INDIVIDUAL HOME WASTEWATER CHARACTERIZATION AND TREATMENT

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by

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INDIVIDUAL HOME WASTEWATER CHARACTERIZATION AND TREATMENT

INTRODUCTION

Owners of homes that rely on individual wastewater treatment and disposal systems face different and more immediate problems than those with homes connected to a central sewer system. Approximately one-third of the homes in the United States utilize on-lot sewage systems. These include rural and mountain homes, and suburban developments in the peripheral areas of cities.

In the past ten years, there has been accelerated building in the front range of the Colorado Rocky Mountains. This building has consisted mainly of recreational and permanent housing. Because of the remoteness of these homes, it has been financially prohibitive to connect to existing sewer lines. To be certified for residency and financing, some type of sanitary facilities have been required. Due to the simplicity and ease of maintenance of the septic system, it has usually been the first method of treatment considered for private wastewater streams. Health officials, although sometimes dubious of the widespread adaptation of the septic tank and leaching field method of treatment, have had no real alternative to its use for installation where the conditions were suitable.

Typically, the feasibility of using a septic system has been determined by running a percolation test as described in the Manual of Septic Tank Practice.[1] Failure of this test, eliminating the use of a septic system, has been usually due to one of the following: Proximity to bedrock or natural ground water table, lack of sufficient soil cover, sloping lots, or percolation rates which either were too fast or too slow. Many areas of Colorado, both in the mountains and on the plains, are unsuited for the application of septic systems. As a result, the Colorado Department of Health, Water Pollution Control Commission has identified areas in the state where "special authorization from the Water Pollution Control Commission is required for the installation and use of septic tanks."[2]

On a national basis, a large portion of the country has experienced similar problems with septic system applications. This is shown in Figure 1.

For installations in areas where the leaching field criteria cannot be met, the owner must utilize a system that is designed by a professional engineer. Many different types of systems have been developed to meet this situation. Generally, this facet of engineering practice must be considered to be in the experimental phase.

Engineered systems have been designed to utilize one of two discharge points. One approach has been to provide a very high degree of treatment and the release of the effluent to a surface water course. Under those conditions, the efficiency

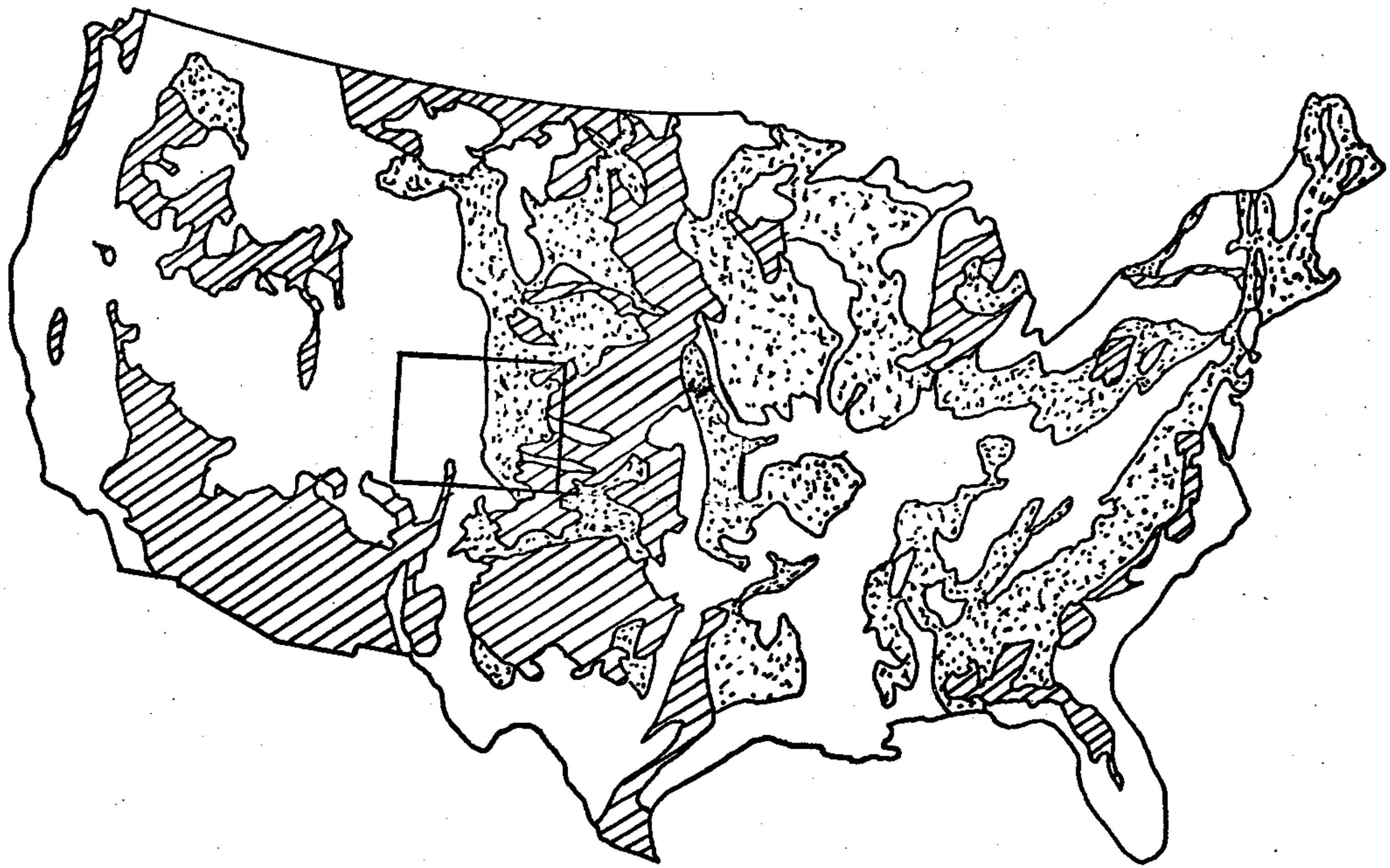

FIGURE 1. LIMITATIONS ON SEPTIC TANK AND LEACHING FIELD OPERATION (3)

and reliability of the system, under the conditions of operation by homeowners, have been major concerns. A highly reliable disinfection method must accompany the system.

The use of surface discharge systems has placed a large burden on regulatory officials. They must accept an implied responsibility to aid the uninformed home owner in selecting a satisfactory and economical system. At the same time, they must enforce statutory requirements relating to the effluent that protect downstream land owners who may come in contact with the discharged effluent. Environmental monitoring of a large number of very small systems has become an extremely demanding task. Rigid enforcement of discharge standards often places regulatory officials in conflict with private citizens, consulting engineers, and suppliers of proprietary equipment, creating a very undesirable situation. Some health officials have concluded that the interests of all parties could be best served by the prohibition of the use of surface discharge systems for private homes.

Another method of discharge that has been used to some extent in arid regions involves systems that remove all effluent by evaporation to the atmosphere. The regulatory control of this method of disposal has been somewhat less demanding but the basic physical concepts of the technique have not been well defined and accurate design parameters have been difficult to obtain.

Another consideration that should be evaluated in conjunction with any individual system is the benefit obtained from the potential for reduction in water use with water saving appliances and with recycling and reuse of water within the home.

In reviewing the sources of information pertaining to the design of individual home sewage treatment systems, it was found that one of the problems encountered by the designer and health official was the relatively limited number of studies available for defining the flow characteristics and pollutional character of the wastes involved. Therefore, this study was initiated to aid in defining a typical home waste, and to evaluate the effect of the waste characteristics on the various treatment systems.

This report is a summary of findings of a three year study at the University of Colorado, Department of Civil and Environmental Engineering. It was funded by the Office of Water Research and Technology, (Grant #A-021-Colo.). This document summarizes the conclusions of several previous publications.[4-11] based on the master theses research work of Mr. J. T. Felton, C. C. Withee, and R. N. McBride.

CHAPTER II - WATER USE IN THE HOME

In order to define the parameters that affect the design of home wastewater systems, a study was made to determine the flow characteristics in the home in terms of source, time, and volume of discharge. Six homes were used in the study. Although this limited number of sites did not provide a true random sample, the homes were selected to represent different family compositions. Pairing of homes on the basis of number of occupants and age was used to evaluate variations in water use that could occur under the conditions of similar family made-up. The flow meter-recorder linkage was not satisfactory in one of the homes and therefore the flow data are presented based on a one to two week study on five homes. The composition of the families that occupied each of the homes is shown in Table 1.

Table 1

Composition of Family

Station	Designation	Adults	Children
1	NE	2	3 (1-13 yrs)
2	SW	2	3 (1-13 yrs)
3	NW	2	0
4	N	2	0
5	S	2	2 (13-20 yrs)

The homes were located within the city of Boulder, Colorado and were served by the municipal water department and central sewage collection system. All homes had been constructed since 1950 and had modern appliances. All the homes represented the middle income group. This was done to simulate the conditions to be expected for isolated mountain home developments. In every location the male head of household was away from the home for the normal working period, the older children were in school, and the wives were away part of the time for employment or community work. The results obtained represent the water actually used in the home, with no attempt made to determine water use per person while away from the test location. The study was made in the winter period when virtually no consumptive use of water occurred.

With the aid of the City of Boulder Water Department, a recording device was installed in place of the water meter head at each of the study sites. These devices recorded the time and volume of each water use in the home. The installation of the recorders was such that they imposed no flow restrictions and imparted no head loss other than that imparted by the normal water meters. The actual recordings were done on wax discs by a reciprocating arm and scribe. The recorders could be set to record either one hundred gallons or ten gallons on full scale deflection. Since the intent of the investigation was to study individual appliance and sink uses, the recorders were set for ten gallons per full deflection. The recorders could also be operated with settings of twelve hours per revolution or twenty-four hours per revolution. For convenience, they were set for twenty-four hour operation. The wax discs were changed and the recorders wound every morning. A typical chart recording is shown in Figure 2.

There was no way of knowing which appliance generated each use from the recorder data alone. Therefore, data sheets were prepared and the times were logged by the users for the sink, toilet, garbage disposal, bath or shower, washing machine and dishwasher. These data were subsequently correlated with the water meter charts to establish the amount of water used for each appliance or function. The type of data sheets kept in each home each day is shown on the following pages. The data sheets were issued and their use explained at the time of installation of the recorders. In addition, each family was asked to indicate who used the water by entering an A-Adult, B-Teen (13-21), C-Child (0-12), or F for general family use. With current trends being three to ten year occupancy of homes, it was felt that it would be desirable to determine the relative contributions of the different age groups.

In addition to the normal use, some stations were requested to do some special use studies. That is, determine the minimum water for a shower, do dishes in a sink rather than in a dishwasher, and operate the washing machine without any clothes to determine the water requirement for each setting. The volumes of water used for these exercises were not included in the daily use amounts for the stations.

