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Performance Evaluation of Greywater Recycle Systems

by

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PERFORMANCE EVALUATION OF GREYWATER RECYCLE SYSTEMS

#1.12

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INTRODUCTION

Traditional approaches to water resource management have given little consideration to the cautious, non-wasteful use of water. As water demands and waste flows increased, new sources of supply were developed and water and wastewater facilities were expanded. For the most part, water conservation and wastewater reclamation were viewed as eccentric strategies, appropriate for only a few isolated areas or occasions. However, the need for these alternative approaches as part of an overall water resource management strategy has gained increased recognition during the past five years as concerns over U.S. water resources have grown [1-2].

A significant portion of the nation's consumptive water use and concommitant wastewater flow results from domestic activities. As of 1975, domestic uses accounted for over 40% of the water use that produced waste flow requiring subsequent treatment [3]. In residential dwellings, various in-home activities contribute to an annual per capita consumption of potable water in excess of 69,000 L [4]. Of this, over 75% results from toilet usage, bathing and clotheswashing, with over one-third due to toilet usage alone. For the average American, yearly toilet flushing results in the contamination of nearly 23,000 L of fresh potable water to transport a mere 490 L of body waste. Serious questions have been raised regarding the need for water of potable quality to perform various domestic functions. Onsite recycling of residential wastewater has been suggested as a strategy to provide water of a suitable quality for the intended use, while reducing potable water demands and wastewater loadings. Since the performance requirements of any recycle system are governed by the influent wastewater characteristics and the intended reuse activity, major emphasis in onsite home recycling has been directed toward reclamation of the greywaters (non-toilet wastes), for reuse in non-body contact functions such as toilet flushing and lawn irrigation. The purpose of this paper is to provide an evaluation of the performance of these home greywater recycle systems. This assessment is based upon a review of the literature as well as a demonstration study conducted at the University of Wisconsin.

LITERATURE SUMMARY

One of the first and most comprehensive investigations into the feasibility of household wastewater reuse was reported by Bailey et.al [5]. This study analyzed the feasibility of four different household reuse schemes: (1) reuse of all wastewater for all uses except drinking; (2) reuse of non-sanitary wastes for toilet flushing and laundering; (3)

AWWA Water Reuse II, Washington, D.C. (August, 1981)

aerobic treatment of all wastewater for lawn watering; and, (4) reuse of greywaters (bath, shower, clotheswasher), for toilet flushing. Treatment requirements were suggested for each reuse scheme based on a water quality required as a function of the intended use. Although all schemes appeared to be technically feasible, results of the study indicated that the only reuse scheme which even approached potential cost-effectiveness was the reuse of greywaters for toilet flushing. Prohibitive costs arose in the other three reuse schemes because of the treatment required prior to reuse. Bailey, et.al., projected a 39% reduction in wastewater flow from an "average" home which recycled washwater for toilet flushing.

Other investigations into the feasibility of onsite recycling have reported similar projections and have agreed with the practicality of recycling greywaters or washwaters for non-body contact functions such as toilet flushing and lawn irrigation [6-11].

Studies that actually demonstrated residential greywater reuse have been few and somewhat limited. A summary of the more comprehensive studies is given in Table 1. The studies by McLaughlin [12], and Cohen and Wallman [13], were the most complete and yielded similar results with respect to flow reduction and system performance. Based on the results of these investigations (Table 1), greywater reuse was shown to be technically feasible and a disinfection process and routine system maintenance were identified as essential for effective recycle system performance. While significant water savings and waste flow reductions were realized, home recycle systems were assessed as economically attractive only under extreme water cost or wastewater disposal conditions, and then only in reuse for non-body contact functions such as toilet flushing and lawn irrigation.

The greywater recycle systems evaluated in previous studies were generally prototypes or "owner built" systems, and much experimentation by the investigators accompanied their use. More recently, a number of proprietary systems have become available or are under various stages of development. To provide performance information about the systems, the National Sanitation Foundation (NSF), has recently adopted standards and laboratory testing procedures for commercially manufactured wastewater recycle/reuse systems [17]. Systems are tested by NSF at the manufacturer's request and must meet standards for design, construction and performance during a laboratory test. Thus far, no results from tests of greywater recycle systems have been published by NSF.

UNIVERSITY OF WISCONSIN DEMONSTRATION PROJECT

To enhance the existing data base, a field study was initiated at the University of Wisconsin in the Fall of 1978 under sponsorship of the U.S. Office of Water Research & Technology and the State of Wisconsin. The objectives of the study were to identify residential greywater recycle systems being commercially manufactured and to evaluate the systems under actual residential usage. This evaluation was to determine the magnitude of water savings and waste flow reductions achieved; delineate system installation, operation and maintenance requirements; characterize the water quality of various waste streams and the recycle water; identify the potential for long-term user acceptance; determine potential health concerns; and estimate system costs. The methods and results of this investigation have been documented elsewhere [18], and only a brief synopsis is presented herein.

