REPORT DOCUMENTATION FORM
WATER RESOURCES RESEARCH CENTER
University of Hawaii at Manoa

[1]Report Number Technical Memorandum Report No. 73	[2]FCST Category 03-C; 05-E
[3]Title *Greywater Reuse*	[4]Report Date January 1983
	[5]No. of Pages viii + 42
	[6]No. of Tables 11 / [7]No. of Figures 6
[8]Author(s) Mr. Wesley M. Hirano, Dr. Reginald H.F. Young	[9]Grant Agency
	[10]Grant/Contract No.

[11]Descriptors: Wastewater renovation, household wastes, wastewater disposal

Identifiers: Greywater, greywater treatment, blackwater, reuse, individual systems

[12]Abstract (Purpose, method, results, conclusions)

Household wastewater can be divided into "blackwater" (toilet wastewater and "greywater" (non-toilet wastewater). Recently, schemes have been proposed for the segregation of the two streams with subsequent treatment and reuse of the greywater fraction, thereby resulting in a reduction in the amount of water used and wastewater produced, recycling of nutrients, and replenishment of the groundwater. Greywater, while making up about 60 to 65% of the wastewater flow, is weaker in pollutant concentration than blackwater. Greywater contributes much of the BOD_5, about half of the suspended solids, little nitrogen, and most of the phosphorus to the total wastewater flow. It also contains low levels of indicator bacteria and so must be handled and treated properly before being reused. Strategies for segregation and management of the blackwater and greywater streams are outlined. Greywater treatment schemes that include anaerobic and aerobic treatment, disinfection or filtration have been proposed and studied by a few investigators; however, substantial data are still lacking. Household greywater reuse systems have been built and found to be simple, reliable, and aesthetically acceptable. A typical system would consist of a settling/storage tank with disinfection, followed by a filter, and a pump and pressurized tank for distribution to the toilets or for lawn irrigation. Savings of 30 to 40% of the total water flow can be achieved. When reused for irrigation, a number of factors including the type of soil, topography, climate, selection of plants, method of irrigation, and quality of the greywater must be considered. Reuse of greywater for rural or suburban households in Hawaii may prove to be feasible due to the number of failing cesspools, the larger land area available for irrigation, and the rising cost of water. It could even be used in a residential house in a sewered community. At the present time, however, the cost of this system outweighs the benefits or savings achieved. In view of the increasing shortage of water though, a greywater reuse system may be an attractive alternative in the near future and should be investigated further.

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GREYWATER REUSE

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Technical Memorandum Report No. 73

January 1983

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ABSTRACT

Household wastewater can be divided into "blackwater" (toilet wastewater) and "greywater" (non-toilet wastewater). Recently, schemes have been proposed for the segregation of the two streams with subsequent treatment and reuse of the greywater fraction, thereby resulting in a reduction in the amount of water used and wastewater produced, recycling of nutrients, and replenishment of the groundwater.

Greywater, while making up about 60 to 65% of the wastewater flow, is weaker in pollutant concentration than blackwater. Greywater contributes much of the BOD , about half of the suspended solids, little nitrogen, and most of the phosphorus to the total wastewater flow. It also contains low levels of indicator bacteria and so must be handled and treated properly before being reused.

Strategies for segregation and management of the blackwater and greywater streams are outlined. Greywater treatment schemes that include anaerobic and aerobic treatment, disinfection or filtration have been proposed and studied by a few investigators; however, substantial data are still lacking.

Household greywater reuse systems have been built and found to be simple, reliable, and aesthetically acceptable. A typical system would consist of a settling/storage tank with disinfection, followed by a filter, and a pump and pressurized tank for distribution to the toilets or for lawn irrigation. Savings of 30 to 40% of the total water flow can be achieved. When reused for irrigation, a number of factors including the type of soil, topography, climate, selection of plants, method of irrigation, and quality of the greywater must be considered.

Reuse of greywater for rural or suburban households in Hawai'i may prove to be feasible due to the number of failing cesspools, the larger land area available for irrigation, and the rising cost of water. It could even be used in a residential house in a sewered community. At the present time, however, the cost of this system outweighs the benefits or savings achieved. In view of the increasing shortage of water though, a greywater reuse system may be an attractive alternative in the near future and should be investigated further.

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INTRODUCTION

Wastewater from a residential dwelling can be divided into two streams: "Blackwater," which is the wastewater from toilets; and "greywater," which is all the wastewater generated within the house, excluding blackwater. Thus, greywater includes wastewater flow from showers and bathtubs, clothes washers, kitchen and bathroom sinks, and other fixtures in a house other than the toilet.

In the majority of wastewater disposal systems in use today, no distinction is made between greywater and blackwater. Instead, they are usually combined and treated as a whole. In the past 10 to 15 years, however, the mixing of greywater with blackwater has been questioned, and systems have been proposed for the segregation of the two wastewater streams with subsequent reuse of the greywater fraction for irrigation or toilet flushing after adequate greywater treatment. Furthermore, with the recent development of nonwater carriage toilets which eliminate the need for a treatment and disposal system for blackwater, the problem of handling the remaining greywater requires study. Thus, interest in the separate treatment and disposal or reuse of greywater has developed.

This method of handling wastewater by segregating greywater from blackwater with reuse of the former has been especially considered in small communities or rural areas where on-site wastewater treatment and disposal alternatives would be more feasible than a centralized sewered treatment system. Segregation and reuse would reduce the volume of wastewater requiring extensive handling, and therefore would be one of the on-site alternatives to be considered for these types of communities.

RATIONALE FOR SEGREGATION

Five major reasons for looking into greywater segregation and reuse include the following.

1. Reduction in the amount of water use. In many homes a significant portion of the drinking water is wasted to flush toilets. Reuse of greywater for toilet flushing will reduce the per capita demand on potable water supplies which in some areas may be already limited

or in a critical situation. Greywater reused for irrigation will also help in conserving water intended for drinking use.

2. Reduction in the amount of wastewater produced. Reusing greywater will reduce the volume of wastewater requiring extensive treatment that is produced in a home. This may aid on-site treatment systems, such as a soil-absorption system, that are presently overloaded or, if not built yet, may result in a smaller system being required.
3. Recycling of nutrients. Reuse of greywater for irrigation will provide nutrients in the greywater for plant growth, and thus require less fertilizer.
4. Replenishing of groundwater. Greywater use for irrigation will eventually seep down to the groundwater and replenish underground water supplies. Because this process is a natural purification, no energy consumption is required.
5. Energy costs. The energy costs required for treating water for potable use and for pumping to residential areas continues to increase. Although resulting in energy savings, the savings in cost due to a decrease in water usage when utilizing a reuse system will have to be compared to the cost of a greywater segregation and treatment system in order to be a feasible alternative to a homeowner. In an area with high costs for water and sewage treatment, this type of system may be attractive.

GREYWATER CHARACTERIZATION

Before a greywater treatment scheme can be developed, greywater must first be characterized in terms of its quality and quantiity. The characteristics of residential greywater have been found to vary depending on a number of factors, such as housing location, standard of living, life-style, and living habits of the occupants.

Volume

The volume of water used in a household will vary depending on the situation. For example, the water usage per capita is generally correlated

with an increase in standard of living because of the use of water-consuming modern appliances. Furthermore, homeowners with on-site treatment and disposal systems usually use less water than those whose homes are connected to public sewerage systems. The volume of water that is used will also depend on the amount that one has to pay for the water. Like the volume of water used in a household, the proportions of wastewater flows from different household uses also vary greatly (Winneberger 1974a).

Bailey et al. (1969) estimated that the water usage per capita varied from 0.076 to 0.379 m^3 (20-100 gal) per capita per day when lawn sprinkling was excluded. They also reported the breakdown of water usage in a household to be 45% for toilet flushing, 30% for bathing, 6% for the kitchen, 5% for drinking, 4% for laundry, 3% for cleaning, 3% for sprinkling, 1% for car washing, and 3% for miscellaneous purposes.

Bailey and Wallman (1971) estimated that in the daily activity of an average house of two adults and two children, the typical breakdown for water use is as shown in Figure 1. This chart was constructed from the results of various investigators studying water use. Thus, from the studies, approximately 40% of the total water use is used for toilet flushing. The major source of the greywater flow is from bathing and the laundry (combined flow of 45%).

Data from more recent studies on wastewater flow for different home

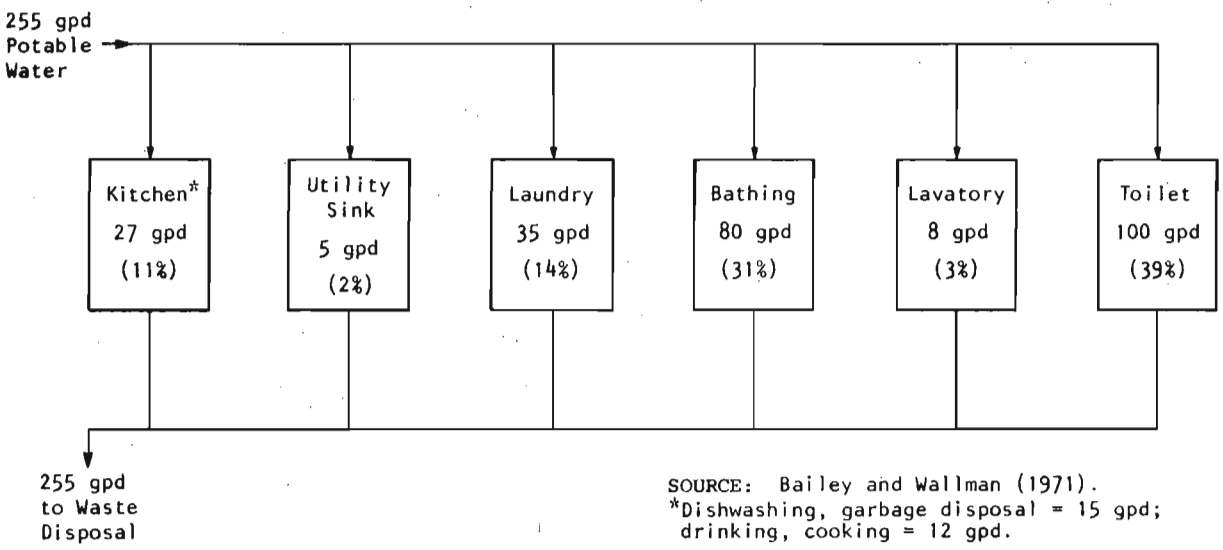


Figure 1. Average household water requirements for a family of two adults and two children

TABLE 1. STUDY COMPARISON OF DAILY HOUSEHOLD WATER USE

Event	SOURCE OF STUDY				
	Laak (1974)	Wallman and Cohen (1974)	Ligman, Hutzler, and Boyle (1974)	Bennett and Linstedt (1975)	Univ. of Wisconsin (1978)
	(gal/capita/day)				
Toilet	19.8	17.2	20.0	14.7	9.2
Bath/shower	8.5	6.3	12.5	8.7	10.9
Bathroom Lavatory	2.1	---	----	5.0	----
Kitchen sink	3.6	18.0	----	2.6	----
Dishwashing	---	----	3.5	1.1	4.9
Garbage disposal	---	----	1.5	0.8	---
Laundry	7.4	10.5	10.0	11.6	10.5
Water softening	---	----	----	----	2.6
Miscellaneous	---	----	----	----	5.4
TOTAL	41.4	52.0	47.5	44.5	42.6

SOURCE: University of Wisconsin (1978).

uses are shown in Table 1. The water usage per capita per day for the studies were in reasonable agreement (about 0.151-0.189 m^3 [40-50 gal]/capita/day). The percentage of the total water used for the toilet varied but makes up about 30 to 40% of the total water used as noted earlier. Thus, about 60 to 70% of the total water use results in greywater. This amounts to about 0.114 to 0.132 m^3 (30-35 gal)/capita/day of greywater.

Quality

Like the volume, characterization of the quality of the greywater also yields varying results. The physical, chemical, and microbiological characteristics of the greywater will be affected by the different household and bathing liquids and cleaning agents used and therefore will vary between families.

