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Water Conservation and Wastewater Disposal

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WATER CONSERVATION AND WASTEWATER DISPOSAL

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Clean water has for many years often been regarded as one of nature's bountiful free goods. As such, the unlimited use of water has been considered by many to be an acceptable practice and little if any consideration has been given to the cautious, non-wasteful use of water. However, an increasing realization of the problems and impacts associated with water consumption is rapidly exposing the fallacy of this attitude. Concerns over water supply and wastewater disposal and an increasing recognition of the benefits that may accrue through water conservation are serving to greatly stimulate the development and application of water conservation practices.

In this paper, one aspect of the broad and complex subject of water conservation and wastewater disposal is considered, that being residential water conservation and onsite wastewater disposal. A discussion of residential water conservation practices including operation and performance data on selected major practices has been given and the impact of these practices on waste loads and various onsite wastewater treatment and disposal methods has been assessed.

RESIDENTIAL WATER USE/WASTEWATER PRODUCTION

Water Use/Wastewater Flow Volume

To identify the water use/wastewater production of various household activities, several extensive characterization studies have been conducted (Wallman, et al. 1974; Ligman, et al. 1974; Laak 1974; Bennett and Linstedt 1975; Siegrist, et al. 1976). A summary of the average values determined by these investigations is presented in Table 1.

The quantity of water actually used and wastewater produced by a given household has been shown to be influenced primarily by (1) family size, (2) socioeconomic status, and (3) source of water supply, the billing method and to a lesser extent, its cost (Andrews and Hammond 1970; Hanke 1970; Hollman and Primeaux 1973; Linaweaver, et al. 1966). Additional influences appear to include, (1) type of dwelling unit, (2) geographic location, and (3) methods utilized for wastewater disposal. As a result of these diverse and in certain respects intangible influences, day-to-day variations about the values presented in Table 1 must be expected by a given individual/household and between different individuals/households.

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Table 1. Characteristics of Residential Water-Using Activities

Activity	Gal/use	Uses/cap/day	Gal/cap/day
Toilet Flush	4.3[a] 4.0 - 5.0[b] (1,2,4,5)[c]	3.5 2.3 - 4.1 (1,2,4,5)	16.2 9.2 - 20.0 (1,2,3,4,5)
Bathing	24.5 21.4 - 27.2 (2,4,5)	0.43 0.32 - 0.50 (2,4,5)	9.2 6.3 - 12.5 (1,2,3,4,5)
Clotheswashing	37.4 33.5 - 40.0 (2,4,5)	0.29 0.25 - 0.31 (2,4,5)	10.0 7.4 - 11.6 (1,2,3,4,5)
Dishwashing	8.8 7.0 - 12.5 (2,4,5)	0.35 0.15 - 0.50 (2,4,5)	3.2 1.1 - 4.9 (2,4,5)
Garbage Grinding	2.0 2.0 - 2.1 (2,4)	0.58 0.4 - 0.75 (2,4)	1.2 0.8 - 1.5 (2,4)
Miscellaneous	-	-	6.6 5.7 - 8.0 (2,4,5)
Total	-	-	45.6 41.4 - 52.0 (1,2,3,4,5)

Note: Litres = 3.8 x gallon. Gal/cap/day may not equal gal/use multiplied by uses/cap/day due to difference in the number of study averages used to compute the mean and ranges shown.

[a] Mean of study averages.

[b] Range of study averages.

[c] References included in determining mean and/or range: (1) Wallman and Cohen 1974; (2) Ligman, et al. 1974; (3) Laak 1975; (4) Bennett and Linstedt 1975; (5) Siegrist, et al. 1976.

Wastewater Quality

Several investigations have been conducted to identify the qualitative characteristics of the wastewaters generated by individual household activities and/or the household in total (Olsson, et al. 1968; Ligman, et al. 1974; Laak 1974; Bennett, et al. 1975; Siegrist, et al. 1976). Based on the results of these studies, the individual water-using activities which typically occur within the home may be grouped to yield three major waste fractions: (1) garbage disposal wastes, (2) toilet wastes, and (3) sink, basin and appliance wastewater. A summary of the average pollutant contributions identified for these three waste fractions is presented in Table 2.

In addition to the pollutant contributions shown in Table 2, the microbiological characteristics of household wastewater are of equal or perhaps greater importance. Intuitively, it would seem that the majority of any pathogens shed into a household's wastewater stream would be via the toilet wastes with the other waste fractions comparatively innocuous. To delineate the microbiological character of the wastewaters produced by major non-toilet use activities, studies have been conducted by Siegrist (1977a, 1977b). As shown in Table 3, a wide range of indicator organisms can be expected in the wastewaters produced by bathing and clotheswashing.

Table 2. Average Pollutant Contributions of Major Residential Wastewater Fractions, grams/cap/day

Pollutant	Garbage Disposal	Toilet	Basins, Sinks, Appliances	Approximate Total Contribution
BOD_5	18.0[a] 10.9 - 30.9[b] (1,2,3)[c]	16.7 6.9 - 23.6 (1,2,3,4,6)	28.5 24.5 - 38.8 (1,2,3,4,6)	63.2
Suspended Solids	26.5 15.8 - 43.6 (1,2,3)	27.0 12.5 - 36.5 (1,2,3,4)	17.2 10.8 - 22.6 (1,2,3,4)	70.7
Nitrogen	0.6 0.2 - 0.9 (1,2,3)	8.7 4.1 - 16.8 (1,2,3,4)	1.9 1.1 - 2.0 (1,2,4)	11.2
Phosphorus	0.1 0.1 - 0.1 (1,2)	1.2 0.6 - 1.6 (1,3,4)	2.8 2.2 - 3.4 (1,3,4)	4.0
Approximate Flow[d] gal/c/d	2 (1,2,3)	16 (1 - 6)	29 (1 - 6)	47

[a] Mean of study average values.