Methods

At the onset, a search was made to identify commercially available home greywater recycle systems. Three systems that purified bathing and laundry washwaters for reuse in toilet flushing were initially selected for study (Table 2), but only the Aquasaver system [19], proved to be truly available. This system employed the unit processes of sedimentation, pressure cartridge filtration (20 μ), and chlorine disinfection in a small inhouse module (Fig. 1-2). Two Aquasaver units were installed in two homes and monitoring of their performance occurred over a total of 647 days. Volumetric flow data were collected automatically for interior water use, toilet water use, makeup water use and unit overflow water using specially altered water meters and flow indicating switches interfaced with occurrence counters and continuous strip-chart recorders. In addition, toilet fixture use data was also automatically monitored. Data were collected at each home over many multi-day periods and analyzed on an hourly and daily basis. System operations were monitored with separate power meters and elapsed time indicators, and maintenance requirements were delineated in a log. User acceptance was assessed through recordings in a user log and responses to a final questionnaire. Qualitative characterization was also accomplished through collection of grab and 24-hour flow composited samples with analyses for various parameters performed according to Standard Methods [20].

Results

Water Use and Wastewater Flow. The inhouse water use and waste flow characteristics measured at the two homes with the recycle systems in use are summarized in Table 3. The average daily freshwater flow was 78.0 and 126.7 Lpcd (Table 3). It should be noted that the residence with lower use also possessed conventional water saving faucets and showerheads with flow rates of 8 to 12 Lpm. Day to day variation, shown by the limits of the 95% confidence interval for daily flow expressed as a percent of the mean day, were 75 to 125% and 89 to 111%. Since toilet water use was recycled washwater, freshwater use for flushing was essentially eliminated as long as washwater production and storage met toilet flushing demands. At home NE no additional freshwater was needed for flushing, while at home VAR an average of 2.3 Lpcd was required. This was due to occasional unfavorable balances between available washwater and required flushwater, as well as to a slight difference in recycle system design requiring freshwater for chlorine feed with each use. The maximum daily freshwater flow at the two homes was 280 Lpcd and 364 Lpcd (Table 3). Hourly water use data indicated wide fluctuations with minimum flows of zero and maximum flows of 68.1 and 113.6 Lpch. Maximum day and hour flows were due almost entirely to non-toilet water use at these sites. Assessing the impacts of water-saving technologies on the water use characteristics at a given home can be a complex task. At first glance, the most direct method would appear to be a comparison of data obtained prior to installation of the water-saving technologies to post-installation data. However, this approach suffers from several potentially serious shortcomings. For new homes this comparison is impossible. At existing homes, changes in water demand and fixture usage totally unrelated to the water-saving technologies employed can yield inaccurate results. These changes in water use can be due to rapidly changing lifestyles of growing children, changing work schedules and lifestyles of adult residents, and changes in the physical characteristics of the dwelling including water-using fixtures, water supply pressure, and so forth.

For these reasons, an alternative strategy was used to evaluate the

impact of the water recycle system. The measured fixture usage data was utilized to determine the water use characteristics that would have occurred if conventional toilet systems had been used instead of the recycle systems. The results of this analysis showed that the use of the recycle systems resulted in reductions of 24 and 35 Lpcd compared to a 13.2 L toilet and 36 and 50 Lpcd compared to a 18.9 L toilet. (Table 4). These reductions represented 24 and 22%, and 31 and 28% reductions in total daily freshwater flow, respectively, and compared closely to the results of previous demonstrations of greywater recycling (Table 1). Day-to-day variations in freshwater use were not significantly altered. The maximum days were reduced by 7 to 16% while the maximum hourly flows were not changed.

Water Quality. The quality characteristics of various process streams associated with the recycle system are shown in Tables 5 and 6. Appreciable amounts of pollutants were found in the raw greywater, confirming the results reported by previous investigators [14, 15, 21]. The recycle water quality varied widely and was generally of a much lower quality than a typical freshwater toilet supply. Variations in coliform bacteria concentrations in the recycle water corresponded closely to variations in residual chlorine levels. As long as a measurable chlorine residual was present, total and fecal coliform values were <10 org./100 mL.

Only limited pollutant removals were achieved by the recycle system. At home NE, pollutant reductions ranged from 0 to 70%. The increase in total solids from raw to recycle was expected due to the addition of calcium hypochlorite in the disinfection process. Results at home VAR revealed increases in many pollutant levels. The reason for this was not clear, but day-to-day variability in the raw washwater and attenuation in the storage tank may have been responsible. At both homes, 20 μ pressure cartridge filtration afforded minimal pollutant removals, with the bulk of any renovation occurring as a result of the sedimentation and disinfection processes.

