# - GREYWATER REUSE IN WASHINGTON STATE -

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**Date Assigned:** 6/2/2009
**Date Completed:** 9/17/09
**Research Requested by:** ☐ RDC ☐ TRC ☒ Other: Greywater Rule Investigation
**Issue Subject:** Technical ☒ Issue ID: **GW1**
Administrative ☐
Regulatory ☐
Definitions ☐

**Specific WAC Section Reference, if WAC related:** **CR-101 - Reuse of greywater outside the building for subsurface dispersal and irrigation. Will be added to Title 246 WAC as Chapter 246-274 WAC**

## Topic & Issues:

- **Summary**
- **Introduction**
- **Greywater Quantity by Source**
- **Characteristics of Greywater by Source**
    - **Greywater vs. Blackwater**
    - **Pathogens**
    - **BOD**
    - **TSS**
    - **Fats, Oils, and Grease**
    - **Detergents, Salts, Cleaning Products, etc.**
- **Conclusion**
- **References**

## Summary:

This report summarizes the literature on the characterization of greywater by source inside of a home for nonpotable reuse in the State of Washington for single family homes, multi-family homes, and businesses. It summarizes available data related to the average quantity and constituents of concern associated with a variety of sources of greywater. It is meant to be used as a tool by the greywater rule advisory committee during rule development.

In RCW 90.46.010 (8), the State of Washington defines “greywater” as “wastewater having the consistency and strength of residential domestic type wastewater. Greywater includes wastewater from sinks, showers, and laundry fixtures, but does not include toilet or urinal waters.”

This literature review demonstrates that the level of pollution in the total greywater stream that includes kitchen sinks, dishwashers, laundry machines used to wash dirty diapers can be equal to or greater than blackwater and requires regulations consistent with on-site sewage regulations. Wastewater from kitchens can be heavily polluted with pathogens, chemicals from dish detergents, and fats, oils and grease. Wastewater from clothes washing machines used for washing soiled diapers contains increased levels of bacteria.

Many studies have measured the level of pollution in a variety of sources that make up greywater. The findings show that some greywater sources contain fewer pollutants than the total greywater stream. The sources of greywater that contained the least amount of pathogens and toxic chemicals were bathrooms (hand washing sinks, showers, and bathtubs) and clothes washing machines in homes without children living in them. These sources should be evaluated by the Greywater Rule Advisory Committee (GRAC) to determine how the new greywater rules can be drafted to safely regulate the reuse of greywater while continuing to protect the public’s health and environment. All untreated greywater sources contain increased levels of pollutants to the extent

that they are not suitable for direct exposure like washing cars, toilet flushing, and spray irrigation. However, subsurface irrigation could be an acceptable use for untreated greywater.

KEYWORDS: greywater, grey water, graywater, gray water, reuse, recycling, greywater quality, greywater characteristics, greywater risk,

## Body:

### Introduction

DOH has been authorized by the state legislature to develop standards, procedures, and guidelines for the reuse of greywater, consistent with RCW 43.20.230 (2). DOH is expected to develop criteria, with input from technical experts, with the objective of encouraging the cost-effective reuse of greywater and other water recycling practices, consistent with protection of public health and water quality. To assist the GRAC, this paper summarizes information taken from reports to describe the quantity and parameters of concern by source related to greywater.

Increased water demands and changing climate patterns can result in water shortages. The easiest and most efficient method for reducing potable water use is to conserve water by using less of it. Water conservation is an easy and affordable mechanism to save water. However, many people want to go beyond conservation by using greywater in place of potable for subsurface irrigation, toilet flushing, fighting fires, washing cars, and other possible uses. The Washington State Department of Health has the authority to regulate treatment and subsurface distribution of greywater outside of a building.

Using greywater for subsurface irrigation is a preferred method for reducing the use of potable water because it is cost effective and has relatively low risk of exposure. More expensive and complicated methods for greywater reuse include treating greywater to a safe level for other non-contact uses. The Leadership in Energy and Environmental Design (LEED) certificate and other green building certification programs reward developers for including greywater reuse systems into building designs. The expanded use of green building certificates and programs is increasing the demand for permitted greywater systems.

The increased focus on reclaimed water and greywater led the State's legislature to call on the Department of Health (DOH) to adopt rules for greywater reuse. In 2006 RCW 90.46.015 was amended to include, "The department of health shall, in coordination with the department of ecology, adopt rules for greywater reuse…..All rules required to be adopted pursuant to this section must be completed no later than December 31, 2010." A scoping paper, *Greywater Rule Development Non-technical Issues Scoping Paper* (Lopez, 2009), outlines the authorities related to greywater reuse in Washington and neighboring states and provides several examples of other states' regulation of greywater reuse.

State regulations currently allow greywater subsurface distribution systems to be permitted by a local health jurisdiction under the on-site sewage systems rules, Chapter 246-272A WAC. The design standards for greywater systems are addressed under the DOH's Water Conserving Recommended Standards and Guidance (RS&G). The RS&G recognizes that the lower volume of water in a greywater system, as compared to a grey and blackwater combined wastewater system, may allow a smaller system. The state and local health department's authority for regulating on-site sewage small systems is authorized by RCW 43.20.050 (3).