[b] Range of study average values.

[c] References used in mean and range calculations as follows; (1) Siegrist, et al. 1976; (2) Bennett and Linstedt 1975; (3) Ligman, et al. 1974; (4) Olsson, et al. 1968; (5) Wallman and Cohen 1974; (6) Laak 1975.

[d] L/cap/day = 3.8 x gal/cap/day.

Table 3. Bacteriological Characteristics of Bath and Laundry Wastewaters[a] (Siegrist, 1977b)

Event	Organism	Samples	Mean[b] No./100 mL	95% Confidence Interval - No./100 mL
Clotheswashing[c]	Total Coliforms	41	215	65 - 700
	Fecal Coliforms	41	107	39 - 295
	Fecal Streptococci	41	77	27 - 220
Bathing	Total Coliforms	32	1810	710 - 4600
	Fecal Coliforms	32	1210	450 - 3240
	Fecal Streptococci	32	326	100 - 1050

[a] The results shown are from in-house sampling at each of six residences.

[b] Log-normalized data.

[c] Samples were obtained from the middle of the wash cycle. Samples taken from 15 rinse cycles were consistently lower than the corresponding wash cycle values.

Characterization of 85 fecal coliform and 48 streptococcal isolates taken from the samples obtained at three of the six homes, indicated that much of the bacterial contamination in the wastewaters was probably from the natural environment or skin flora of man. However, the incidence of certain enterobacteriaciae did indicate possible fecal contamination. Further analyses were performed on the samples obtained from the other three study homes for two common pathogens, Pseudomonas aeruginosa and Staphylococcus aureus. The results indicated a very low incidence of Pseudomonas aeruginosa (1 of 3 homes, 7 of 47 samples), and where isolated, concentrations were below 20/100 mL. Staphylococcus aureus was not isolated in any of the 45 samples analyzed. The results of these studies have demonstrated that the bath and laundry wastewaters possess a potential for containing enteric organisms, as well as non-enteric organisms. However, this potential appears substantially lower than that of either the toilet wastes or combined household wastewaters.

Similar to water use/wastewater production, there are a variety of factors affecting the quality of household wastewater. As a result, variation in wastewater quality produced by a given household activity and/or the household as a whole will occur.

WATER CONSERVATION PRACTICES

An extensive array of concepts, techniques and devices to reduce average residential wastewater loadings (flow volume and/or pollutant contributions) are under various stages of development and/or application. The diverse array of water conservation practices may, in general, be divided into three major categories: (1) elimination of non-functional water use, (2) water-saving devices, fixtures and appliances, and (3) wastewater recycle/reuse systems.

Elimination of Non-Functional Water Use

Non-functional water use is typically the result of (1) wasteful, water-use habits, (2) excessive water pressure in the house supply, and (3) inadequate plumbing and appliance maintenance. As a direct result of these, unnecessary quantities of water are consumed and wastewater produced.

Wasteful, Water-use Habits: A few illustrative examples of wasteful, water use habits include using a toilet flush to dispose of a cigarette butt, allowing the water to run while brushing teeth or shaving, or operating a clotheswasher or dishwasher with only a partial load. The potential for waste flow reductions through elimination of these types of wasteful use would vary tremendously between homes, from minor to significant reductions, depending on existing habits.

Excessive Water Supply Pressure: The water flow rate through sink and basin faucets, showerheads and similar fixtures is highly dependent on the water pressure in the house water supply lines. For most dwellings, a water supply pressure of 40 psi (276 Pa) is adequate and a pressure in excess of this can result in unnecessary water use and wastewater generation, especially with wasteful, water-use habits. Fortunately, many homes, particularly those in rural areas, have water supply pressures in or below the 40 psi (276 Pa) range.

Inadequate Plumbing and Appliance Maintenance: Unseen or apparently insignificant leaks from household fixtures and appliances can waste large volumes of water and generate similar quantities of wastewater. Most notable in this regard are leaking toilets and dripping faucets. For example, even a pinhole leak which may appear as a dripping faucet can waste up to 640 L/day (170 gal/day) at a pressure of 40 psi (276 Pa). More severe leaks can generate even more massive quantities of wastewater.

Water-saving Devices, Fixtures and Appliances

The quantity of water traditionally used by a given household fixture or appliance, often times is considerably greater than actually needed. Certain tasks may even be accomplished without the use of water. As presented in Table 1, toilet flushing, bathing and clotheswashing collectively account for over 70 percent of a typical household's interior water use and waste flow volume. Additionally, toilet use (as well as garbage grinding) has been shown to contribute substantial quantities of pollutants to the household wastewater stream (Table 2). Thus, efforts to accomplish major reductions in the wastewater flow volume, as well as its pollutant mass, have logically been directed toward the toilet flushing, bathing and clotheswashing areas. In the following section, selected water conservation/waste load reduction devices and systems developed for these household activities are briefly discussed.