The quality of the recycled water is important for health, safety and operational considerations. Presently, no regulatory standards exist regarding recycle water quality for home toilet flushing and lawn irrigation [22]. NSF Standard 41 [17], has set recycle water quality standards for systems approved by their test laboratory, but at present no home greywater recycle system has been approved under this standard. The Aquasaver system was tested by NSF under laboratory conditions before adoption of Standard 41 and was approved under NSF Basic Criteria C-9. The recycle water quality values required by Basic Criteria C-9 and Standard 41 are listed in Table 7. Based on the results of this study, under field conditions, the Aquasaver recycle water met NSF Standard 41 limits, except BOD_5 at both homes and TSS at home VAR.

Water quality criteria for landscape irrigation have been suggested by Culp et.al [23], as shown in Table 8. Comparison of the recycle water quality data to these criteria revealed that the recycle water was of marginal quality for lawn irrigation in terms of BOD_5, dissolved and suspended solids and coliform bacteria. In addition, the occasional high chlorine residuals could cause turf bleaching and discoloration.

System Installation. Installation of the Aquasaver recycle system can be readily accomplished in a new dwelling. Additional plumbing requirements over a conventionally plumbed house include separate toilet supply lines, washwater drain lines, and recycle system vents and connections. Retrofitting such a system is very site specific, and can pose substan-

tial difficulties due to venting requirements and the need for separate toilet supply lines, especially in two-story houses with second floor bathroom facilities.

Operation and Maintenance. The only major operational problem encountered with the recycle system was in maintaining a proper chlorine residual in the recycle water. Residual chlorine values fluctuated widely (0 to 25 mg/L), due to fluctuations in raw washwater quality as well as system design, and caused infrequent odor problems at both homes. Operation at a desired constant residual chlorine level would require considerable monitoring and adjustment. Chlorine use by the system was approximately 0.20 gm/L at home NE and 0.30 gm/L at home VAR in the form of calcium hypochlorite tablets of 70% available chlorine content. Power use by the recycle system was 0.021 and 0.013 kilowatt-hours/cycle at homes NE and VAR, respectively. Scheduled maintenance was performed quarterly in a total of approximately 3 man-hours and consisted of cleaning an influent screen, washing cartridge filters, replenishing chlorine tablets and removing sludge from the washwater storage tank. Results of this study indicated that the maintenance required for the washwater recycle system may vary from home to home due to differences in water use and raw washwater quality. At home NE, quarterly maintenance as described was readily accomplished and sufficient to maintain the system. In contrast, at home VAR, the influent screen and cartridge filters clogged more severely and made cleaning much more difficult. At this home more frequent maintenance with annual replacement of the cartridge filters appeared necessary. Sludge accumulations were noted at both homes and consisted of a wispy black layer occupying the bottom 2 to 10 cm of the storage tank. Analyses of several grab samples of this material revealed high concentrations of organic materials and suspended solids (Table 9). Sludge disposal via the house sewer system was felt to be the most practical scheme.

Costs. The costs to purchase, install and operate the washwater recycle system as well as a conventional toilet system are outlined in Table 10. These costs are based on those actually encountered in this study, supported by estimates from equipment manufacturers and local plumbers.

ASSESSMENT OF HOME GREYWATER RECYCLING

In the past, greywater was considered by many to be relatively innocuous, unlike a real domestic wastewater. Even today, this belief prevails in many areas. Data from characterization studies have demonstrated that greywater is indeed a wastewater which contains appreciable quantities of oxygen-demanding substances, suspended solids, nutrients and fecal organisms [14, 18, 21]. It seems reasonable that varying amounts of organic materials, solids and nutrients are routinely added to the raw greywater by soil from bathing and laundering as well as from the various consumer products used in these activities. However, the high concentrations of fecal organisms measured in this and other studies are somewhat surprising and conventional interpretation would suggest that greywater may be routinely contaminated with fecal material. To yield a measured level of 10^5 fecal coli/100 ml would require that approximately 150 mg of wet fecal material (2.7×10^9 E. coli per wet gram of human feces), were contributed daily to a greywater stream of 400 Lpd. This amount conceivably could be added via laundering and personal hygiene functions. Until proven otherwise, it seems prudent to assume that raw greywater does present a potential health hazard and the treatment system prior to reuse should address this fact.

The results of the field study and previous studies have shown that the

use of a system to recycle home greywaters for toilet flushing can significantly reduce household water use and wastewater flows. Although the magnitude will vary between households, the reductions potentially achievable at "typical" American homes are outlined in Table 11. These results are based on the reuse of greywater for toilet flushing only, and higher reductions (theoretically 65% or more), could be achieved if reuse for lawn watering occurred as well. Several potential problems exist with this reuse strategy, however. In many areas of the U.S., the need for lawn watering is limited, and any additional reduction from such reuse may be negligible. This fact is supported by the very slight increases in flow reductions achieved by Cohen and Wallman [13], when reuse for both toilet flushing and lawn watering were evaluated (Table 1). Furthermore, the quality of the recycle water as measured in the field study was marginal for lawn watering compared to recent landscape irrigation criteria (Table 8).

