PUBLIC WORKS TECHNICAL BULLETIN 200-1-101
30 SEPTEMBER 2011

GRAYWATER APPLICATION FOR ARMY INSTALLATIONS

Public Works Technical Bulletins are published by the U.S. Army Corps of Engineers, Washington, DC. They are intended to provide information on specific topics in areas of Facilities Engineering and Public Works. They are not intended to establish new Department of Army policy.

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
441 G Street NW
Washington, DC 20314-1000

CECW-CEP

Public Works Technical Bulletin 30 September 2011

No. 200-1-101

FACILITIES ENGINEERING
ENVIRONMENTAL

GRAYWATER APPLICATION FOR ARMY INSTALLATIONS

1. Purpose.

a. The purpose of this Public Works Technical Bulletin (PWTB) is to transmit general information on the topic of graywater application at US Army installations (although graywater systems have been identified on installations at this time). This PWTB will enable installation personnel to determine the potential to recycle graywater or to institute graywater applications at their facilities as part of a sustainable water program.

b. All PWTBs are available electronically at the National Institute of Building Sciences' Whole Building Design Guide webpage, which is accessible through this link:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability. This PWTB applies to all U.S. Army facilities engineering activities within the United States.

3. References.

a. Executive Order (EO) 13423, "Strengthening Federal Environmental, Energy, and Transportation Management," 26 January 2007.

b. International Plumbing Code (IPC), published by International Code Council, 5203 Leesburg Pike Suite 708, Falls Church, VA, 22041-3401.

c. US Department of Defense (DoD), Unified Facilities Criteria (UFC) 3-420-01, “Plumbing Systems.”

d. US Department of Energy, Federal Energy Management Program, “Best Management Practices.”.

e. U.S. Green Building Council (USGBC), Leadership in Energy and Environmental Design (LEED), has developed rating systems, certification tools and resources, programs and application guidelines, etc. (www.usgbc.org).

4. Discussion.

a. Graywater use allows installations to get maximum benefit from the existing water supply through water reuse. However, while many states encourage the use of graywater, others discourage graywater use. Consequently, Army installations must consider applicable laws and regulations regarding graywater use.

b. Also, use of graywater is an important factor contributing to resource efficiency. Organizations such as LEED, the International Code Council (ICC) with “National Green Building Standard,” and The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) with “Standard 189.1-2009 - Standard for the Design of High-Performance Green Buildings” all recognize the use of graywater to meet the prescriptive option for building water use reduction.

c. This PWTB presents information to help determine the feasibility of graywater use at a military installation or USACE facility, and if feasible, to implement a graywater program.

d. Appendix A to this PWTB provides:

i. overview of graywater

ii. definitions of relevant terminology

iii. discussion of the pros and cons of graywater use

iv. review of regulatory and health considerations

v. discussion of appropriate scenarios for use for toilet flushing or landscape irrigation or acceptable uses

vi. description of various types of systems and potential military installation applications

e. Appendix B provides a list of references and resources.

f. Appendix C provides a list abbreviations used in this document.

5. Points of Contact.

a. Headquarters, U.S. Army Corps of Engineers (HQUSACE) is the proponent for this document. The point of contact (POC) at HQUSACE is Mr. Malcolm E. McLeod, CEMP-CEP, 202-761-5696, or e-mail: Malcolm.E.Mcleod@usace.army.mil.

b. Questions and/or comments regarding this subject should be directed to the technical POC:

U.S. Army Engineer Research and Development Center
Construction Engineering Research Laboratory
ATTN: CEERD-CN-E (Richard J. Scholze)
2902 Newmark Drive
Champaign, IL 61822-1072
Tel. (217) 398-5590
FAX: (217) 373-3430
e-mail: Richard.J.Scholze@usace.army.mil

FOR THE COMMANDER:

JAMES C. DALTON, P.E., SES
Chief, Engineering and
Construction Division
Directorate of Civil Works

Appendix A

GRAYWATER APPLICATION FOR ARMY INSTALLATIONS

Introduction

Before considering alternatives to increasing the available water supply, it makes sense to ensure that the available water supply is being used efficiently. One commonly unused but available water supply is "graywater." The term "graywater" (and all its variant spellings: greywater, gray water, or grey water) is defined as the effluent from laundry and bath/shower use in residential facilities.

Another definition of "graywater" (although not used in this document) includes other reclaimed water; specifically, wastewater treated to high standards at municipal treatment facilities and then delivered to customers via a "purple pipe" system, a practice common in water-short areas in states such as Texas, California, Arizona, and Florida. "Graywater" does not include water from dishwashers and other kitchen waste water, or water from toilets or urinals; these are collectively called "blackwater." Table 1 lists sources of graywater and blackwater.

It is estimated that up to 40 gal of graywater per day per person is available for reuse (Cohen 2009). Consequently, graywater use has a long history in arid parts of the United States where it is common in rural areas. While many states encourage graywater use, others discourage its use. Army installations must then consider locally applicable laws and regulations regarding graywater use. While graywater use is technically still illegal in many places, applicable laws and regulations are rapidly changing. These constantly evolving regulations vary among states and even among municipalities within states. Local plumbing codes that govern graywater use also can vary, making all applications local. However, two primary uses have been generally established for the use of graywater: irrigation and fixture flushing. (Most irrigation applications are for subsurface or drip systems.) If graywater is given higher levels of treatment, an additional option is to use treated graywater in cooling towers.

Table 1. Graywater sources and percent of household flow (Lesikar 2005).

Source	Percent	Category
Toilet	40	Blackwater
Kitchen waste	10	Blackwater
Misc	5	Graywater
Laundry	15	Graywater
Bath/Shower	30	Graywater

Background

Water resources for the nation and for military installations have been receiving increased attention due to both water quantity and water quality concerns. In addition, water scarcity is expected to worsen in coming years, both nationally and globally.

Up to 40 percent of typical household water consumption is for toilet and urinal flushing, although less if low-flow toilets are used (Lesikar 2005). Water use for irrigation shows a wide variance across the country for military installations (golf courses, parade grounds, cemeteries, athletic fields, etc.) as much as 50 percent in some cases (Bandy and Scholze 1983). Cooling tower and boiler makeup are also significant consumptive activities at installations. These and a number of other activities could all have their needs met through the provision of nonpotable water. Potable water is required for bathing, drinking, food processing, and similar direct personal contact activities.

Additionally, a number of legislative and executive drivers are impacting water use on installations. These include, for example, the Clean Water Act, the various iterations of Energy Policy Acts, and EO 13423 which requires that all installations reduce consumption of potable water by 2 percent annually. A number of Department of Defense (DoD) and Army strategies and policies also promote efficient use of water and encourage water reuse. Among these are:

- *The Strategic Plan for Army Sustainability*. (Graywater use can contribute to increased sustainability by capturing water that would normally be discarded and beneficially using that water for irrigation or toilet flushing.)
- *Army Strategy for the Environment*.
- *Army Energy and Campaign Plan for Installations*.

- *Individual Installation Sustainability Plans*, addressing water conservation goals.
- LEED (Leadership in Energy and Environmental Design), which is required in all new construction, and gives points and credits for reductions in water consumption and wastewater generation.

The Federal Energy Management Program (FEMP) collection of Federal Water Efficiency Best Management Practices (BMPs) addresses water efficiency (Table 2). The use of graywater addresses several of these BMPs, most noticeably "Other Water Uses" and "Alternate Water Sources," by providing an option for reuse of water.

Table 2. FEMP's Federal Water Efficiency Best Management Practices (http://www1.eere.energy.gov/femp/program/waterefficiency_bmp.html).