Siegrist (1977) summarized the results of studies by other investigators on the characteristics of greywater and blackwater (Table 2). It should be kept in mind that the contribution of household grinders has been omitted in these results. As shown in the table, greywater contributes

TABLE 2. BLACK AND GREY HOUSEHOLD WASTEWATER CHARACTERISTICS

POLLUTANT	GREYWATER				BLACKWATER			
	Mean (%)	Range (%)	Mean (g/c/d)	Mean*	Mean (%)	Range (%)	Mean*	Mean (mg/ℓ)
BOD	63	51-80	28.5	255	37	20-49	16.7	280
Suspended Solids	39	23-64	17.2	155	61	36-77	27.0	450
Nitrogen	18	1-33	1.9	17	82	67-99	8.7	145
Phosphorus	70	58-86	2.8	25	30	14-42	1.2	20
Flow	65	53-81	29.4		30	19-47	15.9	

SOURCE: Siegrist (1977).
NOTE: Based on the results of studies by:
1. Olsson, Karlgren, and Tullander (1968)
2. Cohen and Wallman (1974)
3. Ligman, Hutzler, and Boyle (1974)
4. Bennett and Lindstedt (1975)
5. Siegrist, Witt, and Boyle (1976).

Excluding garbage disposal contributions.
*In gal/capita/day.

over half of the flow (65%), much of the BOD_5 (63%) and the phosphorus (70%); whereas blackwater contributes most of the suspended solids (61%), the majority of the nitrogen (82%), and a little less than half of the BOD_5 (37%). Overall, greywater is weaker in strength than blackwater.

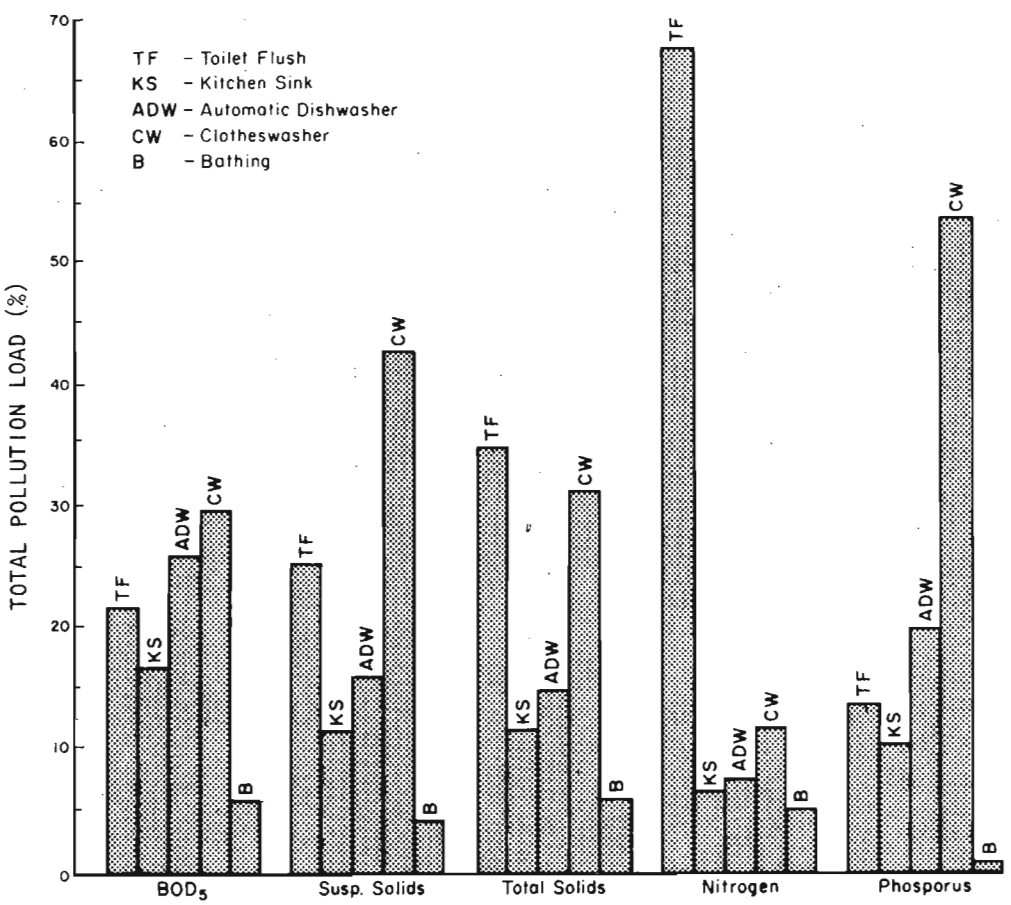
The University of Wisconsin Small Scale Waste Management Study (1978) published a good literature review on studies conducted of the quality of greywater in terms of concentration and pollutant loads. The study's investigators determined the contribution of blackwater and greywater from various uses in a household (Table 3, Fig. 2), excluding garbage disposal contributions. Blackwater contributes less than half of the BOD_5 and suspended solids, most of the nitrogen, and little phosphorus. Greywater contributes more than half of the BOD_5 and suspended solids, little nitrogen, and most of the phosphorus, mainly from the laundry. A small greywater pollutant load is contributed from the bath flow as compared to that from dishwashing and clothes washing greywaters.

If garbage disposal wastes were included in the data, a substantial quantity of pollutants would be contributed by this source. For example, the Wisconsin study grouped the major watewater activities into three fractions: (1) garbage disposal, (2) toilet wastes, and (3) sink basin and appliance wastewaters; and summarized the data for the contribution of key pollutants as reported by other investigators (Table 4). The inclusion of

TABLE 3. MEAN PER CAPITA POLLUTANT CONTRIBUTIONS

PARAMETER	IN-HOUSE SOURCE			
	Toilet Flushing	Dish-washing	Laun-dry	Bath-ing
	--------(% of Daily Total)--------			
Organic matter, BOD_5	21.7	42.3	29.8	6.2
Total suspended solids	35.7	26.7	31.2	6.4
Total nitrogen	68.1	15.0	11.9	5.0
Total phosphorus	13.8	31.2	54.1	1

SOURCE: University of Wisconsin (1978).
NOTE: Excludes garbage disposal results.



SOURCE: University of Wisconsin (1978).

Figure 2. Mean per capita daily contributions, percent of total daily

TABLE 4. AVERAGE POLLUTANT CONTRIBUTIONS OF MAJOR RESIDENTIAL WASTEWATER FRACTIONS

Fraction	Garbage Disposal	Toilet	Basins Sinks, Appliances	Approx. Total Contrib.
	(gal/capita/day)			
BOD_5	18.0*	16.7	28.5	63.2
	10.9-30.9†	6.9-23.6	24.5-38.8	
	(1, 2, 3)‡	(1, 2, 3, 4, 6)	(1, 2, 3, 4, 6)	
Suspended Solids	26.5	27.0	17.2	70.7
	15.8-43.6	12.5-36.5	10.8-22.6	
	(1, 2, 3)	(1, 2, 3, 4)	(1, 2, 3, 4)	
Nitrogen	0.6	8.7	1.9	11.2
	0.2-0.9	4.1-16.8	1.1-2.0	
	(1, 2, 3)	(1, 2, 3, 4)	(1, 2, 4)	
Phosphorus	0.1	1.2	2.8	4.0
	0.1-0.1	0.6-1.6	2.2-3.4	
	(1, 2)	(1, 3, 4)	(1, 3, 4)	
Approx. Flow (gal/capita/day)	2	16	29	47
	(1,2,3)	(1,2,3,4,5,6)	(1,2,3,4,5,6)	

*Mean of study average values.
†Range of study average values
‡Sources used in mean and range calculations:
1. Siegrist, Witt, and Boyle (1976)
2. Bennett and Lindstedt (1975)
3. Ligman, Hutzler, and Boyle (1974)
4. Olsson, Karlgren, and Tullander (1968)
5. Cohen and Wallman (1974)
6. Laak (1974).

garbage disposal wastes contributes a large load of BOD_5 and suspended solids although very little flow is added. This fact is even more evident when reviewing the increase in various pollutant loads due to garbage disposals as summarized in the Wisconsin study (Table 5). The use of a garbage disposal can increase the BOD_5 and suspended solids loading in household wastewater by 22 to 64% and 43 to 94%, respectively, while adding only little to flow, nitrogen, and phosphorus.

This result is similar to that reported by others (Hypes 1974; Ligman, Hutzler, and Boyle 1974; Watson, Farrell, and Anderson 1967). Watson, Farrell, and Anderson (1967) also stated that the load of grease is increased 35% as a result of using a garbage disposal. Since a garbage disposal can contribute substantial quantities of pollutants, some investigators eliminate garbage disposals from any segregation scheme (Milne 1979;

TABLE 5. INCREASE IN POLLUTANT MASS DUE TO GARBAGE DISPOSALS

Pollutant	Ligman, Hutzler and Boyle (1974)	Bennett and Lindstedt (1975)	Wisconsin Study (1978)
	(gal/capita/day)		
BOD_5	30.9 (64%)	12.3 (35%)	10.9 (22%)
Suspended solids	43.6 (94%)	20.2 (43%)	15.8 (45%)
Nitrogen	0.9 (5%)	0.2 (3%)	0.6 (10%)
Phosphorus	--- ----	0.1 (3%)	0.1 (3%)

SOURCE: University of Wisconsin (1978).

Siegrist 1977) because, aside from the increased pollutant loads, grease can clog pipes, filters, and other equipment when it cools and hardens, and thus present the greatest problems to recycling systems. Separate handling and disposal of the garbage as solid wastes or directly connecting the kitchen sink to the blackwater system will allow simplified treatment and reuse of greywater. Hypes (1974), in comparing greywater with and without the contribution of garbage disposal, gives a detailed analysis of the physical and chemical (including metals) characteristics of greywater (Tables 6, 7).

The microbiological characteristics of blackwater and greywater are also of interest. Although little research has been done on the bacterial levels in raw individual household wastewater, the levels in septic tank effluents (McCoy and Ziebell 1975) and also in bath and laundry greywaters (Siegrist 1977) have been examined (Tables 8, 9). Septic tank effluent is probably a worst case example of the microbiological characteristics of wastewater from a typical household. The indicator bacteria are found in high levels in the septic tank effluent as opposed to the greywater. Fecal contamination of the greywater was determined to be possible despite these lower levels which could in turn be indicative of pathogenic contamination. Besides enteric organisms, nonenteric organisms could be discharged into the greywater from bathing or from sputum of an individual with an infection. In fact, *Pseudomonas aeroginosa*, pathogen found in the septic tank effluent, also occurred but in very low incidence in the greywater. Thus, although the potential pathogenic contamination of greywater is less than blackwater

TABLE 6. CHEMICAL/PHYSICAL CHARACTERISTICS OF GREYWATER WITH GARBAGE DISPOSAL SOLIDS

CHARACTERISTIC	GREYWATER			
	Tap Water	Low	High	Avg.
	(mg/ℓ)			
METALS				
Arsenic	<0.01	<0.01	<0.01	<0.01
Barium	<1	<1	<1	<1
Cadmium	<0.01	<0.01	<0.01	<0.01
Chromium	<0.05	<0.05	<0.05	<0.05
Copper	0.08	0.14	0.20	0.17
Iron	0.18	0.19	0.64	0.46
Lead	<0.01	0.02	0.04	0.03
Magnesium	----	----	----	----
Manganese	<0.05	<0.05	<0.05	<0.05
Nickel	<0.05	<0.05	<0.05	<0.05
Selenium	<0.01	<0.01	<0.01	<0.01
Silver	<0.05	<0.05	<0.05	<0.05
Sodium	8	71	78	75
Zinc	0.39	0.35	0.53	0.45
IRONS				
Ammonia	0.06	0.05	1.50	0.49
Calcium	24	14	17	15
Chloride	19	25	45	33
Cyanide	<0.02	<0.02	<0.02	<0.02
Fluoride	0.75	0.73	1.00	0.87
Nitrate/Nitrite	0.2	<0.01	<0.01	<0.01
Phosphates	1	7	9	8
Sulfate	40	96	110	103
ORGANICS				
BOD	NA*	210	650	480
CCE	<10	13	63	42
COD	12	176	836	582
MPAS	<1	1	9	4
TOC	<5	77	360	169
PHYSICAL				
Color, $PtCl_6$ equiv. units	<5	>100	>100	>100
Conductivity, μ/mhos/cm	207	340	460	417
Odor, Threshold no.	1	2	4	3
pH	7.2	6.9	8.5	7.8
Susp. Solids, mg/ℓ	<10	72	183	115
Total Solids, mg/ℓ	108	435	654	559
Turbidity, mg/ℓ (SiO_2 equiv.)	1	60	150	114

SOURCE: Hypes (1974).
*NA = not applicable.