### Greywater Quantity by Source

The American Water Works Association Research Foundation summarized data from approximately 1,200 households located in 14 North American cities (Roesner, et al., 2006).

Figure 1 and Table 1 display the average quantities of water used in the 14 North American cities.

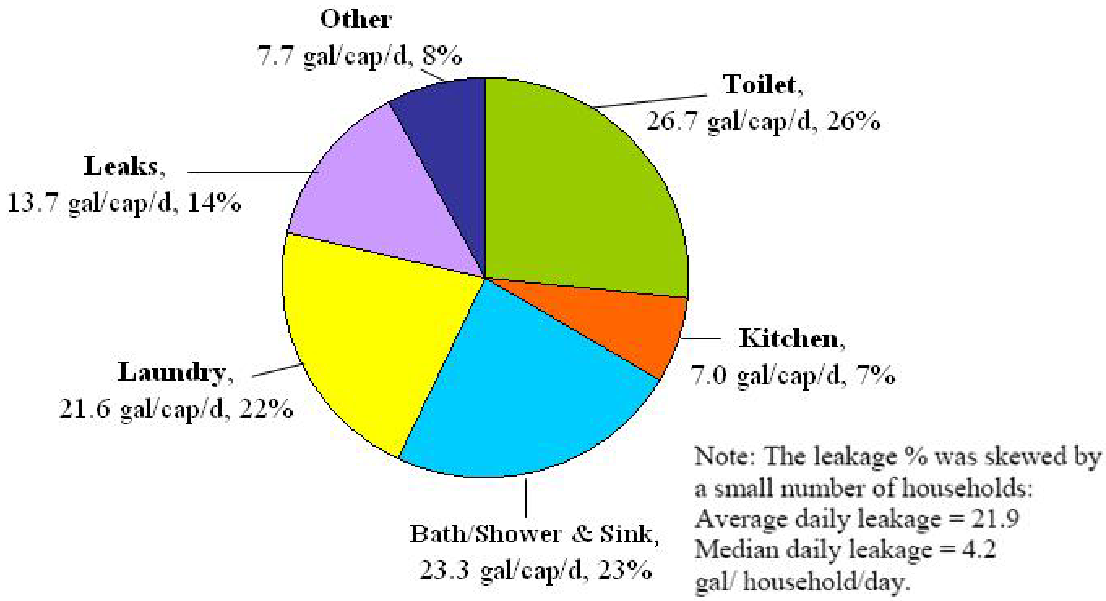


Figure 1 Average Indoor Residential Water Usage for 12 North American Cities. This information was adapted from the Water Environment Research Foundation's Long-term Effects of Landscape Irrigation Using Household Graywater report (Roesner, et al., 2006). The data was collected via a research project completed by the American Water Works Association Research Foundation.

| Source | Gal/Cap/Day | Percent |
|---|---|---|
| Toilet | 26.7 | 26.0 |
| Kitchen | 7.0 | 7.0 |
| Laundry | 21.6 | 22.0 |
| Bath/Shower/Sink | 23.3 | 23.0 |
| Leaks | 13.7 | 14.0 |
| Other | 7.7 | 8.0 |
| **Total** | **100.0** | **100.0** |

Table 1 Average Indoor Residential Water Usage for 12 North American Cities. Data is taken from Figure 1.

The above figure describes total volumes per person per day. To evaluate the potential potable water savings through greywater irrigation systems, it's important to note that the results from a greywater reuse study conducted in Tucson, Arizona in 2000 (Little, 2000) demonstrated that people did not hook up all of the sources within a home. In fact, the majority of greywater usage came from the laundry. This can be explained by the relative ease related to washing machines due to the fact that a pump is already built into the machine. The potential for expanded use of greywater for re-use inside or outside of the building is greatest when the greywater system is built into new homes. Recent regulations passed by the Tucson City Council (Tuscon City Council 2008) require all new construction to have greywater plumbing stub-outs.

Taking the total household use per person and subtracting the amount used by toilets and leaks, the typical average greywater flow is 60% of the total wastewater produced. This is the same percentage that is referenced in EPA's Onsite Wastewater Treatment System Manual and close to the 65% estimated by Rose, et. al. in their 19991 study (Rose, et al., 1991).

The amount of water available for irrigation from a washing machine used by a family of four is roughly 30,000 gallons per year. In Western Washington irrigation water is only needed for an average of about 4 months a year resulting in a potential water savings of 10,000 gallons per year. For an area like Olympia, Tumwater, and Lacey (estimated population of 100,000 people) a potential water savings of 250 billion gallons of potable water could be saved each summer if only one quarter of the homes used a greywater irrigation system for their laundry water.

The potential for water savings goes up dramatically in Eastern Washington where irrigation water can be used during a much longer growing season. For homes that have individual wells that tend to run dry in the summer, this water savings could expand the size of family gardens and the potential area available for growing crops such as apples.

One study completed in Australia demonstrated a potential need to educate people using greywater systems. The study showed that homes that use greywater systems used about 45 gallons per day more water than those not using greywater systems. The researchers postulated that people thought it okay to use extra water because it was being reused in the garden. To ensure a water savings is accomplished, people using greywater systems will need to continue to be conscientious not increasing water usage (Crook, et al., 2009).