1.	Water Management Planning
2.	Information and Education Programs
3.	Distribution System Audits, Leak Detection, and Repair
4.	Water Efficient Landscaping
5.	Water Efficient Irrigation
6.	Toilets and Urinals
7.	Faucets and Showerheads
8.	Boiler/Steam Systems
9.	Single-Pass Cooling Equipment
10.	Cooling Tower Management
11.	Commercial Kitchen Management
12.	Laboratory/Medical Equipment
13.	Other Water Use
14.	Alternate Water Sources

Use of Graywater

Irrigation

Graywater is suitable to irrigate plants, trees, and shrubs. Irrigation should (ideally) be carried out by gravity distribution to avoid the need for pumping. Drip irrigation hoses should have holes with a diameter of at least 3 mm to reduce the potential for clogging from solids present in the graywater or from algae growing in the hose. Figure 1 shows a typical household graywater reclamation/irrigation system.

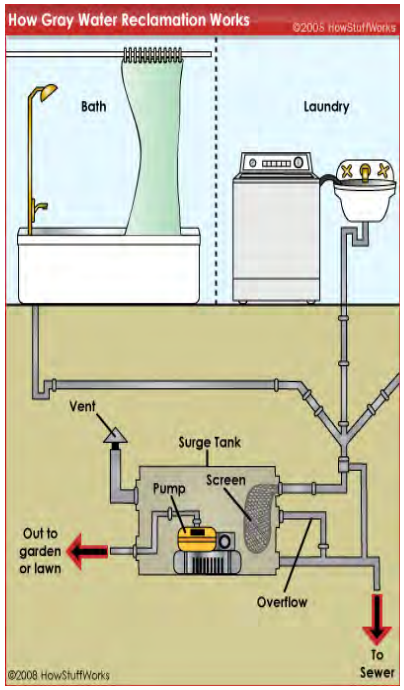

Figure 1. Graywater reclamation system for a typical household.

Graywater can be used for subsurface irrigation (Figure 2) of ornamental plants, fruit trees, and lawns, and is best suited for use with mature plants (not saplings), which have considerable tolerance to salinity, sodium compounds, and high pH levels (Figure 3). It should not be used to irrigate vegetables or fruit-bearing plants if the edible portion may come in contact with the graywater.

As noted earlier, many of the potential risks to human health and other possible unfavorable side effects of graywater reuse (for example odors, encouraging breeding of mosquitoes, etc.) are reduced or eliminated by eliminating storage. It is important that the graywater be applied no faster than the soil can absorb it, to avoid saturation and pooling of the graywater. Usually, plants are healthier when the soil is allowed to dry out between irrigations. Therefore, for best results, one should wait until the soil in the root zone is half dried out before re-irrigating.

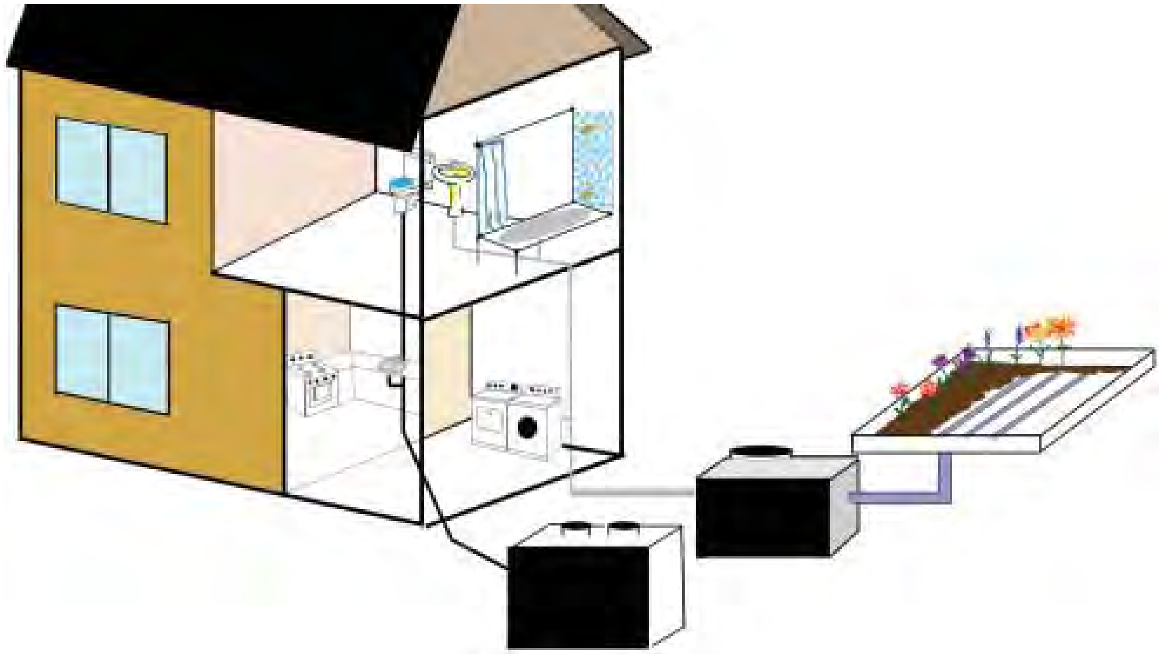

Figure 2. Example of Texas household use of graywater for subsurface irrigation (Lesikar et al. 2005).

Figure 3. Example of drip irrigation.

One important potential issue in using graywater for irrigation is the danger of clogging the irrigation network from particles in the graywater. This can be eliminated by either removing solid particles from the water (by filtering or settlement) and by increasing the diameter of the holes in the irrigation pipe. It is recommended that drip irrigation hoses (with small outlets) not be used for graywater irrigation unless the solid particulates have been removed. Some sources have reported a buildup of algal growth in the irrigation pipe work, which is a natural result of the presence of nutrients in the graywater. This does not pose a risk to either plants or humans, but should be taken into account in the design of the system. Algae may be removed by periodic chlorination of the graywater, although care should be taken in such circumstances to avoid harm to the plants.

Toilet Flushing

Figure 4. Example of simple Japanese technology to reclaim graywater for toilet flushing.

Graywater can be used for toilet flushing to offset potable water demands (Figures 4 and 5). Issues concerning graywater use for toilet flushing include fixture staining, water discoloration, water quality, safety hazard for children and pets, and odor. It is recommended that graywater be treated to prevent odors and discoloration of flush toilet fixtures, and to address any health-related concerns (e.g., splash back onto sensitive tissues). One caution before installing a graywater recycle system is that additional support may be needed, such as overflow piping, small sump pump, or an additional electrical circuit may be needed as part of a graywater recycle system. Figure 5 shows the AQUS Graywater System. It should be noted that installation of this system takes 1–1.5 hr and includes an overflow bypass. An under-counter electrical connection also is necessary, to support a small sump pump.

Figure 5. Another example of graywater toilet-flushing technology (AQUS Graywater System).

Engineered Systems

"Engineered systems" are project-specific applications that are tailored to the specific facility and end use. A wide variety of systems and unit processes can be used depending on end use. Examples include the following projects:

- constructed wetlands or combinations of living systems along with sedimentation (holding tanks)
- filtration of various types such as basic sock filters through sand filtration
- disinfection if required, usually through application of chlorine or ultraviolet light

Pros and Cons

The following are the advantages of using graywater:

- It saves water (less potable water is consumed).
- It reduces wastewater discharge (by reducing sewage generated, which often costs more to treat than potable water).
- It reduces energy expenditures and chemical use for the water utility or provider.
- It recovers nutrients (nitrogen and phosphorous present are essential nutrients for plant growth).
- It reduces the hydraulic load on existing sewer systems.