Toilet Devices and Systems: As indicated in Table 1, the flush of a conventional water carriage toilet consumes about 16.3 L (4.3 gal) of water. A variety of devices have been developed for use with a conventional flush toilet to reduce the volume of water used in flushing. In addition, alternatives to the conventional water-flush toilet have been developed.

Toilet Tank Inserts: Toilet tank inserts are devices which are placed into the storage tank of a conventional water-carriage toilet to reduce the volume of water stored in the tank, but not its height. As a result, the quantity of water used per flush is reduced but the scouring velocity of the flush water is maintained. These devices take a variety of forms including, a water-filled and weighted plastic bottle and commercially marketed flexible panels or dams.

The water-filled plastic bottles are cheap and readily available in that they may be fashioned out of materials found around most homes. The waste flow reduction achieved is typically, between 1.9 and 3.8 L (0.5 to 1.0 gal) per flush which would yield a daily reduction of about 6.7 to 13.3 L/cap/day (1.8 to 3.5 gal/cap/day) or 3.9 to 7.7 percent of the total daily flow volume.

The commercially available flexible panels or dams typically cost from $2 to $6 and may be readily installed by the homeowner. The waste flow reduction achieved is dependent on the dimensions of the toilet tank and somewhat on the proprietory device utilized, but is typically about 7.6 L (2.0 gal) per flush or 26.6 L/cap/day (7.0 gal/cap/day), 15.4 percent of the total daily flow volume.

In regard to all forms of toilet tank inserts, the installation of a particular device should be done carefully and the device should be monitored after installation to ensure its proper operation. The Washington Suburban Sanitary Commission (1974) found that up to 1.4 man-hours of effort were required to properly install and subsequently inspect and adjust a single device.

Dual-Flush Toilet Devices: These devices are made for use with conventional flush toilets and enable the user to simply select from two or more flush volumes based on the materials to be disposed of, liquids or solids. It is difficult to predict the flow reduction achieved by these dual-flush devices, since the homeowner is free to select the flush volume. Wallman and Cohen (1974) installed four dual-flush devices (two proprietary devices) at each of three homes and identified an average flush volume reduction of about 24 percent. Of the total daily flow, the average flow reduction determined was 6.4 percent corresponding to 17.1 L/cap/day (4.5 gal/cap/day). The investigators did measure wide variations in the flush volume reduction (6.4 percent to 33.2 percent) and the total daily flow reductions (1.9 percent to 12.3 percent).

The installation of these devices should be accomplished by most homeowners. Maintenance should be minimal, possibly consisting of minor adjustments after installation, as supported by the findings of Wallman and Cohen (1974). These types of devices are commercially available on a limited scale, typically costing between $5.00 and $15.00.

Shallow-Trap Toilets: The shallow-trap toilet is a variation of the conventional flush toilet, being similar in appearance and operation. However, the flushing rim and priming jet have been designed to initiate the siphonic flushing action in a smaller diameter trapway with less water than required by conventional fixtures. Most shallow trap fixtures utilize about 13.2 L (3.5 gal) whereas monitoring of conventional toilets has demonstrated a flush volume of 16.3 L (4.3 gal) (Table 1). Based on these figures, the use of a shallow trap toilet would yield a flush volume reduction of 19 percent or about 6.8 percent of the total daily waste flow corresponding to 11.6 L/cap/day (3.1 gal/cap/day).

The installation of a shallow trap toilet is similar to that of the conventional as is fixture maintenance once installed. Shallow trap toilets are available from most major appliance manufacturers and generally cost about $10.00 to $15.00 more than the equivalent conventional flush unit. Shallow trap toilets were retrofitted in each of six homes by Wallman and Cohen (1974). No problems were encountered in retrofitting the units, the average installation time being about 30 min. The average flush volumes measured for the six units were 11.8 (3.1 gal) versus 16.0 L (4.2 gal) for the conventional fixtures, a reduction of about 25 percent. The measured reduction in total daily flow volume ranged from 0 percent to 11.2 percent, with an average of 6.9 percent, corresponding to 14.8 L/cap/day (3.9 gal/cap/day).

Very Low-Volume Flush Toilets: These toilets, typically very similar to the conventional flush toilet in appearance and user operation, are specially designed to utilize very low volumes of water for flushing, commonly less than one gallon (3.8 L) per flush. This is normally accomplished by (1) gravity discharging the toilet wastes through a high-slope, relatively short discharge line to a holding tank, or to a sewer line where co-mingling with other household wastewaters will provide the necessary carriage waters, or by (2) employing compressed air, a vacuum or a grinder pump to assist in the flushing. A discussion of the compressed air toilet follows.

The compressed air toilets normally utilize about one cubic foot of free air at 60 psi (413 Pa) to assist 1.9 Litres (0.5 gal) of water in flushing. The compressed air may be either bottled or from a small air compressor. For a single family dwelling a 1/2 hp air compressor with a 45 Litre (12 gal) reservoir appears suitable. The wastes are discharged from the toilet as a liquid plug in one and one-half inch diameter plastic pipe laid on a 1 percent to 2 percent slope and reportedly can be transported satisfactorily for 9 m (30 ft) or more. This type of toilet would yield a flush volume reduction of about 14.4 L (3.8 gal) or 88 percent, producing a reduction in total daily flows of about 52.9 L/cap/day (14 gal/cap/day) or 31 percent.