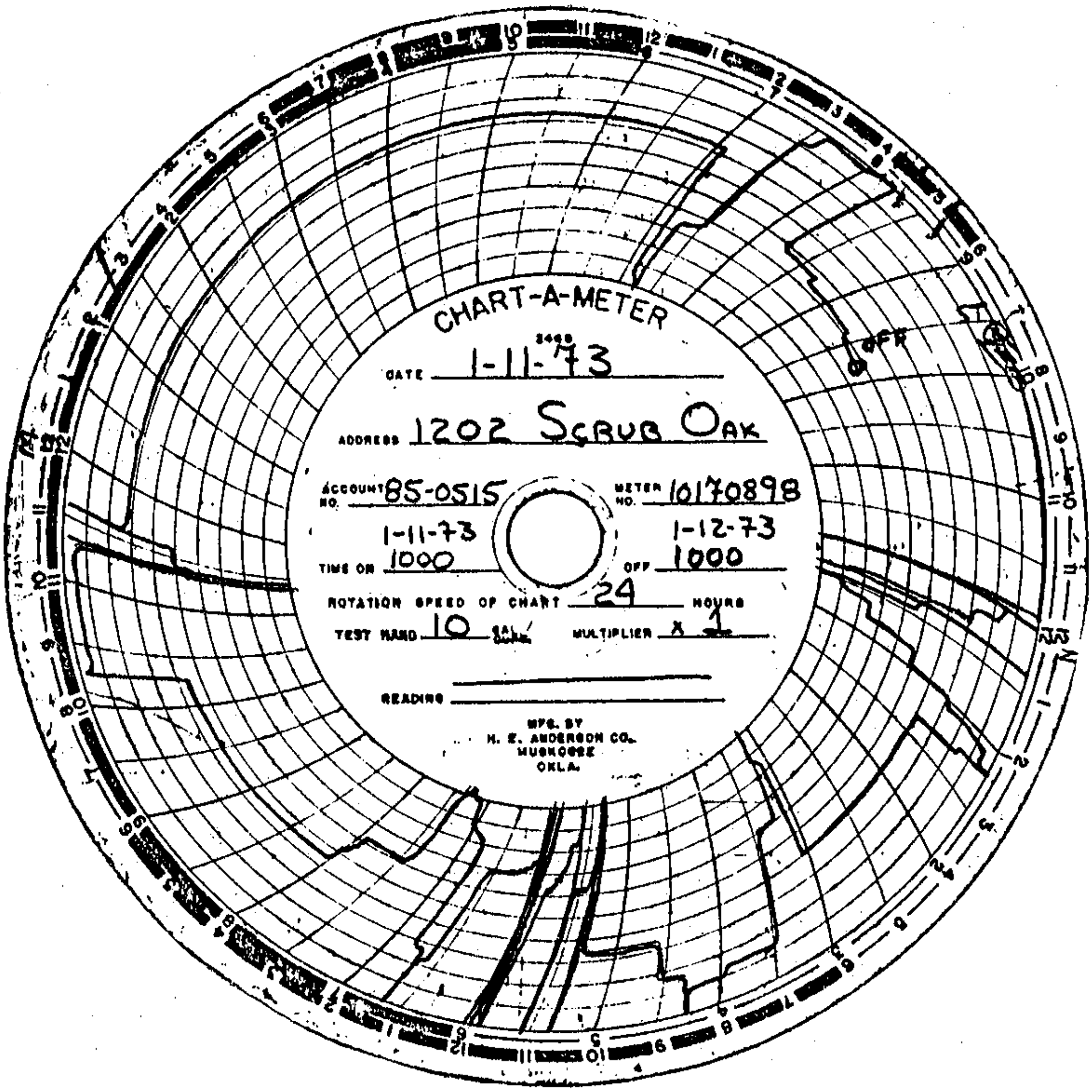

FIGURE 2 WAX RECORDING DISC

Home Water Use Recording Sheet

TIME A.M.	SINK (Any Gen. Use)	TOILET	GARBAGE DISPOSAL	BATH OR SHOWER	WASHING MACHINE	DISHWASHER	OTHER (Wash floors, etc	TIME P.M.	SINK (Any Gen. Use)	TOILET	GARBAGE DISPOSAL	BATH OR SHOWER	WASHING MACHINE	DISHWASHER	OTHER (Wash floors, etc
Midnite								Noon		A			C		
12:15								12:15	F						
12:30								12:30	F						
12:45								12:45	F						
1:00								1:00	A						
1:15								1:15	C						
1:30								1:30	A						
1:45								1:45							
2:00								2:00							
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6:45	A							6:45		AA					
7:00		C						7:00	A						
7:15								7:15		A					
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The general water usage for the entire study group is shown in Table 2. The average water usage for the entire study group was found to be 44.4 gallons per person per day. It should be noted that the results for the first and last days shown in Table 2 were combined to form one twenty-four hour period.

Table 3 gives a breakdown of the use characteristics by appliance and function for each station studied. The usage for each appliance as a function of age group is shown in Table 4. In viewing Tables 2, 3, and 4, it can be seen that a representative domestic per capita water use figure was a highly variable quantity. Water usage seemed to be a function of life style rather than family size or age. The families of stations one and two were quite similar, yet there was a significant difference in the water use from the two stations. From interviews with the two families, the only major difference that could be found was one of life style. Both families were the same size, the children of both families were approximately the same age, both homes were the same size, and had the same appliances. The only major difference was that the housewife of station two was out of the home doing community service work most afternoons. She and her youngest child were consequently using other people's water for drinking, toilet, and washing. The small families in stations three and four were very similar in most respects but their daily per capita water uses were quite different. It can be concluded from the data of this small sampling that family size was not the most significant variable in daily household water use.

Table 2

Total Water Use in Study
(Amounts in Gallons)

Day	Date	Sta. 1	Sta. 2	Sta. 3	Sta. 4	Sta. 5
Tues	Jan 9	194.5	127.5		78.5	81.0
Wed	Jan 10	288.0	88.5		138.5	217.5
Thur	Jan 11	220.0	282.5			99.5
Fri	Jan 12	136.5	39.5		201.5	99.5
Sat	Jan 13	265.0	202.0		119.0	106.0
Sun	Jan 14	175.0	194.5		115.5	129.5
Mon	Jan 15	309.5	144.0		289.0	100.0
Tues	Jan 16	41.0	48.0	142.0	34.0	120.0
Wed	Jan 17			93.5		205.5
Thur	Jan 18			200.0		154.0
Fri	Jan 19			204.5		180.0
Sat	Jan 20			41.0		94.0
Sun	Jan 21			118.0		149.0
Mon	Jan 22			59.5		234.5
Tues	Jan 23			47.0		10.0
Average GPD		244	159	129	165	145
Average GPCD		49	31.8	64.5	82.5	36.3

Average GPD/Home = 165 Average GPCD = 44.4

Table 3

Use Characteristics
(Amounts in Gallons)

Station		Sink	Toilet	Garbage Disposal	Bath & Shower	Washing Machine	Dish Washer
	Times Used	255	125	10	5	14	6
	Tot. V Used	335	592.5	23	124	513	41
1	Tot. Use %	20%	38%	1%	8%	31%	2%
	Uses/Day	37.3	19.3	1.4	0.7	2.0	0.9
	Volume/Use	1.28	4.71	2.3	24.8	36.64	6.83
	Times Used	69	78	1	12	6	2
	Tot. V Used	161	356.5	4	295	247	12
2	Tot. Use %	15%	33%	0.4%	27.4%	23%	1.2%
	Uses/Day	9.86	11.14	0.14	1.71	0.86	0.29
	Volume/Use	2.33	4.61	4.0	24.58	41.17	6.0
	Times Used	78	85	7	12	2	4
	Tot. V Used	169	333.5	15	229	85	27
3	Tot. Use %	20%	39%	1.8%	27%	10%	3.2%
	Uses/Day	11.14	12.14	1	1.71	0.26	0.57
	Volume/Use	2.17	3.92	2.14	19.08	42.5	6.75
	Times Used	125	93	24	6	4	
	Tot. V Used	243.5	344	51.5	94	189	
4	Tot. Use %	26%	37%	5%	10%	20%	
	Uses/Day	20.8	15.5	4	1	0.67	
	Volume/Use	1.95	3.70	2.15	15.67	47.25	
	Times Used	135	144	12	13	13	8
	Tot. V Used	243.5	520.5	24	563	472	51
5	Tot. Use %	13%	28%	1%	30%	25%	3%
	Uses/Day	10.31	11.08	0.92	1.0	1.0	0.62
	Volume/Use	1.79	3.61	2.0	43.31	36.31	6.38

<u>Total Study Group</u>

	Sink	Toilet	Garbage Disposal	Bath & Shower	Washing Machine	Dish Washer
Times Used	662	525	54	48	39	20
Tot. V Used	1152	2146.5	117.5	1305	1506	131
Tot. Use %	18%	34%	2%	20%	24%	2%
Uses/Day	16.55	13.13	1.35	1.20	0.98	0.56
Volume/Use	1.74	4.09	2.16	27.19	38.62	6.55

NOTE: Station four was the only study group to report 'other uses'. This occurred five times using 18 gallons of water. This use accounted for two percent of this station's use.

Table 4

Individual Appliance Water Use

Appliance	Gallons per Use Mean	Gallons per Use Model	Uses per Person per Day (Avg. 3.8 people/home)		Gal/Per. Day
Toilet	4.1	4.0-4.5	All people	= 3.6	14.7
			Adults (21+ yr)	= 4.5	
			Teenage (13-20)	= 2.4	
			Child (1-13)	= 2.4	
Sink	1.7	1.0	All people	= 4.5	7.6
35% Kitchen			Adults (21+ yr)	= 5.8	
65% Bath			Teenage (13-20)	= 2.9	
			Child (1-13)	= 3.1	
Garbage Disposal	2.1	2.0	All people	= 0.40	0.8
Bath and Shower	27.2	21	All people	= 0.32	8.7
			Adults (21+ yr)	= 0.27	
			Teenage (13-20)	= 0.76	
			Child (1-13)	= 0.16	
Dishwasher	6-7	6-7	All people	= 0.15	1.1
Washing Machine	38.6	40	All people	= 0.30	11.6
			Adults (21+ yr)	= 0.29	
			Teenage (13-20)	= 0.09	
			Child (1-13)	= 0.32	
TOTAL WATER USE PER DAY				gcpd	
			All people	= 44.4	
			Adult	= 49	
			Teenage	= 41	
			Child	= 34	