The following are the disadvantages of using graywater:

- Using graywater may be more costly. (Policymakers need to balance the need for larger quantities of water against costs.)
- Graywater use may decrease flow to the sewage plant. (Some areas have a requirement to deliver a certain amount of return flow to existing streams; otherwise, water may be reclaimed and used for irrigation or other uses.)
- There is a small potential for spreading disease through human contact if graywater is not properly handled or treated.
- There is a small potential for odors in surge or storage tanks if graywater is not handled properly.
- There is the potential that decreased use of potable water may create “stagnation areas” in potable water distribution zones. In an area where graywater use is significant and in an older building designed with flatter slopes, there is the potential for inadequate discharge in the distribution pipeline.
- It is possible that the slope of sewer lines might need to be increased if cleaner non-solids wastewater doesn’t occasionally flush the pipes used to dispose of toilet water.

Policy and Regulations

If its reuse is lifecycle cost-effective, water that has been reclaimed or treated recycled water can be used for irrigation and other non-potable uses according to current Army policy. However, graywater or untreated effluent from laundry, dishwashing, and personal hygiene/bathing will not be recycled or reused as part of a USGBC-sanctioned program for a LEED credit without approval from the US Army Installation Management Command (IMCOM).

Although the International Plumbing Code includes provisions for graywater systems, guidelines also vary internationally. Australia, Germany, Japan, and the United Kingdom are the current leaders in the use of graywater. In the United States, there currently are no federal regulations governing use of reclaimed water, including graywater. The lack of national guidelines has encouraged lobbying for federal legislation to recognize graywater use.

Individual states, however, are becoming proactive in encouraging use of graywater and state regulations are constantly evolving. Currently, graywater regulations vary widely from state to state. Some states have comprehensive regulations and guidelines; others define graywater without any provisions for irrigation, and others have no mention of graywater at all. Many states also allow systems to be installed on a research or case-by-case basis. Many states allow the direct reuse of untreated graywater for subsurface watering of ornamental gardens and lawns. Other common elements in regulations include a minimum distance to highest groundwater level, sealed and vented tanks, and proper labeling. Roesner et al. (2006) summarizes recent state regulations. The following sections illustrate the variety of regulations that now exist within the United States.

Arizona

Arizona regulations for surface application for irrigation require:

- settling or holding tanks and filtration,
- sump surge tank,
- filter for lint and hair,
- pump to toilet or landscape,
- state review of the design and construction,
- disinfection if the water is applied to surface vegetation, and
- system monitoring.

Arizona discourages direct discharge of washing machine wash water to any outside surface.

Cochise County, AZ, provides an example of regulations on the local scale (which applies to both single-family and multi-family and commercial projects):

> New residential construction shall have graywater lines plumbed to stub out, and be capped and clearly marked so as to permit the optional use of graywater by residents. The graywater plumbing must connect at least two plumbing fixtures, and preferably those that produce the most graywater without compromising the efficient evacuation of the black water pipes.

Arizona requires no project specific permission for existing homes using less than 400 gal/day of graywater. Regulations vary by jurisdiction and Arizona has provided a national precedent with a set of comprehensive, user-friendly regulations and requirements for permits for new construction.

California

California regulations for surface application for irrigation require a surge tank, no holding or settling, and then drip irrigation. California is also one of the states where local control can vary the requirements.

Florida

Florida Plumbing Code allows the use of graywater for flushing of water closets and urinals and for subsurface landscape irrigation. The state allows a retention time up to 72 hrs for flushing water closets and urinals with a tank holding capacity of twice the daily needs, but no less than 50 gal. Graywater is also required to be dyed blue or green with food grade vegetable dye and piping distribution and reservoirs must be identified as containing non-potable water. Potable water is to be used as a source of makeup water, with protection against backflow. Subsurface irrigation systems must be sized to limit retention time to a maximum of 24 hours. Commercial uses are covered in the Building Code.

Texas

Texas also has graywater regulations. However, the requirements specify separate pipe collection systems with houses (Figure 6). Once separated, graywater can be diverted for reuse in applications such as landscape irrigation, or it can be directed to an onsite wastewater treatment system for further treatment. In anticipation that some graywater systems may be used seasonally, or may be abandoned in the future, a diversion valve should be placed in the line (Figure 7).

Figure 6. Separate faucets for potable and nonpotable graywater.

Graywater can be collected, treated, stored, and reused. The type of treatment system chosen depends on the constituents present in the graywater and on the level of treatment desired. In some cases, a settling tank with a gravity fed pipe to the distribution system is adequate. Another case may use a secondary tank, from which the water will be pumped to a pressurized subsurface reuse system (Figure 8) that can be controlled.

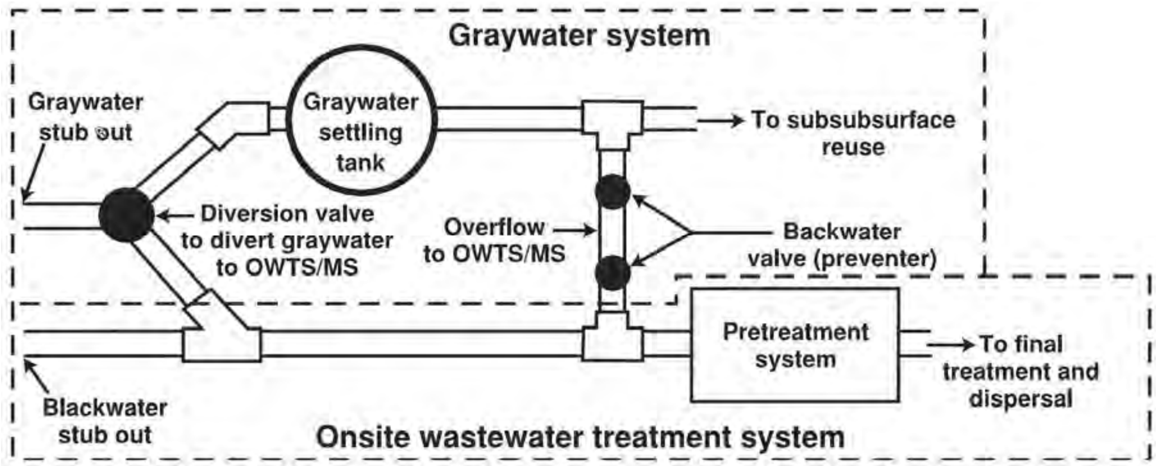

Figure 7. Diverted graywater plumbing system (Lesikar et al. 2005).

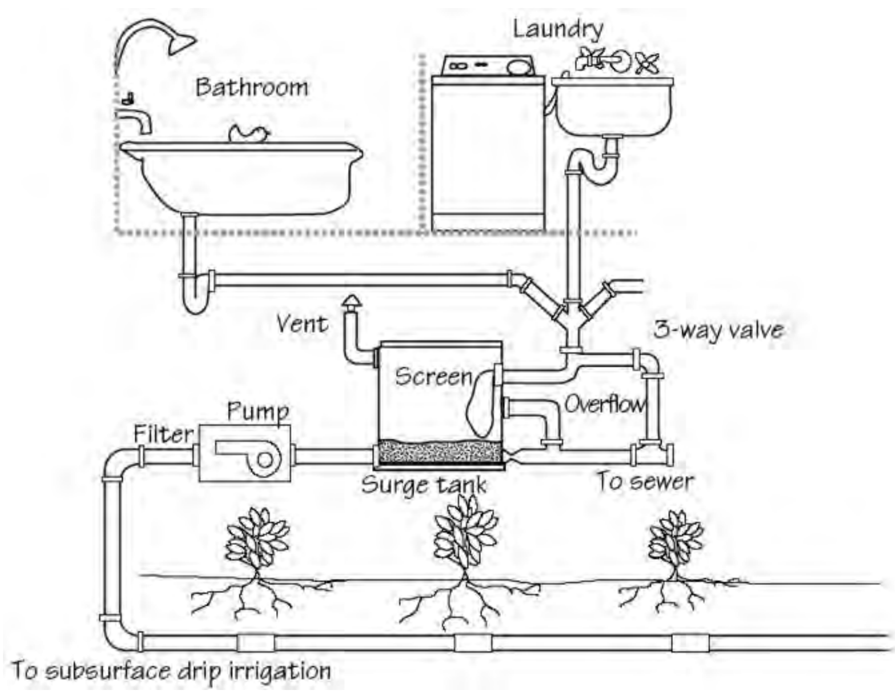

Figure 8. Graywater system schematic showing subsurface drip irrigation.