If recycling greywaters for toilet flushing is the only reuse mode contemplated, the level of treatment required deserves careful consideration. Investigations have shown that the water standing in a normal toilet bowl between flushes often contains levels of fecal bacteria equal to or greater than those in raw greywaters [24,25]. Thus, purification to a potable water quality prior to toilet flushing reuse seems unreasonable. Minimal treatment to ensure aesthetic acceptance (odors, foaming, discolored water...), and maintenance of near-normal functioning of the toilet fixture (staining, corrosion), appear adequate. In the field evaluation, the pressure filtration process added little to the performance of the recycle system, while representing a significant part of the system cost. This result has also been reported previously [12]. Since the disinfection process proved to be the most important unit process in providing an acceptable flush water, perhaps a more cost-effective system could be designed utilizing only sedimentation and disinfection.

The proper operation of the recycle system evaluated in the field study required regular monitoring. While the operation and maintenance needs were simple, homeowners may not be willing or able to perform them regularly and poor operation could result. For this reason, strong consideration should be given to the use of maintenance contracts with plumbing contractors or other trained personel. As discussed previously, user acceptance of the greywater recycle system was both positive and negative. In general, both the field evaluation and previous studies have revealed that people are not reluctant to reuse greywaters for such non-body contact functions as toilet flushing and lawn irrigation. The main negative comments received from homeowners in the field study involved problems (odors, discolored bowl water...), caused by less than optimum system performance.

Although significant reductions in water use and wastewater flow can be obtained by a greywater reuse system, the high capital cost may limit the economic benefits of such a system. An abbreviated economic analysis was performed for several common residential applications in the U.S. (Table 12). While the data presented are only estimates and subject to considerable variability due to site specific factors, only the holding tank application offered potentially significant savings in water supply and sewage disposal costs. Similar results have been reported in the literature (Table 1). Additional reuse for lawn watering could render a greywater reuse system more economically attractive. The previously mentioned problems with lawn watering reuse would have to be considered, however. Multi-dwelling use of a recycle system may also make them more cost effective.

In summary, household greywater is a wastewater containing sufficient quantities of organic materials, suspended solids and fecal bacteria to warrant careful treatment prior to reuse. While the onsite recycling of greywaters has been demonstrated as an effective, user acceptable water reuse strategy, the technology has only limited application at this time. While simple homeowner-built and commercially manufactured systems can produce an effluent suitable for toilet flushing, effluent suitability for regular lawn watering is marginal. Further, demands for lawn irrigation water are limited in many parts of the United States. Yet, if only reuse for toilet flushing is proposed, simpler, more cost-effective water conservation fixtures are available that provide similar flow reductions [18]. Finally, potential problems exist with installation of the typical systems and routine homeowner maintenance is required for their proper functioning.

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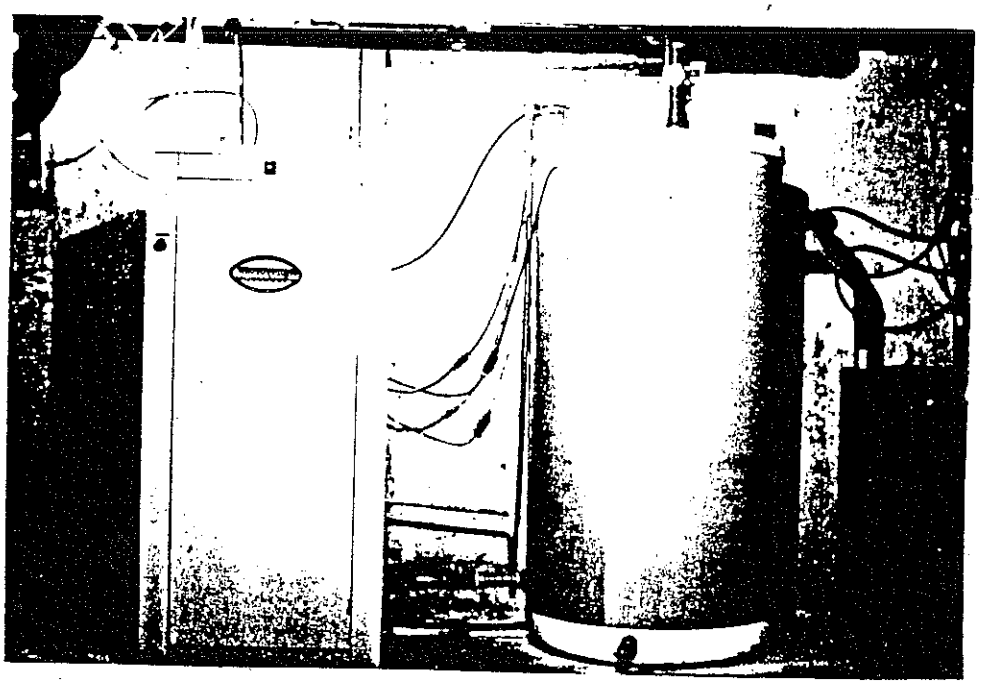