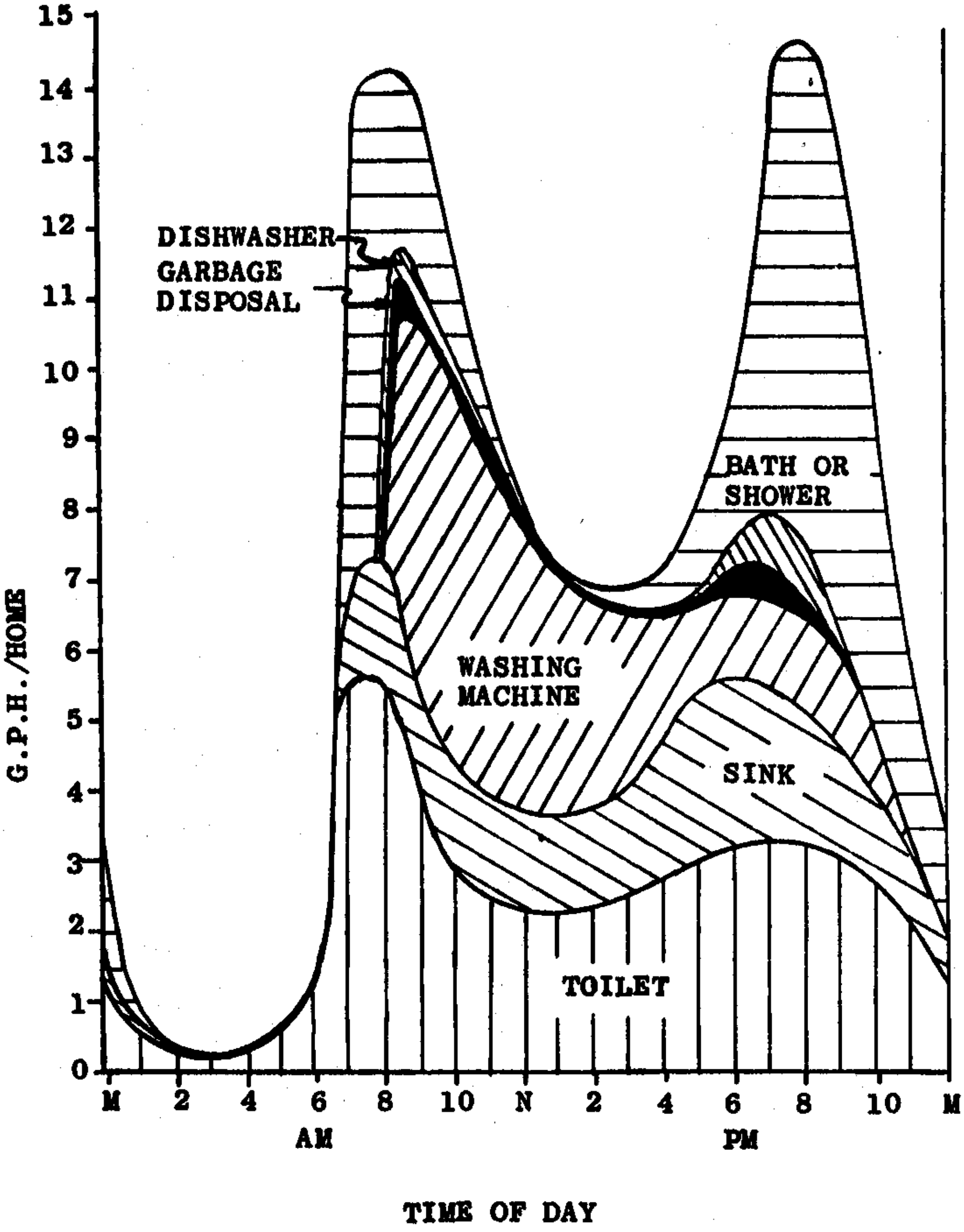


FIGURE 3. DAILY HOUSEHOLD WATER USE

The flow data for the individual homes were analyzed to establish hourly water use patterns. The results reflected highly variable patterns between homes, influenced by the personal habits of the occupants. When the flow patterns from the five stations were combined, the bimodal curve of Figure 3 resulted. The morning peak resulted from a combination of functions at the beginning of the day, while the evening peak was predominantly due to bathing habits.

Evaluation of the distribution of water use for each function is shown in the six histograms of Figures 4 and 5.

Toilet uses occurred during every time slot of the day on at least one of the 45 questionnaire sheets. Most toilets took four gallons per flush but the range was two gallons to five and one half gallons. Some of the homes studied had toilets that flushed with the same amount of water every time and some that could vary as much as a gallon per flush.

The exact reason or location for each sink use was not determined. A sink use generally followed a toilet use and many sink uses were recorded before and after each meal. The volume of the sink use was the most varied of all of the uses studied. The mean use of ~1+ gallons was by far the most prevalent volume, but the range of values was from a trace to forty-eight gallons.

The exact amount of water used for each garbage disposal use was very difficult to determine. There was always a sink use accompanying a disposal use. In most cases, disposal uses occurred immediately after meal time.

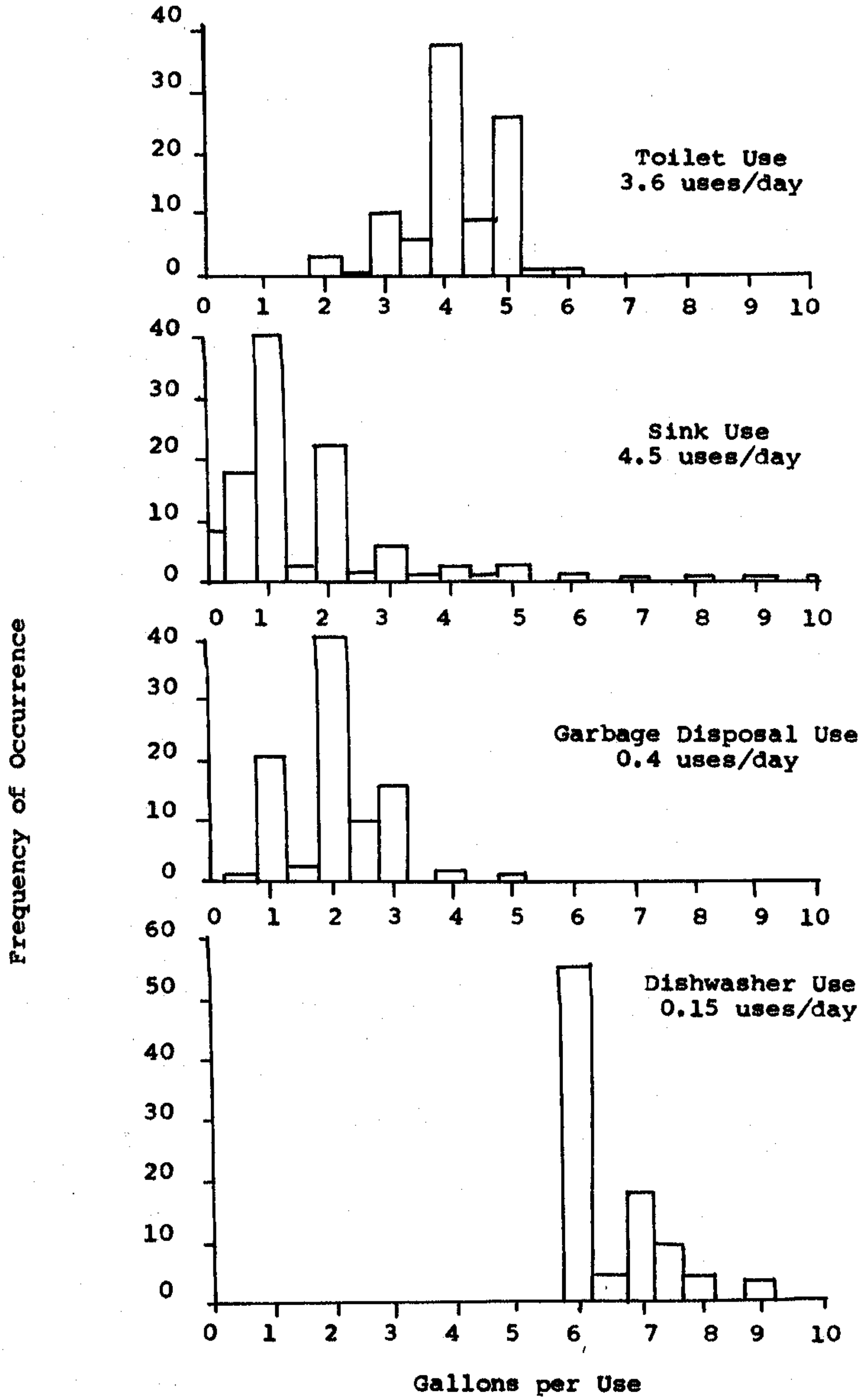


FIGURE 4 WATER USE FREQUENCY HISTOGRAMS

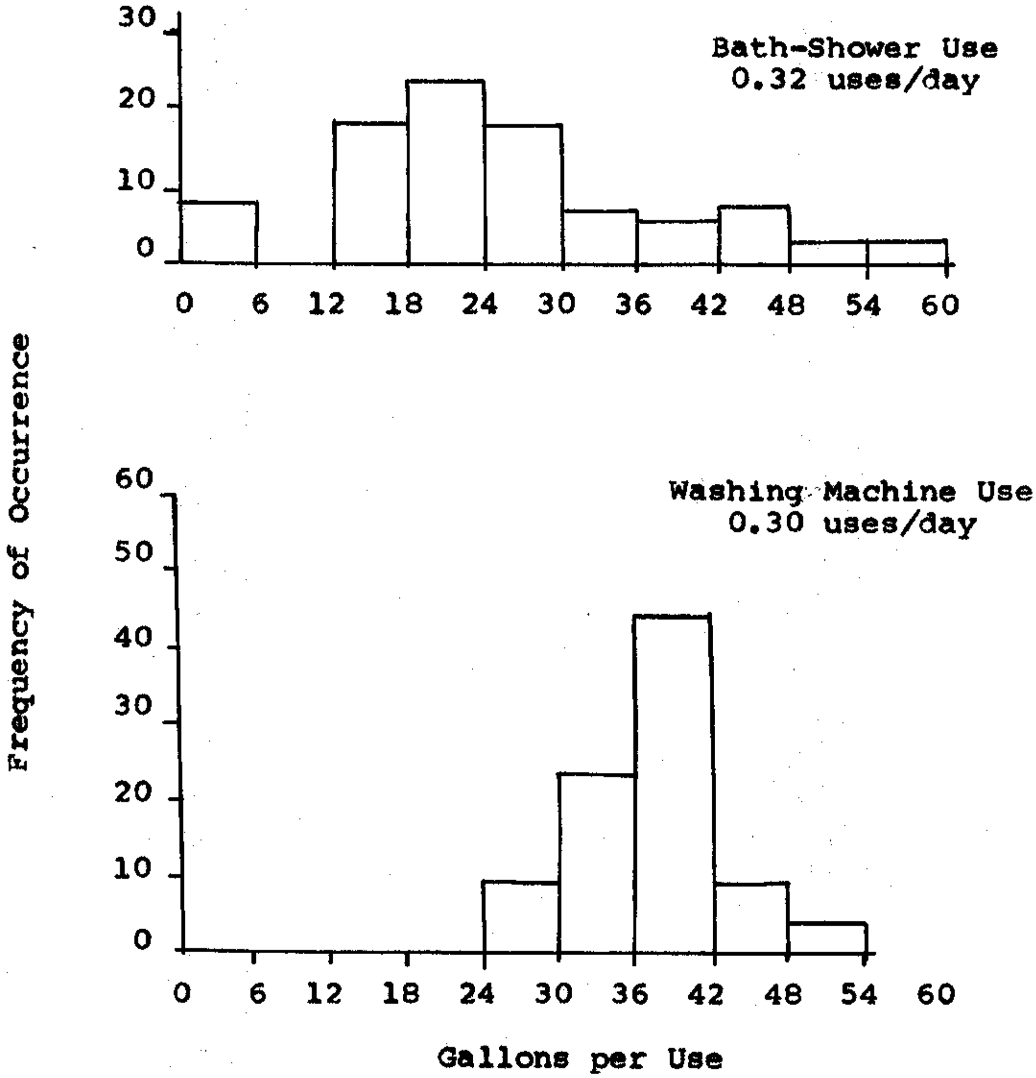


FIGURE 5 WATER USE FREQUENCY HISTOGRAMS

There was no special time for the dishwasher to be used, although the use generally occurred around a meal time. All of the dishwashers studied ran in cycles. Each cycle used approximately one and one-half to two gallons of water. The number of cycles varied from three to nine. In the case of the nine cycles, the housewife stopped the machine prior to all nine cycles being completed. A determination was made of the amount of water needed to wash dishes by hand. The amount was generally much higher than that used by the dishwasher. The variables seemed to be the number of washing sinks needed and the way the dishes were rinsed. If the water was left running during the entire washing process, the amount of water used was as high as thirty-eight gallons. If, however, the water was turned off and all of the dishes rinsed together, the amount of water used was reduced to eight gallons.