Other States

New Mexico has a program similar to Arizona's. Other states with graywater policies or adding laws, regulations, codes, or guidelines include: Nevada, Massachusetts, Georgia, Oklahoma, Idaho, South Dakota, Utah, Colorado, and New York. Other states show a wide variation in their regulations for surface application for irrigation; some require use of separate septic tanks before use. However, it is important to note that as changes are made, states are becoming more liberal.

Quality of Graywater and Health Considerations

Compared to combined wastewater, graywater is lower in biochemical oxygen demand (BOD), lower in suspended solids, lower in nitrogen, lower in phosphorous, is more alkaline, and is higher in salts. Components in graywater that may raise concern are: micro-organisms; dissolved salts such as sodium, nitrogen, phosphates, and chloride; other chemicals such as oils, fats, soap, and detergents; and physical qualities such as soil and lint. As a review, Table 3 lists graywater source characteristics while Tables 4 and 5 list graywater constituents and characteristics.

Table 3. Graywater sources and percent of household flow.

Source	Percent	Category
Toilet	40	Blackwater
Kitchen Waste	10	Blackwater
Misc	5	Graywater
Laundry	15	Graywater
Bath/Shower	30	Graywater

Table 4. Graywater source characteristics that make it necessary to handle graywater carefully (Georgia Gray Water Recycling Guidelines 2009).

Source	Characteristics
Clothes Washer	Bacteria, Bleach, High pH, Sodium, Oil and Grease, High Suspended Solids, High Biological Oxygen Demand, Nitrates, Foam, Hot Water
Bathtub and Shower	Bacteria, Oil and Grease, Surfactants, Suspended Solids, Hair, Hot Water, Odor
Sinks	Bacteria, High pH, Organic Matter, High Biological Oxygen Demand, Chemicals (mouthwash, toothpaste, etc.), Cleansers, Hot Water

Table 5. Graywater characteristics from three studies (adapted from Roesner et al. 2006).

Characteristic	Eriksson et al. (2003)	Rose et al. (1991)	Casanova et al. (2001)
Source Concentration (mg/L)	Composite Range	Composite	Composite
Temperature (°C)	21.6 — 28.2		
pH Level	7.6 — 8.6	6.54	7.47
Chemical Oxygen Demand (COD)	77 — 240		
BOD	26 — 130		64.85
Total Suspended Solids (TSS)	7 — 207		35.09
Turbidity (NTU*)		76.3	43
NH4-N	0.02 – 0.42	0.74	
NO3-N	<0.02 – 0.26	0.98	
Total-N	3.6 — 6.4	1.7	
PO4-P		9.3	
Tot-P	0.28 — 0.779		
Sulfate		22.9	59.59
Chloride		9	20.54
Hardness		144	
Alkalinity		158	
Ca	99 - 100		
K	5.9 – 7.4		
Mg	20.8 — 23		
Na	44.7 — 98.5		
Total Bacterial Pop.(CFU**/100mL)**	4.0×10^7 — 1.5×10^8	6.1×10^8	
Total coliform (CFU/100mL)		2.8×10^7	8.03×10^7
Fecal coliform		1.82×10^4 — 7.94×10^6	5.63×10^5
Fecal Streptococci (CFU/100mL)			2.38×10^2
E.Coli (CFU/100mL)	<100 — 2800		

*NTU = nephelometric turbidity units
**CFU = colony-forming units

As shown in Table 5, there can be variability in graywater. For example, larger buildings such as barracks may show a wider range of constituents, indicating a graywater treatment strategy may need to be more complex and have a wide range of application and control.

There may be controversy and reluctance in some areas to use graywater. The most common concern is the potential health threat. However, most graywater is expected to have a low enough concentration of contaminants and disease-causing microorganisms that it can be reused in applications without biological treatment or disinfection as long as the application has a low risk of direct public contact (e.g., subsurface irrigation and toilet or urinal flushing and when storage is not required). The only form of graywater treatment typically provided in these cases is sedimentation to remove coarse solids and grit, and coarse filtration to remove hair and lint. If there is a need to store the water, a more advanced level of treatment and disinfection is required. However, there have been no cases reported to the Centers for Disease Control (CDC) related to graywater use.

Since graywater contains organic matter, if it is stored, it will quickly turn septic, generate offensive odors, and promote growth of microorganisms. Thus it is critical to size the graywater settling tank and pump tank so that they do not hold water for extended periods of time. Generally, to keep graywater fresh, it should be stored for less than 1 day. This storage limitation is a critical consideration if graywater is to be dispersed onto the ground surface.

Lesikar et al. gives the specific rules for Texas tanks. Graywater reuse in Texas is allowed for gardening, landscaping, composting, and for application around soil foundations to prevent soil movement and cracking. Surface graywater application in Texas must follow onsite wastewater treatment rules (i.e., a septic tank system). Subsurface application is encouraged. Spray systems are forbidden. Lesikar et al. presents guidance for several methods of pressurized drip irrigation.

The following are other guidelines (not requirements) for graywater use.

- Do not use graywater on edible root crops.
- Use graywater for well-established plants, not seedlings.
- Avoid using graywater on plants that thrive in acidic soils.
- Spread graywater over a wide area to avoid salt buildup in the soil (Table 6). To further avoid salt buildup in soils, avoid use of water softeners and periodically flush with non-graywater such as rain water.
- Match graywater applications with the amount of water generated.
- Systems that use laundry wastewater should have a lint trap and use detergents that do not have significant amounts of phosphorous, boron, or sodium.

Table 6. Mini leach field design criteria for six typical soil types (http://www.water.ca.gov/wateruseefficiency/docs/Revised_Graywater_Standards.pdf).

Type of Soil	Minimum irrigation area per 100 gal of discharge per day (sq ft)	Maximum Absorption capacity in 24-hr for irrigation area (minutes per inch)
Coarse sand or gravel	20	5
Fine sand	25	12
Sandy loam	40	18
Sandy clay	60	24
Clay with considerable sand or gravel	90	48
Clay with small amount of sand or gravel	120	60

Treatment of Graywater

There are four reasons why graywater may need to be treated:

1. to remove substances that may be harmful to plants,
2. to remove substances that may be harmful to human health,
3. to remove substances that may be harmful to the wider environment, and
4. to remove substances that may clog the graywater system.

A number of methods for treating graywater are available. The type of treatment required largely determined by the following variables:

- quality of the incoming graywater,
- end use, and
- degree of care and intervention desired by the user.

Treatment by Filtration

The use of a filter is a simple, first level of treatment that may be advisable in some cases to prevent solid material (e.g., hair, lint, food particles) from entering the graywater system. A number of sources propose the use of a natural mulch basin filled with stones and organic mulch (e.g., leaves, tree bark) to filter and treat the graywater. Rather than containing inert material such as sand, a mulch basin of this type provides a medium for the natural digestion of organic substances and removes solid material from the graywater.

