However, many greywater sources contain substances which may have harmful effects on plants. Laundry products, in particular, use a variety of chemicals that can be harmful to plants. Most soaps and detergents—including baking soda—contain sodium compounds. High levels of sodium can cause discoloration and burning of leaves, and can contribute toward an alkaline soil condition. In addition, high sodium can be toxic to certain plants and can prevent calcium from reaching them [10]. A second possible effect of some types of sodium is a disturbance of the soil's ability to absorb water. The sodium adsorption ratio (SAR) is the parameter that measures the effect on the soil's structure of sodium compounds. A high SAR (13 or above) will result in soils with reduced permeability and aeration, and a general degradation of the soil's structure [10]. Therefore, a build-up of sodium over time will reduce the soil's ability to support plants. This is probably one of the most serious potential long-term consequences of irrigation with greywater [36].

Detergent and laundry products also contain other chemicals that are harmful to plants, such as boron, chlorides and peroxides. Boron, for example, is very toxic to most plants. Plant damage from exposure to excessive amounts of boron is first displayed by a burnt appearance to the edges of the leaves. Other symptoms of boron toxicity include leaf cupping, chlorosis, branch dieback, premature leaf drop and reduced growth.

Bleaches commonly contain chlorides that can also damage plants, particularly if the bleach water actually touches the foliage. One symptom of chlorine-induced damage is a tendency for new, expanding leaves to appear bleached. Ammonia is often used as a substitute for bleach, as it also breaks down grease, and is preferable as a household cleaning and deodorizing agent [10].

All of the above-mentioned threats to plant health can be avoided by adopting the correct use of greywater as will be discussed later.

The general effects of greywater chemical contents on plants [29] include the following.

Boron is considered a plant micronutrient and is required in small concentrations. Most soils provide adequate amounts of this chemical.

Concentrations slightly higher than those considered beneficial can cause damage or death to plants.

Nitrogen is a necessary nutrient for plant growth, and is extremely beneficial as a supplement to landscape plants.

Phosphorus is a necessary nutrient for plant growth, and is very beneficial as a supplement to landscape plants.

Potassium is a plant nutrient, which is, in general, beneficial, especially in soil with high alkalinity.

Sodium can act as a poison to plants by reducing the plant's ability to take up water from the soil. It can build up in the soil gradually and increases the soil's toxicity.

Chlorine is undesirable for plants in large amounts, although it is found in small amounts in many municipal water supplies. Bleaches and detergents carry large amounts of chlorine.

To minimize the adverse effects of greywater reuse on plant health the following considerations are important:

- Plants irrigated with greywater must be monitored regularly for symptoms of damage.
- Water quality and nutrients to be used for irrigation must be monitored and applied at a rate required to meet the demand of the vegetation. Application beyond this rate poses a threat of surface run-off, or contamination of groundwater.
- If any signs of plant injury appear, greywater use must be discontinued or reduced.
- Particular care should be given to water containing detergents, bleach or boron; in addition, only detergents that contain small amounts of chloride and boron must be used.
- Applying greywater directly to foliage or stems must be avoided.
- Greywater should only be used on well-established plants, not on seedlings or young plants, as they are more sensitive to the impurities in the greywater.

6.3 Effects of greywater reuse on soil

The main effects of greywater on soil are:

- a tendency to raise soil alkalinity and salinity; and
- a reduction in the ability of soil to absorb and retain water;
- an increase in alkalinity due to the presence of sodium, potassium or calcium salts in the greywater, particularly from laundry detergents.

Water retention is also affected by some forms of sodium—an effect measured by a parameter known as the sodium adsorption ratio (SAR). A sandy, well-drained soil will be less affected by greywater application than a poorly-drained clay soil [10].

To minimize the adverse effects of greywater reuse on soil the following considerations are useful:

- Application of gypsum (calcium sulfate) to the soil in order to reduce the pH levels (a rate of 100g/m^2 each month is suggested, until the pH of the soil drops to 7);
- Dilution of greywater by rainfall or fresh water before irrigation helps to clean the soil from the build-up of sodium, excess salts, and other soil contaminants; and
- The soil should not be allowed to dry out as this causes the concentration of salts in the remaining water to become very high.

6.4 Effects of greywater reuse on the environment

The importance of sustainable development cannot be overemphasized. Sustainable development is development which uses, conserves and enhances community resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future can be improved. The reuse of greywater is an example of sustainable development in practice through water conservation.

The most obvious benefit of greywater reuse is water conservation. Domestic reuse of greywater will help the environment by reducing demand on higher quality water resources.

One of the main environmental risks resulting from greywater reuse is that of groundwater pollution. It is possible that some of the substances found in greywater may find their way into the groundwater reserves underlying the area of reuse.

To minimize the adverse effects of greywater reuse on groundwater and in order to ensure that the greywater system is used effectively the user must analyse and study the nutrients required by the plants and soil [37].