The compressed-air toilets are installed similar to the conventional except that the discharge sewer line need be only one and one-half inch diameter plastic pipe and provisions for an air supply line must be made. Maintenance of the toilet fixture appears to be similar to the conventional; however, the source of compressed air will require attention. These types of units are commercially available, typically retailing for about $400, with the additional costs of an air compressor or bottled air. Operating costs include those for electricity if a compressor is used, with power consumption for a 1/2-hp compressor of about 0.01 kwh per flush.

Non-Water Carriage Toilets: Many alternative toilets have been developed which do not use fresh tap water as the flushing medium nor produce wastewater requiring daily disposal (Rybczynski and Ortega 1975; Orr and Smith 1976; Milne 1976; Stoner 1977). For a typical household utilizing a non-water carriage toilet, waste flow reductions would be about 62 L/cap/day (16.3 gal/cap/day) or 35 percent of the total daily flow (Table 1). In addition, these toilet systems also provide for the removal of substantial quantities of pollutants and pathogenic organisms from the liquid wastewater stream (Table 2). A brief discussion of the composting, closed-loop recycle and incineration systems follows.

Composting toilets accept the toilet wastes and commonly garbage wastes and attempt to utilize the natural process of composting to affect their decomposition. Two general varieties of composting toilets are commercially available: those which have the point of use separated from a large decomposition chamber ("separated systems") and those which have the point of use directly attached to a comparatively small decomposition chamber ("non-separated systems"). The separated systems accept and actually rely on receiving the kitchen garbage wastes (or other carbonaceous matter) in addition to the toilet wastes, both of which are deposited into a decomposition chamber through a vertical chute from the toilet stool and possibly the kitchen. The chamber, commonly located in the basement, usually has a sloping bottom and the waste materials are oxidized by aerobic microorganisms as they slowly move down the sloping bottom. The chamber is well vented and in cold environments a small space heater may be required. Any odors or vapors produced are conducted upward through a vent pipe to the roof, naturally or with the aid of a small fan. Over time, stabilized waste materials accumulate at the chamber bottom and their removal is required, reportedly less than two or three times yearly for an average family of four.

The non-separated composting toilets usually have a much smaller decomposition chamber which is attached directly to a toilet seat, the entire unit being located on the same floor. After being deposited directly into the decomposition chamber, toilet wastes are oxidized by aerobic microorganisms to a stable, humus material. Due to their smaller size, these units oftentimes include heating elements in the chamber to accelerate the decomposition process. The chamber is vented to ensure aerobic conditions and any odors and vapors produced are conducted through a vent pipe to the roof, naturally or with the aid of a small fan. Removal of the accumulated waste materials is usually required yearly for a family of four.

When contemplating the installation of the large, separated units the requirements of the unit must be considered, in certain cases including (1) the need for a basement or crawlspace, (2) use of a common wall by bathroom and kitchen, and (3) restriction of toilet to first floor installations. The installation of the small, non-separated units should be more easily accomplished since the units simply sit on the bathroom floor. For both varieties, the hookups required typically include a 10 to 15 cm (4 to 6 in) diameter vent to the roof and an electrical outlet.

A number of composting toilets are commercially available with at least six models being actively distributed in the United States. The smaller units typically retail for about $800.00 plus shipping with the larger units varying from $1000 to $1700 plus shipping. Installation and operation costs will vary depending on the application.

In addition to the commercially available composting toilets, several concepts and designs for low-cost, owner-built compost privies are under development. Common varieties include the Farallones composting privy and the 55-gallon drum compost privy. Fairly detailed discussions of these units may be found elsewhere (Farallones 1977; RAIN 1977; Stoner 1977).

As one might expect, major concerns surrounding the use of composting toilets relate to the unit operation and maintenance, especially the probability of long-term user acceptable operation and the provision for safe, ultimate handling of the toilet residues. Several investigations have been conducted to evaluate the performance of various composting toilets and have provided valuable information (Norwegian Consumer Council 1975; McKernan and Morgan 1976; Moreau 1977; Stoner 1977). To summarize briefly, experiences to date with both commercially available and home-built composting toilets have indicated a number of potential operational problems: (1) accumulation of fluids, (2) fly infestation, (3) odors and (4) residue infectivity capability. For the most part, these problems appear to have occurred as a result of improper use and/or inadequate user maintenance, caused by a lack of understanding of the operation of the composting toilet. The small, non-separated toilets have been shown to be particularly susceptible to failure as a result of inadequate user care, while the large, separated units have demonstrated their increased tolerance to abuse as a result of their increased size. If the composting toilets are used and maintained properly to ensure the proper decomposition conditions, they appear capable of providing simple and effective sanitation of human wastes. In order for this to occur, however, the toilet owner must make a significant commitment to understanding, using and maintaining the system.

Incinerator toilets are small, self-contained units which effectively burn the solid wastes and evaporate the liquids. The incineration is usually fueled by propane/natural gas, electricity or a combination of the two and usually lasts for 10 to 15 minutes followed by a 5-minute cooling period. Most units are equipped with a blower and vent pipe to remove any odors and the vapors and heat produced. The incinerated waste materials must be removed periodically and the unit cleaned. For a family of four, this would typically occur weekly.