Bath use was generally twenty gallons per use while shower use was generally thirty gallons per use. The bath use did not vary much throughout the study. The shower use did vary quite a bit. Upon instruction, one person took a shower with as little water as possible. This shower took two and one-half gallons. The figure of less than five gallons appeared four times in the study for shower use. The longest showers were taken by a teenaged girl who averaged over fifty gallons per shower. This amount apparently was limited by the size of the hot water heater.

The volumes of water, reported in Table 5, for washing machine uses were collected without any clothes in the machines.

Most washing machines fill to a level determined by weight. Therefore, these figures would generally be slightly less with clothes in the machine. This proved to be true with every washer in the study, although the difference was always less than two gallons per cycle. The short cycle in the middle of each run occurs as the wash water is leaving the machine. The reason that its volume is so greatly increased for the permanent press cycles is that the clothes are kept wet at all times. Therefore, the washer fills as it empties. The figures in the table represent most of the machines used in the study. 1975 model machines tend to use more water, ranging from 36 to 60 gallons on the normal setting and 36 to 71 gallons in the permanent press mode. Average quantities of water use are 48 gallons in the normal setting and 52 gallons in the permanent press mode for new machines.

Table 5

Washing Machine Water Use

Setting	Wash (gal)	Pre-rinse (gal)	Rinse (gal)
Small load	10	5	10
Small load, perm. press	10	13	11
Medium load	15	7	15
Medium load, perm. press	15	18	15
Normal load	18	4	18
Normal load, perm. press	18	18	18

Another item studied with regard to appliance use was peaking factors. Figure 6 shows the flow peaks for all of the stations in the study. It can be seen that the peak flows lasting one hour or more were generally the same for all of the stations.The homes could receive water at approximately ten gallons per minute through the 5/8" meters and plumbing. From the data in this study, it is postulated that all homes will display this type of curve for peak water demands. The only difference in curves for different homes would be the upper boundary. That is, a home receiving well water at four to six gallons per minute would display the same type of curve with a longer, flatter upper boundary. This would be due to the longer time required to meet demands such as filling the washing machine.

While the time required for different drains to empty appliance basins may differ,[12] the peaking factors as applied to waste disposal systems should not be overlooked. Some appliances, such as washing machines and dishwashers, pump their effluents. As a consequence peak loading from this type of discharge may approach twenty gallons per minute. The simultaneous discharge of two or more appliances may pulse load a treatment system even more severely. In general, it can be seen that pulse loads of sixty gallons within a few minutes were not uncommon. Peaking factors are very important in the small treatment systems used in individual homes. A pulse flow of sixty gallons can wash out the settling tank of an aerobic unit

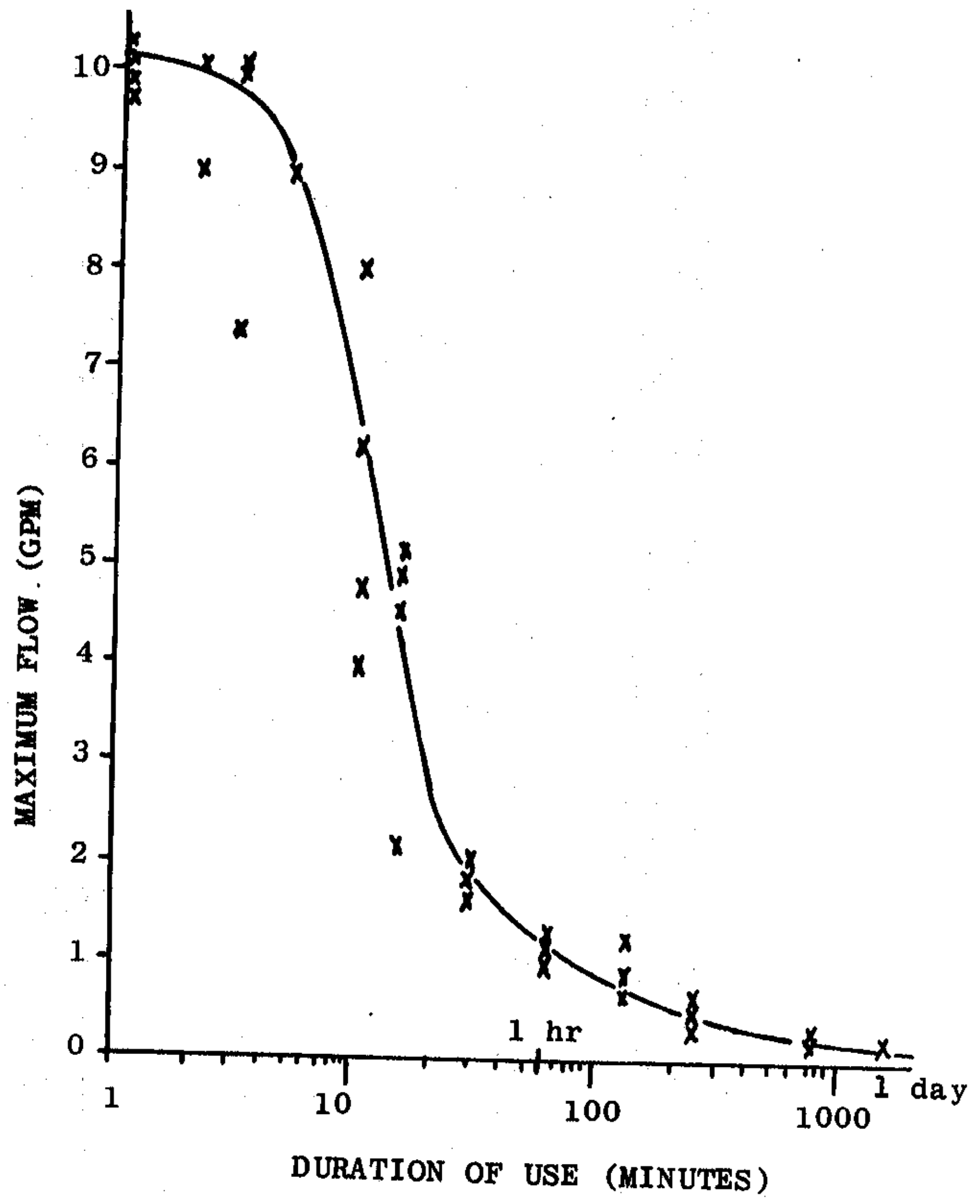


FIGURE 6 DURATION-MAXIMUM INTENSITY FLOW CURVE FOR INDIVIDUAL HOME WATER USE

and remove the necessary biological floc. Peak flows also cause problems with disinfection systems.

Comparison with Published Data

The results of three recent comprehensive field studies from throughout the United States have become available within the past year. These data are summarized in Table 6.

Table 6

Sources of Wastewater Flows
(gallons/person/day)

Source	This Study	Cohen[13] et al	Witt[14] et al	Ligman[15] et al	Range	Average	%
Toilet	15	13	9	20	9-20	14	32
Laundry	12	8	11	10	8-12	10	22
Bath-total	11				5-12	10	22
tub, shower	(9)	5	10	12		(9)	
sink	(2)					(2)	
Kitchen-total	7	13			5-13	8	18
sink	(5)					(5)	
dishwasher	(1)		5	4		(3)	
garbage disp.	(1)			2		(1)	
Misc.	0	5	8	0	0-8	3	6
Total	44.5	43.8	42.6	47.5	42.6-47.5	44.6	100

Although the studies were conducted in somewhat different ways, and in widely separated parts of the country, the results show a very close correlation, with only a ±4% variation from the mean for total per capita water usage. These results are significantly lower than the values given in the Manual of Septic Tank Practice[1] of 75 gallons per capita per day for a single residence or 60 gallons per capita per day for multiple family residences. Other sources of published literature 16,17,18,18,20 have produced a wider range of values. The quantities used in Table 6 were selected because they were felt to represent very recent field measured values for the wastewater generation in individual homes.

The maximum flows near 8 o'clock in the morning and again at the same hour in the evening as shown in Figure 3 can be observed at most sewage treatment plants and have been reported by many authors. The hourly distribution of flow was the result of personal habits involved in the normal work day.

The variation in total daily flow throughout the week has been reported by others.[14,15] Based on long term studies, they have found that the average daily flow varied from a low of 38 gallons per person per day on Wednesdays[15] or Fridays[14] to a maximum of 50 gallons per person per day on Mondays[14] or Saturdays.[15] Because of the short duration of this study, a greater variation in the average daily flow resulted. The results from this study are shown in Figure 7. Mondays were found to have been the days of greatest flow and Saturday those of least flow. Superimposed on the figure are the data of Witt, et al.[14]

It can be noted from the data of Table 2, that small families (Stations 3 and 4) had a higher per capita water use than larger

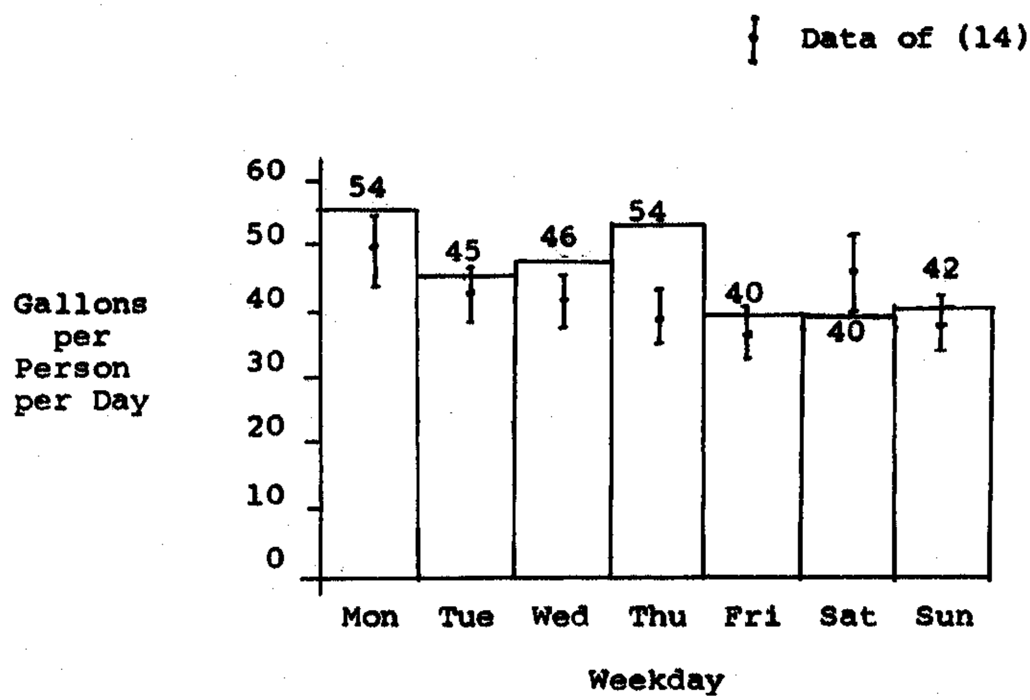


FIGURE 7 DAILY WATER USE VARIATIONS

families (Stations 1 and 2). The reasons for this were probably related to the fact that all homes had appliances such as washing machines and dishwashers that used the same amount of water and the finding that adults used considerably more bathing water than children, as evidenced in Table 4. The families of five persons had average weekly water uses of only about one-third greater than that of the families of two persons. A rough estimate of water use as a function of family size based on this report and the work of others[13,14] is that daily household water use,

$$Q \text{ gal/house/day} = 60 \text{ gal} + 40 \text{ gal/adult resident} + 20 \text{ gal/child resident},$$

assuming that all fixtures and appliances were available and used.