7. General guidelines for the reuse of greywater in a healthy manner[1]

7.1 Sources of greywater

1. In order to reuse greywater from a particular building, a 'dual plumbing' system is required to separate the usable greywater from the more contaminated blackwater. The outputs from toilets, bidets and kitchen sinks are not suitable to be used in irrigation without proper treatment, and should be diverted to the existing sewer system. Only wastewater from 'cleaner' sources, such as baths, showers, hand basins, and laundry should be included in the greywater system.
2. Care should be given to limit the release of inappropriate substances into the greywater system. Heavily-soiled or bloodstained clothes, such as diapers, should not be washed in sinks draining to the greywater system. Chemicals such as bleach, cleaning agents and paints should not be disposed of into the greywater system.
3. It is recommended that each household use its own greywater for its own purposes rather than sharing greywater with other households. This avoids potential conflicts and increases confidence in the quality of the greywater. [3].
4. There should be no cross connection of greywater with the drinking-water supply.

7.2 Greywater treatment

1. Relatively clean greywater needs little treatment before it can be used to irrigate trees or shrubs via a subsurface irrigation system [29].
2. All primary treatment greywater systems must incorporate a sedimentation tank to remove fats, grease and solids.
3. Greywater that contains lint, hair, or other solid material may cause periodic clogging of the irrigation system. A simple filter may be required, for example, a screen mesh in the surge or storage tank. This filter will require periodic cleaning.
4. Greywater should not be applied directly to plants if it is hot. If hot water is being used for laundry, the greywater should be stored temporarily to cool down before use for this purpose.
5. Greywater may be stored for short periods if desired. However, this may give rise to unpleasant odours, and therefore, the storage tank should be covered to prevent the escape of odours to areas where they

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[1] Healthy manner: a manner that protects human health, plants, animals and the environment.

would cause annoyance. They should also be vented appropriately to allow odours to escape to the atmosphere, away from areas frequented by people (such as the roof, for example).

6. All pipes containing greywater should have a slight gradient to prevent greywater from lying in the pipes, and should be designed to avoid traps where greywater can settle.
7. System flow rates on coarse sandy soil or gravel should be designed carefully to avoid greywater leaching into groundwater or surface water bodies.
8. All primary greywater reuse systems are to incorporate subsurface irrigation methods. If the secondary treated greywater is disinfected, it could be irrigated above ground level and be used in toilet flushing [11].
9. The treatment level depends on the purpose behind the use of the greywater, whether for toilet flushing or for irrigation. Toilet flushing requires secondary treatment and disinfection whereas irrigation of specific crops does not require high-quality water.
10. The diversion system must have a valve to allow greywater to be diverted back to the sewer when it is too wet to go onto the garden, or in the event of the existence of inappropriate substances.
11. The sedimentation tank and other treatment units may require desludging at regular intervals.
12. The appropriate greywater irrigation method depends on the treatment level as shown in the tables below (Tables 8 and 9).
13. Manufacturers of mechanical greywater reuse systems must adequately demonstrate to the satisfaction of the Department of Health that the system can be operated effectively in the long term without blockages.

All greywater that does not meet the secondary effluent standard, which is given in Table 9, must be discharged to a subsurface land application system (subsurface irrigation). Greywater does not normally require disinfection prior to discharge to a subsurface land application area.

Greywater that has been treated in order that the effluent quality after treatment meets the secondary effluent standard (Table 9) may be discharged to a land application area by surface irrigation.

Table 8: *Greywater irrigation options according to treatment [9]*

Treatment	Greywater reuse application
Untreated greywater	Bucketing (carry greywater manually)
Primary treated greywater	Subsurface irrigation
Secondary treated to a 20 mg/L BOD_5, 30 mg/L SS and possible disinfection to achieve 10 cfu thermotolerant coliforms/100 mL	Micro-drip and spray irrigation

Table 9*: Effluent quality based on level of treatment [38]*

Parameter	Primary effluent g/m3	Secondary effluent g/m3	Advanced secondary effluent g/m3
Biological oxygen demand (BOD_5)	120–240	20	10
Total suspended solids	65–180	30	10
Thermotolerant organisms (cfu/100 mL)	Not applicable	200	10

7.3 Use of greywater

1. Greywater is best suited to the irrigation of plants, trees and shrubs. Ideally, the area to be irrigated should be at a lower level than the greywater output so that the entire system can be operated by gravity, and thus there is no need for a pump [39].
2. Drip irrigation hoses with small holes may clog due to the presence of solid material in the greywater, or following the growth of algae in the hose. Therefore, holes of at least a 3 mm diameter should be provided [39].
3. For untreated greywater, the possibility of human contact should be avoided. Greywater, therefore, should not be used for the irrigation of lawns, unless they are for ornamental purposes only and are not used by children or household animals, or are irrigated by subsurface irrigation systems that reduce the risk of human contact. However, surface irrigation is permitted provided that the user is careful to avoid contact with the greywater.
4. Irrigation of vegetables that will be cooked before they are eaten is also permitted, provided that the greywater makes no contact with the vegetables. However, irrigation of vegetables that have contact with the ground (such as potatoes), or those that are likely to be eaten raw (such as lettuce, carrots, and tomatoes), should be avoided, in addition to leafy edible plants (such as mint and parsley). Greywater is best suited

for the irrigation of mature plants (not saplings) that have considerable tolerance to salinity, sodium compounds and high pH levels [39].