FIGURE 1. AQUASAVER GREYWATER RECYCLE SYSTEM

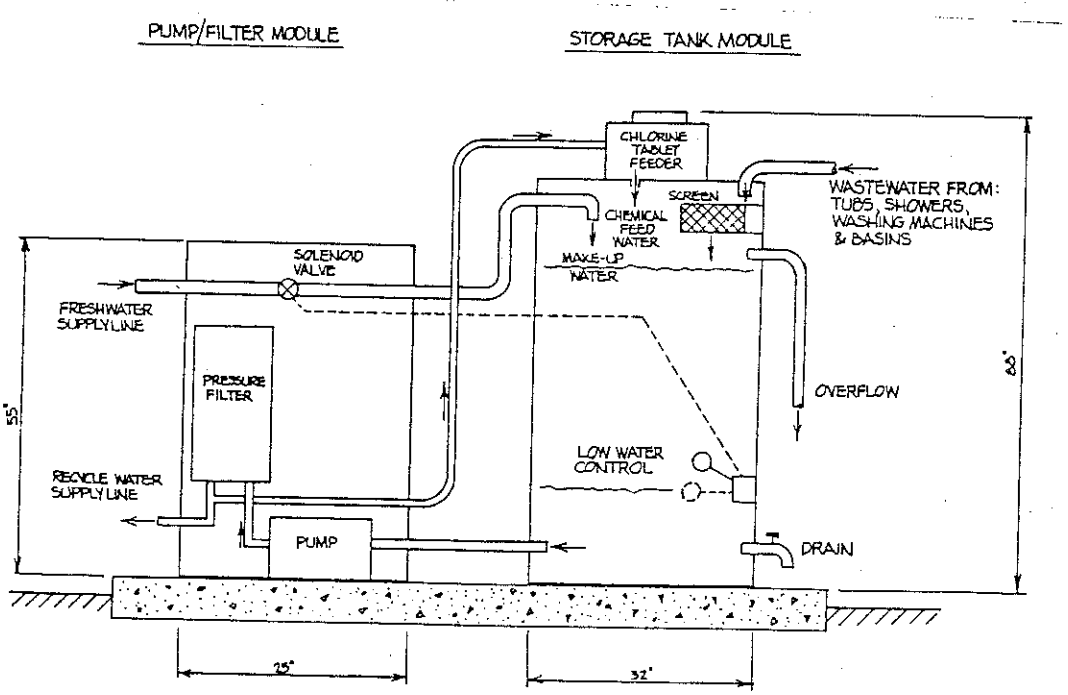

FIGURE 2. AQUASAVER SYSTEM SCHEMATIC

TABLE 1. SUMMARY OF PREVIOUS DEMONSTRATION PROJECTS - HOUSEHOLD WATER REUSE

STUDY	TYPE OF STUDY	REUSE SCHEME	UNIT PROCESSES	FLOW REDUCTION	COST EFFECTIVE	COMMENTS
o McLaughlin, (1975)	o Demonstration of one pilot system in actual residence	o Reuse of bathing and laundry waste-waters for toilet flushing	o Sedimentation o Diatomite filtration	o 22.6 percent reduction in total water use	o Cost effective only in areas where water was very limited or waste disposal systems were severely over-loaded	o Need for filter was questionable o Disinfection process was recommended o Minimal O & M but maintenance was req'd approx. every 6 months
o Cohen & Wallman, (1974)	o Demonstration of three prototype systems in actual residences	o Reuse of bathing and laundry waste-waters for toilet flushing & lawn watering	o Sedimentation o Chlorine disinf. o Diatomite & cartridge filt.	o 29% average flow reduction for toilet flush and lawn watering o 25% average flow reduction for toilet flushing only	o Economically attractive only in areas where septic systems with poor soils or other inade-quacies were encountered	o Regular Main-tenance req'd at approx. 3 mo. intervals o Homeowner acceptance was fairly positive o Improved septic system was noted
o Hypes & Collins (1974)	o Laboratory simulation of household use	o Reuse of bathing and laundry waste-waters for toilet flushing	o Sedimentation o Diatomite filt. o Chlorine disinf.	o 77% reduction in freshwater requirements for flushing when compared to a standard toilet	o Not assessed	o Unprocessed bath and laundry waters cannot be reused without treatment due to odors & particulate matter o Disinfection process recommended
o Bennett & Linstedt (1975)	o Laboratory evaluation of unit processes to treat waste-water for reuse	o Reuse of bathing, laundry and dish-washer wastewaters for toilet flushing and lawn watering	o Aerobic biotreatment o Sedimentation o Dual media filtration o Carbon adsorp.	o None reported	o Economical only under extreme water cost and wastewater dis-posal conditions	o Dual media filtra-tion relatively ineffective o Disinfection process recommended
o Putnam (1977)	o Laboratory evalu-ation & assessment of washwater reclamation technology at NASA	o Treatment of laundry, shower, sink, dishwater and experiment wastewaters for removal of suspended, dissolved & microbiological materials	o Filtration o Ultrafiltration o Carbon adsorp. o Ion exchange o Chem. pre-treatment o Reverse osmosis o Hyperfiltration	o None reported	o Not assessed	o Cartridge filtra-tion, carbon adsorption, ion exchange & Pasteurization chosen in final assessment on the basis of simpli-city, weight, oper. pressure & reliability