Discussion

From the results of several studies, it can be concluded that average daily per capita water use in the individual home is 45 gallons per day. Average peak hour flows were found to be approximately twice that value. For design purposes two values are important, the average flow for a family on the maximum day and the short term maximum pulse flow that could occur. The family generated maximum day flow should be used in the design of biological system detention times, and for the infiltration rate of percolating systems. A value of 250 gallons per household per day is recommended for medium and large size individual residences with only a slight reduction for very small, non-expandable, residences. The maximum pulse flow is important in the design of hydraulic elements such as settling tanks in aerobic units. A short term surge flow of sixty gallons per residence has been established and was found to occur with flow rates as great as 10 gallons per minute.

CHAPTER III - WASTEWATER POLLUTIONAL STRENGTH CHARACTERIZATION

The same homes evaluated in the water use study were investigated in this phase of the investigation. In addition to the homes in the first phase of the study, other homes were sampled and tested. When samples were collected, no special preparation was required of the household. The people were requested to use their appliances normally and give no consideration to the sampling or testing. The method of testing and storage of samples was in accordance with the procedures stated in "Standard Methods for the Evaluation of Water and Wastewater," 13th Edition,[21] except for the MBAS test. Each water use function, as well as each water using cycle of the appliance, was tested for the following pollutional parameters:

COD - Chemical Oxygen Demand - A measure of the amount of oxygen required to oxidize all carbonaceous matter in the waste. It was measured with dichromate oxidation under strong acid conditions.

BOD - Biochemical Oxygen Demand - A measure of the oxygen used by micro-organisms in the oxidation of the degradable matter in the waste, over a period of five days at 20°C. Some investigators[22] have predicted low and erratic BOD_5 results from samples containing mostly detergent wastes. It was found that this could be avoided by the use of secondary clarifier effluent from an activated sludge treatment facility as seed water.

<u>TOC - Total Organic Carbon</u> - The carbon content of organic compounds was measured using an Oceanographic Ins. Co. analyzer that vaporized the sample with heat and oxidized carbon compounds to carbon dioxide. The CO_2 content was measured with an infrared spectrometer and read out on a digital recorder equipped with an integrator. Corrections for carbonate carbon were made.

<u>MBAS - Methylene Blue Active Substance</u> - Surface active agents, primarily from detergent sources, were measured using a slight modification of the standard MBAS test. Vigorous shaking and swirling to break the emulsion was used in place of the rocking of the mixture in the separatory funnels as suggested in Standard Methods to give reproducable results. A wavelength of 645 mu was used in the spectrographic analysis.

<u>TS - Total Solids</u> - A measure of the total weight of suspended and dissolved organics and salts remaining after evaporation of all water. The <u>% Organic</u> matter in the residue was measured by the loss of weight due to burning off of the organic matter at 550°C.

<u>TSS - Total Suspended Solids</u> - The dry weight of all materials retained on the filter disk in a gooch crucible was recorded as total suspended solids. The <u>% Organic</u> matter was determined by loss of weight on ignition at 550°C.

<u>PO_4 - Total Phosphate</u> - The total phosphate content of the samples was measured by the stannous chloride photometric test after digestion of all complex phosphates to the ortho form.

NH_3-N - Ammonia Nitrogen - This compound was measured using the Kjeldahl distillation method and titration of the reacted boric acid solution. A small piece of parifin was used in each sample to prevent foaming. An ammonia free sample of water was tested to ensure that the results were not affected by the parifin.

Temp. - Temperature - Measurements were made with a laboratory thermometer at the time of sampling.

pH - The hydorgen ion concentration was measured with a laboratory pH meter.

The method of sampling generally involved grab samples from each of the water use points at several of the homes. Two additional homes were used in this portion of the work, to bring the total to eight.

Sink and bath samples were obtained by simply stoppering the drain, using the fixture in the normal manner, mixing the resulting water thoroughly, and taking a sample.

Sampling the garbage disposals required disconnecting the flexible discharge hose so that the total discharge for each use could be caught in a five gallon bottle. The appliance was used in the normal manner and the total discharge was blended and sampled.

The dishwashers and washing machines were equipped with flexible hoses that were easily removed from the drain fixture. It was possible to collect the total discharge from each cycle of operation for blending, sampling, and analysis.

The pollutional strength characteristics of the toilet wastes were the most difficult to establish. The approach that was used was to establish the pollutant concentrations of human wastes and to calculate the resulting strength characteristic when diluted in the volume of carriage water used for the average fixture.

A review of the medical literature yielded no quantitative values for mass, volume, or strength of human discharges but it was often pointed out that the values are extremely variable and dependent upon the dietary intake of the persons involved. Five sources[23-27] were found that produced some data to be used as a starting point for the estimation of pollutional values for human wastes. Rafter and Baker[23] gave the data in Table 7 collected over a one year period in the 1890's from 100,000 people. In addition to the data presented in the table, Rafter and Baker also reported that human feces contain 77.2% water and 19.8% organic matter while urine contains 96.3% water and 2.4% organic matter.

Table 7

Human Excrements*
(Pounds per Capita per Day)

	FECES			URINE		
	Total	Organic Nitrogen	Phosphates	Total	Organic Nitrogen	Phosphates
Men	0.33	0.0038	0.0072	3.29	0.032	0.013
Women	0.10	0.0022	0.0024	2.96	0.024	0.012
Boys	0.24	0.0040	0.0035	1.25	0.010	0.005
Girls	0.05	0.0013	0.0008	1.01	0.008	0.004
Mean	0.18	0.0028	0.0035	2.13	0.019	0.009

*After Rafter and Baker
Totals are wet weight basis

From the data in Table 7, one can calculate the dry weight total solids per person per day to range from 35 gms for children to 90 gms for adult males.

Metcalf and Eddy[24] used measurements of the average contributions to the total solids in the sewage of one eastern city, and reported water supply 13.2%, feces 21.2%, urine 44.9%, and toilet paper and newspaper 20.7% for a total of 96.5 grams per capita day. This would result in an average of approximately 65 to 80 gms per person per day for an average of all people.

Ehlers and Steel[25] have stated that the per capita daily loading of human wastes average about 83 gms of feces at 20% solids and 970 gms of urine at 2.5% solids. This calculates to approximately 40 gms dry weight per person per day.

The staff of the Research and Education Association[26] reported the work of the Swedish National Institute for Building Research findings of 53 gms of total residue per person per day of which 73% was volatile.

Hawk[27] has shown values in the Physiological Chemistry Handbook of fecal dry weight of 25 to 45 grams per day for adult males and 22 grams per day for all people based on 1000 samples. Dry weight of urine was listed as 50-60 grams per capita per day made up of nitrogen 13.2 gms, chlorides 10 gms, sodium 4 gms, phosphate 1.1 gms, potassium 2 gms, sulfur 2 gms, and ammonia nitrogen 0.1 gms.

A brief evaluation was made as a part in this study involving several persons of different ages and sizes for a period of one to three days using a camping toilet approach. These data along with the literature values were used to construct Figure 8. The figure should be considered to contain information that is only an approximation. It was used along with the average body weight of the persons in the five house study to derive the total solids pollutional characteristics for toilet wastes. COD and BOD levels for toilet wastes were based on measured values of the ratio with total volatile solids. The ratios obtained are shown in Table 8.

Table 8
Pollutional Ratios for Human Wastes

	COD/TVS	BOD/TVS
Feces	2 mg/mg	0.28 mg/mg
Urine	0.5 mg/mg	0.085 mg/mg
Paper	1.3 mg/mg	0 mg/mg

It can be noted that the BOD values were quite low. Seeding procedures were followed but it is felt that low results were obtained when measuring the BOD of diluted samples of wastes containing only fecal matter or urine samples.

The results obtained in the evaluation of the pollutional characteristics of home wastes are shown in Tables 9 and 10. It can be noted that for the pollutional parameters of COD, BOD, and solids, the contribution from each source was approximately: toilet 40%, garbage disposal 20%, sink 20%, clotheswasher 15%, bath 4% and dishwasher 1%. The relationship