TABLE 7. CHEMICAL/PHYSICAL CHARACTERISTICS OF GREYWATER WITHOUT GARBAGE DISPOSAL SOLIDS

CHARACTERISTIC	Tap Water	GREYWATER Low	High	Avg.
	(mg/ℓ)			
METALS				
Arsenic	<0.01	<0.01	<0.01	<0.01
Barium	<1	<1	<1	<1
Cadmium	<0.01	<0.01	0.03	0.01
Chromium	<0.05	<0.05	<0.05	<0.05
Copper	0.08	0.08	0.16	0.11
Iron	0.18	<0.05	0.20	0.11
Lead	<0.01	<0.01	0.10	0.04
Magnesium	2.4	1.5	2.8	2.0
Manganese	<0.05	<0.05	<0.05	<0.05
Nickel	<0.05	<0.05	<0.05	<0.05
Selenium	<0.01	<0.01	<0.01	<0.01
Silver	<0.05	<0.05	<0.05	<0.05
Sodium	8	68	93	80
Zinc	0.39	0.37	1.60	0.62
IRONS				
Ammonia	0.06	<0.05	0.80	0.18
Calcium	24	15	17	16
Chloride	19	20	30	25
Cyanide	0.02	0.02	0.02	<0.02
Fluoride	0.75	0.70	0.95	0.81
Nitrate/Nitrite	0.2	<0.1	2.1	0.9
Phosphates	1	50	68	59
Sulfate	40	83	160	117
ORGANICS				
BOD	NA*	270	360	328
CCE	<10	11	41	20
COD	12	283	549	452
MBAS	<1	16	39	22
TOC	<5	60	92	80
PHYSICAL				
Color, $PtCL_6$ equiv. units	<5	30	>100	68
Conductivity, μ/mhos/cm	207	320	390	358
Odor, Threshold no.	1	2	4	3
pH	7.2	6.9	7.5	7.2
Susp. Solids, (mg/ℓ)	<10	17	68	33
Total Solids, (mg/ℓ)	108	113	451	382
Turbidity, mg/ℓ (SiO_2 equiv.)	1	30	68	49

SOURCE: Hypes (1974).
*NA = not applicable.

TABLE 8. BACTERIOLOGICAL CHARACTER OF HOUSEHOLD SEPTIC TANK EFFLUENT

Organism	Data Points	Mean*	95% Confidence Interval*
		(No./100 mℓ)	
Fecal Streptococcus	97	3,800	2,000-7,200
Fecal Coliform	94	420,000	290,000-620,000
Total Coliform	91	3,400,000	2,600,000-4,400,000
Pseudomonas aeroginosa	33	8,600	3,800-19,000
Total Bacteria	88	34×10^7	$25 \times 10^7 - 48 \times 10^7$

SOURCE: McCoy and Ziebell (1975).
NOTE: Samples from septic tank effluents at 5 residences.
*Log-normalized data.

TABLE 9. BACTERIOLOGICAL CHARACTERISTICS OF BATH AND LAUNDRY WASTEWATERS

Event	Organism	Samples	Mean*	Confidence Interval* 95%	99%
			(No./100 mℓ)		
Laundry†	Total Coliform	41	215	65-700	45-1020
	Fecal Coliform	41	107	39-295	28-405
	Fecal Streptococcus	41	77	27-220	19-305
Bathing	Total Coliform	32	1810	710-4600	530-6160
	Fecal Coliform	32	1210	450-3240	330-4410
	Fecal Streptococcus	32	326	100-1050	70-1510

SOURCE: Siegrist (1977).
NOTE: Results from in-house event sampling at each of 6 residences.
*Log-normalized data
†Samples obtained from the middle of wash cycle. Samples taken from 15 rinse cycles were consistently lower than corresponding wash cycle values.

or combined wastewater, greywater is by no means uncontaminated, and proper handling and treatment will be required prior to its reuse.

In summary, greywater makes up a little over half of the total wastewater flow from a house, at the same time contributing little more than half of the BOD_5 (63-75%), about half of the suspended solids (39-64%), a small part of the nitrogen (18-32%), and the majority of the phosphorus (70-86%) to the pollutant load in the combined greywater and blackwater flow. Its bacterial levels are also sufficient to indicate a potential for fecal contamination and thus pathogenic contamination of the laundry and bath wastewaters.

Laak (1980) gave concentration values of various constituents in greywater to be used for the design of treatment systems (Table 10). These values were based on total excrement per capita and mean maximum monthly wastewater flows.

WASTEWATER SEGREGATION SCHEMES

Segregation schemes suggested have been numerous and varied. Strategies for greywater management for a household are shown in Figure 3.

Although not part of the reuse scheme, greywater disposal in a soil absorption field must be mentioned. Since greywater makes up about 65% of the total wastewater flow, an absorption field for greywater disposal could be reduced in size as compared to that for combined sewage (Siegrist 1978). In fact, several states allow soil absorption fields to be sized at two-thirds or even one-half the size that is typically required. This seems reasonable because of the lower hydraulic loading and reduction in quantity and concentration of certain pollutants. Winneberger (1974b) provided good information on the disposal of greywater using fields, trenches, and pits.

Greywater can also be treated and disposed into surface waters. However, this will require adequate treatment including filtration, disinfec-

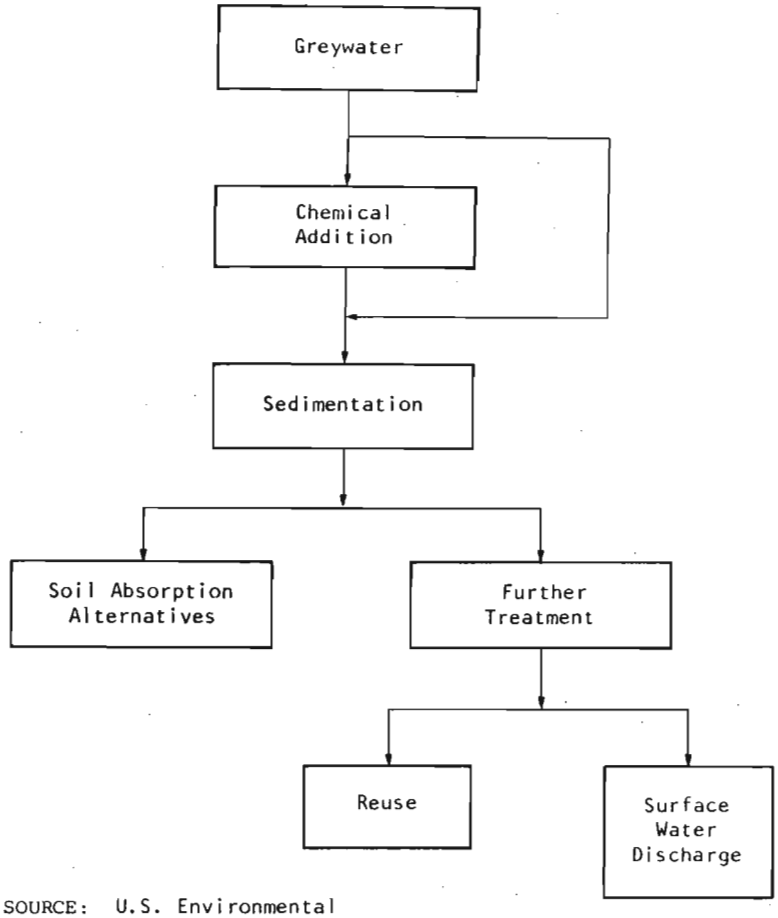
TABLE 10. GREYWATER DESIGN VALUES

Parameter	Design Value
Suspended Solids	250 mg/ℓ
BOD_5	200 mg/ℓ
PO_4	50 mg/ℓ
TN	15 mg/ℓ
Temperature	50°C
Total Coliform	25×10^3/100 mℓ

SOURCE: Laak (1980).

NOTE: Design flow for leaching field = 0.15 × 1.5 × 0.60 = 0.13 m^3/capita/day; Design flow = annual mean flow × 1.5 (peaking factor for mean max. monthly flow) × 60%.

NOTE: Design flow for tank = max. day flow × 60% = 0.5 × 0.60 = 0.3 m^3/capita/day.



SOURCE: U.S. Environmental Protection Agency (1980).

Figure 3. Strategies for management of residential greywater

tion, and possibly nutrient removal depending on applicable regulations. The treatment system must reliably produce an effluent of high quality.

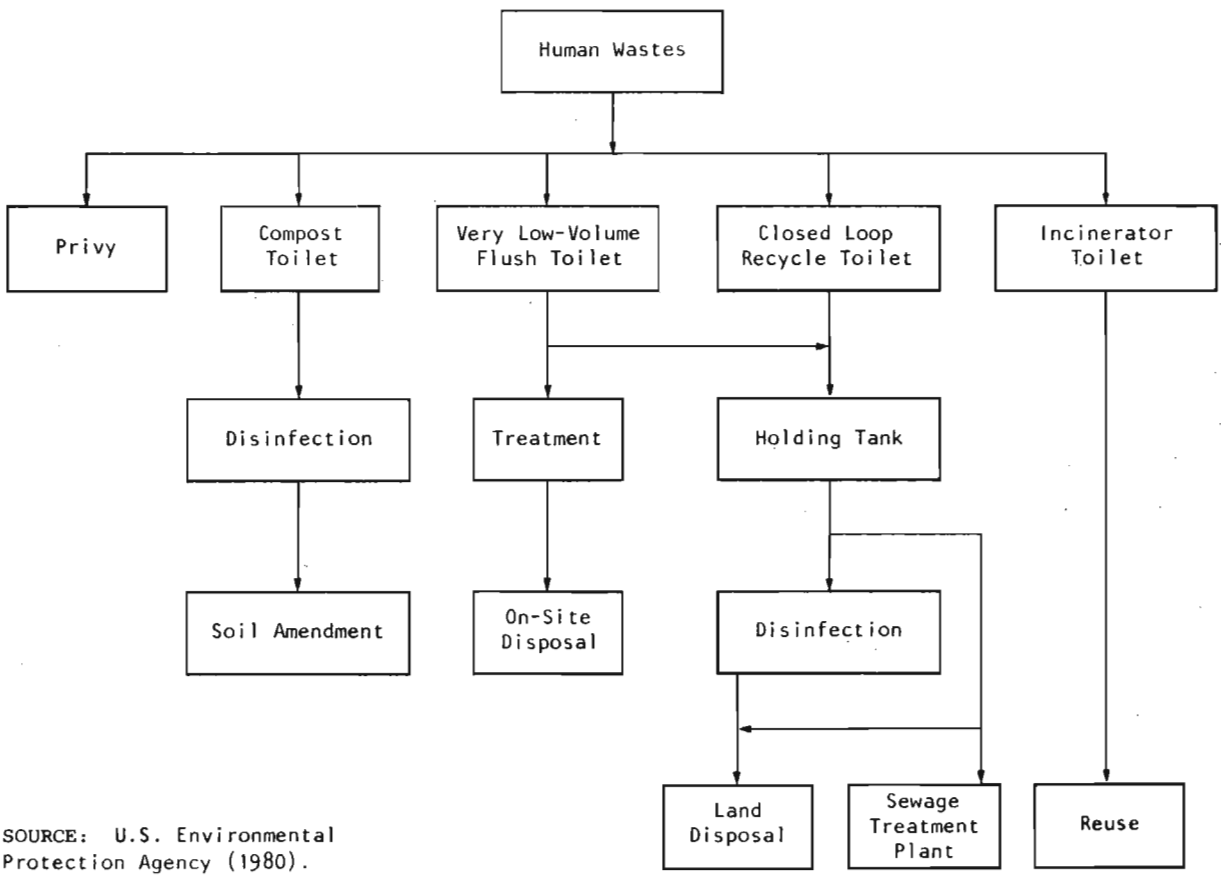
The major emphasis of this report, however, is on the treatment and recycling of greywater for use in flushing toilets and for irrigation. Most investigators propose recycling greywater from the laundry and bath since greywater from the kitchen with a garbage grinder would result in problems with grease and high loads of pollutants as mentioned previously. Also, the volume of greywater from laundry and baths is usually more than the amount that is used for toilet flushing (see section on Volume, p. 2).

The degree of greywater treatment (Fig. 3) required will depend on the proposed reuse. For example, more treatment will be necessary if the greywater is applied in irrigation by spraying or even surface flooding. This may require sedimentation along with filtration and disinfection to reduce

the public health hazard of disease transmission. The same type of treatment will be necessary for use within the home for toilet flushing. However, if greywater is to be used for irrigation in subsurface distribution, disinfection may not be required because there would be no direct exposure to the greywater and passage through soil may purify the water, thereby reducing any hazard from pathogens.

To segregate greywater, dual piping systems (one for greywater and one for blackwater) will have to be installed in a house. With a dual piping system, the potential hazard of cross-connections or misuse of the water can be minimized by approved plumbing systems, proper plumbing codes, and education of the homeowners utilizing a greywater recycling system.

With the separate collection and treatment of greywater, another problem is management of the blackwater stream. Strategies for blackwater management for a household are shown in Figure 4.



SOURCE: U.S. Environmental Protection Agency (1980).