5. Greywater should be used in quantities that can be taken up by the plants and the soil. Excess greywater will flow to the groundwater and may cause contamination.
6. Greywater tends to be slightly alkaline. Shade-loving and acid-loving plants do not like the alkalinity of greywater. Following is a list of some of the plants that are not suited to alkaline conditions [36]:

• Rhododendrons	•Bleeding Hearts	• Oxalis	• Hydrangeas
• Impatiens	• Begonias	• Ferns	• Foxgloves
• Gardenias	•Philodendrons	• Camellias	• Primroses
• Azaleas	• Violets		

Additional plants that are especially susceptible to high sodium and chloride, that may be present in greywater, are:

• Crape Myrtle	• Redwoods	• Star Jasmine	• Holly
• Deodar Cedar			

Plants that would probably do well with greywater irrigation are:

• Oleander • Bougainvillea • Agapanthus • Bermuda Grass • Purple Hopseed Bush	• Oaks • Ice plant • Juniper • Fan and Date Palms	• Rose • Rosemary • Honeysuckle • Australian Tea Tree	• Italian Stone Pine • Arizona Cypress • Cottonwood • Olive

7. Only products with very low phosphorous content should be used. Phosphorous content ranges from 0.05% up to 10% in various detergents. Plants of the *Proteaceae* family (such as Grevillea, Hakea, Banksias and Silky Oak) are susceptible to excess phosphates. These plants are not ideally suited to greywater reuse [36].
8. Detergents and powder cleaners that contain boron should be used sparingly to protect plant life.
9. It is important to check the facility on a regular weekly basis to ensure that greywater is not surfacing or ponding, that the plants and the soil are healthy, and that the equipment is working properly.

7.4 Effluent quality

Although few countries and organizations have an interest in greywater effluent quality, the United States Environmental Protection Agency (USEPA), the US Agency for International Development (USAID), and Mexico and Germany have standard guidelines for greywater quality; some of these standards are strict and others are flexible.

United States Environmental Protection Agency (*USEPA*) *and US Agency for International Development* (*USAID*)

USEPA and USAID have recommended strict guidelines for treated greywater reuse. For unrestricted irrigation (that is, for uses that include crops likely to be eaten uncooked), no detectable faecal coliform bacteria are allowed in 100 mL, and for irrigation of commercially processed and fodder crops, the guideline limit is < 200 cfu/100 mL [40].

The State of California has a number of the strictest standards, requiring < 2.2 total cfu/100 mL for irrigation of food crops (to be achieved through secondary treatment followed by disinfection) and < 23 cfu/100 mL for irrigation of pasture and landscaped areas (through secondary treatment and disinfection) [41].

World Health Organization (WHO)

WHO has undertaken many studies to evaluate the risk that may be caused from reusing wastewater in irrigation. They depend on epidemiological studies and on the quantitative microbial risk assessment (QMRA) technique to estimate the risk and to produce suitable guidelines (Table 10).

***Table 10**: WHO guidelines for using treated wastewater [a] in agriculture [42]*

Category	Reuse condition	Intestinal nematodes (no. of eggs/L)	Faecal coliforms (cfu/100 mL)
a)	Irrigation of crops likely to be eaten uncooked, sports fields, public parks [b]	≤ 1	≤ 1000
b)	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees [c]	≤ 1	No standard recommended

[a] The requirements for treatment and land application of greywater are the same as for wastewater.

[b] A more stringent guideline limit (< 200 faecal coliforms/100 mL) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

[c] In the case of fruit trees, irrigation should be ceased two weeks before the fruit is picked. Sprinkler irrigation should not be used.

Mexico

Mexico introduced standards of ≤ 5 nematode eggs/L, and for unrestricted irrigation introduced a daily mean of ≤ 2000 cfu/100 mL and a monthly mean of ≤ 100 cfu/100 mL [43].

Germany

Guidelines for service water reuse were introduced in 1995 by Berlin Senate Department for Building and Housing. Parameters defined among others for total coliforms < 100 mL^{-1}, faecal coliforms < 10 mL^{-1} [44].

7.5 Guidelines for vertical and horizontal separation distances

In 2003, Queensland Government/Natural Resources and Mines prepared guidelines for the use and disposal of greywater. The government recommends specific separation distances to protect public health by ensuring that risks associated with the discharge of greywater to the environment are minimized (as shown in Tables 11, 12, and 13) [12].

The recommended separation distance in Table 11 should be applied to primary effluent, secondary effluent and advanced secondary effluent.

***Table 11**: Recommended horizontal separation distances for subsurface land application areas*

Feature	Recommended horizontal separation distance
Footings of buildings	Boundaries of land application areas should be positioned at least 2 m down slope, or 4 m up slope from the footing or where the site is flat, 2 m from any point of the building footing.
Property boundaries, pedestrian paths and walkways, recreational areas	Boundaries of land application areas should be positioned at least 2 m down slope, or 4 m up slope from the feature or where the site is flat, 2 m from any points of the feature.
In ground swimming pool	Boundaries of land application areas should be positioned at least 6 m down slope, or 6 m up slope from the feature or where the site is flat, 6 m from any points of the pool.