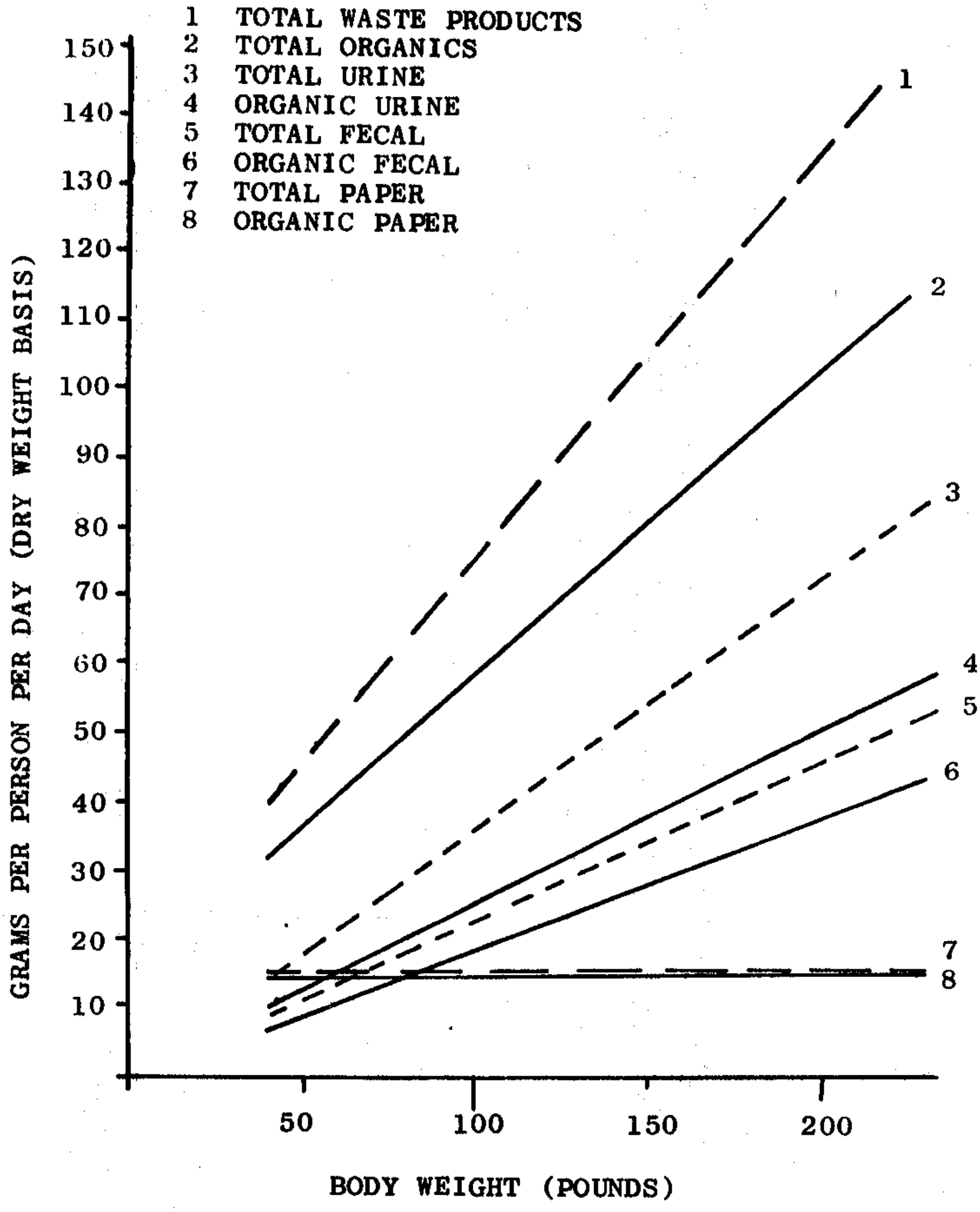


FIGURE 8 APPROXIMATE VALUES UTILIZED FOR TOTAL AND ORGANIC SOLIDS ESTIMATES FOR HUMAN WASTES

Table 9

Average Characteristics of Home Wastewater Sources

	Flow/Use (gal)	COD mg/ℓ	BOD mg/ℓ	TOC mg/ℓ	TS mg/ℓ	% Org.	SS mg/ℓ	% Org.	MBAS mg/ℓ	PO_4 mg/ℓ	Total N mg/ℓ	Temp °C	pH
Sink													
Kitchen	1.0	1652	1082		1328	71	209	100	-	1	114	43	6.6
Bathroom	2.0	495	261		480	23	228	100	6	0	1	20	7.9
Average		850	533	370	760	53	215	100	-	1	38	28	7.2
Bath-Shower	27.2	220	100	21	339	6	27	100	53	0	0	38	8.2
Toilet													
Feces (gm/CD)		(34)	(4.7)		(22)	78	(22)	78		(2.2)*	(1.7)*		
Urine (gm/CD)		(13)	(2.2)		(40)	65	(0)	0		(0.9)	(3.5)		
Paper (gm/CD)		(18)	(0)		(14.5)	95	(14.5)	95			0		
Average	4.1	1180	124		1400	73	650	85	-	55	95	21	5.6
Washing Machine													
Cycle 1	17.2	1050	400	174	1185	17	128		77	30	8	55	8.5
Cycle 2	4.2	185	46	4	421	6	0		4	3	1	39	7.9
Cycle 3	17.2	130	39	10	527	20	46		2	1	1	55	7.0
Average	38.6	550	200	82	760	16	78	95	35	14	5	53	7.8
Garbage Disp.	2.1	11780	4065		10748	68	6672	95	-	24	285	30	6.4
Dishwasher													
Cycle 1	2.0	620	363	137	2207	20	83		0.3	15	0	58	10.9
Cycle 2	1.0	210	99	47	1083	16	16		0.1	1	0	58	8.3
Cycle 3	2.0	44	23	18	412	3	0		0	0	0	58	7.0
Cycle 4	1.0	35	6	5	75	0	0		0	0	0	58	6.9
Cycle 5	1.0	11	2	0	73	0	0		0	0	0	90	7.0
Average	7.0	225	125	50	920	16	26	100	0.1	4	0	62	7.6
Combined (mg/ℓ)		930	278		1080	55	396	90	15	22	44	36	7.4
Average (#/CD)		0.34	0.11		0.40	0.22	0.15	0.14	0.005	0.008	0.015		
Witt (#/CD)			0.13		0.31	0.19	0.11	0.09		0.009	0.015		

*Literature values

Table 10

Mass Characteristics of Home Wastewater Sources

	Flow/Use (gal)	Flow gcd	COD gmcd	BOD gmcd	TS gmcd	TVS gmcd	SS gmcd	VSS gmcd	PO_4 gmcd	Total N gmcd
Sink										
Kitchen	1.0	2.6	16.2	10.6	13.4	9.5	2.1	2.1	0.0	1.1
Bathroom	2.0	5.0	9.2	4.9	9.4	2.2	4.3	4.3	0.0	0.0
Total		7.6	24.4	15.5	21.8	11.7	6.4	6.4	0.0	1.1
Bath-Shower	27.2	8.7	7.2	3.2	10.9	0.6	0.9	0.9	0.0	0.0
Toilet										
Feces			34.0	4.7	22.0	17.2	22.0	17.2	2.2	1.7
Urine			13.0	2.2	40.0	26.0	0	0	0.9	3.5
Paper			18.0	0	14.5	13.5	14.5	13.5	0	0
Total	4.1	14.7	65.0	6.9	76.5	56.7	36.5	30.7	3.1	5.2
Washing Machine										
Cycle 1	17.2	5.1	20.4	7.7	22.0	3.7	2.5		0.6	0.2
Cycle 2	4.2	1.4	1.0	0.3	2.2	0.1	0.0		0.0	0.0
Cycle 3	17.2	5.1	2.6	0.7	9.1	1.8	0.9		0.0	0.0
Total	38.6	11.6	24.0	8.7	33.3	5.6	3.4	3.2	0.6	0.2
Garbage Disp.	2.1	0.8	35.6	12.3	32.5	22.1	20.2	19.2	0.1	0.2
Dishwasher										
Cycle 1	2.0	0.3	0.7	0.4	2.5	0.5	0.1		0.0	0.0
Cycle 2	1.0	0.17	0.1	0.1	0.7	0.1	0.0		0.0	0.0
Cycle 3	2.0	0.8	0.1	0.0	0.3	0.0	0.0		0.0	0.0
Cycle 4	1.0	0.17	0.0	0.0	0.1	0.0	0.0		0.0	0.0
Cycle 5	1.0	0.17	0.0	0.0	0.1	0.0	0.0		0.0	0.0
Total	7.0	1.1	0.9	0.5	3.8	0.6	0.1	0.1	0.0	0.0
Combined (gmcd)			157	47.1	178.8	97.3	67.5	60.5	3.8	7.4

gmcd = grams/capita/day

of the flow distribution of each functions in the home to one of the pollution parameters, COD, is shown in Figure 9. It can be noted that toilet and garbage disposal wastes accounted for more than two-thirds of the pollutional load (COD), but comprised only about one-third of the flow. It can be seen from Table 10 that much of the detergents (shown as MBAS) resulted from the washing machine and shower wastewaters. It is well known that the major nitrogen and pathogen sources are from human wastes. Through laboratory determinations it was found that approximately two-thirds of the COD in the laundry and bathing wastes was in the soluble form and was almost exclusively dissolved detergent. The values of pollutional parameters for washing appliances used without detergents are shown in Table 11.

The waste strength values have been combined with the hourly flow data of Figure 7 to produce a curve of hourly pollutional distribution shown in Figure 10. A bimodal curve resulted which was similar in some ways to Figure 7, but for quite different reasons. The toilet and garbage disposal contributions were the major factors that affected the shape of Figure 10.

Work of Other Researchers

Two recent publications have presented comprehensive field and laboratory evaluations of individual home wastes.

Witt, et al,[14] in reporting an excellent study, have presented the results on flow and pollution strength characteristics