Figure 4. Strategies for management of segregated human wastes

The use of a nonwater carriage toilet, such as a compost or incinerator toilet has received increased attention and is usually considered in conjunction with greywater reuse schemes. If a water carriage toilet is used (conventional or low flush), the blackwater would still have to be collected, treated, and disposed of separately. Thus, two separate systems would be required. The cost of separate systems for handling greywater and for handling blackwater would have to be weighed against the benefits derived from greywater reuse. For example, with greywater reuse, the volume of water and pollutant load to be treated is reduced. In addition to conserving water, this might serve to also extend the life of an existing disposal system, such as a soil absorption field or cesspool.

Although much of the emphasis has been on rural homes that are in nonsewered areas, greywater reuse such as for toilet flushing could also be practiced in areas that have a sewer system. In this case, the blackwater would be transported and treated at a sewage treatment plant as opposed to an on-site treatment system.

GREYWATER TREATMENT

Although greywater contains pollutants and must be managed properly, it may be easier to manage than the total household wastewater flow due to the reduced flow volume and pollutant concentrations. However, not very much research has been conducted on greywater treatment systems. Some of the proposed treatment schemes include anaerobic treatment (septic tank), aerobic treatment, filtration, and disinfection.

Although greywater may vary in its characteristics, it is amenable to treatment. Olsson, Karlgren, and Tullander (1968) reported that when compared to blackwater BOD, greywater BOD decomposes much more readily. This may not be surprising since the BOD load of greywater is high and much more is in a soluble phase unlike toilet paper and fecal matter found in combined wastewater or blackwater. Thus, the BOD can be reduced more quickly. Laak (1974), using the ratio of COD to BOD as a measure of resistance to biodegradation, also concluded toilet wastes to be more difficult to treat.

A few studies have been conducted on the use of septic tanks in treating greywater. Brandes (1978) reported that effluent from a septic tank

treating greywater (3-day detention time) and another tank treating blackwater (10-day detention time) had similar average concentrations of total solids, suspended solids, BOD^5, TOC, and COD. Total Kjeldahl nitrogen was 14 times lower in the greywater septic tank effluent. Indicator bacterial levels in the greywater effluents were about two orders of magnitude higher than in the blackwater effluents. This was attributed to the greywater having more organic matter that had undergone little breakdown as opposed to fecal matter in blackwater, resulting in the greywater being more readily biodegradable.

The University of Wisconsin Small Scale Waste Management Project (1978) investigators also found similar results for septic tanks of the same size treating greywater (8-day detention time) and combined wastewaters (5-day detention time). However, for a detention time of 4 days (tank of half the size), the greywater effluent BOD_5 and COD values were higher. Indicator bacterial levels were also high in the greywater effluent even after a long period of operation, thereby pointing out active reproduction in the septic tanks.

The septic tank will allow for the removal of solids by sedimentation, biological decomposition of organic matter under anaerobic conditions, and sludge and scum accumulation for periodic removal. The effluent from the tank can be disposed of in a tile field or cesspool; however, if it is to be reused, further treatment including disinfection will be required because of the high bacterial levels in the effluent. Winneberger (1978b) gives a good discussion on the selection of septic tanks for greywater treatment prior to disposal and includes details about the sizing, capacity, material, design, location, and cleaning of a greywater septic tank.

Two aerobic processes that are in use in treating wastewater are the suspended-growth and fixed-growth systems. These biological treatment processes are capable of removing large amounts of BOD_5 and suspended solids, and can be used on-site. However, these units also are susceptible to upsets, require regular supervision and maintenance, and generally cost more to construct, install, and operate. Aerobic systems would appear to be most cost-effective for treating normal household wastewater for surface discharge. Field data on the aerobic treatment of greywater is lacking in the literature.

Filtration such as the use of sand filters can be part of the treat-

ment scheme. These filters are quite suited for on-site use and if designed properly can produce effluents of high quality. Minimal operation and maintenance is required. Usually, the filters would be placed after some type of pretreatment of the wastewater (at least sedimentation). There is some evidence that higher loading rates and longer filter runs can be achieved when the filters receive pretreated greywater as compared to pretreated combined wastewater. The Small Scale Waste Management Study (University of Wisconsin 1978) investigators obtained a filter-run length twice as long for filtration of greywater septic tank effluent. Furthermore, there was 140% more BOD_5 and 60% higher suspended solids removal. Intermittent sand filtration of the greywater produced completely nitrified effluents that were low in BOD_5 and suspended solids and with unchanged phosphorus content.

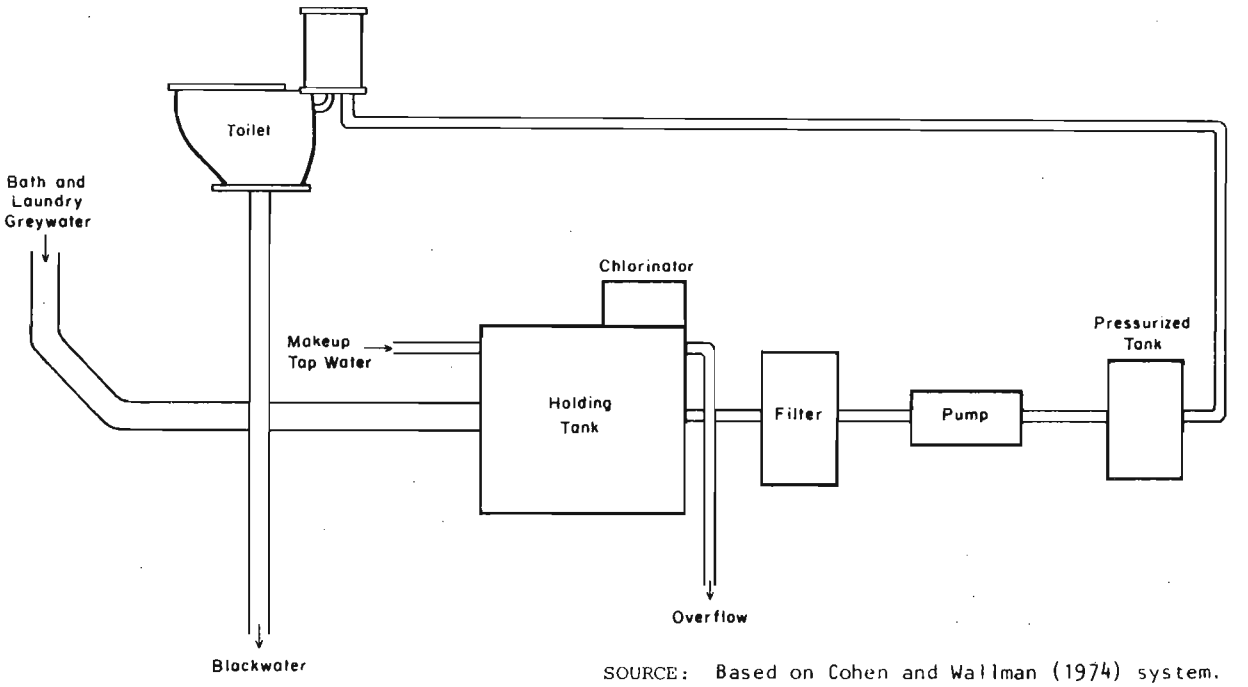
Since individuals may come in contact with recycled greywater, disinfection would be required to destroy bacteria in the water. This is espepecially so since bacteria which are indicative of possible pathogen contamination have been found to be present in greywater. Also, storage of greywater does not result in a drop in bacterial levels. Hypes (1974) showed that there was a significant increase in total and coliform bacteria in greywater after a 24-hr hold in the collection or settling tanks.

Disinfection can be applied in any of the methods used for on-site wastewater treatment. These may include injection into the greywater of liquid hypochlorite, in-line chlorine tablet dispensers, iodine saturators, ozonation, or use of ultraviolet light.

Although treatment methods for greywater have been proposed, substantial field data have not been conducted in most cases. Until further field evaluations have been performed, the U.S. EPA (1980) recommends that greywater treatment and disposal or reuse systems be designed as for typical residential wastewater.

WASTEWATER REUSE SYSTEMS

Proposed wastewater reuse systems vary considerably. However, a typical household system may consist of greywater separation, filtration, disinfection, and storage (Fig. 5). Most recycle systems that are presently available generally utilize the principle of recycling greywater (without



SOURCE: Based on Cohen and Wallman (1974) system.

Figure 5. Typical household greywater reuse system

contribution from the kitchen sink) for reuse in toilet flushing and outside irrigation. A few experimental systems have been constructed and are in operation.

Siegrist, Woltanski, and Waldorf (1978) described a typical home system as consisting of a 0.379 to 0.946 m^3 (100-250 gal) storage/settling tank which collects bath and laundry water through conventional plumbing. The settled greywater then passes through a pressure filter (paper cartridge, diatomaceous earth, or sand) and is disinfected (chlorine or iodine) and stored in a pressure tank which supplies water for toilet flushing and outside irrigation. Any excess bath or laundry greywater would overflow into the sewer lines, and tap water can also be supplied if there is not enough greywater. A commercial system is available at a capital cost of $2500 plus shipping. Operating costs are about $45 per year, and quarterly operation and maintenance include replacement of disinfectant and filter media, cleaning of storage reservoir and residual disposal, and maintenance of any mechanical equipment including pumps. A flow reduction of 35% of the total flow along with a limited removal of certain pollutants in filtration and disinfection is achieved.

In another study, Cohen and Wallman (1974) in the early 1970s installed

two systems in three houses which recycled bath and laundry greywater for toilet flushing and lawn irrigation. One system included storage with liquid "Chlorox" disinfection followed by cartridge filtration, a pump and pressurized tank, and reuse. The other system was similar except for the use of a different filtration (diatomaceous earth) and disinfection (chlorine tablets) method. Storage tanks of 0.379 to 0.568 m^3 (100-150 gal) were used. The capital costs of the systems were about $500 to $600 with a $21 to $45 yearly operating cost. These systems were found to be simple, reliable, safe to operate, and aesthetically acceptable by the user. Maintenance at 1- to 3-mo intervals required cartridge and disinfectant replacement. A 26% decrease in water consumption was attained. Cohen and Wallman concluded that this system would result in cost savings in areas with high water and sewer user rates. These systems are also definitely warranted in households having septic systems that have poor drainage.

A system developed by McLaughlin (1975) in 1967 was basically the same as the Cohen and Wallman system although disinfection was not included. The operation and performance results of this system were also similar. McLaughlin concluded that a disinfecting agent should have been included in the system due to bacterial growth and odor production in the storage tank.

Hypes, Batten, and Wilkens (1975) experimented with a system to treat bath and laundry greywater for reuse in toilet flushing. This consisted of filtration through a diatomaceous earth cake filter followed by activated charcoal adsorption for further improvement. Furthermore, heating the water to 145°F for 30 min along with chlorination was determined to be adequate for public health safety. A makeup tap water and overflow was also supplied to the collection tank. The amount of energy required to operate the system was reported to be relatively low. Hypes (1979) later described a bath and laundry wastewater reuse system that was installed at the NASA Technology Utilization House and appeared to be feasible after a period of operation and study. It included a 0.416 m^3 (110 gal) polyethylene collection tank, a diatomaceous earth particle filter, a shallow well jet pump and pressure tank, and a chlorinator.

Other greywater treatment and reuse systems have been documented. Systems utilizing filtration, storage or holding tanks, and/or disinfection for eventual greywater reuse have been described by Toms (1980), McCormick, G.L. (1979), McCormick, D.J. (1979), Olson (1975), and Hall, Batten, and

Household systems that treat the combined domestic wastewater with reuse of the effluent have also been developed. A system involving reuse of a portion of the total household wastewater flow for toilet flushing was developed by Waldorf (1977) in the Boyd County Demonstration Project. This system consisted of an aerobic treatment unit and a settling tank for the treatment of the total household flow. Part of the effluent from the tank was then disinfected using an iodinator and a contact chamber, filtered through activated charcoal, and then stored in a pressure tank for reuse. An acceptably clear, odorless water low in BOD_5 and suspended solids with zero fecal coliform was produced.

Other investigators such as Farrell (1974) have described aerobic treatment processes with partial reuse. Shoupp (1978) developed for a laboratory study a closed recycled-water sanitary waste disposal system utilizing an aerated biodegradation tank. Purecycle has also developed a recycling module consisting of a rotating disc reactor and filters, a demineralizer, and a disinfector for purifying and recycling domestic wastewater as reported in The American City and County (1977, vol. 92, no. 9, p. 50).

A comprehensive report by Milne (1979) gives an excellent description of experimental reuse/recycle systems that have been developed and studied along with proprietary and home-built systems. Design proposals of systems that have not been built or tested are also included in the report.