Table 12: *Recommended horizontal separation distances for surface irrigated land application areas*

Feature	Recommended horizontal separation distance
Property boundaries, pedestrian paths and walkways	Secondary effluent: 2 m from the edge of the irrigated wetted area to any point of the feature. Advanced secondary effluent (disinfection): 2 m from the edge of the irrigated wetted area to any point of the feature.
Dwellings, recreational areas	Secondary effluent: 15 m from the edge of the irrigated wetted area to the dwelling or designated edge of the recreational area. Advanced secondary effluent: 10 m from the edge of the irrigated wetted area to the dwelling or designated edge of the recreational area.

Table 13: *Recommended separation distances for protection of water quality*

Feature	Recommended separation distance
Top water level of surface water source used for agriculture	Primary effluent: 50 m (horizontal) Secondary effluent: 30 m (horizontal) Advanced secondary effluent: 10 m (horizontal)
Bore or a dam used or likely to be used for human and/or domestic consumption	Primary effluent: 50 m (horizontal) Secondary effluent: 30 m (horizontal) Advanced secondary effluent: 10 m (horizontal)
Unsaturated soil depth to a permanent water table	Primary effluent: 1.2 m (vertical) Secondary effluent: 0.6 m (vertical) Advanced secondary effluent: 0.3 m (vertical)

8. Regulations and codes

8.1 General requirements

Several countries have issued regulations and codes for greywater treatment and reuse, such as the United States of America and Australia. These regulations set out the technical requirements for the sustainable management, site and soil evaluation, design installation and operation of on-site sewerage facilities.

8.2 United States of America (USA)

The following section summarizes greywater regulations and codes for nine states in the United States of America.

California/California Department of Water Resources

California's Greywater Code mandates that all greywater systems must be discharged into subsurface irrigation fields, and sets procedures for estimating greywater discharge volumes and for determining the irrigation capacity of the soil. The code requires soil percolation tests and/or soil analyses as the basis for determining the required area of disposal. This code also sets standards for greywater subsurface drip irrigation systems.

To reduce possible health risks that may result from the reuse of greywater, residents in California are prohibited from applying greywater above land surface or discharging it directly into storm sewers, or into any body of water. In addition, people must not come into contact with greywater, except as required to maintain the greywater treatment and distribution system. Greywater must not be used for irrigation of vegetable gardens.

The following is part of California's Greywater Code, which is related to health and safety [37]:

1. Greywater may contain faecal matter as a result of bathing and/or washing of diapers and undergarments. Water containing faecal matter, if swallowed, can cause illness in a susceptible person.
2. Greywater shall not include laundry water from soiled diapers.
3. Greywater shall not be applied above the ground level, or be allowed to surface, and shall not be discharged directly into or reach any storm-water sewer system or any body of water.
4. No direct contact should be allowed between greywater and human beings except as required to maintain the greywater treatment and distribution system.
5. Greywater shall not be used for vegetable gardens.
6. The location of the greywater system must be identified in line with the following table (Table 14).

Table 14: *Location of greywater system [36, 37]*

Minimum horizontal distance from:	Surge tank (metre)	Irrigation field (metre)
Buildings or structures [a]	1.5[b]	2.5[c]
Property line adjoining private property	1.5	1.5
Water supply wells [d]	15.0	30.0
Streams and lakes [d]	15.0	15.0
Seepage pits or cesspools	1.5	1.5
Disposal field and 100% expansion area	1.5	1.2
Septic tank	0	1.5
On-site domestic water service line	1.5	1.5[e]
Water ditches	15.0	15.0

[a] Including porches and steps, whether covered or uncovered, but does not include carports, covered walks, driveways and similar structures.

[b] The distance may be reduced to 0 m for above ground tanks if approved by the Administrative Authority.

[c] The distance may be reduced to 0.6 m, with a water barrier, by the Administrative Authority.

[d] Where special hazards are involved, the distance may be increased by the Administrative Authority.

[e] A 0.6 m separation is required for subsurface drip systems.

Arizona/Arizona Department of Environmental Quality

In 2001, the Arizona Department of Environmental Quality published regulations for residential greywater reuse. These regulations follow a three-tiered approach whereby systems that use under 1500 L per day must meet a list of reasonable conditions, and are covered by a general permit without the need for the householder to apply for an individual permit.

The conditions for the private residential reuse of greywater include avoidance of human contact between greywater and soil irrigated by greywater, containment of greywater from a particular residence within the property boundary, and greywater usage only for household gardening. In addition, surface application of greywater may not be used for irrigation of food plants, except for fruit trees, and surface irrigation by greywater should be restricted to flood or drip irrigation. Sprinkling is prohibited. The greywater should not contain water that is used to wash diapers or similarly soiled or infectious garments unless the greywater is disinfected before irrigation. Likewise, greywater should not contain hazardous chemicals, for example, taken from cleaning car parts, washing greasy or oily rags, or disposing waste solutions from home photographic laboratories.

The regulations require that greywater systems should be constructed so that if blockage, plugging, or backup of the system occurs, greywater can be directed into the sewage collection system or into an on-site wastewater treatment system. The greywater system can include a means of filtration to reduce plugging and to extend the lifetime of the system [45].