## Characteristics of Greywater by Source

The characteristics of greywater are as varied as the sources it comes from. A sink used for hand washing will have minimal pathogens and harmful chemicals. However, sinks that have a garbage grinder and are used for washing raw meat or dishes and washing machines used to wash soiled diapers can contain more pollution than a toilet.

### Greywater vs. Blackwater

The constituents of blackwater and greywater from all sources including kitchen sinks and dishwashers but excluding waste from garbage disposals are summarized in Table 2. This data is taken from Robert Siegrist's 1977 report titled, *Segregation and Separate Treatment of Black and Grey Household Wastewaters to Facilitate Onsite Surface Disposal* (Siegrist, 1977). This data demonstrates that greywater and blackwater contain similar quantities of BOD.

| | Source - Greywater includes wastewater from the kitchen sink and dishwasher but excludes the garbage disposal | | Source - Blackwater | |
|---|---|---|---|---|
| Constituent or Parameter | Mean | Mean gallons/cap/day | Mean | Mean gallons/cap/day |
| $BOD_5$ (mg/L) | 255 | 28.5 | 280 | 16.7 |
| TSS (mg/L) | 155 | 17.2 | 450 | 27 |
| $N_{total}$ (mg/L) | 1.9 | 17 | 145 | 8.7 |
| $P_{total}$ (mg/L) | 2.8 | 25 | 20 | 1.2 |

Table 2.The results are Mean values for households with typical conventional appliances, excluding the garbage disposal. The values are reported from the results of six studies. (Siegrist, 1977)

### Pathogens

One of the greatest concerns with the reuse of greywater is the potential for spreading illness. It is important to know the levels of indicator organisms found in greywater to determine what measures should be required to protect public health. All studies on greywater found indicator organisms in all sources of greywater.

Fecal coliform bacteria specifically originate from the intestinal tract of warm-blooded animals. These organisms are used as indicators of the presence of pathogenic microbes or level of disinfection because they occur naturally in the feces of warm-blooded animals and are easily detectable. Increased levels of fecal coliform bacteria indicate the potential presence or concentration of pathogenic bacteria. However, the indicator is not as reliable for predicting the potential presence or concentration of viruses or protozoa.

There is some question related to the degree of risk based on the indicator bacteria. Because greywater is contained in pipes or stored in warm, wet tanks, some researchers (Ottoson, et al., 2003) have suggested that the conditions are favorable for growth of indicator organisms but less favorable for pathogens. Despite the presence of fecal indicator organisms and pathogens, a consistent relationship between greywater reuse and illness rates is unknown at this time. The greywater rule advisory committee will need to use the best available science to determine what levels of protection are necessary to protect public health.

Two researchers summarized fecal coliform data from a variety of studies based on the source of the greywater. Table 3 summarizes the findings from Jakob Ottoson and Thor Stenstrom in their report titled, *Faecal Contamination of Greywater and Associated Microbial Risks* (Ottoson, et al., 2003).

| Wastewater Origin | Fecal Coliforms Most Probable # (MPN)/100 mL | Study | Year of Study |
|---|---|---|---|
| Greywater | $6.3 \times 10^5$ | Chemical and Mircobial Characterization of Household Graywater - Casanova, et. al. | 2000 |
| Greywater | $6.3 \times 10^5$ | Swedish EPA. Vad innehaller avlopp fran hushall? Naringoch metaller i urin och fekalier samt i disk-, tvatt-, bad- & duschvatten (What does household wastewater contain? Nutrients and metals in urine, faeces and dish-, laundry and shower water). Naturvardsverket. Rapport 4425, 1995. | 1995 |
| Greywater | $1.5 \times 10^5$ - $1 \times 10^7$ | Lindgren S, Grette S. Vatten- och avloppssystem. Ekoporten Norrk.oping (Water and sewerage system. Ekoporten in Norrk.oping). SABO Utveckling. Trycksak 13303/1998-06.500, 1998. | 1998 |
| Greywater | $2 \times 10^5$ - $7.9 \times 10^6$ | Microbial Quality and Persistance of Enteric Pathogens in Graywater from Various Sources - Rose, et al. | 1991 |
| Kitchen Sink | $4 \times 10^7$ | Swedish EPA. Vad innehaller avlopp fran hushall? Naringoch metaller i urin och fekalier samt i disk-, tvatt-, bad- & duschvatten (What does household wastewater contain? Nutrients and metals in urine, faeces and dish-, laundry and shower water). Naturvardsverket. Rapport 4425, 1995. | 1995 |
| Hand Basin, Kitchen Sink | $1 \times 10^5$ | Stenstrom T. Infiltration i mark. (Infiltration into soil). Swedish EPA, snv pm 3051, 1985. | |
| Shower, Hand Basin | 158 - $3.2 \times 10^3$ | Christova-Boal D, Eden RE, McFarlane S. An investigation into greywater reuse for urban residential properties. Desalination 1996;106(1–3):391–7. | 1996 |
| Shower, Bath | 0 - $5.0 \times 10^3$ | Faechem RG, Bradley DJ, GarelickH, Mara DD. Sanitation and disease: health aspects of excreta and wastewater management. Washington: Wiley, 1983. | 1983 |
| Laudry | $1 \times 10^2$ - $1 \times 10^3$ | Christova-Boal D, Eden RE, McFarlane S. An investigation into greywater reuse for urban residential properties. Desalination 1996;106(1–3):391–7. | 1996 |
| Laudry, Wash | 10 - $1.0 \times 10^4$ | Faechem RG, Bradley DJ, GarelickH, Mara DD. Sanitation and disease: health aspects of excreta and wastewater management. Washington: Wiley, 1983. | 1983 |
| Laudry, Rinse | 0 - $2.5 \times 10^5$ | Faechem RG, Bradley DJ, GarelickH, Mara DD. Sanitation and disease: health aspects of excreta and wastewater management. Washington: Wiley, 1983. | 1983 |