In any proposed system, public acceptance of the system must be considered. Most of the objections to greywater reuse would be to the potential health hazards of reused water, the aesthetics of recycled water, the odors, the staining and depositions on toilets and other appliances and the problems resulting from residuals disposal and maintenance of the system. However, the majority of these objections would not be raised if proper treatment schemes are used, such as chlorination to remove bacteria and odors and sedimentation, and filtration to remove particulates and turbidity. The public may object just to the idea of reusing wastewater. However, in a survey described by Bailey and Wallman (1971), 82% of homeowners and 86% of architect/engineers gave favorable responses or acceptance to the practice of reusing wash waters for either toilet flushing or lawn irrigation.

GREYWATER REUSE

Irrigation

If treated greywater is to be used for lawn irrigation, a number of important factors which must be considered include: type of soil, topography, selection of plants, method of irrigation, climatic influences, and the water quality. The report by Milne (1979) gives a good discussion on the major aspects of using greywater for irrigation.

The main methods of irrigation of treated greywater for a household include furrows and basins, sprinklers or sprayers, drip irrigation, or subsurface irrigation. Of the methods, the first three may require some form of disinfection to minimize transmission of pathogens from contact with the greywater or its aerosols, as well as reducing odor problems and attracting animals and insects.

The furrow and basin method is relatively simple, however, furrows would have to be dug and they should be properly constructed to prevent overflow or surface runoff.

The method of using sprinklers and sprayers would be more efficient in evenly applying the greywater over a lawn area. This would be the method most homeowners would probably use. Use of a sprinkler or sprayer, however, would require the use of a pump in the system to get a high enough pressure for distribution. Also because of possible bacterial aerosol contamination, the greywater definitely should be disinfected.

Drip irrigation consists of pipes or hoses that carry the water to the site to be irrigated. Holes or nozzle-like fittings called emitters are spaced along the distribution laterals, permitting discharge of the water along the distribution line. This method provides efficient use of the water and can be used on uneven terrain. Furthermore, less pressure is needed (34 475-96 530 Pa or 5-14 psi) in this method than for spray irrigation. The drawbacks of drip irrigation include the higher initial investment (installation and materials) and the problem of clogging from particulate matter found in greywater if a filter is not used in the greywater treatment system. If the kitchen flow is also included in the greywater reuse, the presence of grease could clog the lines. Thus, as mentioned earlier, the kitchen flow should not be included with the other household greywater flow. Although the potential for contact with greywater is less in this method, disinfection may be recommended to prevent the growth of

slime and subsequent clogging in the lines.

Subsurface irrigation can take the form of gravel-filled trenches, evapotranspiration beds, or buried perforated pipes. More elaborate construction and layout would be required for these systems.

The character of the greywater is also important in irrigation. Potential damage to plants can result from excessive amounts of certain constituents in greywater, such as chlorine, sodium, and boron.

Although disinfection with chlorine is suggested, it can have a detrimental effect on plants if in excessive concentration (Aryes, Branson, and Madison 1977). However, Milne (1979) stated that if the chlorine concentration does not exceed 10 mg/l, the presence of chlorine will be beneficial. In addition to the disinfecting action, it will prevent septic conditions in storage and holding tanks, thus minimizing the need to use the greywater right away or the need to require constant emptying or flushing of the tank.

Sodium can be detrimental to plants at high concentrations and can also have an adverse effect on the soil. Sodium reacts with soil, preventing it from clumping together into crumbs. The soil then becomes impervious preventing good percolation of water through the soil. This, however, can be counteracted by the addition of gypsum to the soil as reported in "An Antidote for Greywater" in Sunset (1977, vol. 158, no. 6, p. 219).

Boron can also be toxic to some plants in concentrations found in laundry greywater (Aryes, Branson, and Madison 1977). Fruit and citrus trees are more sensitive to boron as opposed to grasses which are quite tolerant (U.S. EPA 1981). Products such as boron or boraxo contain the highest amount of boron and should be avoided.

Many different cleaners and agents may contain toxic chemicals or compounds that may be detrimental to plants. It is recommended that products of such nature be used sparingly and, if used, adequate dilution must be provided before reuse for irrigation. A pamphlet by Javits (1978) contains useful information on practices to be followed by a homeowner utilizing greywater for garden irrigation.

Because of the nitrogen found in greywater, nitrogen-fixing plants or legumes would be suitable for irrigation with greywater. Phosphorus which is required for the energy or metabolic processes of these plants will also be supplied by the greywater. However, the nitrogen to phosphorus ratio in

greywater is relatively low, and so these plants might have to be provided with a supplemental nitrogen source.*

Furthermore, because of the alkaline nature of greywater, calciphytes (plants that grow at a pH greater than 7) should be selected for greywater irrigation as opposed to acidophytes (plants that grow at a pH less than 7) such as rhododendrons, azaleas, and citrus fruits* (Milne 1979).

The presence of salt in the greywater might affect the plants, therefore plants that are relatively salt tolerant would be preferred (Milne 1979). Generally, grasses are most salt-tolerant and so irrigation of lawns would be the first choice for greywater irrigation. It is recommended that greywater be used on ornamental rather than food-producing plants and it should not be sprayed or come into direct contact with edible portions of plants due to the potential hazard of pathogen contamination.

Although the selection of plants is important when using a greywater irrigation system, research on this topic is very scarce. Much more investigation is needed on the use and effect of greywater on plants in order to determine the types of plants which would be most suitable for greywater irrigation.

Reuse of greywater for irrigation will not only conserve water, but also will recycle the nutrients such as phosphorus and nitrogen found in greywater for plant growth. In addition, groundwater recharge can occur if greywater is applied over a large area. Reuse for irrigation should be favored in areas where water is in short supply.

Toilet Use

The functions of toilet water are to rinse the bowl, remove the wastes, and carry the waste from the house to the site where it is to be treated. Greywater can serve this same purpose in place of potable water. Reuse of greywater for toilet flushing would result in a substantial savings in the amount of water used, more so than in irrigation. A conventional water carriage toilet will use 0.015 to 0.023 m^3 (4-6 gal) of water per flush and is flushed 4 to 6 times a day per family member. Thus a reduction of water usage by 0.061 to 0.136 m^3 (16-36 gal) of water per person per day can be achieved (Bailey and Wallman 1971). The amount saved could range anywhere

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*L.L. Handley 1983: personal communication.

from 30 to 40% of the total water flow as was pointed out earlier. Any objections to this use of greywater would be due to odors, deposition or staining in the toilet and piping, and turbidity and color of the greywater. Proper treatment of the greywater, however, would solve most of these problems. Also, a pump would have to be used in the system to get the greywater to the toilet unless the baths and greywater treatment system are above the level of the toilet.

GREYWATER REUSE IN HAWAI'I

For communities and households that are not served by a sewered wastewater system, alternatives for on-site wastewater treatment, including segregation of blackwater and greywater with reuse of the greywater, should be considered.

In Hawai'i, there are a number of municipal as well as privately-owned treatment facilities serving the population. However, many families still rely on on-site systems, mainly cesspools. Table 11 lists the number of cesspools in the various counties in Hawai'i and the population using cesspools as reported by the Hawaii State Department of Health (1980) in the 208 Water Quality Management Plan. Even for the City and County of Honolulu where there are extensive sewer systems, a substantial number of families still use cesspools. Furthermore, many cesspools do not work properly (Table 11), requiring constant pumping. Thus, some of the existing on-site treatment systems pose a constant problem as well as cost to the homeowner.

Reuse of greywater for suburban homes in Hawai'i may prove to be feasible. With the reduction in wastewater flow from the household as a result of reuse, the lifespan of the existing cesspool could be prolonged. Areas with marginal soils that might be prone to cesspool failure may also be acceptable for this type of reuse system because of the lower hydraulic loading. However, adequate field testing and investigation would have to be undertaken to confirm this. The increasing shortage of water as well as rising costs of water are also factors that would favor this type of system. However, the cost of a reuse system and the fact that more energy is required would have to be weighed against the benefits to be gained from utilizing a greywater reuse system.

Greywater reuse might also be considered in residential homes that are

TABLE 11. CESSPOOL DATA, STATE OF HAWAI'I, 1980

County	Est. Population Using Cesspools	Approximate Wastewater Flow (gal/day)	Number of Cesspools	Number of Defective Cesspools	Percent Defective
Hawai'i	74,000	7,470,000	23,988	50	1
Honolulu	70,170	7,017,000	20,638	8,133	39.4
Maui	22,800	2,280,000	7,244	576	8
Kaua'i	28,550	2,855,000	14,275	327* 1,190†	2* 8†
Total	195,520	19,622,000	66,145	9,086* 9,949†	50.4* 56.4†

SOURCE: Compiled from county reports (Dept. of Health 1980).
*Suspected to be low in view of amount of chemicals sold to treat defective cesspools.
†Based on amount of chemicals sold to treat defective cesspools; others based on data obtained from private cesspool pumping companies.

already served by sewers. An important factor for use of a greywater system for these homes would be the reduction in the amount of water used by the household and the savings to be realized from using less water. However, for these homes reuse for irrigation may not be as practical as in a rural home because of the limited space and lot sizes and, consequently, smaller lawns or planted areas that can be irrigated. Thus, greywater would be more likely reused for toilet flushing. As far as the cost savings to be realized, Bailey and Wallman (1971) reported that when comparing the economics (water and waste costs) of water reuse schemes to that of normal water use, the only scheme coming close to the cost for a conventional home would be reuse of wash waters for toilet flushing. However, since it was still slightly higher in cost than the municipal system they concluded that, at the time, waste treatment and reuse in a household did not appear practical. The technology for greywater reuse systems exists, and such systems may become feasible as the availability of drinking water becomes more restricted and water rates continue to increase.

If used in Hawai'i, adoption of regulations as well as management of the reuse system must be considered. Building regulations and plumbing codes would have to be revised to allow greywater reuse systems to be used. For example, pipes conveying greywater would have to be identified as nonpotable and each outlet labelled to prevent any misuse of the greywater or

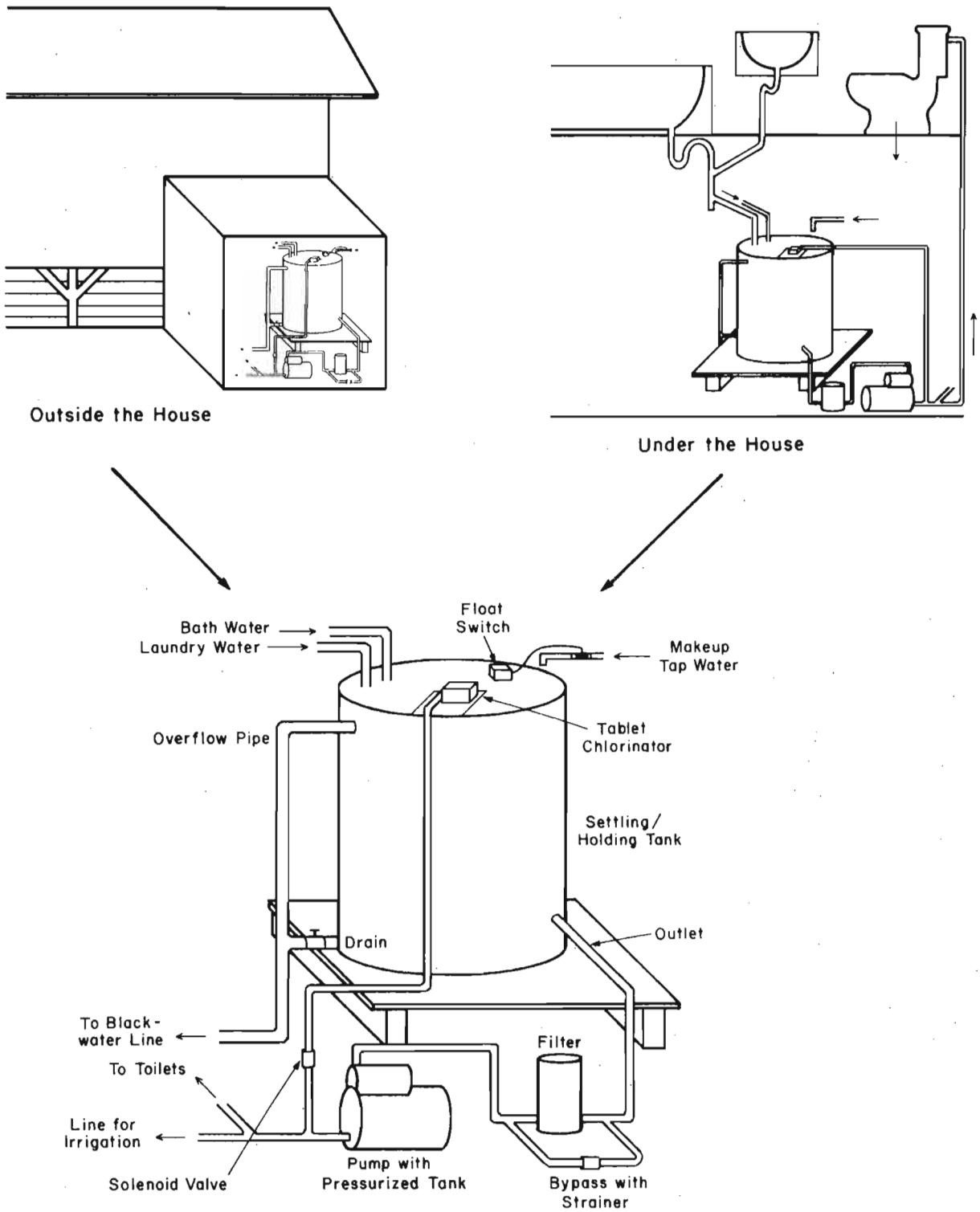
misconnections with pipes conveying potable water. Furthermore, backflow prevention devices or measures would have to be placed in lines which discharge into blackwater lines or in a system containing contaminated water. Thus, a backflow device included in the overflow line from the holding tank would prevent backflow from blackwater to the greywater supply. Similarly, a backflow device in the inlet line to the holding tank would prevent contamination of potable water with greywater. The type and sizes of pipes, the design of storage tanks, and pumps supplying adequate pressure in the system would have to be approved before being used.