The installation requirements and difficulties for these incinerating toilets vary depending on the type of unit and the application. Typically a hook-up for electricity and/or gas are required, as is a 10 cm (4 in) vent pipe. Maintenance of the unit once installed involves periodic cleaning and ash disposal, and if bottled gas is used, refilling or exchanging of the cylinders.

Incinerating toilets are commercially available from a number of manufacturers with capital costs usually around $700.00. Installation costs vary with the application and type of unit, but have been reported less than $100 (Milne 1976). Basic operating costs include power and/or fuel requirements which for three representative proprietary units were calculated to be: .06 kwh/use and 90 grams (0.2 lb) LP gas/use; 1.2 kwh/use; and 135 grams (0.3 lb) LP gas/use.

Field evaluations of incinerator toilets in household applications appear to be lacking. General observations by various authorities have indicated certain problems with these units for home use: noise and odors produced during the incineration cycle; inability of a unit to handle more than a few successive users; potential fire hazards, if improperly installed; and high operating costs (Orr and Smith 1976; Milne 1976).

Closed-loop recycle toilets are similar to the conventional flush toilet in that a liquid is utilized to cleanse the toilet bowl and transport the waste materials. However, these systems are markedly different in that they purify and use the same fluid repeatedly (usually water or a mineral oil). The actual process used to purify the flushing medium varies considerably, but commonly includes separation, aeration, and/or filtration. The purification normally is accomplished in a treatment/storage tank, typically sized so that removal of accumulated solids is required yearly. Once removed, the solids or sludge are typically disposed of at a municipal treatment facility or a suitable land disposal site. Any discussion as to the installation, operation and maintenance of the recycle toilet systems is difficult due to the considerable variation in the unit processes employed. Typically, yearly residue removal is required at which time routine maintenance of the unit processes is performed.

Retail costs for a recycle toilet system for a single-family home are typically in the $4000 to $5000 range, the high cost partly due to the limited nature of the current market and partly due to the mechanical sophistication of the system. Economy of scale obviously makes the application of these types of systems more feasible for multi-family or high-use applications. Yearly operation costs although variable, are likely on the order of $100 or more which includes routine unit process maintenance, power consumption, and storage tank pumping.

Controlled evaluations of recycle toilet systems in household applications are lacking at present. Evaluations of the oil-flush recycle toilets in non-residential applications such as recreation area restrooms have been conducted, however, and have demonstrated their reliability and acceptable performance (Cotten 1976; Cook 1977).

Bathing Devices and Systems: The occurrence of a typical bath/shower consumes approximately 92.6 L (24.5 gal) of water, representing 34.8 L/cap/day (9.2 gal/cap/day) or about 20 percent of an individual's total daily flow (Table 1). The majority of devices available to reduce bathing waste flow volumes are concentrated around the activity of showering, with their objective being to reduce the normal 18.9 to 37.8 L/min (5 to 10 gal/min) showering flow rate.

Shower Flow Control Devices: These devices reduce the flow rate by reducing the diameter of the water supply line just ahead of the showerhead. These devices are of two basic forms, an actual pipe fitting or a plastic insert and yield flow rates between 5.7 and 11.3 L/min (1.5 and 3.0 gal/min). Installation of these devices may be readily accomplished in most conventional plumbing systems. The devices themselves are commercially available at a cost typically less than $5.

Reduced-Flow Shower Fixtures: A variety of reduced-flow showerheads and supply fittings are commercially available which utilize between 5.7 and 11.3 L/min (1.5 and 3.0 gal/min). Installation of these fixtures is accomplished in a manner similar to that for conventional fixtures with their capital cost being very similar to that for conventional fixtures.

It is difficult to estimate the flow reduction provided by these types of flow control devices and fixtures since it is highly dependent upon (1) the flow rate through the existing or proposed conventional fixtures, (2) the time spent in the shower, and (3) the user preference for baths versus showers. Assuming all bathing is in the form of showers, the existing flow rate is 22.7 L/min (6 gal/min) and the shower time does not change with the reduced flow, the installation of an 11.3 L/min (3 gal/min) device or fixture would yield a waste flow reduction as high as 17.4 L/cap/day (4.6 gal/cap/day) or 10 percent of the total daily flow.

The performance of shower flow reducing devices and fixtures has been evaluated in the field. The Washington Suburban Sanitary Commission distributed a large number of plastic showerhead inserts (11.3 L/min) to single-family homeowners free-of-charge (Bishop 1975). A 12 percent reduction in water use was attributed to the use of the shower inserts based on one-year of monitoring. In contrast to these results, similar showerhead inserts were installed in 100 townhouses and based on water-use monitoring over a ten-month period, the water use was found to increase by about 2.5 percent. The investigators attributed the increase and the contradictory results of the two studies to user lifestyle habits.

Eleven flow-limiting showerheads (three 9.5 L/min and eight 13.2 L/min fixtures) were installed in eight homes for a one-year period by Wallman and Cohen (1974). Water consumption and waste flow were found to increase in three homes, be essentially the same in two, and decrease in three. The extremes were an increase of 6.8 L/cap/day (1.8 gal/cap/day) or 3.8 percent of total flow, to a reduction of 10.6 L/cap/day (2.8 gal/cap/day) or 2.8 percent of total flow. The average for all eight homes was less than 3.8 L/cap/day (1.0 gal/cap/day) or 1 percent of the daily flow. The investigators attributed the overall lack of effectiveness of the fixtures to be a function of the users' bathing habits. An aspect of particular interest in reducing showering flow rates related to how the reduced flow-rate showers "feel" to the user and what the lowest acceptable flow rate is. Based on the results of questionnaire surveys, Wallman and Cohen (1974) found that the 9.5 L/min (3.5 gal/min) showerheads were favorably accepted in all five homes studied while the 13.2 L/min (2.5 gpm) were only favorably accepted in 2/3 of the three homes they were installed in.