TABLE 2. CHARACTERISTICS OF HOME WASHWATER RECYCLE SYSTEMS*

UNIT	AQUASAVER	WATER WAY	ETOMS
Processing scheme	Coarse straining, Chlorination, Sedimentation/holding Pressure filtration	Sedimentation Pressure filtrations (sand, limestone, charcoal), Chlorination, Pressure tank	Fiberglass filter Sedimentation/holding Sand filtration, Iodination, Pressure tank
Resource Requirements:			
Water	Maybe	Maybe	Maybe
Power	Yes	Yes	Yes
Fuel	-	-	-
Other	Chemicals	Chemicals	Chemicals
Application Considerations:	o Separate toilet supply and drain lines o Vent lines for system o Space for unit	o Separate toilet supply and drain lines o Vent lines for system o Space for unit	o Separate toilet supply and drain lines o Vent lines for system o Space for unit
Additional Maintenance	Quarterly: Replenish chemicals, clean filter cartridge, clean storage tank, clean influent screen.	Semi-annually: Reactivate carbon. Other?	Replenish disinfectant chemicals once a year, change fiberglass filter every 2-3 months. Other?
Development Stage	Fully developed	Final development	Significant development remaining
Manufacturer/ approximate cost	Aquasaver, Inc., Baltimore, Md. $2850	Owl Corp., Verona, WI $3500	Water-Cyk Corp., Vienna, WA -----

*Based upon manufacturers' literature and communication with manufacturer by project staff.

TABLE 3. WATER USE AND WASTE FLOW CHARACTERISTICS[a]

Usage	Statistic	Unit	Residence	
			NE	VAR
Interior Water Use	Mean	Lpcd	126.7	78.0
	S.D.	Lpcd	58.1	68.1
	95% CI	Lpcd	112.7-140.6	58.8-97.2
	Range	Lpcd	47.3-364.3	15.1-280.1
	Max.	Lpch	113.6	68.1
Toilet Water Use[b]	Mean	Lpcd	33.1	24.7
	S.D.	Lpcd	18.2	10.7
	Range	Lpcd	9.4-106.2	7.3-49.8
	Max	Lpch	22.0	22.3
Non-Toilet Water Use	Mean	Lpcd	126.7	75.7
	S.D.	Lpcd	58.1	67.6
	Range	Lpcd	47.3-364.3	14.2-274.2
	Max	Lpch	113.6	68.1
Toilet Fixture Use	Mean	Lpcd	2.65	2.00
	Volume	L	12.5	12.3
System Overflow	Mean	Lpcd	32.7	17.2
	S.D.	Lpcd	30.8	34.1
	Range	Lpcd	0-137.1	0-160.6
Freshwater Makeup	Mean	Lpcd	0	0.33
	S.D.	Lpcd	-	1.5
	Range	Lpcd	-	0-9.7
Data Points	Total	Days	69	51
Usage Period	Total	Days	329	318
Residents[c] =	——	——	4(17,19)	5(4,6,14)

[a] Results of individual hourly and daily measurements collected during usage period.

[b] Toilet water use is recycled greywater, not freshwater.

[c] Total residents with childrens' ages (yrs.) in parentheses.

TABLE 4. REDUCTIONS IN DAILY INTERIOR FRESHWATER USE AND WASTEWATER FLOW[a]

Comparison	Statistic	Home NE		Home VAR	
		Lpcd	%	Lpcd	%
Existing Toilet vs Recycle System[b]	Mean	32.9	20.6	22.3	22.3
	UL 95% CI	34.4	19.7	23.7	19.6
	Maximum	20.8	5.4	23.7	7.8
13.2 L Toilet vs Recycle System[b]	Mean	34.8	21.6	24.2	23.7
	UL 95% CI	36.3	20.6	25.7	20.9
	Maximum	26.9	6.9	25.7	8.4
18.9 L Toilet vs Recycle System[b]	Mean	50.0	28.3	35.6	31.3
	UL 95% CI	52.6	27.2	37.8	28.0
	Maximum	70.8	16.3	39.4	12.3

[a] Based upon analysis of individual daily measurements from the data period with the recycle system by utilizing the measured fixture usage data and the stated toilet flush volumes. Assume no freshwater is needed to meet flushwater demands.