The type of treatment requirements and the reuse scheme would have to be defined for local use. These would include restrictions, such as the type and degree of treatment, disinfection, storage, and method of irrigation to be used. Treatment standards may be more applicable rather than standards for specific pollutants. Also, characterization of a typical household wastewater (greywater and blackwater) in Hawai'i would have to be conducted.

A reuse system in Hawai'i could typically consist of a treatment train including a settling or holding tank, disinfection, filtration, and a pump with a pressurized tank for distribution. An example of this type of greywater reuse system follows for a three-bedroom rural house in Hawai'i that already utilizes a cesspool for disposal of wastewater. Laundry and bath greywater would be treated by the proposed reuse system. The kitchen wastewater contribution should not be included in the greywater reuse scheme because the heavy pollutant load and large amounts of grease but instead should be directed to the blackwater flow for disposal in the cesspool.

The treatment system should be placed at a lower level than the level of the washing machine and the bath to allow for gravity flow into the collection tank. It could be in the lower floor or basement of a two-story house, or for a house with one floor, it may be situated under or just outside of the house. It must also be located in an area with easy access to allow for periodic maintenance of the system. A schematic diagram of the treatment system and its location in the household is shown in Figure 6.

The size of the holding tank is a critical factor because the laundry and bath will provide large volumes of greywater over a short period at infrequent intervals whereas the toilet uses small volumes of water at short although fairly regular intervals. The tank size may also be an important



SOURCE: Cohen and Wallman (1974).

Figure 6. Greywater reuse system and its location in the household

factor in areas where rainfall is frequent, and in such a case, the disinfection provided will prevent septic conditions and odors (as well as reducing bacterial levels).

According to Chapter 38 of the Hawaii State Department of Health, Public Health Regulations (1979), the design flow for individual wastewater systems serving dwellings shall be based on at least 0.757 m^3 (200 gal)/bedroom/day. Thus, for a three-bedroom house, a design flow of 2.271 m^3 (600 gal)/day must be used. Since bathing and laundry greywater contributes about 45% of the wastewater flow, about 1.02 m^3 (270 gal)/day of greywater would have to be treated by the reuse system. Most investigators have used a household system including a 0.379-0.946 m^3 (100 to 250 gal), settling tank (Siegrist, Woltanski, and Waldorf 1978; Cohen and Wallman 1974; McLaughlin 1975). If a 0.946-m^3 (250-gal) tank is used for the house in Hawai'i, an average detention time of close to one day can be expected. This would allow for sedimentation as well as cooling of the greywater before reuse. The size would be adequate to accommodate the infrequent but large greywater flows from the laundry and bath over a day's time.

Since about 30 to 40% of the total wastewater flow is used for toilet flushing and about 3% for sprinkling (varies depending on the weather and land area to be irrigated), the combined reuse for toilet flushing and irrigation would usually be less than the amount of bathing and laundry greywater produced (45% of the wastewater flow). Thus, an overflow outlet should be provided from the tank which can be directed to the blackwater stream for disposal into the cesspool. In addition to this, an inlet to the system for makeup tap water should be included in cases where the amount of reuse increases.

The reuse of greywater for irrigation would be more suited for a rural house rather than for an urban house because of the larger land area and lawn that can be irrigated. A simple system such as the use of sprayers or sprinklers to evenly distribute the water over the area can be utilized. A pump supplying 13.79 x 10^4 to 27.58 x 10^4 Pa (20-40 psi) pressure should be adequate.

The amount of greywater used for irrigation will depend on the amount of rainfall in the area where the house is situated. This is especially important in Hawai'i where a steep rainfall gradient can occur between areas separated by only a few miles. Compared to mainland areas, Hawai'i's rain-

fall is more evenly distributed throughout the year; therefore, greywater can be easily used to supplement the natural watering from rainfall. Slightly more greywater reuse for irrigation can be expected during the drier summer months. The settling or storage tank with inlet and outlet pipes should be adequate to accommodate the variations in greywater flow for irrigation.

Soil properties and depth to bedrock or groundwater table in the vicinity of the household will have to be evaluated. For example, a soil of moderate permeability is desired because too low a permeability may create runoff problems and too high a permeability will result in inadequate treatment of the greywater as it passes through the soil. Also, the topography of the area must be flat or gently sloping to prevent surface runoff and erosion.

Plant selection for a household reusing greywater for irrigation is important. Because of the year-round constant supply of greywater that is available, plants that require constant watering can be selected. In fact, it is recommended that drought-tolerant species not be mixed with high water consuming plants in plant groupings because the drought-tolerant plants may become overwatered and die. It is suggested that plant species be selected that are indigenous to climates that have more rainfall than the local climate or to climates that have fairly constant rainfall all year round (Milne 1979).

The characteristics of greywater will determine the type of plants that can be selected for irrigation with greywater. As mentioned earlier, calciphytes should be selected instead of acidophytes such as rhododendrons, azaleas, and citrus fruits because of the alkaline nature of greywater. Furthermore, because of the nutrients in greywater, nitrogen-fixing plants which also require much phosphorus would be better suited for irrigation with greywater. In Hawai'i, plants that could be irrigated with greywater include Leucaena leucocephala (haole koa), Auracaria equisetifolia (ironwood), Acacia koa (koa), Cassia, indigo, Mucuna (Mauna loa), peas, and fruits and flower crops such as bananas, ginger, heliconias, and anthuriums; orchids, however, may not be suitable because they must be stressed in order to bloom.*

Ornamental plants, trees, shrubs, and lawns would be better suited for

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*L.L. Handley 1983: personal communication.

greywater irrigation rather than food-producing plants with edible parts that come into direct contact with the greywater. Furthermore, plants that are relatively tolerant to salt, such as grasses and seashore plants, would be better suited for irrigation with greywater rather than sensitive crops, such as certain fruit crops and vegetables, most notably beans (Milne 1979). In general, grasses because of their salt tolerance and high water demand would be best suited for greywater irrigation.

Because of the limited capacity of the greywater storage tank used in a household, sprinkling with greywater should be carried out using small volumes at frequent intervals (every day or every other day) rather than a large volume at infrequent intervals (every week or every other week); otherwise, a larger more costly storage tank would be required. The amount and frequency of irrigation with greywater will also depend on the amount of rainfall, the waterholding capacity of the soil, and the water demand of the plants. Any detrimental effects of the greywater on the plants will also limit the amount of greywater irrigation. Investigations on the frequency and amount of greywater for optimal irrigation have not been reported. Thus, it is recommended that the amount and frequency of watering be determined by plant observation and actual demand rather than by a predetermined schedule.

The cost of the reuse system which consists of a settling tank, filter, disinfection, and a pump and pressure tank will range anywhere from $500 to $3000 for the installed system and $25 to $45 per year for operation and maintenance as reported by various investigators (Otis and Boyle 1980). Using the capital cost figure of $2500 with operating costs of about $45 per year for a commercial system reported by Siegrist (1978) and assuming it to be for 1978, the cost for a system in Hawai'i in 1982 would be about $4470 for the installed system and about $80 a year for operation and maintenance (the cost figures were updated using the Engineering News-Record construction cost indexes and also allowing for a 30% markup for Hawai'i). When amortized over a 20-yr period at a 7% interest rate, the cost for this reuse system would be about $500 per year.

This cost has to be compared to the amount saved due to the decrease in water use when utilizing this system. With a flow reduction of about 35% of the total water flow to the household, a decrease of approximately 0.795 m^3

(210 gal) in water use per day for the household can be realized (or 289.93 m^3 [76,600 gal]/yr). The Honolulu Board of Water Supply user rates in 1982 for residential houses on the island of O'ahu was \$0.84/3.785 m^3 (1000 gal). Thus, there would be a savings of \$64 per year due to the decrease in water use.

It appears that this type of commercial system if installed today is not feasible. In fact, the yearly savings would not even totally offset the yearly operation and maintenance cost alone. However, the amount saved was based on a constant water user rate of \$0.84/3.785 m^3 over the 20-yr period, and user charges for drinking water are continually rising. For example, the Engineering News-Record index allows for a 37% increase in the cost of the system when updating from 1978 to 1982. However, the increase in user rate for drinking water on O'ahu from 1978 (\$0.45/3.785 m^3) to 1982 (\$0.84/3.785 m^3) was much more rapid—about a 87% increase). Furthermore, although a \$2500 (installed commercial system) estimate was used in this example, the actual cost may range anywhere from \$500 to \$3000. With more research and development in greywater reuse systems, systems in a lower cost range may be readily available in the future.

A greywater reuse system will not only result in a decrease in the amount of drinking water used and conservation of our limited water supply, but it will also contribute to groundwater recharge and recycling of nutrients to plants. Furthermore, because of the reduced wastewater flow, the life of the cesspool may be increased. Cost incentives, such as a decrease in water-user rate or a tax credit (like that for solar energy systems) could also be instituted for people installing greywater reuse systems.

Greywater reuse systems could also be considered for a residential house in a sewered community. In this case, reuse for irrigation may be limited. However, because toilet water flow is much more than the flow for lawn spraying, greywater reuse would still result in a considerable decrease in the amount of water used by the household. Savings from the decrease in the amount of drinking water used as well as from a lower sewer charge (since sewer charge is based on the amount of water used) can be realized.

With the critical situation that Hawai'i is beginning to face with regards to the limited amount of drinking water available from our water sources, alternative methods such as desalinization and recycling are being considered. A greywater reuse system may be an attractive alternative in

the near future and should be studied further.

SUMMARY

Greywater can be a valuable resource. Although it generally has a lower pollutant concentration and bacterial levels than that of blackwater, it still can pose a potential health hazard and nuisance and therefore must be handled and managed properly. Before reusing greywater, it should be treated to prevent problems of clogging, odors, and transmission of disease. A simple treatment train could consist of sedimentation, disinfection, filtration, followed by a pump and pressurized tank for distribution. With this type of treatment, greywater could be safely used for irrigation and toilet flushing. The feasibility of this system will have to be determined by the balance between the cost of the system and the benefits or savings achieved when reusing greywater. It may be favorable in areas with limited water and high water and sewer user fees.

REFERENCES

Aryes, R.S.; Branson, R.L.; and Madison, J.H. 1977. Using household waste water on plants. Leaflet 2968, Division of Agricultural Sciences, University of California.

Bailey, J.R.; Benoit, R.J.; Dodson, J.L.; Robb, J.M.; and Wallman, H. 1969. A study of flow reduction and treatment of wastewater from households. USDI, FWQA, Rep. No. 11050 FKE.

Bailey, J., and Wallman, H. 1971. Flow Reduction of Waste Water From Households. Water and Sewage Works 118:68-70.

Bennet, E.R., and Lindstedt. 1975. Individual home wastewater characterization and treatment. Completion Rep. Ser. No. 66, Environmental Resources Center, Colorado State University, Fort Collins, Colorado.

Brandes, M. 1978. Characteristics of effluents from gray and black water septic tanks. J. Water Pollut. Control Fed. 50:2547-59.

Cohen, S., and Wallman, H. 1974. Demonstration of waste flow reduction from households. EPA-670/2-74-071, Cincinnati, Ohio.