Clotheswashing Devices and Systems: Based on home water use monitoring, an average flow volume of about 140 L (37 gal) per use has been identified, with the clotheswasher contributing about 38 L/cap/day (10.0 gal/cap/day) or 22 percent of the total daily flow (Table 1). Waste flow reductions may be accomplished through use of a clotheswasher with a suds-saver attachment. The suds-saver feature is included as an optional cycle setting on several commercially made washers. The selection of the suds-saver cycle when washing provides for storage of the washwater from the wash cycle for subsequent use as the wash water for the next wash load. The rinse cycles remain unchanged. Since the wash cycle comprises about 45 percent of the total water use per operation, if the wash water is recycled once, about 64.3 L (17 gal) will be saved, if twice, 129 L (34 gal), and so forth. These values represent 8.3 L/cap/day (2.2 gal/cap/day) or 4.8 percent and 11.7 L/cap/day (3.1 gal/cap/day) or 6.8 percent of the total daily waste flow. Clotheswashers with suds-saver features are commercially available at an increase in cost over a conventional washer of approximately $20.

Wastewater Recycle/Reuse Systems

These systems provide for the collection and processing of all household wastewater or the fractions produced by certain activities for subsequent reuse. The flow sheets suggested have been numerous and vary considerably. A system which has received a majority of development efforts includes the recycling of bathing and laundry wastewaters for flushing water-carriage toilets and/or outside irrigation. This type of recycling system typically provides for the collection of the bath and laundry wastewaters through conventional plumbing and transport into a 380 to 950 L (100 to 250 gal) storage/settling tank. The settled wastewater is commonly processed through some type of pressure filter (paper cartridge, diatomaceous earth, or sand) and then disinfected prior to storage in a pressure tank for reuse. A supply line connects this pressure tank to the water carriage toilets and/or exterior house faucets. Make-up water (fresh tap water) is normally supplied as needed automatically and any excess bath and laundry wastewater, overflows to the household sewer line.

At least one recycle system, as described, is commercially available at a capital cost of $2500 plus shipping. Scheduled operation and maintenance requirements to occur quarterly, include (1) replenishment of disinfection chemicals, (2) replacement of filter cartridges and (3) drain and clean storage reservoir. The annual operating costs as estimated by the manufacturer are ($45/year which includes the filter cartridges, disinfectant and power. Unscheduled maintenance of the recirculating pump and other mechanical parts may increase these charges.

If all toilet flushing requirements were met by this type of recycle system, a flow reduction similar to that for a non-water carriage toilet would be achieved, 62 L/cap/day (16 gal/cap/day) or 35 percent of the total daily flow. The filtration/disinfection system would also remove limited quantities of certain pollutants from the household wastewater stream.

To evaluate the performance of bath/laundry wastewater recycle systems, two prototype systems were installed at three homes and monitored for a period of one year by Wallman and Cohen (1974). One system included storage, cartridge filtration, liquid chlorox disinfection and reuse while the other included storage, diatomaceous earth filtration, chlorine tablet disinfection and reuse. Reuse included the flushing of water carriage toilets and lawn sprinkling. The waste flow reduction achieved by the units as a result of reuse for toilet flushing averaged about 41.6 L/cap/day (11 gal/cap/day) or 24 percent of the total daily wastewater flow. The recycle systems were found to be manageable and simple to use and capable of reliable and safe operation. The operation of conventional flush toilets was not impaired by the recycled bath/laundry waters and the performance of the systems was found to be aesthetically acceptable to the users. Maintenance of the units, readily accomplished by the homeowners, was typically required at one to three month intervals to replace filter cartridges and/or disinfection chemicals. The costs for the "homebuilt" systems were about $500-$600 for capital plus installation in retrofit applications, and yearly operating costs were $21 to $45. Another limited field study of a similar prototype system was conducted by McLaughlin (1975) with the operation and performance results generated, basically similar to those found by Wallman and Cohen (1974).

In addition to the bath/laundry wastewater recycle system discussed, efforts have been directed toward evaluating the feasibility of recycling a portion of the total household wastewater flow for toilet flushing. As part of the Boyd County Demonstration Project, four recycle systems were installed to serve five homes (Waldorf 1977). These recycle systems included an aerobic treatment unit to which all wastewater generated in the home was transported. The effluent from the aerobic unit flowed into a 4 m^3 (1000 gal) settling chamber from which the effluent was either processed further for recycling or directed to a disposal system. Further process units included a iodinator which provided a constant 0.5 mg/L dose of iodine followed by a small contact chamber (20 min contact time). The wastewater was then filtered through an activated charcoal filter and stored in a pressure tank, ready for reuse. The performance of the recycle system was monitored closely for a period of one year. Based on analyses of six samples of the recycled water, the recycle systems were found to produce a generally clear and odorless water, low in BOD_5 and suspended solids (mean values of 2.1 and 8.8 mg/L, respectively) with zero fecal coliform counts. Also noted was a high degree of consumer satisfaction with the day-to-day use of recycled water.