[b] Recycle system used to produce flushwater for stated toilet unit.

TABLE 5. PHYSICAL-CHEMICAL WATER QUALITY, RESIDENCE [NE]

PARAMETER	UNITS	STATISTIC	RAW WASHWATER	STORAGE EFFLUENT	RECYCLE WATER
BOD_5	mg/L	Mean (n) S.D. Range	125 (7) 52 33-193	100 (6) 28 52-130	74 (10) 25 34-110
COD	mg/L	Mean (n) S.D. Range	242 (5) 73 169-355	204 (6) 46 123-259	216 (7) 28 171-256
TS	mg/L	Mean (n) S.D. Range	794 (6) 168 626-1076	950 (7) 114 770-958	1040 (9) 172 860-1400
TVS	mg/L	Mean (n) S.D. Range	128 (6) 48 62-180	166 (7) 59 126-262	172 (8) 69 124-324
TSS	mg/L	Mean (n) S.D. Range	36 (4) 14 21-55	18 (4) 7 13-28	12 (5) 3 8-15
TVSS	mg/L	Mean (n) S.D. Range	33 (4) 11 20-47	15 (4) 5 11-22	10 (5) 3 6-15
TKN	mg/L	Mean (n) S.D. Range	5.8 (6) 2.7 2.0-10.1	4.8 (7) 2.8 1.5-9.2	5.2 (10) 3.8 0.3-10.8
NH_4-N	mg/L	Mean (n) S.D. Range	0.6 (4) 0.6 0.35-1.4	0.5 (4) 0.8 0.1-1.6	0.2 (6) 0.3 0-0.7
NO_2-NO_3-N	mg/L	Mean (n) S.D. Range	0.5 (4) 0.5 0.3-1.23	0.5 (3) 0.2 0.35-0.67	0.4 (5) 0.4 0-0.9
Total P	mg/L	Mean (n) S.D. Range	1.0 (6) 0.5 0.08-1.7	2.8 (7) 3.6 0.18-10.5	1.0 (11) 0.6 0.2-2.1
TURB	NTU	Mean (n) S.D. Range	42 (5) 13 26-55	42 (6) 6 30-47	36 (9) 6 27-41
pH	-	(n) Range	- -		13 7.0-7.8
Total Avail. Cl_2	mg/L	Mean(n) S.D. Range	- - -		4.2 (15) 6.1 0-19
Fecal Coli	Log no./ 100/mL	Mean (n) Range	- (5) 1.90-7.34	- -	-(8) 0-<2.7

TABLE 6. PHYSICAL-CHEMICAL WATER QUALITY, RESIDENCE [VAR]

PARAMETER	UNITS	STATISTIC	RAW WASHWATER	STORAGE EFFLUENT	RECYCLE WATER
BOD_5	mg/L	Mean (n)	147 (6)	200 (6)	185 (8)
		S.D.	45	89	80
		Range	80-215	60-319	58-317
COD	mg/L	Mean (n)	276 (5)	389 (6)	383 (8)
		S.D.	56	134	133
		Range	230-359	136-511	201-577
TS	mg/L	Mean (n)	810 (6)	1143 (7)	1108 (9)
		S.D.	215	248	298
		Range	623-1086	834-1503	536-1496
TVS	mg/	Mean (n)	179 (6)	282 (7)	259 (9)
		S.D.	56	93	91
		Range	117-259	142-394	92-369
TSS	mg/L	Mean (n)	92 (6)	71 (7)	66 (9)
		S.D.	64	24	31
		Range	39-211	40-100	27-124
TVSS	mg/L	Mean (n)	38 (6)	38 (7)	36 (9)
		S.D.	19	24	15
		Range	16-68	12-86	17-56
TKN	mg/L	Mean (n)	5.7 (5)	9.8 (3)	9.1 (5)
		S.D.	2.4	6.3	4.8
		Range	2-8	5.4-17.0	4.0-16.0
NH_4-N	mg/L	Mean (n)	1.2 (4)	1.8 (2)	1.6 (3)
		S.D.	1.1		1.7
		Range	0-2.6	1.4-2.2	0-2.0
NO_2-NO_3-N	mg/L	Mean (n)	0.4 (3)	1.1 (2)	1.2 (4)
		S.D.	0.2		0.8
		Range	0.2-0.6	0.2-2.0	0.2-2.0
Total P	mg/L	Mean (n)	0.3 (2)	-	-
		S.D.	-	-	-
		Range	-	-	-
TURB	NTU	Mean (n)	-	-	-
		S.D.	-	-	-
		Range	-	-	-
pH	-	(n)	-	-	6
		Range	-	-	6.8-8.2
Total Avail. Cl_2	mg/L	Mean (n)	-	-	4.7 (11)
		S.D.	-	-	7.8
		Range	-	-	0-25
Fecal Coli	Log no./ 100 ml	Mean (n)	- (5)	-	- (6)
		Range	5.04-7.78	-	2-4.78