In addition, any greywater storage tank should be covered to restrict access and to discourage the breeding of mosquitoes or other disease-bearing insects. The greywater system should not be sited in a floodway and should be operated to maintain a minimum vertical separation distance of at least 1.5 m from the point of greywater application to the top of the seasonally high groundwater table. Any pressurized pipe used in a greywater system which may be susceptible to cross contamination with a potable water system should clearly indicate that the pipe does not carry potable water. The blanket prohibitions ensure the protection of human and plant health.

The following is part of Arizona's Administrative Greywater Code, which is related to health and safety [46]:

a) A Reclaimed Water General Permit allows private residential direct reuse of greywater for a flow of less than 400 gallons per day, if all the following conditions are met:

1. Human contact with greywater and soil irrigated by greywater is avoided.
2. Greywater originating from the residence is used and contained within the property boundary for household gardening, composting, lawn watering or landscape irrigation.
3. Surface application of greywater should not be used for irrigation of food plants except for citrus and nut trees.
4. The greywater does not contain hazardous chemicals derived from activities, such as cleaning car parts, washing greasy or oily rags, or disposing of waste solutions from home photographic laboratories.
5. The application of greywater is managed to minimize standing water on the surface.
6. The greywater system should be constructed so that in case blockage, plugging, or backup of the system occurs, greywater can be directed into the sewage collection system or on-site wastewater treatment and disposal system, as applicable. The greywater system may include a means of filtration to reduce plugging and to extend the lifetime of the system.

7. Any greywater storage tank should be covered to restrict access and to eliminate a habitat for mosquitoes or other vectors.
8. The greywater system should be operated to maintain a minimum vertical separation distance of at least 1.5 m from the point of greywater application to the top of the seasonally high groundwater table.
9. For residences using an on-site wastewater treatment facility for blackwater treatment and disposal, the use of a greywater system does not change the design, capacity, or reserve area requirements for the on-site wastewater treatment facility at the residence, and ensures that the facility can handle the combined blackwater and greywater flow if the greywater system fails or is not fully used.
10. Greywater applied by surface irrigation does not contain water which is used to wash diapers or similarly soiled or infectious garments unless the greywater is disinfected before irrigation.
11. Surface irrigation by greywater should only be done by flood or drip irrigation.

b) Prohibitions

The following are prohibited:

- Greywater use for purposes other than irrigation; and
- Spray irrigation.

c) A person shall file a Notice of Intent to operate a greywater irrigation system with the Department at least 90 days before the starting date of the proposed activity. The Notice of Intent to operate shall include:

- The name, address and telephone number of the applicant;
- A legal description of the direct reuse site, including latitude and longitude coordinates; and
- The design plans for the greywater irrigation system.

Alabama/Alabama Department of Public Health, Division of Community Environmental Protection [47]

Greywater is that portion of sewage generated by a water-using fixture or appliance, excluding the toilet and possibly the garbage disposal. Water from these systems can circumvent a septic tank and go into a separate effluent disposal field (EDF). Under current regulations, when water under pressure is absent, greywater shall be disposed by an effluent distribution line of 50 linear feet per dwelling.

Colorado/Colorado Department of Public Health and Environment [48]
Greywater systems shall meet at least all design and construction standards for septic tank systems based on the amount and character of wastes for the fixtures and the number of persons served.

Florida/Florida Department of Health [49, 50]
When a separate system is installed to dispose of greywater, the retention tank for such systems shall meet certain design standards. The minimum effective capacity of the greywater retention tank shall be 100 litres, with such a system not receiving not more than 280 litres of flow per day. Where separate greywater and blackwater systems are used, the size of the blackwater system can be reduced by not more than 25%. All greywater tanks distributed by the state shall be approved for use by the department prior to being installed. Such approval shall be obtained only after the manufacturer of a specific model has submitted engineering designs of the tank. Greywater retention tanks shall meet the following minimum design standards: a) liquid depth shall be at least 75 cm; and b) retention tanks shall be baffled and vented.

Hawaii/Department of Health, Wastewater Branch [51]
Greywater means liquid waste from a dwelling or other establishments produced by bathing, minor laundry, and minor culinary operations, and specifically excluding toilet waste. Greywater conveyance systems include: sand filters, absorption trenches and beds, mounds or seepage pits. A greywater system shall be designed in accordance with the following criteria: (1) The design of greywater systems for dwelling units shall be based on a minimum greywater flow of 560 litres per day and per bedroom; and (2) greywater tanks, when required, shall be of a size of no less than a 2 m^3 capacity and must conform to the requirements of the health department.

Idaho/Division of Environmental Quality [52]
A greywater system consists of a plumbing system separated from the black waste and kitchen plumbing, a surge tank to temporarily hold large drain flows, a filter to remove particles that could clog the irrigation system, a pump to move the greywater from the surge tank to the irrigation field, and an irrigation system to distribute the greywater. Greywater may not be used to irrigate vegetable gardens. Greywater systems may only be permitted for individual dwellings. Also, greywater shall not be applied on the land surface.