WASTE LOAD REDUCTION SUMMARY

In general, water-saving devices or systems can be characterized as being *reliable* or *unreliable* in yielding a projected waste flow reduction. The reliable methods are those which are not significantly affected by user habits and are largely *passive* methods. In contrast, the unreliable methods include those which are very subject to user habits and require a preconceived *active* role by the user. Use of a reliable method can be expected to produce a projected reduction whereas the unreliable methods may or may not produce the expected reduction, depending on the habits of the users.

A summary of the projected and documented flow reductions when utilizing the previously discussed water conservation methods is shown in Table 4. Also presented is a judgment as to whether the method is reliable or unreliable, taking into consideration the characteristics of the method and the results of field monitoring. For those methods judged reliable, the "expectable" flow reductions have been presented.

Reducing the household wastewater flow volume without reducing the mass of pollutants contributed will effectively increase the concentration of pollutants in the wastewater stream. However, the increase in concentration will likely be insignificant for most water conservation devices. The increase in pollutant concentrations in any case may be readily estimated utilizing Figure 1.

In addition to reducing waste flow volumes, certain of the techniques discussed can greatly reduce the concentration of pollutants in the household wastewater stream and/or decrease their mass. These methods, collectively referred to as *in-house waste segregation practices,* consist primarily of utilizing an alternative toilet system (e.g. a non-water carriage toilet) to remove the toilet waste from the household wastewater stream and/or eliminating

Table 4. Waste Flow Reduction Summary, Percent of Total Daily Flow

Device or System	Flow Reductions[a] Protected[b]	Flow Reductions[a] Documented[c]	Active or Passive	Expectable Reduction of Daily Flow
Toilet-Tank Inserts	3.9 - 15.4	-	P	3 - 14
Dual-Flush Devices	-	6.4	A	-
Shallow-Trap Toilets	6.8	6.9	P	6
Very Low-Volume Flush Toilets	31.0	-	P	31
Non-Water Carriage Toilets	35.0	-	P	35
Shower Flow Controls	10.0	-2.5,[d] 12.0	A	-
Low-Flow Showerhead	10.0	-3.8,[d] 2.8	A	-
Suds-Saver Clotheswasher	4.8 - 6.8	-	A	-
Washwater Recycle for Toilet Flushing	35.0	24.0	P	24

[a] For details, refer to appropriate section of text.

[b] Based on typical residential water-use patterns and the characteristics of the device or technique.

[c] Based on the results of actual field monitoring.

[d] The minus indicates an increase in water consumption/waste flow volume was determined.

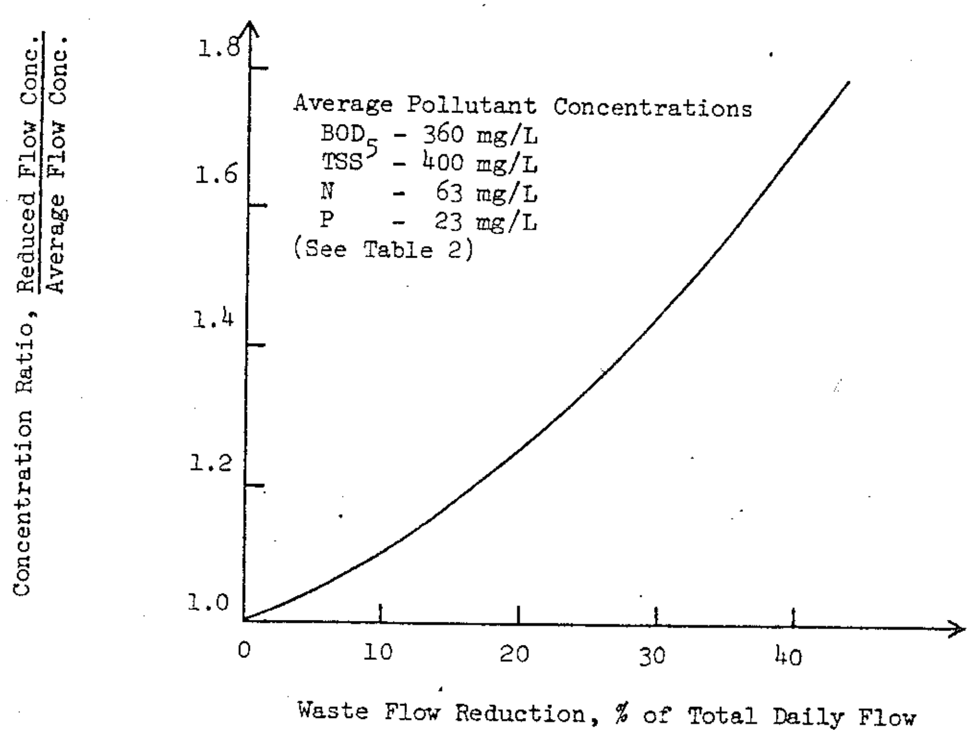

Fig. 1. Flow Reduction Effects on Pollutant Concentrations[a]

[a] Assumes pollutant contributions the same under the reduced flow volume.

the garbage grinder. The characteristics of the remaining household wastewater stream, commonly referred to as *grey water* may be seen in Table 2 and 3.