TABLE 7. NSF RECYCLE/REUSE SYSTEM WATER QUALITY STANDARDS[a]

PARAMETER	CRITERIA C-9	STANDARD 41
Turbidity	≤100 JTU	≤90 JTU
Total Coliform	≤1 org./100 ml.	≤240 org./100 ml.
BOD_5	≤influent	≤45 mg/L as 7 day running ave. ≤30 mg/L as 30 day running ave.
TSS	≤90 mg/L	≤45 mg/L as 7 day running ave. ≤30 mg/L as 30 day running ave.
Odor	acceptable by panel	non-offensive
Total Residual Cl_2	≥ 0.1 mg/L	—

[a] Adapted from NSF Standard 41 and Basic Criteria C-9.

TABLE 8. WATER QUALITY CRITERIA FOR LANDSCAPE IRRIGATION (Culp et al., 1979)

PARAMETER[a]	UNIT	CRITERIA
BOD_5	mg/L	20
Total Dissolved Solids	mg/L	1200
Total Suspended Solids	mg/L	15
Nitrogen	mg-N/L	-
Oils & Grease	mg/L	Free From
pH	-	6.0-9.0
Fecal Coliform	No./100 mL	2.2

[a] plus 21 additional elements and compounds

TABLE 9. STORAGE TANK SLUDGE CHARACTERISTICS[a]

Parameter	Home NE		Home VAR	
	1	2	1	2
BOD_5	3500	5160	8130	-
COD	-	-	15920	-
TS	14150	14240	37200	11000
TVS	6630	7280	10430	5300
TSS	10740	13590	-	-
TVSS	5220	6680	-	-
TKN	75	423	-	-
TP	1.8	10.8	-	-

[a]Based upon analyses of grab samples taken during two different maintenance routines.

TABLE 10. ESTIMATED WASHWATER RECYCLE SYSTEM COSTS[a]

Cost Item	Conventional Toilets	Washwater Recycle System
Capital Cost	$110	$2850
Installation Cost	$ 30	$ 400
Total Installed Cost	$140	$3250
Annual Operating Cost		
Power:	0	$ 3.00/yr.
Chemicals	0	$52.00/yr.
Maintenance Costs	?	≈12 man-hours/year

[a]Based on installation of one fixture in a new dwelling.

TABLE 11. PROJECTED WATER CONSERVATION AT TYPICAL RESIDENTIAL DWELLINGS WITH WASHWATER RECYCLE SYSTEMS[a]

Characteristic	Conventional Toilet Fixtures		Washwater Recycle System
	18.9 L (5.0 gal) (A)	13.2 L (3.5 gal) (B)	
Flush Volume			
L freshwater/use	18.9	13.2	0
% Reduction from (A)	0	30	100
% Reduction from (B)	-	0	100
Daily Water Use			
No Reduction, Lpd	756	-	-
Reduction, Lpd	0	79	265
Reduction, %	0	10.5	35
Reduced flow, gpd	756	677	491

[a]Based on a total daily flow of 756 Lpd with 265 Lpd or 35% contributed by conventional toilet usage of 3.5 uses/person. Recycling for toilet flushing only.

TABLE 12. ABBREVIATED ECONOMIC ANALYSIS OF GREYWATER RECYCLE SYSTEMS AT RESIDENTIAL DWELLINGS [a]

Application / Assumptions	Conventional 13.2 L (3.5 gal) Toilet	Greywater Recycle Systems
Base Conditions		
Installed cost	$140	$3250
Increased cost over conv. toilet	0	$3110
Daily flow reduction	10.5%	35%
Yearly flow reduction	28840 L	96580 L
City Water & Sewer		
Water and sewer cost saving @ $0.50/kiloliter	$14.40	$48.30
Payback period, New	0 years	- [b]
Payback period, Retrofit	9.7 years	- [b]
Rural Holding Tank		
Pumpage cost savings @ 0.5¢/Liter	$144	$483
Payback period, New	0 years	7.3 years[c]
Payback period, Retrofit	1.0 years	7.6 years[c]
Reduced Drainfield Sizing		
Drainfield cost savings @ $13.50/$M^2$; 90 M^2 req'd	$128	$425
Net cost savings, New	$128	-$2685 (loss)
Remedy Overloaded Drainfield		
Drainfield cost savings @ $16.00/$M^2$; 28 M^2 expansion area needed for 30% overload	- [b]	$448
Net cost savings, retrofit	- [b]	-$2802 (loss)

[a] Based on data shown in Tables 8 and 9 and assumptions presented in this table. No maintenance costs were included.

[b] Annual operating costs exceed water/sewer cost savings.

[c] Pumpage cost savings less annual operating costs used in calculation.

[d] Does not provide 30% reduction.