Table 3. Reported numbers of indicator bacteria in grey wastewater (Ottoson and Stenstrom 2003)

It is clear from these studies that wastewater from kitchen sinks contains similar amounts of fecal coliform ($10^7$) as blackwater. The fecal coliform concentration in blackwater was found to be between $10^6$ and $10^8$ (Lowe, et al., 2007). Wastewater from the shower, bath, and hand basins is the least polluted (0 - $10^3$) and laundry water is in the middle ($10^1 – 10^4$).

James Crook and Alan Rimer's *Technical Memorandum on Graywater* summarizes data from 12 studies and presents the range of fecal coliforms found in composite samples of greywater (including wastewater from the kitchen) (Crook, et al., 2009). Their summary shows fecal coliform results ranged from $1.82 \times 10^4 – 7.94 \times 10^6$, are similar to Ottoson's findings.

The warm, wet conditions found in plumbing and greywater storage tanks contribute to increases in indicator organisms when greywater is stored for greater than 24 hours (Rose, et al., 1991). The Water Environment Research Foundation's report (Roesner, et al., 2006) on the Long-tern Effects of Landscape Irrigation Using Household Greywater summarizes the results of studies and found:

> Several studies have demonstrated that indicator organisms can persist and even multiply in stored graywater due to available nutrients and/or biofilm formation which enhances pathogen survival (Rose et al., 1991; Ford et al., 1992). Moreover, pathogens seeded into graywater are capable of reproducing during graywater storage. *Salmonella typhimurium* and *Shigella dysentriae,* for example, survived several days when seeded in graywater at pH 6.5 and 25°C (Rose et al., 1991). On the other hand, a viral pathogen (Poliovirus type 1) decreased 90% or more after 6 days in graywater at pH 6.5 (Rose et al., 1991). This raises the question of whether the typical concentration in wastewater are a meaningful measure of the actual human health risk posed by graywater. Many researchers think not (see Section 1.5 in Chapter 1.0).

Because pathogens can be shed during showering and hand washing and through the laundry, direct routing of greywater should not happen when people living in the home are sick. A diverter should be required to allow residents to divert the greywater to the building's wastewater system if people in the home are sick.

A study completed in Massachusetts (Veneman, et al., 2002) characterized greywater from four public venues (three parks and a tourist information center) over a one year period. Monthly sampling for coliform included tests for both total coliforms (TC), fecal coliforms (FC) and E. Coli. Values for TC generally exceeded maximum countable colonies (TNTC means Too Numerous To Count) and often exceeded $>10^6$ cu/100 mL. Fecal coliforms ranged from 0 to an occasional elevated value (500-10,000 cu/100 mL). E. Coli was not detected in any of the samples. Greywater samples typically averaged between $500\text{-}2.4\times10^7$ TC and $170\text{-}3.3\times10^3$ FC per 100 mL.

To meet the goal of protecting public health and water qualilty, the potential risks assocaited with using greywater for irrigation will need to be assessed. The World Health Organization (WHO) developed WHO Guidelines for the Safe Use of Wastewater and Excreta in Agriculture (Petterson, et al., 2006). They use three types of evaluations to assess risk: microbial analisys, epidemiological studies, and quantitative microbial risk assessemnt. The report states that, "to best protect public health, muliple strategies may be needed simultaneously to add additional barriers to the transmission of diesease". They recommend using multiple barriers like combining crop restriction (not allowing exposure of the greywater to crops) and limiting public access (keeping the greywater to areas not accessable to the public).

A discussion paper written in 1999 regarding health issues related to greywater re-use guidelines for the United Kingdom (Dixon, et al., 1999) characterizes risk using a table, Table 4. This conceptual tool will be helpful for the greywater rule advisory committee to use during rule development. Risk of disease transmission increases with the quantity of greywater used for untreated subsurface irrigation. Arizona, New Mexico, and many states limit the quantity of greywater allowed for re-use by using a regulatory frame work that includes a low risk option that limits the quantity allowed for direct irrigation (Crook, et al., 2009). DOH recommends including a similar frame-work for Washington State.