Department of Health. 1979. Private wastewater treatment works and individual wastewater systems. Public Health Regulations, Chapter 38, Department of Health, State of Hawaii, Honolulu.

_____. 1980. Water quality management plan for the state of Hawaii. Department of Health, State of Hawaii, Honolulu.

Farrell, R.P., Jr. 1974. "Aerobic wastewater treatment process with partial reuse and infrequent dosing to soil," Official Gazette of the United States Patent Office 927(3):1141.

Hall, J.B., Jr.; Batten, C.E.; and Wilkens, J.R. 1974. Domestic wash water reclamation for reuse as commode water supply using a filtration-reverse osmosis separation technique. Rep. No. NASA TND-7600, Langley Research Center, Hampton, Virginia.

Hypes, W.D. 1974. Characterization of typical household grey water. In Manual of Grey Water Treatment Practice, ed. J.H.T. Winneberger. Ann Arbor: Ann Arbor Science.

_____. 1979. Laboratory and family live-in experiences with domestic greywater reuse systems. In Individual Onsite Wastewater Systems, Proceedings of the Fifth National Conference, 1978, ed. N.I. McClelland. Ann Arbor: Ann Arbor Science.

_____; Batten, C.E.; and Wilkens, H.R. 1975. Processing of combined domestic bath and laundry waste waters for reuse as commode flushing water, Report No. NASA TND-7937, Langley Research Center, Hampton, Virginia.

Javits, T. 1978. Greywater use in the home garden. Farallones Institute (Integral Urban House), Berkeley, California.

Laak, R. 1974. Relative pollution strengths of undiluted waste materials discharged in households and the dilution waters used for each. In Manual of Grey Water Treatment Practice, ed. J.H.T. Winneberger. Ann Arbor: Ann Arbor Science.

_____. 1980. Wastewater engineering design for unsewered areas. Ann Arbor: Ann Arbor Science.

Ligman, K.; Hutzler, N.; and Boyle, W.C. 1974. "Household wastewater characterization. J. Environ. Eng. Div., Am Soc. Civ. Eng. 100(EE1):201-13, Proc. Paper 10372.

McCormick, G.L. 1979. Water reuse system. Official Gazette of the United States Patent Office 984(4):936.

McCormick, D.J. 1979. Water recycle unit—Grey water clearifier. Official Gazette of the United States Patent Office 978(3):982.

McCoy, E., and Ziebell, W.A. 1975. Effects of Effluents on Groundwater: Bacteriological Aspects. In Proc. National Sanitation Foundation Conference on Individual Onsite Wastewater Systems, Ann Arbor, Michigan.

McLaughlin, E.R. 1975. A recycle system for conservation of water in residences. In Proc. Conference on Water Conservation and Sewage Flow Reduction with Water-Saving Devices, Pennsylvania State University, University Park.

Milne, M. 1979. Residential water reuse. Rep. No. 46, California Water Resources Center, University of California/Davis, California.

Olson, W.O. 1975. Method and apparatus for conserving water. Official Gazette of the United States Patent Office 939(4):2091.

Olsson, E.; Karlgren, L.; and Tullander, V. 1968. Household waste water. Rep. 24, The National Swedish Institute for Building Research, Stockholm, Sweden.

Otis, R.J., and Boyle, W.C. 1980. On-site alternatives. In Wastewater Alternatives for Small Communities, Proc., Seminar Presented to EPA Regional Coordinators and State Small Community Systems Coordinators, August 1978, S.W. Hathaway, ed., EPA-600/9-80-062, Cincinnati, Ohio.

Shoupp, W.J. 1978. "A recycled-water sanitary waste disposal system." Ph.D. dissertation, NTIS publication PB-291 740.

Siegrist, R. 1977. Waste segregation as a means of enhancing onsite wastewater management. J. Environ. Health 40:5-9.

_____. 1978. Waste segregation to facilitate onsite wastewater disposal alternatives. In Home Sewage Treatment, Proc. 2nd National Home Sewage Treatment Symposium, 12, 13 Dec. 1977, Am. Soc. Agric. Eng., ASAE Publication 5-77, St. Joseph, Michigan.

_____; Witt, M.; and Boyle, W.C. 1976. Characteristics of rural household wastewater. J. Environ. Eng. Div., Am. Soc. Civ. Eng. 102(EE3):533-48, Proc. Paper 12200.

_____; Woltanski, T.; and Waldorf, L.E. 1978. Water conservation and wastewater disposal. In Home Sewage Treatment, Proc. 2nd National Home Sewage Treatment Symposium, 12, 13, Dec. 1977, Am. Soc. Agric. Eng., ASAE Publication 5-77, St. Joseph, Michigan.

Toms, E.P. 1980. Water recycling with solids and foam removal. Official Gazette of the United States Patent Office 993(3):754.

U.S. Environmental Protection Agency. 1980. Design manual—Onsite wastewater treatment and disposal systems. EPA 625/1-80-012, Cincinnati, Ohio.

_____. 1981. Process design manual for land treatment of municipal wastewater. EPA 625/1-81-013, Cincinnati, Ohio.

University of Wisconsin. 1978. Management of small waste flows. Small Scale Waste Management Project, EPA 600/2-78-173, Cincinnati, Ohio.

Waldorf, L.E. 1977. Boyd county demonstration project". Proc. National Conference on Less Costly Wastewater Treatment Systems for Small Communities, U.S. EPA, Reston, Virginia.

Watson, K.S.; Farrell, R.P.; and Anderson, J.S. 1967. Contribution from the individual home to the sewer system. J. Water Pollut. Control Fed. 39: 2039-54.

Winneberger, J.H.T. 1974a. Separation of water-borne wastes. In Manual of Grey Water Treatment Practice, ed. J.H.T. Winneberger. Ann Arbor: Ann Arbor Science.

_____. 1974b. Manual of grey water treatment practice. Ann Arbor: Ann Arbor Science.

ANNOTATED REFERENCES

The American City and County. 1977 Make pure water out of waste. Am. City Cty. 92(9):50, September.

Purecycle, a computer-controlled module to recycle household wastewater, is described. The system does not require water and sewer hookups and is composed of two 440-gal tanks and the processing system. The average treatment capacity of the system is 440 gpd with peak loading capacities of 800-1000 gpd. The processing system includes a biological reactor which uses disc rotation and combination of aerobic and anaerobic digestion to oxidize organics. A pressurized filtration stage removes bacteria, viruses, and suspended particulates. Color, odors, and organic contaminants are removed by a carbon absorption bed. Demineralization removes heavy metals and inorganic salts. Ultraviolet radiation is used to sterilize the recycled water. Processing is continously monitored by a microcomputer. Purecycle of Boulder, Colorado, provides a service center to periodically remove solid organics and provide the initial 500 gal of water to start up the system. At current costs the break-even point is 200 purecycle units per service center. Use of the system is suggested for areas with limited natural water supplies.

wastewater; household biological waste treatment; microcomputer monitoring (Purecycle); UV radiation

Bailey, J.R.; Benoit, R.J.; Dodson, J.L.; Robb, J.M.; and Wallman, H. 1969. A study of flow reduction and treatment of wastewater from households. Water Pollut. Control Res. Ser. 11050 FKE 12/69, Federal Water Quality Administration, U.S. Department of the Interior, 154 p., 18 figures, 14 tables, 108 references.

This study identifies practical means of waste-flow reduction for American households. Commercially available devices for water saving are described and literature on advanced water and waste treatment is reviewed. A consumer survey was conducted and showed that water used in household functions such as bathing and toilet flushing can be sub-

stantially reduced by the use of more efficient appliances and plumbing devices.

water saving; devices; household; wastewater; flow reduction

Bailey, J.R., and Wallman, H. 1971. Flow reduction of wastewater from households. Water Sewage Works 118(3):68-70, March, 4 figures, 3 tables, 8 references.

Water saving devices such as the dual-flush toilet tank system and the vacuum toilet system are currently available. These systems are reported to provide, at no overall cost penalty to the homeowner, a water saving (and waste-flow reduction) of 30-50%. A limited survey indicates that the use of such water-saving devices would be readily accepted by homeowners.

water saving; low-flush toilets; vacuum toilets; flow reduction; public acceptance; devices

Brandes, M. 1978. Characteristics of effluents from gray and black water septic tanks. J. Water Pollut. Control Fed. 50(11)2547-59, 30 references. CODEN; JWPFA5.

The chemical and bacteriological characteristics of septic tank effluents from two separate tanks used by one house (which used phosphorus-free detergents) for greywater and black (toilet) wastewater treatment were studied for nine months. The concentrations of total phosphorus and total Kjeldahl nitrogen in the greywater septic tank effluent were 1.4 and 11.3 mg/l respectively, which is 10 times lower than in the toilet wastewater septic tank effluent.

wastewater, wastewater analysis, sewage tanks, settling tanks, water pollution; septic tanks, wastewater treatment, biological waste treatment

Cohen, S., and Wallman, H. Demonstration of waste flow reduction from households. Rep. No. EPA-670/2-74-071, U.S. Environmental Protection Agency, September, 102 p., 28 figures, 29 tables, 12 references, 1 appendix.

A two-year demonstration program was conducted to evaluate water savings, costs, performance, and acceptability of various water-saving devices. Reduced-flow toilets and flow-limiting shower heads were installd in eight single-family dwellings. In three of the homes, bath and laundry water were filtered, disinfected, and reused for toilet flushing and (or) lawn sprinkling. The experimental portion of the program ran from May 1971 to May 1973. Water requirements for toilet flushing were substantially reduced in an economically attractive and aesthetically acceptable manner. Shallow-trap and dual-flush toilets resulted in average decreases in toilet-water usage of 25% and 23%, respectively. Flow restricting shower heads proved to be relatively ineffective; however, this result may have been due to use patterns unique to this study. Wash-water recycle systems provided satisfactory operation throughout the test period. The average savings for toilet-flushing reuse ranged be between 23% and 26% of total water usage. The incorporation of lawn sprinkling as a supplemental reuse further re-

duced waste flow from homes by 16-18%. For single-family dwellings, recycle systems could affect marginal cost savings in high-water and sewer-use rate areas. They are definitely warrented when septic systems with poor drainage (due to soil or topography) are encountered.

domestic; sewage treatment; water savings; filtration; disinfection; cost analysis; plumbing; reuse; flow rate; toilet performance

Farrell, R.P., Jr. 1974. Aerobic wastewater treatment process with partial reuse and infrequent dosing to soil. Official Gazette U.S. Patent Off. 927(3):1141, October 15.

A waste disposal system is disclosed which is particularly for dwellings having limited drain fields or drain fields or drain field soils having limited capacity. The effluent is removed from an aerobic treatment and settling tank for ultimate return (at least in part) as flushing fluid for toilets, etc. The sludge is removed from the treatment treatment and settling tank for further treatment and settling so that liquid may be removed from the sludge for return ultimately to the treatment and settling tank. The effluent used for flushing purposes is run into a storage tank and may be chemically treated by a treatment solution eductor and stored in the surge tank supplying the toilets until it is used. Wastewater from toilets and other sources is deposited in a small holding tank until a predetermined level has been reached, at which time a grinder-pump will remove the waste from the holding tank and discharge it into the aerobic treatment and settling tank, the liquid removed from the sludge is returned to this holding tank. Various pressure and level sensing controls are used in conjunction with a coordinating and timing control unit to control the sequence of operations for efficiency. Excess effluent is discharged to a drain field in infrequent slug doses in a known manner to enhance performance of any drain field of a given capacity.

wastewater; settling tanks; wastewater treatment

Hall, J.B., Jr.; Batten, C.E.; and Wilkins, J.R. 1974. Domestic wash water reclamation for reuse as commode water supply using a filtration-reverse osmosis separation technique. NASA TN D-7600, Langley Research Center, April.

An evaluation of a combined filtration-reverse osmosis water recovery system was conducted to determine its capacity to reclaim domestic wash water for reuse as a commode water supply. The water produced by this system met all chemical and physical requirements established by the U.S. Public Health Service for drinking water with the exception of carbon chloroform extractables methylene blue active substances, and phenols. This water is considered to be of a quality able to be reused as commode supply water. The filters used to protect the reverse-osmosis unit from plugging were not capable of removing particles less than one micrometer in size from the wastewater. The process rate of the reverse osmosis unit was degraded approximately 46.9% for 713 gallons of filtered wash water processed. Averages of 0.00907 kilowatt-hour per gallon were needed to process the wash water through the filtration unit, respectively. Treatment of the processed water with 5 ppm chlorine was sufficient to reduce the microorganisms in the commode tank to zero. However, efficient mixing of chlorine was necessary in

order to rapidly inhibit microorganisms in the processed water tank. The viability of a combined filtration and reverse osmosis technique for the reclamation of domestic wash water is established by the evaluation. The reverse osmosis module, if sufficiently protected from plugging by a filter capable of removing solid materials less than one micrometer in size, is a good low energy method for removing contaminants from domestic wash water.

filtration; reverse osmosis; domestic; wash water

Hypes, W.D.; Batten, C.E.; and Wilkens, J.R. 1975. Processing of combined domestic bath and laundry waste waters for reuse as commode flushing water. Rep. No. NASA TND-7937, NASA Langley Research Center, Hampton, October, 66 p., 9 figures, 18 tables, 4 references.