Michigan/Department of Environmental Quality, Environmental Health Section [53]
Greywater systems must meet the requirements of the Michigan Construction Code and Michigan Plumbing Code. Greywater systems should be tested by the National Sanitation Foundation (NSF) by an

equivalent independent testing agency and procedure. Lacking this testing procedure, the local health department should require performance data prior to approval. When requested, the Michigan Department of Public Health will assist local health departments in evaluating performance data from the NSF and other sources. The department must provide training and technical field assistance to local health departments regarding the appropriate installation and use of greywater systems.

Nevada/Department of Human Resources, Health Division [54]
Greywater may be used for underground irrigation if approved by the Administrative Authority. A homeowner must obtain a permit to construct, alter or install a system that uses greywater for underground irrigation from the Administrative Authority before the construction of such a system, whether altered or installed. A system that uses greywater for underground irrigation:

a) May be used only for a single family dwelling;
b) Must not be used in soils which have a percolation rate that is greater than 120 minutes per inch;
c) Must consist of a three-way diversion valve, a holding tank for the greywater and an irrigation system;
d) May be equipped with a pump or siphon, or may rely on gravity to cause the water flowing to the irrigation system;
e) Must not be connected to a system for potable water; and
f) Must not result in the surfacing of any greywater.

An application to construct, alter or install a system that uses greywater for underground irrigation must include:

a) Detailed plans of the system to be constructed, altered or installed;
b) Detailed plans of the existing and proposed sewage disposal system; and
c) Data from percolation tests conducted.

A holding tank for greywater must:

a) Be watertight and constructed of solid, durable materials that are not subject to excessive corrosion or decay.
b) Have a minimum capacity of 190 litres.
c) Have an overflow and an emergency drain. The overflow and emergency drain must not be equipped with a shutoff valve. The estimated discharge of a system that uses greywater for underground irrigation must be calculated based on the number of bedrooms in the building, as follows:

    - For the first bedroom, the estimated discharge of greywater is 300 litres per day; and

- For each additional bedroom, the estimated discharge of greywater is 150 litres per day.

The absorption area for an irrigation system that includes a system that uses greywater for underground irrigation must be calculated in accordance with the following parameters: percolation rate of 0–20 minutes per inch (2.54 cm), 20 square feet (minimum square feet per 100 gallons discharged per day); 21–40 minutes/inch (2.54 cm), 150 litres/day; 41–60 minutes/inch (2.54 cm), 230 litres/day.

8.3 Australia

The use of treated blackwater effluent from centralized wastewater treatment plants is gaining popularity in Australia. However, nationwide regulations state that all domestic wastewater—faecal matters, urine, household slops, liquid wastes from sinks, baths, and all similar fixtures—must be disposed of into the sewer system. Greywater reuse therefore is permitted only in non-sewered areas where it is regulated by state and local government health acts. In the Australian state of Queensland, the installation of any greywater system, including those intended for toilet and urinal flushing, must first be authorized by the regulatory authorities. However, Queensland sewage and water supply legislation is currently under review [10, 36].

South Australia

Interest in the use of greywater reuse systems is increasing in South Australia. Some people, even in sewered areas, are obtaining exemptions from the South Australian Water Authority to disconnect greywater from the sewerage system and reuse it. Some of these systems are using greywater for toilet flushing after treatment [3].

Queensland

Queensland appears to be at the forefront of reviewing its legislation in relation to the reuse of greywater. In 1993, the state water conservation strategy identified greywater as an alternative water source. The strategy allows for greywater to be used in garden watering, wetland maintenance, irrigation of recreational areas and toilet flushing provided there is minimal contact with people.

There are several significant pieces of legislation which control the provision of wastewater infrastructure and the management of these services within the state. Section 9 of the Health Act 1937 enables the delegation of health issues to local authorities. Further, Section 93 of the Health Act 1937 requires local government to construct and maintain all sewers, storm water drains and sanitary conveniences within its area so that they do not become a nuisance or are dangerous to health.

Other legislation also applies to the use of greywater in Queensland. Section 87(1) of the Health Act 1937 requires that greywater disposed in an unsewered area must not be allowed to remain in any one place for more than 24 hours after a local government has given notice to remove it. The greywater is also not allowed to run-off from any premises or cause offensive odours. Section 87(2) requires the local government to control any problem which may arise under Section 87(1) [11].

Illnesses due to contact with greywater reuse have not been reported, despite widespread reuse of greywater. This does not necessarily mean that no illness has actually occurred, and does not discount the possibility of disease transmission [4].