Similar to a mulch basin are slow sand filters, which has shallow layers (from bottom to top) consisting of stone, medium gravel, pea gravel, and then covered by a deep layer of sand. These types of filters also include multimedia filters, whose layers are filled with a variety of media in order of size (increasing from top to bottom). Slow sand filters are subject to clogging and very slow percolation rates, so they require regular cleaning and replacement of the top layer of media. Some experts therefore do not recommend their use in domestic contexts (e.g., family housing or barracks where untrained individuals have responsibility for maintenance of the slow sand filters). Multi-media filters require cleaning less frequently. Commercially available water filters also are sometimes used for graywater. These include activated charcoal, cellulose, or ceramic cartridges. However, these are generally designed for higher quality water and may require excessive maintenance if used with graywater.

Treatment by Settlement and Floatation

A settling tank is sometimes recommended as a means of removing solids from the graywater. Substances denser than water will gradually fall out of suspension to the bottom of the tank. On the other hand, grease, oils, and other small particles will float to form a surface scum layer. The remaining liquid can then be reused. A settling tank also has the additional advantage of allowing hot water to cool before reuse.

Treatment by Disinfection

Unless there is risk of human contact with the graywater, there is no particular need to disinfect the graywater before use. Pathogens present in the graywater are typically removed through a relatively short distance of unsaturated soil.

If required, disinfection can be achieved in a number of ways, but generally should only be done where biological treatment is carried out first. One of the most common methods of disinfection is to add chlorine, often (in the case of onsite systems) through the use of chlorine tablets. Ultraviolet (UV) disinfection may also be considered, but its effectiveness is highly dependent on the water quality and the transmission of light through the water. UV disinfection is adversely affected by particulates and colloidal particles. Consequently, biological treatment and filtration is often a prerequisite to UV disinfection. Ozonation is another means of disinfection that involved the onsite generation of ozone gas, and diffusion of that gas into the liquid.

Other, more complex systems are available, but the evidence consistently points to that, in general, simpler systems are reliable, and more complex systems are often abandoned due to their high maintenance costs and large amount of human intervention required. The suitability of the type of filtration system is largely determined by the quality of the incoming graywater, its end use, whether there is a need for storage, and the degree of care and intervention desired by the user. The minimal treatment system is perhaps best suited to users who will take an active interest in controlling what goes into the graywater, and who take a fairly active role in caring and tending for their own plants. The cleaner the graywater to begin with, the less treatment required. A more complex, catch-all system is better suited to an establishment where less attention is paid to what goes into the graywater and how it is used, but where resources are available to maintain (and pay for) the relatively more complex system.

No Treatment Necessary

Often, the best solution is to design, install, and maintain a system so that the graywater needs no treatment at all. The reason why graywater is being considered in the first place as a substitute for potable water is because it is already relatively clean. Many of the substances contained in graywater are not harmful to plants, and some serve as nutrients for plant growth. Contaminants may also be treated within the layer of soil in the vicinity of the application. If human contact with the graywater can be minimized, then the risk to human health is very small. Contact can be reduced by eliminating the need for user intervention in the system and by reducing the possibility of contact at the irrigation stage.

Storage of Graywater

If graywater will be used in applications other than subsurface irrigation (e.g., toilet flushing), it should not be stored unless treated and disinfected. Left untreated, stored graywater can quickly become septic and develop a population of anaerobic bacteria that will proliferate and create noxious odors. Odors generated by storage prior to subsurface irrigation (i.e., within a septic tank) should be properly managed and ventilated in such a way as to not become a nuisance or result in accelerated corrosion of concrete structures (e.g., concrete septic tank, pipe, or distribution boxes; see Figure 9).

Direct reuse without storage is favored as it minimizes the problems of microorganism growth and odor. However, even if storage is not required, each graywater system should be capable of handling sudden, foreseeable inputs of graywater (e.g., from a bath or a washing machine rinse cycle being let out) without overloading or saturating the soil. In these cases, many authors recommend a surge tank (a small facility to allow the flow to surge, while releasing it gradually to the soil).

Even if no storage is provided, an odor problem may also arise if graywater is allowed to pool in parts of the pipe bends, tanks, or other parts of the network. If a graywater system becomes unused for a period of time (e.g., when the householders go on holiday), then there is risk that pools of graywater in the system will begin to digest anaerobically and cause unpleasant odors. Most sources recommend that all pipes be at a gradient, and that all tank bases, etc., be angled (with provision for drainage) so that, if necessary, the entire system can be emptied of water.

Figure 9. Example of Australian technology for graywater storage.

Types of Graywater Systems

Technology

A wide range of technologies have been used to recycle graywater, from simply using rinse water from one load as wash water for the next load, to direct discharge of graywater to irrigation. Many systems are also focused on disposal rather than reuse. Systems can be as simple as collecting graywater without treatment or as complex as including real treatment plants on a miniature scale. Typically, systems designed to provide minimum treatment use coarse filtration or mesh screens to remove large objects such as hair, threads, and lint, and then channel the graywater into an underground irrigation system.

More complex systems are used to process graywater for uses other than irrigation (e.g., toilet flushing). Such systems might include living systems that use water plants, or sand filtration. At the higher end, many commercial package systems produce a filtered, disinfected product.

Package Systems

Commercially available graywater systems vary from simple low-cost systems to highly complex and costly systems. The technology involved in such systems ranges from the sophisticated to the crude, from engineered systems with filters and pumps to a washing machine draining directly to outside shrubbery. The more sophisticated systems are able to remove pollutants and bacteria from graywater. The better systems include settling tanks and sand filters, with improvements in technology regularly occurring.

Package systems can be "off the shelf" systems, ready to be installed. They have a wide application (not specific to a given project). These systems are available for small and large projects. Impediments to widespread installation of package graywater systems include (but are not limited to):

- Restrictive health and safety codes/standards that are inconsistent in their requirements and application throughout the various state and local jurisdictions in North America.
- Product and installation costs are somewhat unknown because the technologies are rapidly evolving and the applications within buildings will vary (e.g., irrigation versus fixture flushing).
- System maintenance requirements and who will be responsible to fulfill them are not always designated.

Code officials often oppose package systems because of concerns over microorganisms or other biological matter, oils, salts, and pathogens in the graywater. In many locations, graywater standards limit application to outdoor landscape uses. Such limitations eliminate indoor uses such as toilet and urinal flushing, initial cycles for laundry, or indoor and outdoor cleanup activities.

Product and System Costs

Because of the limitations in the places where a graywater system may be located and in the end uses of graywater, manufacturers cannot assess the requirements associated with the installation and use of graywater systems. The level of treatment for specific applications (landscape, fixture flushing, etc.) may differ between jurisdictions, resulting in different technical specifications.

The costs of graywater systems will vary significantly, depending on the application and the system's underlying technology. However, it is generally not cost effective to install a retrofitted graywater system for the purpose of reusing water inside the building; graywater systems are better suited to new construction applications.

System Maintenance

System maintenance is primarily a concern with more complex systems. Both residential and nonresidential applications have a need for ongoing maintenance that may the approaches given here.

- Manufacturers' guarantees of performance within a certain set of specifications, coupled with lifetime service and maintenance provided (or arranged) by that manufacturer.
- Independent service contracts with organizations approved by the system's manufacturer. Such evidence should allow the appropriate authority to permit the facility.
- Annual inspections of individual systems by the local authority with a provision that non-compliance with the operating specifications could result in a red-tag disconnection of the graywater system from the building.