| | LOWER RISK | INTERMEDIATE RISK | HIGHER RISK |
|---|---|---|---|
| POPULATION | Small population (single family) | | Large Population (multi-occupancy) |
| EXPOSURE | No body contact (sub-surface irrigation) | Some Contact (WC Flushing, swimming) | Ingestion (Drinking) |
| DOSE-RESPONSE | <1 virus per sample<br><1 Bacteria per sample | | >1 virus per sample<br>>$10^6$ Bacteria per Sample |
| DELAY BEFORE RE-USE | Immediate re-use | Re-used within hours | Re-used within days |

Table 4. Conceptual analysis of range of risk from greywater re-use

**Biological Oxygen Demand**

Biochemical oxygen demand (BOD) is an analytical measure of how much oxygen is consumed in biological processes that degrade organic matter in wastewater. BOD is widely used as an indicator of treatment efficiency, while it has only indirect significance to human and environmental toxicity. BOD can be used to determine the amount of organic pollution in surface water and also is used to determine the strength of wastewater by measuring how much dissolved oxygen is used by microorganisms during biochemical oxidation of any organic matter present in wastewater. High wastewater strength (high BOD values) could change soil properties resulting in poor aeration by further depleting available oxygen and produce reducing conditions in the soil.

Untreated greywater should never be allowed to reach storm or surface water because greywater can contribute high levels of organics that can lead to high levels of dissolved oxygen in the water body. Low dissolved oxygen is one of the leading causes of water quality impairment for rivers, lakes, and estuaries.

High $BOD_5$ effluent discharging to surface water can result in the depletion of dissolved oxygen in the aquatic environment, which can lead to a die-off of aquatic organisms and anaerobic conditions. The $BOD_5$ of raw sewage is about 300 mg/L (Bitton, 1999) and drops to less than 10 mg/L in treated wastewater (EPA, 2003). While the $BOD_5$ of greywater can be high, a study completed in Sweden (Karlgren, 1967) showed the most significant difference between blackwater and greywater lies in the rate of decay of the pollutants in each. After 5 days of blackwater decomposition, only 40% of the ultimate decomposition (UOD) was accomplished. In contrast, UOD of greywater reached about 90% of decomposition. The difference in decay rates, Figure 2, can be explained by the presence of grease, fiber, and particulates (wastewater from the kitchen sink was included in this study).

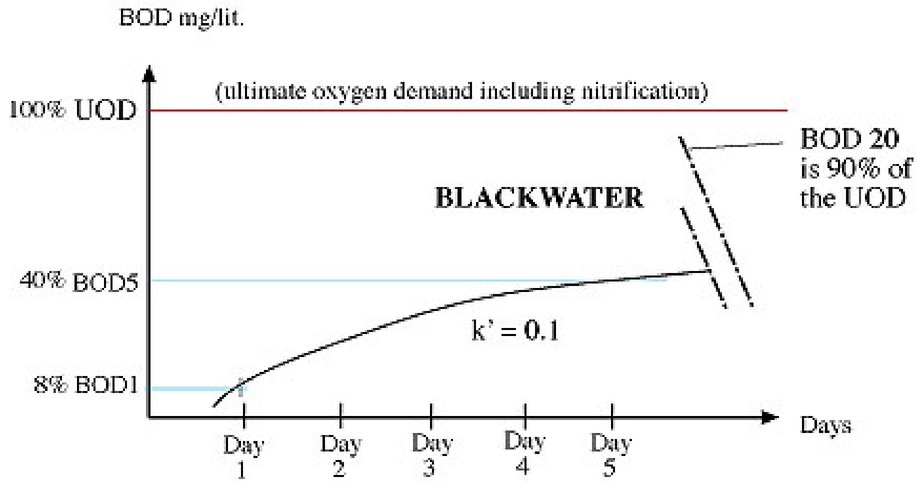


Fig. 1

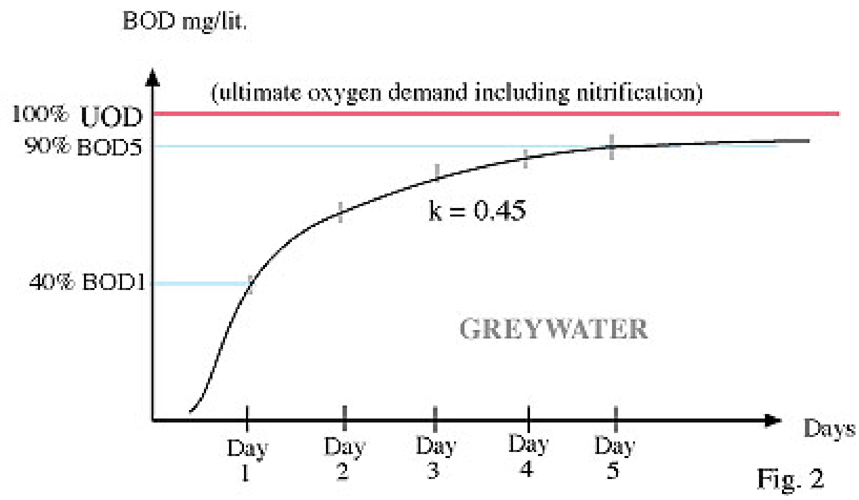


Fig. 2

Figure 2. Comparative rates of Ultimate Oxygen Demand (UOD) from greywater and blackwater, data and graphs extracted from Carl Lindstrom © 2000 summary of greywater scientific data. The original data came from a study completed in Sweden in 1967 (Karlgren, 1967).