An experimental investigation of processes and system configurations for reclaiming combined bath and laundry wastewaters (greywater) for reuse as commode flush water has been conducted. Filtration by single pass (no control of pressure and flow rate), 90-min recycle, and 120-min recycle flows, through a diatomaceous earth cake filter, has been investigated as a means for improving physical/chemical characteristics of the greywater. A 90-min recycle flow is reported to be effective in removing particulates down to 1 m in maximum dimension and in improving other physical characteristics to the extent that the filtered water is subjectively acceptable for reuse. A further improvement in physical and selected chemical characteristics of the treated water can be obtained by activated charcoal adsorption following the 90-min recycle flow that has resulted in noticeable reductions in color, turbidity, and sudsing. Heating of the wastewaters to temperatures of 135°F and 145°F for periods of 15, 30, and 45 min, and chlorination at available chlorine concentrations of 1, 15, 20, and 25 mg/l to reduce/eliminate coliform organism counts have been investigated. A temperature of 145°F for 30 min and chlorine concentrations of 20 mg/l in the collection tank followed by 10 mg/l in the storage tank are determined to be adequate for public health safety. The volume of bath and laundry waters available from a typical American family of four is found to be greater than the volume of water required for commode flushing when the water-conserving shallow-trap commode is used. Losses due to collection-tank overflow and tank drainage to remove accumulated particulates will reduce the volume of wastewater available and could possibly result in the need for a small volume of makeup tap water. The amount of energy required to operate this typical reusing system is reported to be relatively low. A system using diatomaceous earth filtration and chlorine sterilization to process the waters for reuse requires an average of 0.695 kW/gal/day.

Ligman, K.; Hutzler, N.; and Boyle, W.C. 1974. Household wastewater characterization. J. Environ. Eng. Div., Am. Soc. Civ. Eng. 100(EE1): 210-13, Pap. 10372, 46 references; CODEN JEEGAV.

To effectively study alternatives to the treatment and disposal of wastewaters from individual homes, a study was conducted to evaluate the qualitative and quantitative characteristics of wastes generated by both rural and urban households. A survey of a number of holds, in concert with the analysis of current information available in the literature, provided data to establish guidelines characterizing individ-

ual wastewater events within the home. A simulated wastewater was subsequently developed for further research on treatment and disposal alternatives.

sewage analysis; sewage treatment; waste disposal; wastewater; domestic wastes

McCormick, D.J. 1979. Water recycle unit—Grey water clearifier. Official Gazette of the United States Patent Off. 978(3):982, January 16.

The primary object of this invention permits water to be recycled indefinitely for certain operations, such as washing, so that the overall, total use of water in households, and in certain industries can be substantially reduced. A water recycle unit for producing clear water output from greywater input comprises a container which has sufficient capacity to provide the time required for the greywater input to go through all of the physical changes needed to provide a clear water output. These physical changes include the settling of heavy materials, such as sand and dirt, to a lower zone and the rising of lighter clear water between the lower and upper zones within the container. The container includes outlet openings located in a side wall of the container at a level which is normally above the upper side of the zone of clear water within the container. A gate within the interior of the container includes a closed passageway for removing clear water from the central zone through the outlet in response to the inflow of additional greywater. A clear water collecting and filter box is built alongside of and integrally with the container.

McCormick, G.L. 1979. Water reuse system. Official Gazette of the United States Patent Off. 984(4):936, July 24.

A used water reuse system includes a greywater holding tank to which greywater is supplied up to a maximum level through a filter and greywater drain line. Greywater sources, such as kitchen and bathroom sinks, clothes and dishwashers, tubs, and showers, have drains connected through valves to the greywater drain line and to a conventional sewer line. Greywater is transferred, upon demand, from the greywater holding tank to noncritical water-use devices, such as a toilet tank, for reuse and subsequent discarding. A sensor detects achievement of a maximum level in the greywater holding tank and causes the valves at the greywater sources to disconnect the latter from the greywater drain line, so as to discard any further greywater from the sources to the sewer line, and also closes a fail-safe valve to preclude flow from the greywater line to the greywater holding tank. Upon reduction of the tank water level, the sensor reopens the valves. A further sensor notes draining of the tank to a preselected minimum level for admitting fresh water.

Milne, M. 1979. Residential water reuse. Tech. Completion Rep. No. 46, California Water Resources Center, Davis, September.

Greywater, rainwater, groundwater, and surface water are sources of "free" water already available to every homeowner on-site. This book explains the various ways to collect, store, treat, and distribute this water, and gives examples of how it has been successfully reused for toilet flushing, landscape irrigation, washing, bathing, or drinking.

For many of these functions water can be reused directly without treatment. The argument in favor of water reuse is given along with a brief history of residential water reuse, how rainwater and groundwater can be developed as an on-site supply, the uses of greywater for garden irrigation, various residential-scale systems that have been designed for on-site reuse, and an explanation of the components needed to build such systems. The appendix contains a directory of manufacturers, a glossary of specialized terms, units of measure, and an annoteted bibliography containing over 500 citations. The conclusion of this study is that residential on-site water reuse systems are already technically feasible and environmentally sound, and are becoming more economically attractive every day, due primarily to the rapidly increasing cost of energy required for pumping and treatment by centralized water and sewage systems. The objective of this book is to help homeowners, builders, developers, architects, planners, and lawmakers understand the design and installation of small on-site residential water reuse systems.

Olson, W.O. 1975. Method and apparatus for conserving water. Official Gazette of the United States Patent Off. 939(4):2091, October 28.

A process for conserving water in household systems is described. Wastewaters from the nonsanitary and low-dissolved solids generating components of the system are accumulated and pooled. These waters are considered "white water" and are effluents from laundry facilities, bath, shower, and wash basin. A closed loop recirculation of the accumulated wastewater is established through a filter medium comprising of activated carbon for a time sufficient to remove substantially all undissolved solids and at least a portion of the dissolved solids. The filtered and clarified water is diverted from the closed-loop recirculation and accumulated to resupply the household water system.

Olsson, E., Karlgren, L.; and Tullander, V. 1968. Household wastewater. Report 24:1968, UDC 628-31, National Swedish Institute for Building Research, Stockholm, 162 p., 36 figures, 98 tables, 58 references.

The purpose of this investigation was to obtain information about the quantity and characteristics of wastewater from residential dwellings. The study emphasized greywater (wastewater from bathrooms, kitchens, and laundry) and the results obtained were compared with the pollution in wastewater from toilets (black water). About 25 apartments in a suburb of Stockholm, Sweden, were used as the subjects of this experiment. It was established from this extensive study that the flow as well as the pollution, with respect to volume and nature, was the same from day to day without any noticeable differences between days of the week. On the other hand, the variations within the day itself are so great and so unsystematic that the analysis results from separate parts of the day did not provide any useful representative figures of the quantities of pollution. Average flow of the greywater was reported to be 121.5 l/capita-day and of black water 8.5 l/capita-day. Analysis of the composition of the greywater revealed that kitchens contributed nearly 70% of BOD, while approximately 60% of the quantities of phosphorus originated from the laundry. The quantities of nitrogen were split up in such a way that the kitchens supplied 51%, the bathroom 31%, and the laundry 18%. The amount of BOD_5 from the greywater averaged 25 g/capita-day while for black water it was 20 g/capita-day. The

ranges of coliform, bacteria densities were 1.7 x 10^8 to 83.0 x 10^8 and 3.8 x 10^8 to 62.2 x 10^8 bacteria numbers/capita-day for greywater and black water, respectively. The rates of organic decomposition of the greywater were compared with about 65% per 24 hr, which is relatively fast compared with 20% per 24 hr for black water and municipal wastewater. Furthermore, the secondary (indirect) aspect of pollution from the greywater was calculated to yield theoretically about 7.5 more BOD than the primary (direct) oxygen/demand via phosphorus synthesization into plankton cells. These results suggest that special attention must be paid to the greywater and that proper treatment of the greywater the greywater should be carried out before it is discharged into the environment.

greywater; BOD; phosphorus; nitrogen; bacteria; decomposition; Sweden

Shoupp, W.J. 1978. "A recycled-water sanitary waste disposal system." Ph.D. dissertation, NTIS publication PB-291 740, Springfield, Virginia.

A closed, recycled-water sanitary-waste-disposal system for laboratory study was developed. The system was based on a 1000-l capacity, water-filled biodegradation tank. Two specific environmental variables were studied: organic-loading rate of an artificial waste material, based on ground dog-food into the system, and aeration rates imposed on the water column. Two loading rates (2 and 3 persons/day equivalent of sanitary wastes) and two aeration rates (6 and 12 l/min) were imposed on the experimental system. Sampling of the tank was carried out on a weekly schedule by sample withdrawal from ports penetrating the tank walls. Data were collected and analyzed for the following biological and chemical parameters: total aerobic and anaerobic standard plate counts, ATP content, total carbon, inorganic carbon, organic carbon, pH, and dissolved oxygen. In addition, the predominant bacterial genera present during the stationary stages of the experimental runs were isolated and identified. Data response curves were created to follow the effects on the above parameters of the various regimes of loading and aeration during the relatively long-term (about 130 days) experimental runs.

Siegrist, R.; Witt, M.; and Boyle, W.C. 1976. Characteristics of rural household wastewater. J. Environ. Eng. Div., Am. Soc. Civ. Eng. 102 (EE3):533-48. CODEN: JEEGAV.

To effectively study and to improve methods of on-site treatment and disposal of wastewaters from individual homes, quantitative and qualitative characterization of household wastewater is necessary. To enhance the existing characterization data base, field studies were conducted at the University of Wisconsin as part of the Small Scale Waste Management Project. Water use was monitored at 11 homes for a total of 434 days. Various individual household events were studied and their usage characteristics were determined, including frequency of use, flow per use, and flow per capita per day. Daily and weekly flow patterns were also developed. Wastewater quality characterization was accomplished for the various household events by sampling at four homes for a total of 35 days. For each event and the various quality parameters, the concentration and mass of pollutants per event occurrence, and the mass of pollutants/capita/day were determined.

sewage treatment; water reclamation; water pollution; environmental engineering; sewage tanks; settling tanks; wastewater, septic tanks; sewage effluents; water quality Card Alert: 452, 453, 901

Siegrist, R. 1977. Waste segregation as a means of enhancing onsite wastewater management. J. Environ. Health 40(1):5-9, July-August.

Segregation of household wastes by use into black water (toilet wastes) and greywater (other household wastes) is suggested to enhance on-site or septic tank wastewater treatment. Chemical/physical and biological characteristics of household wastewater are described. Surveys indicated that levels of indicator bacteria (coliforms) can be very high in household septic tank effluent, and that pathogenic organisms (*Pseudomonas aeruginosa*, *Staphlococcus aureus*, and salmonellae) can be present. The characteristics of separate greywater and black water waste streams can, however, be very different. Greywater contributes most of the BOD, phosphorus, and flow to the household waste stream at 63%, 70%, and 65% of the total, respectively. Black water contributes most of the suspended solids and nitrogen at 61% and 82%. Indicator organisms and other bacteria are largely contributed by black water, but some proportion may enter the household waste stream from bath and laundry wastewater. Black-water treatment methods include non-water carriage toilets (composting, incinerating, and recycling systems) and low-volume flush toilets with provisions for off-site land disposal. Greywater disposal alternatives include the use of reduced-area soil absorption systems and sand filter systems.

Toms, E.P. 1980. Water recycling with solids and foam removal. Official Gazette of the United States Patent Off. 993(3):754, April 15.

A water economizing system for new or existing buildings is described where the waste lines of lavatory sinks, showers, and clothes washing machines are connected to a storage reservoir for the accumulation of the water. This accumulated water is filtered and treated and then used for the operation of water closets of toilets. The storage reservoir provides for the removal of solids and foam by flushing action at the top and subsequently for the gravitational separation of solids which are periodically flushed from the bottom of the reservoir into the sewer. The pumping action which delivers the accumulated water to the water closets of toilets may be hydraulically operated by a portion of the water drained to the storage reservoir.