The following is part of Queensland's Greywater Code, which is related to health and safety [11, 55]:

For the safe use of greywater, the following requirements must be met:

1. When discharging greywater above ground by surface irrigation, it must be treated to remove or destroy pathogenic microorganisms.
2. Human contact with greywater that has not been treated to remove pathogenic microorganisms must be avoided.
3. The greywater treatment system and land application area must be sited within the property boundaries of the premises producing the greywater.
4. The proposed reuse of the greywater must be appropriate for the site.
5. A reliable treatment process that will achieve the effluent quality criteria must be provided.
6. Operation and maintenance guidelines are available to all owners and users.
7. Operation and maintenance procedures are undertaken to a regular schedule appropriate to the nature, type of treatment and land application facility.
8. Inspection and monitoring by the local government is desirable to:
    - protect the health of residents;
    - to protect bores and other local drinking-water sources from contamination; and
    - to ensure necessary maintenance, repair or component replacement is undertaken.
9. The greywater treatment system must treat and disinfect the greywater before toilet flushing reuse.
10. For urinal and toilet flushing, the microbial quality of the treated greywater must comply with the following [55]:
    - Thermotolerant coliforms less than 1/100 mL.
    - Total coliforms less than 10/100 mL.

9. Regional guidelines and regulations for the reuse of greywater

These guidelines and regulations have been extracted from the international regulations and codes relating to greywater use and the technical requirements for greywater systems summarized in Sections 7 and 8 with adaptation to the local conditions of the Eastern Mediterranean Region. The following guidance for greywater reuse was discussed and approved at the regional consultation on national priorities and plans of action on the management and reuse of wastewater in Amman, Jordan.

9.1 Guidelines for greywater use

a) For ornamental use, fruit trees, and fodder crops, the following guidelines should be adopted:

1. A primary diversion system is sufficient. The use of either a gravity diversion system or a pump diversion system is suitable for transmitting greywater. This system is inexpensive and requires little maintenance.
2. The quantity of water needed for plant irrigation and the type of soil required must be determined before irrigation. (Quantities of discharged greywater must be almost equal to the quantity to be taken up by the plants and the soil), otherwise, the greywater will accumulate and leach into groundwater and cause contamination.*
3. System flow rates on coarse sandy soil or gravel should be carefully designed to avoid greywater leaching into groundwater or surface bodies of water.*
4. Direct contact with greywater must be avoided, and so accordingly all primary greywater reuse systems are to incorporate underground irrigation methods. Otherwise, bacterial transmission to humans and animals may occur and cause infection.
5. Care should be taken to limit the release of inappropriate substances into the greywater system, such as detergents containing bleach or boron. Heavily-soiled or bloodstained clothes, including diapers, should not be washed in sinks draining into the greywater system.
6. The amount of nutrients needed for the plants and the soil needs to be determined before irrigation in order that the nutrients present in greywater can be utilized effectively. This in turn will lead to a reduction in the use of fertilizers, and reduce the risk of nutrients accumulating in the soil and causing soil toxicity.*
7. Plants properties must be fully examined and classified according to their ability to survive in soil containing high alkaline, sodium and/or chloride levels which may be present in greywater.*

8. Greywater is suitable for the irrigation of mature plants as they have considerable tolerance to salinity, sodium compounds and high pH levels.*
9. The plants most likely to do well with greywater irrigation include:

- Oleander
- Bougainvillea
- Agapanthus
- Bermuda Grass
- Purple Hopseed Bush
- Oaks
- Ice plant
- Juniper
- Citrus
- Nuts
- Fan and Date Palms
- Rose
- Rosemary
- Honeysuckle
- Australian Tea Tree
- Italian Stone Pine
- Arizona Cypress
- Cottonwood
- Olive

10. The quality of greywater to be used according to this category (ornamental uses, fruit trees and fodder crops) is: $BOD_5 \leq 240$ mg/L, (TSS) ≤ 140 mg/L,[1] and faecal coliforms are $\leq 1000/100$ mL[2] [2] (see Table 15). All these criteria can be achieved by using a primary diversion system with subsurface irrigation.

11. Greywater systems must be operated so as to maintain a minimum vertical separation distance of at least 1.5 m from the point of greywater application to the top of the groundwater table, and to maintain a horizontal separation distance of at least 2 m from any point of a pedestrian path or walkway, or recreational area.

12. In the case of fruit trees, irrigation should be ceased two weeks before the fruit is picked, and no fruit should be picked off the ground.

13. The storage of greywater must be avoided in order to prevent an increase in the faecal coliform count and to prevent the water developing an offensive odour.*

14. In the case of fodder crops, sprinkler irrigation can only be used on the condition that it is used at some distance from residential areas, in order that the areas treated by sprinkler irrigation are isolated

(* These points can be applied in both (a) and (b) categories.)

b) Irrigation of vegetables likely to be eaten uncooked

1. Secondary treatment is required to reduce the number of faecal coliforms and the presence of organic matter.

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[1] Department of Natural Resources and Mines, *Guidelines for effluent quality.* Queensland, Australia and Jordanian Standards fro Reclaimed Domestic Wastewater, 2002.