Storing greywater for greater than 24 hours can lead to strong odors. Because of the high level of $BOD_5$, oxygen is consumed quickly resulting in anaerobic bacteria growing. When anaerobic bacteria live and multiply they release hydrogen sulfide, an extremely odorous gas. Storing untreated greywater for longer than 24 hours is not recommended (Rose, et al., 1991).

A study (Eriksson, et al., 2003) completed in Denmark in 2003 reported the average $BOD_5$ values ranged between 26 and 130 mg/L. This study was conducted at an apartment building that is plumbed such that the wastewater from the bathroom showers and hand-basins flows into a collection tank in the basement. The samples were collected from the exit pipe of the collection tank (the amount of time the greywater remained in the collection tank is unknown. Casanova's (Casanova, et al., 2000) study in Arizona reported average BOD results of 65 mg/L for a home with two adults. The greywater drained from the washing machine, sinks, and showers.

A study conducted in Queensland, Australia (Howard, et al., 2005) tested wastewater from clothes washing machines. The $BOD_5$ ranged between 48 and 787 mg/L with an average of 227 mg/L. This study found that the major determinant of water quality of laundry greywater is the type of detergent used. Liquid detergents and concentrated powders are manufactured using fewer types of fillers.

Crook and Rimer's (Crook, et al., 2009) Technical Memorandum that summarizes data from 12 studies reports $BOD_5$ data from greywater that includes kitchen wastewater ranges from 26 to 295 mg/L.

A study completed in Massachusetts (Veneman, et al., 2002) characterized greywater from four public venues over a one year period. Greywater samples were collected after storage of greater than 24 hours in three of the locations. The samples from Salisbury were collected directly from the source. Results from the study found the mean $BOD_5$ for Lancaster was 102.0 mg/L (range: 54.9-188.3 mg/L), Walden Pond: 131.6 mg/L (range: 58.3-305 mg/L), Wellfleet: 142.7 mg/L (range: 36.8-286.1 mg/L), and Salisbury: 168.7 mg/L (range: 48.8-358.8 mg/L). Average $BOD_5$ over the entire period for all sampling stations was 128.9 mg/L (range: 22.1-358.8 mg/L).

**Total Suspended Solids**

TSS, total suspended solids, is a measure of the amount of suspended solids found in wastewater effluent. Large quantities of suspended solids in wastewater can affect wastewater treatment processes in several ways. Suspended solids can interfere with the flow of water in transport pipes, distribution components, and soil pores. Plugging of the orifices by these sediments reduces distribution efficiency. Plugging of the soil pores with particulate solids accelerates soil clogging. Suspended solids in groundwater and surface water can cause anoxic conditions.

To use untreated greywater for irrigation, a filter is needed to keep the suspended solids from clogging the irrigation system. While the greatest concern is hair from showers and lint in the laundry, all greywater contains solids (Howard, et al., 2005). Casanova's (Casanova, et al., 2000) study in Arizona reported average TSS results of 35 mg/L for a home with two adults. The greywater drained from the washing machine, sinks, and showers.

Crook and Rimer (Crook, et al., 2009) report the TSS values for composite samples reported from 12 studies averaged between 7 and 330 mg/L for greywater that includes wastewater from the kitchen.

The study completed in Massachusetts (Veneman, et al., 2002) characterized greywater from four public venues over a one year period. Results from the study found the mean TSS values in Lancaster were: 38 mg/L (range: 10-200 mg/L), at Walden Pond: 26 mg/L (10-50 mg/L), at Wellfleet: 68 mg/L (range: 20-200 mg/L), and at Salisbury: 95 mg/L (range: 60-180 mg/L). Mean TSS value of all sites over the entire sampling period was: 53 mg/L (range: 8-200 mg/L).

**Oil and Grease**

If present in excessive amounts, oil and grease will interfere with aerobic biological process and lead to decreased wastewater treatment efficiency. Grease, which is insoluble in and less dense than water, may harden in tanks and can accumulate and completely clog soil pores. Oil and grease are highest in greywater that originates in the kitchen.

A study completed in 2007 (Travis, et al., 2008) demonstrated a tenfold increase in oil and greases from kitchen waste over all other sources of greywater, Figure 3.

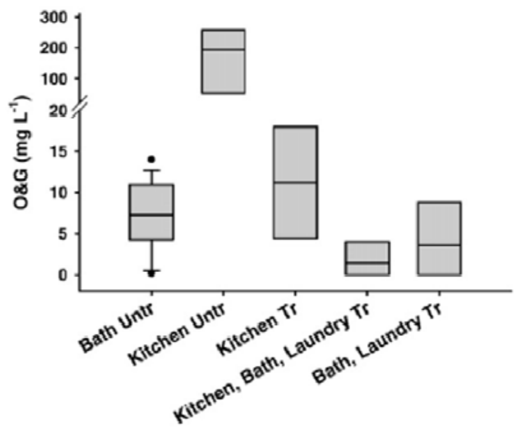


Fig. 3 – Box plot of oil and grease (O and G) concentrations in greywater used for garden irrigation, Midreshet Ben-Gurion, Israel. Greywater sources are as labeled, and indicated as treated (Tr) or untreated (Untr). The boundaries of each box indicates the first and third quartile of the sample data, the solid line within the box marks the median. Whisker bars indicate the 10th and 90th percentiles, and outlying points are presented. For all streams $n=7$, except bath $n=14$.