Vendors

The Alliance for Water Efficiency has identified a number of vendors in the North America that are promoting systems. Note there has been little field investigation of these systems.[1] Buyers are encouraged to do additional feasibility investigation.

AquaCycle by PONTOS

- Vendor is an independent subsidiary of Hansgrohe AG, Schiltach, Germany; a subsidiary in turn of Masco Corporation,
- The system recycles graywater from lavatory sink, shower, tub, and laundry for use in toilet flushing, clothes washing, cleaning, and landscape irrigation.
- Numerous existing systems are operating in small and large residential and institutional applications in Europe.
- Contact:
  - Telephone (from North America): 011-49-7836-51 19 20
  - E-mail: info@pontos-aquacycle.com

[1] Citation of trade names or vendors does not imply endorsement by the US Army nor can it be used for advertising, publication, or promotional purposes..

- URL: http://www.pontos-aquacycle.com/pontos/en/company/pontos.html

Aqus Water Reuse System by WaterSaver Technologies, Louisville, KY

- System recycles graywater from a lavatory sink for use in toilet flushing.
- System is a Uniform Plumbing Code (UPC) listed product.
- Production and deliveries began in 2006.
- Contact:
  - Telephone: 502-741-1859
  - E-mail: info@watersavertech.com
  - URL: http://www.watersavertech.com

Brac Graywater Recycling System by Brac Systems, Montreal, Quebec

- System recycles graywater from lavatory sink, shower, tub, and laundry for use in toilet flushing.
- System is a UPC-listed product, and is now in production.
- Contact:
  - Telephone: 866-494-2722 or 514-856-2722
  - E-mail: info@bracsystems.com
  - URL: http://www.bracsystems.com/home.html

Ecoplay, Mulden, The Netherlands

- The system recycles graywater from shower and tub for use in toilet flushing.
- Note that this system is not readily available in the United States at this time.
- Contact:
  - Telephone: from North America 011-31-294-26 43 11
  - E-mail: info@ecoplay.nl
  - URL: http://www.ecoplay.nl/en/index.html

Perpetual Water, Phillip ACT 2606, Australia

- System captures and recycles graywater from lavatory sink, shower, tub, and laundry for use in toilet flushing, landscape irrigation, and general cleaning.
- System not yet available in North America.
- Contact:
  - Telephone: (from North America) 011-61-2-6162-0650
  - E-mail: sales@perpetualwater.com.au

ReWater by ReWater Systems Inc., Chula Vista, CA

- System captures, filters, and reuses shower, tub, lavatory sink, and laundry water for landscape irrigation.
- System has been available since 1990. There have been numerous existing installations with a proven track record.
- Contact:
  - Telephone: 619-421-9121
  - E-mail: support@rewater.com
  - URL: http://www.rewater.com/

Graywater Applications for the Army

For military applications, the best time to use and design for graywater use is during new construction. The first step is to estimate graywater production and whether there will be enough demand for the volume of graywater generated. A multi-family apartment complex or a large barracks on a small property might generate so much graywater that most of the flow winds up in the sewer system, or a single family residence may require significant potable makeup water.

Planners must first consider whether the regulatory climate allows graywater use either inside or outside the building. As mentioned earlier, some areas welcome and encourage graywater use, while others ban it or have onerous requirements for testing and reporting.

LEED Considerations for Use of Graywater

In the Army's regulatory climate, the Army is a proponent of green technology and has directed that all new construction must meet LEED Silver status. Use of graywater provides access to a number of points achievable for that status during the design process. To achieve that level of certifiability, points related to graywater are available and may be considered (Table 7).

Table 7. LEED points for water harvesting efforts (USGBC).

Goal	Credit	Comments
Water Use: 20% Reduction	1 point (WE Credit Prerequisite 1)	20% reduction in water use for building by using alternative on-site sources of water such as rainwater, stormwater, and graywater

Goal	Credit	Comments
Water Efficient Landscaping: Reduce by 50%	2 points (WE Credit 1.1)	Limit or eliminate the use of potable water for landscape irrigation by using captured rainwater, recycled waste water, groundwater, and other means.
Water Efficient Landscaping: No Potable Water Use or No Irrigation	2 points in addition to WE Credit 1.1 (WE Credit 1.2)	Use only captured rainwater, recycled wastewater, or recycled graywater for site irrigation.
Innovative Wastewater Technologies	2 points (WE Credit 2)	Reduce generation of wastewater and potable water demand, while increasing the local aquifer recharge – use captured rainwater or recycled graywater to flush toilets and urinals or treat 50% of wastewater on-site to tertiary standards.
Water Use Reduction: 30%–40%	2-4 points (WE Credit 3)	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 graywater for non-potable applications such as toilet flushing and urinal flushing.
Innovation Design Credit	1 point. (ID Credit 1-1.5)	Projects that result in exceptional performance above the requirement set by LEED.

Secondly, it is important to consider whether the capital expenditure and operating expenses will offer a payback in a reasonable period. Perform the appropriate calculations, remembering both sewer cost and potable water costs are impacted. If the building is an office, it will probably not be cost effective to incorporate a graywater system. However, if the new building is a barracks, it may very well pay to incorporate a graywater system. Lifecycle cost effectiveness should be addressed, as well as whether any water restrictions exist or are anticipated.

Next, the end use is determined because it will impact system design (i.e., decide whether graywater will be used for toilet flushing or irrigation). If needed, separate systems are best installed during the new construction stage.

Finally, determine if the required system maintenance is appropriate for the type of building. For example, a complex graywater reuse system would be too complicated for most individual residents, but probably would not be beyond the capability of maintenance personnel responsible for large apartment buildings or barracks.

As stated previously, a potential concern for a large graywater project (e.g., a 300- person barracks) is impact on pipeline sizes. Pipeline sizes for a water distribution system are usually dictated by fire flow requirements to the area, although individual buildings are sized more on potential consumption. If water quality is diminished already due to stagnation in an area, for example on a dead end branch (although most water distribution systems are designed to be looping to avoid stagnation problems), a sizable reduction in potable water flow may contribute to the water quality problem. A quick assessment should be conducted using a simple flow model to confirm any impact due to addition of a graywater recycling system.

Although graywater reuse is straightforward in theory, in actual practice there are challenges to making even simple systems perform reliably and without undesirable effects. Collection of graywater from specific fixtures involves the installation of a sanitary drainage piping system in the building. Graywater is then processed by filtration, settling, disinfection, and/or coloring; the type of process depends on the intended end use. A nonpotable water distribution system is then required to route the processed graywater to toilets, urinals, or a subsurface irrigation system. In the case of reuse for toilet flushing, graywater is diverted from the various sources, collected, filtered, treated, dyed, and distributed. Figure 10 shows the components of a typical graywater system.