IMPACT ON ONSITE WASTEWATER DISPOSAL PRACTICES

Impact on the Operation of Existing Systems

Soil Disposal Systems: For an existing system functioning satisfactorily, reducing the wastewater flow volume or eliminating pollutants at the source might serve to extend the life of the soil absorption system. However, by what factor, if at all, is presently unknown. Waste segregation practices which remove quantities of suspended solids from the wastewater stream entering a septic tank may serve to lengthen the time between septic tank pumpings by as much as 25% (with toilet and garbage disposal wastes eliminated; see Table 2).

If the existing system were failing, with wastewater daylighting or backing up, flow reduction efforts could reduce the waste load sufficiently to remedy the situation. If the existing system were installed in a shallow soil over high groundwater, contamination of nearby water resources, including those used for water supply, by nitrates and/or microorganisms might occur, especially if the soil were highly permeable. Waste segregation practices which eliminate the toilet wastes from the onsite wastewater stream could serve to reduce or eliminate this contamination.

Holding Tank Systems: For those households on a holding tank system, waste flow reductions could yield significant savings in pumping charges. The cost for pumping and disposal of a residential holding tank is commonly in the range of \$0.0026 to \$0.0066 per L (0.26 gal); however, costs as high as \$0.0310 per L (0.26 gal) have been noted (Barrows and Bouwes). For a family of four with an average wastewater flow volume of 760 L/d (200 gal/d), and an average pumping charge of \$0.0039 per L (0.26 gal) the annual cost to the family could be \$1100. A 20 percent flow reduction could reduce these charges by as much as \$220/year.

With regard to existing disposal systems, it is important to realize that simple, relatively inexpensive waste flow reduction measures may yield significant benefits, especially to those households which have disposal systems which are hydraulicly overloaded. If a given technique or device does not yield the expected reduction, in many cases little time, effort and money will have been lost. If the objective was to remedy an overloaded system and waste flow reduction techniques proved unsuccessful, alternative, more costly solutions such as expanding or replacing the system, could then be tried.

Impact on the Design and Operation of New Systems

Accounting for the altered waste loads provided by water conservation practices can be a complex task. Two major considerations must be addressed. Firstly, one must be relatively confident that the use of a given device or system will yield the predicted waste load reduction. This relates to the question of reliable versus unreliable discussed previously. The characteristics of flow reduction devices as well as field monitoring can serve to identify those devices that are reliable.

A second major consideration is the necessity that the technique or device utilized be accepted by the present users as well as future users and be used throughout the service life of the disposal system. To ensure continued use of an installed device, several courses of action offer potential: (1) the appropriate regulatory authority could allow only those devices whose characteristics and merits indicate the potential for long-term user acceptance, (2) the plumbing system could be installed in such a way as to discourage disconnection or replacement of a device, or (3) periodic inspection by a local inspector within the framework of a sanitary district or the like may serve to identify plumbing alterations.

If a device or system does not yield an expected reduction or is disconnected or replaced, the waste loads to the onsite disposal system will be greater than expected, possibly resulting in system failure. If this happens, remedial actions could be taken, including upgrading or replacing the disposal system; however, this is often costly and very difficult to accomplish. If modifications are permitted in the design of an onsite waste disposal system due to an expected altered waste load, if at all possible, provisions should be made for alternative waste disposal methods.

Soil Disposal Systems: Simply reducing the waste flow volume to a conventional soil disposal system should ideally enable the size of the system to be reduced in proportion to the expected reduced flow (Table 4). However, any reduced sizing should probably be restricted to the soil disposal field with any pretreatment process maintained largely full-size to provide the necessary capacity to treat and attenuate peak flows. In addition to a reduced flow, water conservation practices involving waste segregation provide for a reduction in the quantity and concentration of certain pollutants, a fact which has been suggested to render the remaining wastewater (e.g. grey water) more acceptable to soil absorption. However, efforts to correlate soil clogging with household wastewater characteristics have been generally unsuccessful, especially in the more problematic structured soils (Small Scale Waste Management Project, 1977). At present, any reduction in field sizing should be based solely on a reduced hydraulic loading.

Holding Tanks: Similar impacts would be realized with a new holding tank as with an existing one, namely a reduction in pumping charges. However, if the system were for a new home, it would be relatively easier and more inexpensive to install water conservation/waste flow reduction devices and/or systems.

Alternative Systems: It is beyond the scope of this discussion to consider all of the various alternative disposal systems (mounds, sand filters, evapotranspiration systems, etc.) and discuss the impacts that reduced waste loading might have on their design and operation. However, a knowledge of the magnitude of the reduced waste loading and the characteristics of a given alternative system, should enable one to predict the impact reduced waste loadings would have.

In-house waste segregation practices appear to offer the potential to facilitate innovative alternative systems, including surface disposal, exterior reuse, or modified subsurface disposal. While preliminary assessment of this possibility has been conducted, detailed field investigations are necessary to adequately evaluate this potential (Siegrist, 1977a; 1977b).

SUMMARY

To reduce the waste loads (flow volume and/or pollutant contributions) generated by a typical household, an extensive array of techniques, devices, and systems are under various stages of development and/or application. Several devices and systems have been developed which should reliably produce waste flow reductions of up to 35 percent and/or significantly lower the concentration and/or pollutant mass in the household wastewater stream. The use of these methods to reduce waste loads represents an onsite waste management tool which deserves consideration when attempting to remedy an existing onsite disposal problem, when designing a new system, and when trying to provide suitable onsite waste disposal for problem applications.

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