**pH**
The pH of greywater ranges from 6.5 -8.7 as summarized in Crook and Rimer's technical memorandum (Crook, et al., 2009). Greywater is typically alkaline due to the use of soaps and detergents.

**Nitrogen**

Nitrogen is a plant nutrient that can be beneficial as a fertilizer, however, it can also contribute to eutrophication and dissolved oxygen loss in surface waters, especially in nitrogen-limited lakes, estuaries, and coastal embayment's. Excessive nitrate-nitrogen in drinking water can cause methemoglobinemia in infants and pregnancy complications.

The majority of nitrogen in wastewater comes from urine. Because urine is not included in greywater, the amount of nitrogen contained in greywater is not of significance. Users of greywater systems should be aware of everything that goes down their drains and into the garden and landscape via a greywater system. They need to make sure that excess nitrogen is not exiting the building.

**Phosphorus**

Phosphorus is essential to the growth of plants, algae and other biological organisms and is most often the limiting freshwater nutrient for algae and aquatic weeds. Excessive algal growth lowers water quality, and its eventual decay at the lake bottom can release stored phosphorus, perpetuating a cycle of recurring algae blooms (Eliasson, 2002).

The main source of phosphorus in greywater is from dishwashing detergents. If soaps and detergents used for washing dishes contain large amounts of phosphorus, the greywater will also have increased levels. Due to increases in water quality problems related to the use of cleaning products that had high levels of phosphorus in them, the State of Washington passed a law limiting the percent of phosphorus allowed in laundry detergent to less than 0.5% beginning in 1994.

Total phosphorus results summarized in Crook and Rimer's technical memorandum (Crook, et al., 2009) ranged from 0.28-27.3 mg/L. When properly managed by people, phosphorus concentrations can be limited to small amounts in the greywater stream.

**Salts**

Laundry detergents contain a variety of salts used as fillers or to enhance the cleaning ability of the products. The concentration of salts varies greatly depending on the brand of detergent and the type of washing machine. Top loading machines designed to save water tend to have higher concentrations of pollutants. A study conducted in Queensland (Howard, et al., 2005) summarizes the range of findings measured from 15 households (30 wash samples), Table 5.

| Characteristic | Unit | Measured Value | | |
|---|---|---|---|---|
| | | *Minimum* | *Average* | *Maximum* |
| EC | µS/cm | 496 | 1037 | 2162 |
| pH | - | 7.32 | 9.23 | 10.32 |
| BOD5 | mg/L | 48 | 227 | 787 |
| TSS | mg/L | 18.3 | 100.6 | 290.3 |
| Total N | mg/L | 3.5 | 11.9 | 30.7 |
| Total P | mg/L | 0.2 | 21.5 | 93.3 |
| Faecal Coliform | cfu/ 100mL | <1 | <1[7] | 19000 |
| SAR | (%) | 2.3 | 12.4 | 32.9 |
| Calcium | mg/L | 0.9 | 7.36 | 16.2 |
| Magnesium | mg/L | 2.3 | 8.31 | 15.1 |
| Sodium | mg/L | 45.6 | 177.9 | 501.0 |
| Potassium | mg/L | 2.6 | 5.5 | 10.2 |

Table 5. Range of water quality data measured from 30 wash samples

From the Queensland study (Howard, et al., 2005):

> The cations that are of interest are calcium, magnesium, sodium and potassium. Of these four, sodium and calcium are of particular interest as they have a significant bearing on whether the application of this water has the potential to cause soil structural problems.
>
> Soils that are relatively low in electrical conductivity (EC) but high in sodium compared to the other cations tend to be unstable in water. Hard surfaces can form, making it difficult for plants to germinate or grow. Infiltration rates are reduced and water-logging may occur as a result. The sodium adsorption ratio (SAR) is the ratio of sodium cations to calcium and magnesium cations. Irrigation waters with SAR values >6.0 are cause for concern. Approximately two-thirds of all the laundry water samples tested had SAR values >6.0, and the long-term application of such water to a single location without some addition of Calcium (e.g., as gypsum) could be expected to cause significant soil structural damage.

Many studies have been conducted to determine the effect greywater irrigation has on the health of plants and impacts to soil. Greywater that includes wastewater from the kitchen was proven to be detrimental to the growth of plants and damaged the soil during tests (Amoozegar, 1998).

Amoozegar notes (Amoozegar, 1998), “The adverse impact of sodium on soil hydraulic properties is well known”.