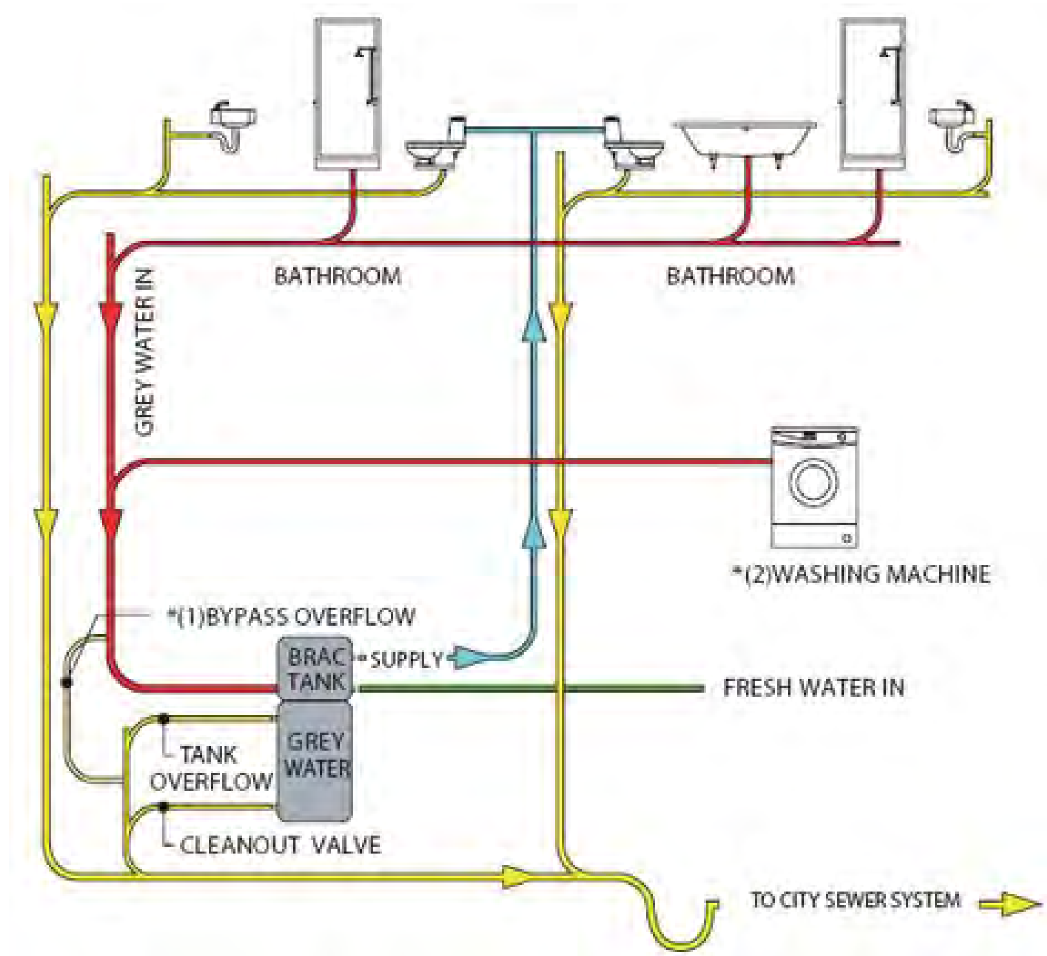

Figure 10. Example of graywater recycling system (courtesy of Brac Systems, Inc.).

Graywater Collection

A piped system requires less user intervention and is better from a public health viewpoint since it eliminates human contact with the graywater. Details will vary, but generally gravity collection systems in compliance with plumbing codes should be used. The plumbing codes will determine choice and use of necessary valves, any air breaks, back-flow preventers, and all venting. Graywater systems must be designed so that during times of system maintenance or failure, the wastewater bypasses, drains, or overflows indirectly to an approved treatment such as a sewer or on-site septic system. New construction separation of usable graywater from blackwater should be simple and require little extra expense. However, retrofitting a separate drainage system into an existing building will require more difficult installation work and expense, depending on the existing plumbing system.

Makeup Water

Design of any graywater system must consider the possibility that the demand for recycled graywater may exceed the supply. A public water system, individual water well, or other source must be used as a backup source of water to ensure proper operation of toilet and urinal fixtures. The non-potable graywater must not be allowed to contaminate the potable water supply. Air gaps, back flow prevention devices, and/or a backflow preventer valve can be used to prevent cross-contamination.

Graywater Storage

Graywater recycling system designs often include tanks for storage, surge, and/or settlement of the effluent. These tanks come in many sizes and are made from different materials. Tanks approved for wastewater storage should be used. Graywater systems should also limit the storage of graywater to the amount that can be used in 24 hours.

Concrete, resins, and sealants used in the tank manufacturing process must be capable of resisting the corrosive and decaying influences of graywater components and possible soil burial. Materials used must be formulated to withstand vibration, shock, normal household chemicals, and earth and hydrostatic pressure when full or empty. Tanks should be constructed to be watertight for the designed life of the tank and protected against light to control algal growth. Lids or covers should be watertight and secured for safety reasons to prevent an unauthorized entry. Since routine maintenance is critical for proper functioning, access to lids and any control panels should be convenient but secure. Vents and other openings should be screened to be protected from vectors. Setbacks may be required when installing tanks external from the structure. Guidelines should be supplied by local authorities. Materials and installation must be in conformance with appropriate standards and manufacturers' recommendations.

If a graywater system becomes unused for a period of time, the stored graywater will become anaerobic and septic, creating unpleasant odors. Most sources recommend that pipes be self-draining, and that tank bases be angled with a provision for slow drainage to allow the entire system to be emptied.

A settling tank is sometimes recommended to remove solids. Substances denser than water will fall out of suspension while greases, oils, and other small particles will float to form a surface scum. The remaining liquid can then be reused. A settling tank will also allow hot water to cool before reuse.

Treatment of Graywater

Treatment must be sufficient to ensure operation and longevity of the plumbing fixtures. All equipment and components in a graywater system should be certified by the manufacturer for use with wastewater. A number of methods of treatment are available, although the type of treatment required should be determined by the quality of incoming water, the planned end use, and the degree of maintenance the system user desires.

Most applications used for flushing toilets or urinals should consider levels of BOD and TSS. High levels make disinfection difficult and may interfere with fixture operation. Because of the potential exposure to graywater by people and pets, any disinfection treatment should reduce the number of pathogens. After disinfection, total coliform bacteria should be reduced to 500 cfu/100 mL or less. Fecal coliform levels should be under 100 cfu/10 0mL. Treated graywater for subsurface irrigation should meet local standards or regulations.

Filtration is essential to remove particles harmful to the system. Filters should be cleaned and changed regularly to ensure proper filtration. Pre-filters are often used to remove large suspended particles such as hair or lint. They should be easily accessible, and are usually placed in the system at some point before the storage tank. Finishing filters capable of removing smaller particles are placed on the discharge side of the pump, which supplies pressure to the plumbing system. Turbidity should be less than 10 NTU to improve the effectiveness of disinfection.

A variety of commercially available cartridge filters is available for graywater systems; the type of cartridge should be matched with size and flow for the intended use. Georgia, for example, recommends filters certified to meet Standard 61 of the National Sanitation Foundation.

Sand filters are another option. They include layers of sand and medium gravel. Multimedia filters require less frequent maintenance and cleaning than a commercially available filter but have higher installation costs. Better filtration may reduce the level of disinfection needed.

Disinfection is essential to reduce the number of potentially pathogenic microorganisms present after filtration. Disinfection also controls microbial growth, which causes offensive odors. Any disinfection method chosen must consider the water's temperature, turbidity, pH, and its contact time with the agent.

Chlorination is one of the most common methods of disinfection. Following filtration, an in-line erosion chlorinator or an injection pump can be used to disinfect graywater. A metering pump using a chlorine solution can also be used. A chlorine residual of 0.2 mg/L must be maintained at all times in the distribution system. Do not use products designed for use in swimming pools as they may contain cyanide-based stabilizers.

UV light disinfection can also be considered, but its effectiveness depends highly on water quality and transmission of light through the water. UV disinfection is adversely affected by particulates and colloidal particles.

Other forms of disinfection include ozonation, which involves the on-site generation of ozone gas and diffusion of that gas into the graywater. Benefits of ozonation are that the process creates no odor and uses no chemicals. However, the process can be expensive, and the treated water must be off-gassed because of ozone's toxic nature. Because of health risks associated with direct contact with ozone, it is recommended that workers take protective measures such as wearing protective eyewear, a mask, and latex gloves when maintaining such graywater systems.