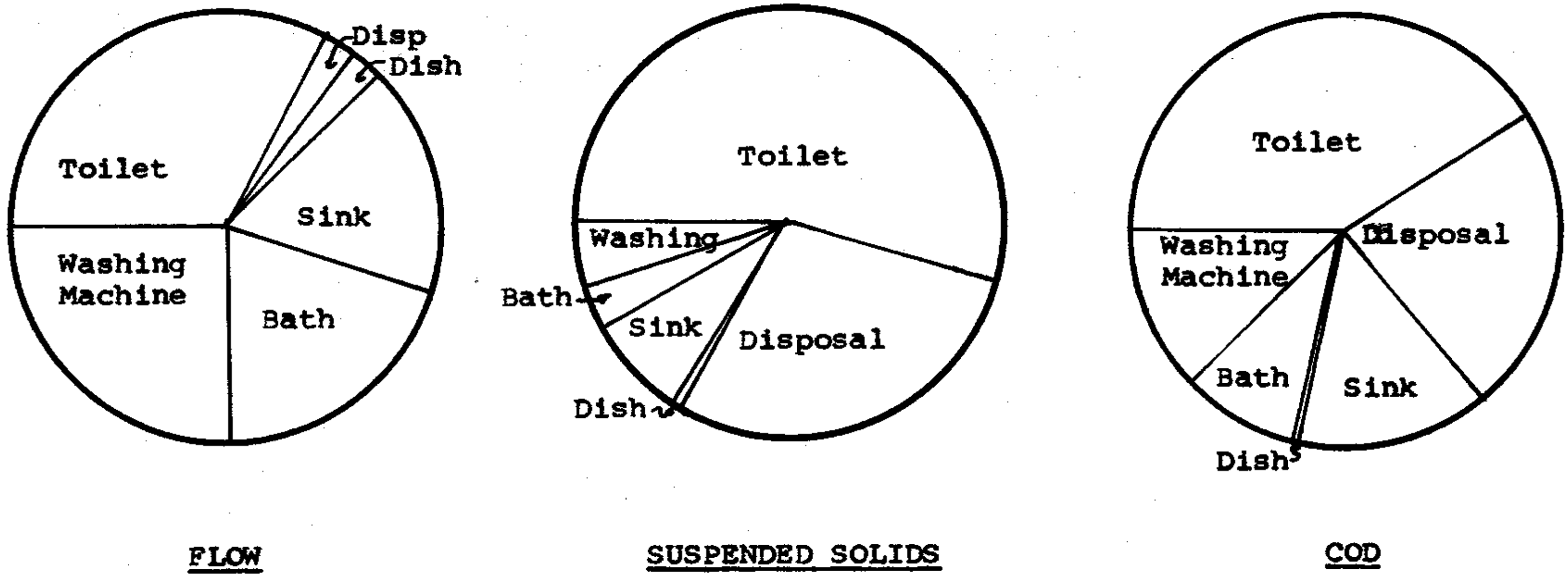


FIGURE 9 DISTRIBUTION OF FLOW AND POLLUTION SOURCES

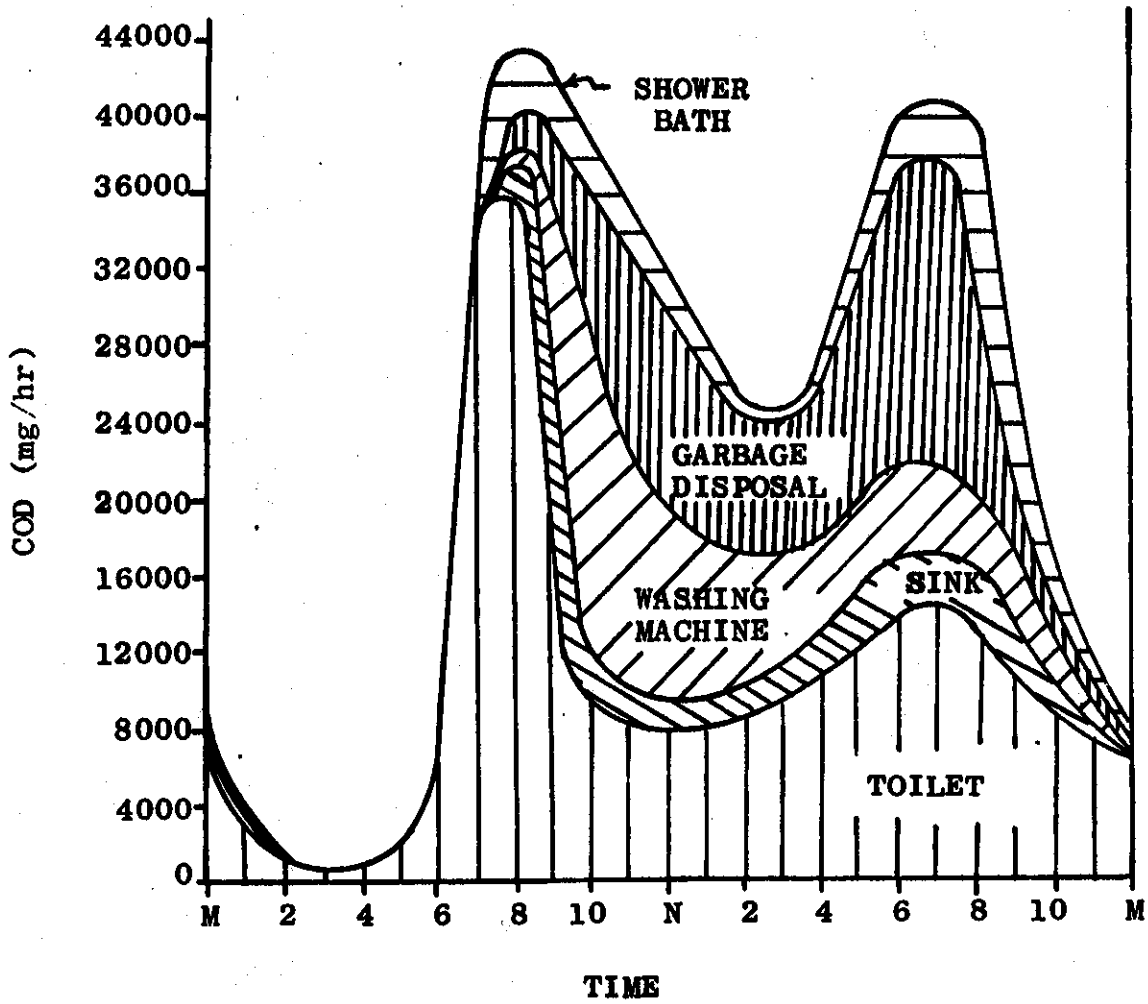


FIGURE 10 HOURLY COD PROFILE

Table 11

Mean Chemical Characteristics of

Appliance Waste Streams Without Detergent

Source	COD mg/ℓ	BOD mg/ℓ	MB-AS mg/ℓ	Total PO_4-P mg/ℓ	TS mg/ℓ	TFS mg/ℓ	TVS mg/ℓ	TSS mg/ℓ	VSS mg/ℓ
Tap water	0.0	0	0.006	0	157	157	0	0	0
Bath/Shower	44.8	38	0.035	0.015	212	178	34	30	30
Washing Machine									
Cycle 1	69.4	5	0.025	0.015	194	174	20	21	21
Cycle 2	12.5	0	0.011	0	172	166	6	9	9
Cycle 3	3.6	0	0.006	0	161	161	0	0	0
Dishwasher									
Cycle 1	92.0	71	0.025	0.015	979	702	277	350	350
Cycle 2	45.0	36	0.025	0	930	726	204	179	179
Cycle 3	10.0	0	0.006	0	825	674	151	0	0
Cycle 4	3.5	0	0.006	0	222	202	20	0	0

of home wastes. These results were developed in a 434 day, University of Wisconsin investigation involving daily evaluation of eleven homes. The results on hourly patterns and daily per capita pollutional input compare very closely with the findings of this investigation.

The Swedish National Institute for Building Research has conducted a study in which they sampled and analyzed the individual discharges from the kitchens, baths, laundries, and toilets of twenty-five homes. This was done in Bromsten, a suburb of Stockholm, over a period of twelve weeks. The work was reported by the Staff of the Research and Education Association.[26] Their work delineated many of the same pollutional parameters used in this study.

The results, expressed as total daily per capita contribution in grams, are summarized in Table 12 for each of the pollutional parameters reported by Witt, et al, the Swedish Institute, and this study.

The close correlation of the results can be noted. The BOD values obtained in this study appeared somewhat low, as discussed earlier. The water use per capita was slightly lower in the Swedish study. This was expected due to the different fixtures and appliances used in Europe. The slight difference in all pollutional parameters between this report and Witt, et al, was due to the amount of toilet usage. Witt, et al, used a total volume per capita per day of 26.6 liters (7 gallons) which is equivalent to 1.75 uses. The homes studied in this report resulted in 3.6 uses per capita per day.

Table 12

Pollutional Parameter Comparison

Pollutant	With Garbage Disposal: This Report gm/d	With Garbage Disposal: Witt et al[14] gm/d	Without Garbage Disposal: This Report gm/d	Without Garbage Disposal: Witt et al[14] gm/d	Without Garbage Disposal: Swedish Study[26] gm/d
COD	155		120		120
BOD	50	61	38	50	45
Total Solids	181	139	149	113	130
Total Vol Solids	101	87	79	63	83
Total Sus Solids	69	51	49	35	48
Vol Sus Solids	65	40	46	26	40
PO_4	3.8	4.1	3.7	4.0	3.8
N	6.7	6.7	5.9	6.1	12.1
Flow gal/cap/day	44.4	42.1	43.6		34.5

In order to assess the pollutional effect of cleaning produces used in the homes in the study, measurements of BOD, COD and TOC were made. A list of the values obtained is shown in Table 13.

Summary

The results of this study correlate well with two other studies of field sampling and laboratory analysis of the pollutional strength of home wastes measured at the individual fixtures.

The results have shown that some fixtures, particularly those associated with food wastes, produced a wide range of pollutional values from one use to the next. The average values obtained from the three studies showed a very close correlation even though the work was carried out somewhat differently and in widely separated areas of the world. It can be concluded that the appropriate average design values for individual home waste water systems are: BOD = 0.13 #/cd, COD = 0.35 #/cd, total solids = 0.38 #/cd, suspended solids = 0.15 #/cd, PO_4 = 0.008 #/cd, N = 0.015 #/cd, and flow = 45 gal/cd for the standard type of residential homes. If garbage disposals are not used, the values for BOD, COD, total and suspended solids can be reduced by approximately twenty percent.

Table 13

Pollutional Contributions of Common Detergent Products

Use	Product	Ratio*	Pollutional Parameter Ratios: COD	BOD**	TOC	TC	MB-AS	Total PO_4-P
Laundry Products	Axion	a	0.3646	0.0115	0.0654	0.0654	0.0769	0.0846
	Burst	a	0.3346	0.0092	0.0346	0.0346	0.0923	0.1115
	Tide	a	0.5469	0.0246	0.0654	0.0654	0.1500	0.0731
	All	a	0.2277	0.0485	0.0346	0.0346	0.0004	0.0731
	Woolite	b	0.4382	0.0673	0.0713	0.0713	0.1117	0.0002
	Borateem	a	0.0608	0.0000	0.0115	0.0115	0.0052	0.0002
Dishwashing Products	Ivory Liquid	b	7.8130	0.6187	0.1133	0.1133	0.0927	0.0014
	Palmolive	b	1.1810	0.2198	0.1950	0.1950	0.2900	0.0000
	All	a	0.0560	0.0000	0.0106	0.0108	0.0001	0.0803
	Electrosol	a	0.0178	0.0000	0.0052	0.0171	0.0000	0.0926
	Alconox	a	0.3938	0.0354	0.0577	0.0577	0.1346	0.0731
Household Cleaners	Comet	a	0.4662	XX	0.0063	0.0063	0.0290	0.0264
	Ajax	a	0.0818	XX	0.0104	0.0104	0.0260	0.0047
	Formula 409	b	1.1000	XX	0.0160	0.0160	0.0000	0.0042
	Lysol Pine	b	0.7931	XX	0.1396	0.1396	0.0000	***
	Spic & Span	a	0.1818	XX	0.0175	0.0455	0.0065	0.0494
	Crystal	b	0.1472	0.0994	0.0198	0.0198	0.0000	0.0000
Hair Care	Fitch Shampoo	b	1.0240	0.0835	0.2583	0.2583	0.0000	0.0000
	Wella w/ Bal.	b	4.7200	0.0258	0.0060	0.0060	0.1450	0.0000
	Breck Set	b	0.05360	XX	8.300	0.0083	***	0.0000
	Fanci Fall	b	0.02340	XX	2.750	0.0028	***	0.0000
Hand Soap	Dial	a	2.3550	1.8090	0.2916	0.2916	0.0007	0.0000
	Unknown	a	2.3750	1.8400	0.3092	0.3092	0.0000	0.0000
Tooth Care	Ultra Brite	a	3.1710	0.2004	0.0561	0.0561	0.0146	0.0977
	Tooth Powder	a	2.6020	0.0825	0.1340	0.1340	***	0.0001

* Ratio is the ratio of mg of pollutional parameter to mg of product (a) or ratio of gram of pollutional parameter to ml of product (b).

** BOD values denoted by XX indicate that the substance was an inhibitory one and that the BOD increased with decreased sample size.

*** Test could not be run on this product.

CHAPTER IV- INDIVIDUAL HOME TREATMENT SYSTEMS

The problems of analysis, design, and operation of small systems are in many ways more difficult than with municipal treatment plants and the subject deserves more attention from the environmental engineering profession.

Currently, three types of home disposal systems are most commonly installed. These include: 1) the septic tank and leaching field; 2) septic tank and evapotranspiration bed; and 3) aerobic treatment units with surface discharge or discharge into leaching fields. Each of these types of systems incorporates special design and operational considerations into their successful application.

Septic Tanks

The use of the septic tank extends for more than a century from the original unit designed by Mouras in 1860 and patented in 1881. The purpose of the septic tank is to settle particulate matter and provide floatation for greases and fats. The unit is of very simple construction, as shown in Figure 11. The first step of anaerobic digestion takes place in the tank with biological conversion of suspended organics to soluble organic acid. In this way the wastes are solubilized before entering the percolation field. Most of the biological decomposition of organic matter takes place in the leaching field.

System failure with septic tanks and leaching fields typically involves either pollution of wells or surfacing of odorous

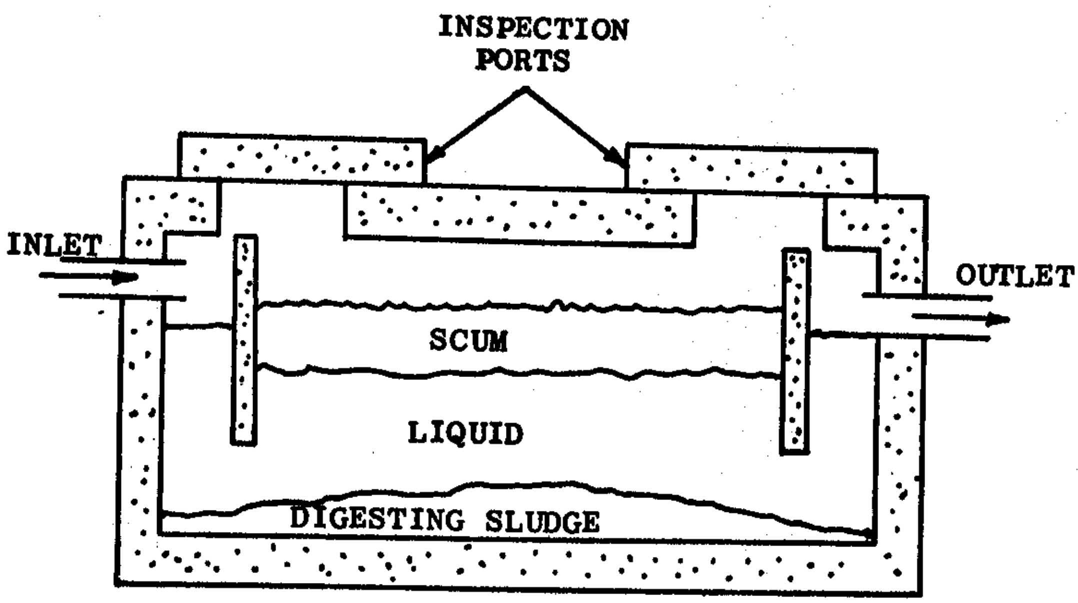


FIGURE 11 SEPTIC TANK

effluent. The latter is usually caused by inadequate cleaning and improper maintenance resulting in a clogged leaching field. Adequate cleaning of the tank, primarily for the removal of grease, is required about once every two years to maintain a satisfactory system. Because of the long settling time in the unit, these systems are rather insensitive to pulse flows and waste strength characteristics.