Studies conducted on the subset of greywater that includes showers, baths, hand-washing basins, and clothes washing machines demonstrated that these sources were not detrimental to plants and soil sampling did not show adverse impacts. When $CaCl_2$ was added to laundry water, Amoozegar demonstrated that azaleas, hollies, and pines performed as well as when watered with potable water (Amoozegar, 1998). Table 6 demonstrates his findings.

| Irrigation treatments | 'Super Olympia Red' begonia | 'Celebrity Neon' petunia | 'Honeybells' hosta | 'Sunglow' azalea | 'Compacta' holly | Willow oak | Loblolly pine |
|---|---|---|---|---|---|---|---|
| Tap water | 4.7 a[z] | 4.8 a | 4.8 a | 4.2 a | 4.9 a | 4.9 a | 5.0 a |
| Laundry wastewater | 3.6 b | 3.9 b | 4.6 a | 2.7 b | 4.0 b | 3.4 b | 4.1 b |
| Laundry wastewater/ $CaCl_2$ amendment | 3.6 b | 4.5 a | 4.4 a | 3.9 a | 4.7 a | 3.9 b | 5.0 a |
| Kitchen wastewater | 1.0 c | 1.0 c | 1.0 b | 1.0 c | 1.2 a | 1.8 c | 2.0 c |

[z]Means (n=12) within each column and species followed by the same letter or letters are not significantly different as determined by Fisher's Protected LSD, $P$=0.05. Scale ranged from 1 to 5 with a score of 5 indicating plants of highest quality. This data was taken immediately prior to harvest.

Table 6. Effect of irrigation treatments on visual appearance of 'Super Olympia Red' begonia, 'Celebrity Neon' petunia, 'Honeybells' hosta, 'Sunglow' azalea, 'Compacta' Japanese holly, willow oak, and loblolly pine.

Many people in California submitted public testimony at a hearing in July 2009 regarding proposed greywater rules for California. More than 10 people spoke about the large number of greywater systems (estimated at well over 100,000 +) that have been used to grow healthy gardens. While there are not studies available on the impacts on vegetation in neighborhoods with lots of greywater irrigation systems, the examples coming from California suggest that when properly managed, greywater reuse can be beneficial to gardens and landscapes. Because greywater is usually alkaline, plants that prefer acidic soil should not be irrigated with greywater. Washington State's greywater guide (Health) lists plants that are not suitable for greywater irrigation and those that might tolerate it. Table 7 summarizes the list.

| Plants that are **not suitable** for irrigation with greywater | | |
|---|---|---|
| Azaleas | Ferns | Magnolias |
| Begonias | Foxgloves | Oxalis (Wood Sorrel) |
| Bleeding Hearts | Gardenias | Primroses |
| Crape Myrtle | Holly | Redwoods |
| Deodar Celular | Hydrangeas | Rhododendrons |
| Dogwood | Impatiens | Violets |

| Plants that **might** tolerate greywater irrigation (except greywater from kitchens with dishwashers) | | |
|---|---|---|
| Bearded Iris | Junipers | Rosemary |
| Burning Bush | Oaks | Roses |
| Cottonwood | Pine, Austrian | Russian Olive |
| (Many Native) Desert Plants | Pine, Italian Stone | Sage, Big Basin |
| Fringed Sage | Pine, Mugo | Sedum |
| Honeysuckle | Rabbit Brush | Sumac (staghorn) |

Table 7. Plants that are not suitable or might tolerate greywater irrigation

## Conclusions:

A comprehensive review of the literature to address key issues on the subject of greywater reuse was completed by DOH. The following conclusions can be drawn from the information available in the literature:

1. Greywater reuse is a viable option for maximizing the use of potable water.

2. Greywater comes from a variety of sources including bathrooms, kitchens, and washing machines. The characteristics of greywater vary greatly depending on the source. A subset of greywater (bathroom washbasins, showers and baths, and the laundry wastewater) contains fewer pollutants than greywater that includes wastewater from the kitchen and laundry machines used for washing dirty diapers. This is especially true when people do not use cleaners that contain harsh chemicals, bleaches, disinfectants, or phosphates.

3. Greywater is a source of bacteria, virus, and protozoa which can cause illness. Direct exposure routes should not be allowed. Subsurface irrigation is acceptable, however, ponding and other direct contact paths need to be avoided.

4. Greywater does need to be managed properly to avoid exposing people to pathogens, harming plants, clogging the irrigation system, and creating unpleasant odors. Management options used to address the risk associated with greywater re-use include using a graduated frame-work to manage risks. Potential risks can be reduced by regulating the following:
    - Limiting the use of direct routing for greywater to the lowest risk sources
    - Limiting the volume of greywater allowed for direct routing to the irrigation system
    - Ensuring that untreated greywater does not flow to surface or ground water
    - Ensuring that greywater stays below the surface by specifying the correct cover material
    - Limit storage of untreated greywater to less than 24 hours
    - Require filters be used to remove lint, hair, and other solids
    - Not allowing hazardous chemicals down the drain and recommending greywater tolerant plants and plant friendly cleaning products be used
    - A diverter should be required to allow residents to divert the greywater to the building's wastewater system if people in the house are sick or during times irrigation is not needed

- **How do we match risk reduction strategies to the actual receiving environmental risk factors?**
  The greywater rule advisory committee should categorize greywater by risk. Using a graduated frame-work to apply risk based regulations will effectively protect public health and water quality. To accomplish this, the greywater rules advisory committee should identify the level of wastewater treatment needed to protect water quality and match site vulnerability and relative risks to the required treatment standards.

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