Graywater in many states must be dyed with a food-grade vegetable dye before supplying a toilet or urinal. To further distinguish the recycled nonpotable water supply, all piping must follow the criteria from the UPC, section 608.8, for purple piping. Graywater systems must be identified with a label, signs, or placards, as "NON POTABLE;" this labeling must be on the distribution piping and the reservoir tanks. The lettering should be bold and clearly visible. Every toilet and urinal fixture should also be permanently identified to indicate that nonpotable water is being used.

It is worthwhile to note here that “purple pipe” is usually associated with reclaimed water that has been treated to a very high level at a wastewater treatment plant. There is a substantial lobbying effort by trade organizations to restrict the use of purple pipe to water of that quality.

Note that no graywater systems have been identified in the US Army at this time.

Pumps

It is important to use the correct pump for a graywater system, or problems may result. To keep a graywater system pump from burning or clogging (which can cause failure), consider the following factors that affect performance:

- characteristics of the graywater,
- desired flow rate and/or operation pressure, and
- total dynamic head.

The selected pump should be designed to handle graywater effluent. It must be constructed of corrosion-resistant materials, and it must be capable of delivering the fixture's required flow rate at the designed total dynamic head. Larger systems such as an institution or barracks should be equipped with a spare pump so that maintenance and repairs can occur without service disruption.

Future and International Applications

In the future, larger scale, more complex commercial graywater applications will become available to the Army in the United States and throughout the world (Figures 11 and 12). Such systems will collect larger quantities of used water, and city blocks and large buildings will have dual plumbing and communal treatment systems. Additionally, graywater will be combined with other reuse sources such as rainwater.

Figure 11. Example of emerging future graywater use of more complex (indoor) treatment.

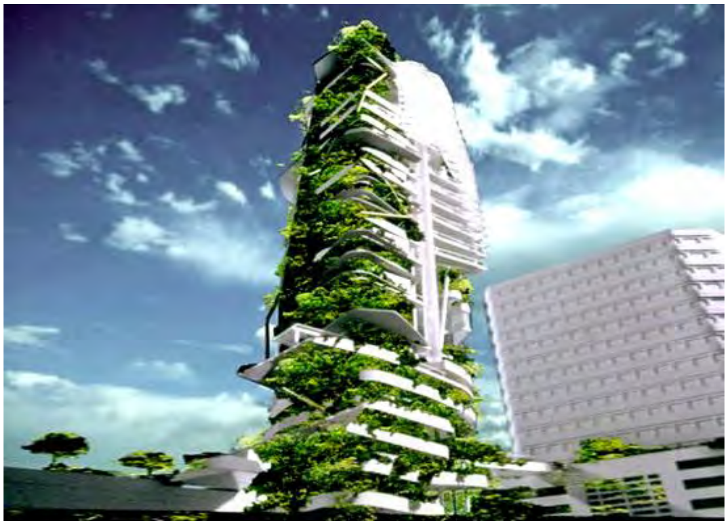

Figure 12. Example of emerging future graywater use with more complex (outdoor) treatment system.

Summary

In summary, numerous drivers currently exist to promote water efficiency. Graywater reuse is one option that can enable Army installations to reduce their use of potable water. Available quantities of graywater can be significant (up to 40 gal per person per day.) Many different treatment processes are available. To make best use of the available technologies, it is essential to match water quality with end use, while remaining cognizant of health considerations. Regulations are rapidly changing as the United States is playing catch-up with other countries in the area of graywater reuse.

It would also be useful to state that a uniform set of national health and safety requirements would help manufacturers design universally compliant systems and would likely result in lower design and manufacturing costs as well.

Although no graywater systems have been identified in the Army at this time, information is available that should encourage their application in the right circumstances.

Appendix B

REFERENCES and RESOURCES

References

Alliance for Water Efficiency. 2010. "Package Graywater Recovery and Treatment Systems." Available at (accessed June 2011): http://www.allianceforwaterefficiency.org/Package_Graywater_Recovery_and_Treatment_Systems.aspx?terms=Graywater

Bandy, John and Richard J. Scholze. 1983. Distribution of Water Use at Fixed Army Installation, TR N-157. Champaign, IL: U.S. Army Construction Engineering Research Laboratory.

Center for the Study of the Built Environment (CSBE). 2003. *Graywater Reuse in Other Countries and Its Applicability to Jordan*. Funded by the Ministry of Planning, Kingdom of Jordan. Available at (accessed June 2011): http://www.csbe.org/graywater/report/report_final.pdf

Cohen, Yoram. 2009. "Graywater: A Potential Source of Water" in Southern California Environmental Report Card Fall 2009. Los Angeles: UCLA Institute of the Environment. http://www.environment.ucla.edu/reportcard/article.asp?parentid=4870

Georgia Gray Water Recycling Guidelines: In accordance with Appendix C 'Gray Water Recycling Systems' of the 2009 amendments to the 2006 International Plumbing Code. 2009. Available online (accessed June 2011) at http://www.dca.ga.gov/development/constructioncodes/programs/downloads/GeorgiaGrayWaterRecyclingSystemsGuidelines_2009.pdf

Lesikar, Bruce, Rebecca Melton, David Smith, and Courtney O'Neill. 2005. *On-site Wastewater Treatment Systems: Graywater*. Publication B-6176. College Station, TX: The Texas A& M University System: Texas Cooperative Extension. Available at (accessed June 2011): http://nctx-water.tamu.edu/media/1603/B-6176.pdf

Roesner, L., M. Criswell, Y. Qian, M. Stromberger, and S. Klein. 2006. *Long-Term Study on Landscape Irrigation Using Household Graywater: Literature Review and Synthesis*. Document No. 03-CTS-18CO (technical report). Fort Collins, CO: Colorado State University; in conjunction with Alexandria, VA: Water Environment Research Foundation (WERF). Available at (accessed June 2011): http://www.urbanwater.colostate.edu/A1_Published_Report_03CTS18CO.pdf

U.S. Green Building Council. 2005. "LEED for New Construction and Major Renovations," Version 2.2. Washington, DC: USGBC

Resources:

Other organizations which have significant information on the subject of graywater use in addition to state or municipal websites include:

The American Society of Plumbing Engineers (ASPE) which has published several articles and has been making presentations on gray water from their viewpoint. http://aspe.org/

The National Small Flows Clearinghouse, operated by the National Environmental Services Center of West Virginia University publishes "Small Flows" which has several articles on graywater for use in individual residences. http://www.nesc.wvu.edu/

Additionally, a wide variety of information can be found at a website operated by Oasis design dedicated to graywater. http://oasisdesign.net/

Appendix C

ACRONYMS AND ABBREVIATIONS

Term	**Spellout**
BOD	biochemical oxygen demand
CDC	Centers for Disease Control
CFU	colony-forming units
COD	chemical oxygen demand
CSBE	Center for the Study of the Built Environment
EO	Executive Order
FEMP	Federal Energy Management Program
HQUSACE	Headquarters, U.S. Army Corps of Engineers
ICC	International Code Council
IMCOM	U.S. Army Installation Management Command
IPC	International Plumbing Code
LEED	Leadership in Energy and Environmental Design
NTU	Nephelometric Turbidity Units
POC	point of contact
PWTB	Public Works Technical Bulletin
TSS	total suspended solids
UFC	Unified Facilities Criteria
UPC	Uniform Plumbing Code
USACE	US Army Corps of Engineers
USGBC	US Green Building Council
UV	ultraviolet
WERF	Water Environment Research Foundation