[2] Health guidelines for the use of wastewater in agricultural and aquaculture, Geneva, WHO, 1989. Technical report series No. 778

2. Surface irrigation is permitted through use of drip irrigation or flood irrigation systems.
3. Greywater must not come into contact with the vegetable crop.
4. The greywater system must be operated so as to maintain a minimum vertical separation distance of at least 0.6 m from the point of greywater application to the top of the groundwater table, and to maintain a horizontal separation distance of at least 2 m from any point of a pedestrian path, walkway, or recreational area.
5. The quality of greywater to be used in this category is: $BOD_5 \leq 20$ mg/L, (TSS) ≤ 20 mg/L,[1] [1]and faecal coliforms ≤ 200 [22] (Table 15). All these criteria can be achieved by using primary diversion systems, followed by secondary treatment systems.

c) For toilet flushing and car washing

1. The recommended level of treatment is secondary treatment in addition to disinfection.
2. Treated water can be stored from between 24–48 hours, as the maximum allowable period.
3. The quality of greywater to be used in this category is: BOD5 ≤ 10 mg/L, (TSS) ≤ 10 mg/L,3 and faecal coliforms ≤ 10 4 (Table 15). All these criteria can be achieved by using primary diversion systems, followed by secondary treatment systems and a disinfection unit.

9. 2. Suggested regulations

The following greywater regulations are suggested:

1. A comprehensive greywater reuse management plan for the discharge and reuse of greywater from residential, commercial and public buildings and facilities must be developed by the relevant department.
2. The relevant department in any country must conduct a review of greywater systems, taking into account all the relevant environmental

[1] Department of Natural Resources and Mines. *Guidelines for effluent quality.* Queensland, Australia

[2] Health guidelines for the use of wastewater in agricultural and aquaculture, Geneva, WHO, 1989.

[3] Guidelines for service water reuse. Berlin, Germany, 1995 and Guidelines for water reuse, US Environmental Protection Agency (USEPA), 1992

4. Report on reuse of treated wastewater, Tokyo, Japan, 1995.

issues, and must conclude that the reuse of greywater has no adverse impact on groundwater and surface water.

3. Types of plants, greywater systems and irrigation systems must be determined as regulations vary according to plant type and types of greywater and irrigation systems (subsurface or surface system).

Table 15: *Permitted limit for greywater reuse according to the use type*

Test	Permitted limit		
	a) Irrigation of ornamentals, fruit trees and fodder crops	b) Irrigation of vegetables likely to be eaten uncooked	c) Toilet flushing
Biological oxygen demand BOD_5 (mg/L)	≤ 240	≤ 20	≤ 10
Samples number	Sample/month	Two samples/month	Sample/week
Total suspended solids TSS (mg/L)	≤ 140	≤ 20	≤ 10
Samples number	Sample/month	Two samples/month	Sample/week
Faecal coliforms cfu/100 mL	≤ 1000	≤ 200	≤ 10
Samples number	Two samples/month	Sample/two weeks	Sample/week

4. The system must include a watertight settling or holding tank to remove the grit.
5. The system must be approved for a domestic greywater flow rate that does not exceed 500 L per day.
6. The system must only be approved for a maximum of four people in any one household.
7. Greywater, including effluent from the system, must not be discharged beyond the property boundary.
8. The irrigation area must be marked by signs indicating that treated domestic greywater is being used in the area.
9. There must be no access for people or livestock to the irrigation area during spray irrigation.
10. The system must be designed to achieve the required effluent quality.
11. Inspection and maintenance of the system must only be carried out by a competently trained person.

12. Samples of the effluent from the system must be taken weekly or monthly (depending on the purpose behind the use of the greywater), and analysed for BOD_5, TSS and thermotolerant coliform organisms.
13. An alarm system with a suitable visual and/or audio warning (including a mute facility) must be installed in an appropriate location, approved by the relevant department of the country, to indicate a failure of any pump.

10. Conclusion

1. Greywater reuse is an increasingly common household practice in a number of arid countries. A range of technical solutions are available and there are simple ways to minimize the potential adverse impacts on plant and human health.
2. The most commonly used indicators of faecal pollution in greywater are coliforms and entercocci. Several studies have reported high numbers of these organisms which indicate substantial faecal contamination of the greywater.
3. Treatment level depends on the purpose behind the use of the greywater, whether for toilet flushing or for irrigation. Toilet flushing requires secondary treatment and disinfection whereas irrigation of specific crops does not require high-quality water.
4. The reuse of greywater in countries of the Region will solve many problems related to water scarcity, and will lead to the saving of financial resources which in turn helps to support the economy.
5. CEHA provides guidelines for the reuse of greywater. The guidelines have been extracted from international regulations and codes with adaptation to local conditions of the Eastern Mediterranean Region (Section 9).
6. Environmental legislation and laws have to be enacted to help in the treatment of greywater and its reuse.

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Glossary

1. BOD_5 (Biological oxygen demand): A measure of the dissolved oxygen required for the breakdown of organic material in contaminated water, usually refers to a five-day test, which typically represents 70%–80% of the total BOD in a sample.
2. COD (Chemical oxygen demand): Expresses the total amount of oxygen required to oxidize the organic material in wastewater.
3. Setback distances: Applied as a buffer distance between a wastewater or greywater disposal area and down-gradient features such as property boundaries, water bores and receiving waters. Its purpose is to minimize the potential threat both to human health and the environment.
4. Subsurface drip irrigation: This term is commonly used to denote utilization of wastewater or greywater by trickle or micro-drip irrigation which is at a minimum depth of 150 mm below ground level.
5. TSS (Total suspended solids): Solids retained after filtration of water sample through a glass fibre filter paper followed by washing and drying at 105 °C, expressed in mg/L.