The required size of the leaching field has usually been determined from an in-situ percolation test. The method used by most public agencies for conducting the percolation test to determine the leaching capability of the sub-soil has been very similar to that found in the U.S. Public Health Service Septic Tank Manual of Practice #526.[1] It involves digging a hole of 4 to 12 inches diameter to a depth of 3 to 4 feet on the potential site. The hole is then filled with about 2 inches of fine gravel and 12 inches of water. The water level is maintained for 4 to 24 hours to accomplish wetting of the soil and then a determination is made of the time required for water to drop a distance of one inch. The value obtained is an indication of the water conducting ability of the soil. The results are then matched with the criteria established by the work of Ryon[28] in the 1920's and the U.S. Public Health Service test of 1947.[29]

The percolation test was originally proposed in this country by Henry Ryon in an unofficial publication of the New York State Department of Health. It must be stated that Ryon did not intend this test to be used worldwide, or that his results could be applied to any and every type of soil condition. Since the publication of his results in 1928, the percolation test has become the most important consideration in installing a septic tank system. The percolation test was aimed at determining the percolation capacity of a given soil where the test was being performed.

Ryon adopted the procedure of inspecting cesspools and tile fields where there had been complaints or difficulties with the existing units.. The load on the system and the conditions prevailing were noted. It was determined if the systems had overflowed at times, or if they were overflowing at the time of the inspection. The type of soil at the site was recorded, and a number of percolation tests were run at each site. The data that he obtained were then plotted to develop his charts.

After World War II, construction in the United States started to boom and with it came widespread use of the septic tank system in suburban areas. The variance in design standards soon became evident when the failure of as many as one-third of the percolation systems in single subdivisions occurred within the first 3 or 4 years after construction. The Federal Housing Administration (FHA) at that time was the principal insurer of housing loans and felt the full thrust of the failing septic tank systems. The FHA took immediate action and tried to determine the cause of these failing systems. Their investigation revealed little evidence of unapproved practices or careless construction habits. The results of the investigation prompted the FHA to look into the matter of the actual design criteria that had been established up to that point in time. Their initial report consisted of a literature search, review of controls and practices of local health units, and some experimental studies of septic tanks and absorption fields. A closer look was taken at Ryon's previous work to determine if his method was a valid one and if it could be used to standardize septic tank practice.

The Public Health Service conducted experiments to study Ryon's work by making field inspections of 300 homes in 9 areas of the United States during the period of February 1947 to July 1948. Their initial intentions were to examine both the septic tank and the soil absorption system. However, as the survey progressed, it became evident that the time required to study the soil absorption system would seriously limit the number of inspections, therefore the evaluation of the soil absorption system was limited to every fifth installation.

The research team performed three different types of percolation tests: 1) An unconfined percolation test, run in a soil area in the tile field unaffected by the septic tank effluent; 2) A confined percolation test, run in the unaffected area using a 10-inch diameter cylinder forced 2 inches into the soil; and 3) A confined test was also made in the bottom of the tile trench; that is, in the affected soil area. These three different types of test were performed in three different types of efficiency conditions. The efficiency conditions refer to the efficiency of the absorption field. The efficiency categories were: 1) Good - tile field has never given any trouble; 2) Fair - seepage to the ground surface has been observed occasionally; and 3) Poor - the tile field has given trouble continuously. Figure 12 refers to the test sites used for the unconfined percolation test and the first graph is Ryon's curve with the new test data plotted on the

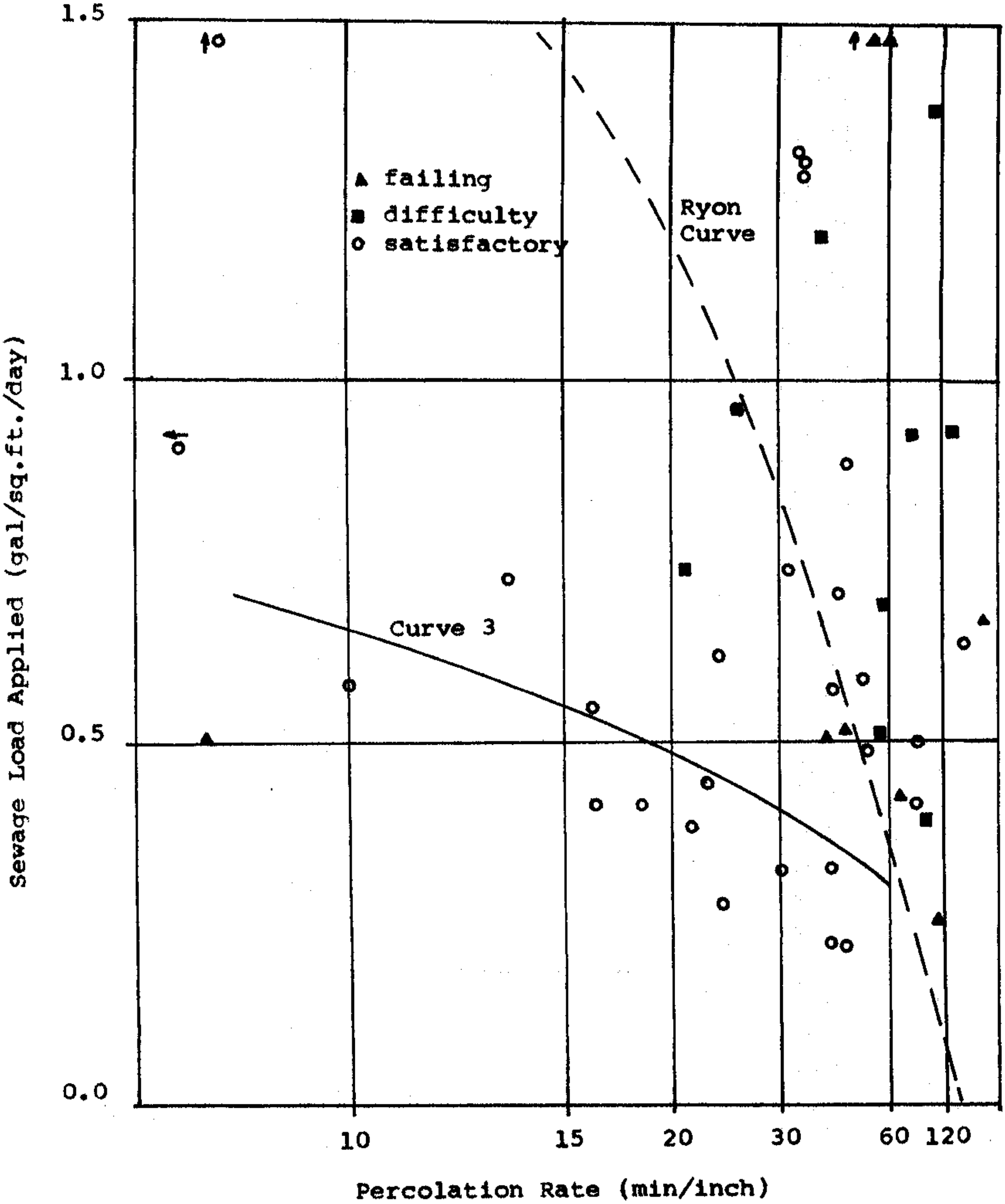


FIGURE 12 FIELD LOADING SUCCESS AS A FUNCTION OF PERCOLATION RATE

same graph. From this data and the other two types of tests, the committee concluded that the original Ryon study was in agreement with the percolation tests performed. From that point on, the Ryon curve was used as a standard for installing absorption fields.

Results of studies at the time revealed that: 1) The comparison of percolation rates measured in affected soil areas with percolation measured in unaffected soil areas showed significant correlation in a trend toward reduced rates in the affected soil; 2) With the use of a 4-inch auger hole, the amount of water needed was far less; 3) The size of hole used did not affect the rate of soil percolation; 4) A more representative rate was obtained if more holes are tested over the proposed tile field; 5) If the holes were allowed to remain saturated over night, the test data were more representative of the true absorption rate; 7) The soaking procedure was more important in soils containing appreciable amounts of clay; 8) The amount of clogging that took place when sewage effluent was used instead of clean water while running percolation test in soil cores was affected by the amount of suspended solids present; 9) The greater the biological activity, the slower was the clogging; 10) Clogging was accelerated in the following order of effluents: normal effluent, fresh sewage, and disinfected effluent; and 11) The percolation rate decreases tremendously over a period of time if the fluid being added was septic tank effluent.

In all, approximately 40 correlation tests have been reported in the two studies for soils in the permeability range of 1"/5 minutes to 1"/60 minutes. From the tests, most of the procedures and standards used today have emerged in the form of the table from MOP526 shown below.

Table 14

Required Adsorption Area
(Includes garbage grinder and washing machine)

Percolation rate (time required for water to fall one inch, in minutes)	Required absorption area in sq. ft. per bedroom - 2 or more bedrooms
5	125
10	165
15	190
30	250
45	300
60	330

If a value of one hundred gallons per day per bedroom is assumed, the values given in the table translate to curve number 3 on Figure 12. The total number of data points in Figure 12 is approximately 40 and most are for percolation test rates of less than 2 inches per hour. More data, particularly in the higher percolation rates, would be valuable. Most regulatory agencies do not allow the use of leaching systems if the percolation test rates are greater than 12 inches per hour or less than 1 inch per hour. Exceedingly high percolation rates indicate the possibility of poor filtration and the potential for ground water pathogen pollution. Very low percolation rates are considered a precursor to plugging and ponding.

There are several problems associated with the percolation test and chart (Table 14) approach to leaching field design. 1) There are uncertainties with the percolation test. This will be discussed. 2) There is a questionable correlation between the percolation test and the infiltration capacity of an actual operating system after a slime layer of organics, bacteria and ferrous sulfate have built up in the soil interface. 3) The design approach based on number of bedrooms results in very large systems for large homes. This seems to be unjustified based on the results of Chapter 2. 4) The difficult choice of a suitable alternative to leaching systems if the percolation test results fall outside the established limits is a significant problem.

Although the major purpose of this research did not include the investigation of leaching systems, a small amount of field evaluation of the percolation test was accomplished.

A site was selected that was to be used for an individual home septic tank system. A properly run percolation test had been accomplished by others with the results that the percolation rate was less than one inch per hour and, therefore, the area was deemed unsuitable for a leaching field.

After several preliminary measurements, the following procedures were established:

A. Five-inch diameter holes, three feet deep were used. The side and bottom of the hole was carefully prepared to eliminate smearing. Two inches of pea gravel was placed in the bottom of each hole.

B. A four-inch diameter perforated plastic soil tube was secured in the hole so that water could be introduced without turbulance.

C. A $3\frac{1}{2}$-inch diameter styrofoam float was placed in the tube. It was affixed with a balsawood stick that acted as a guide for the float and as a measuring rod. A drilled metal rod was used to center the guide rod and act as a reference point for measurement. The apparatus is shown in Figure 13.

D. A simple siphon device with a tube attached to the float rod was used to feed water from a surface pan for the overnight prewetting phase.

E. The siphon tube was disconnected and the amount of depression of the float rod was measured as a function of time.

Seven holes within a 0.2 acre area were used for the measurements. The soil was a very uniform decomposed shale. The tests were continuous for four hours and the holes were refilled to a level of six inches of water six times during the period. Individual tests were made after each filling. A typical profile of the water surface is shown in Figure 14.

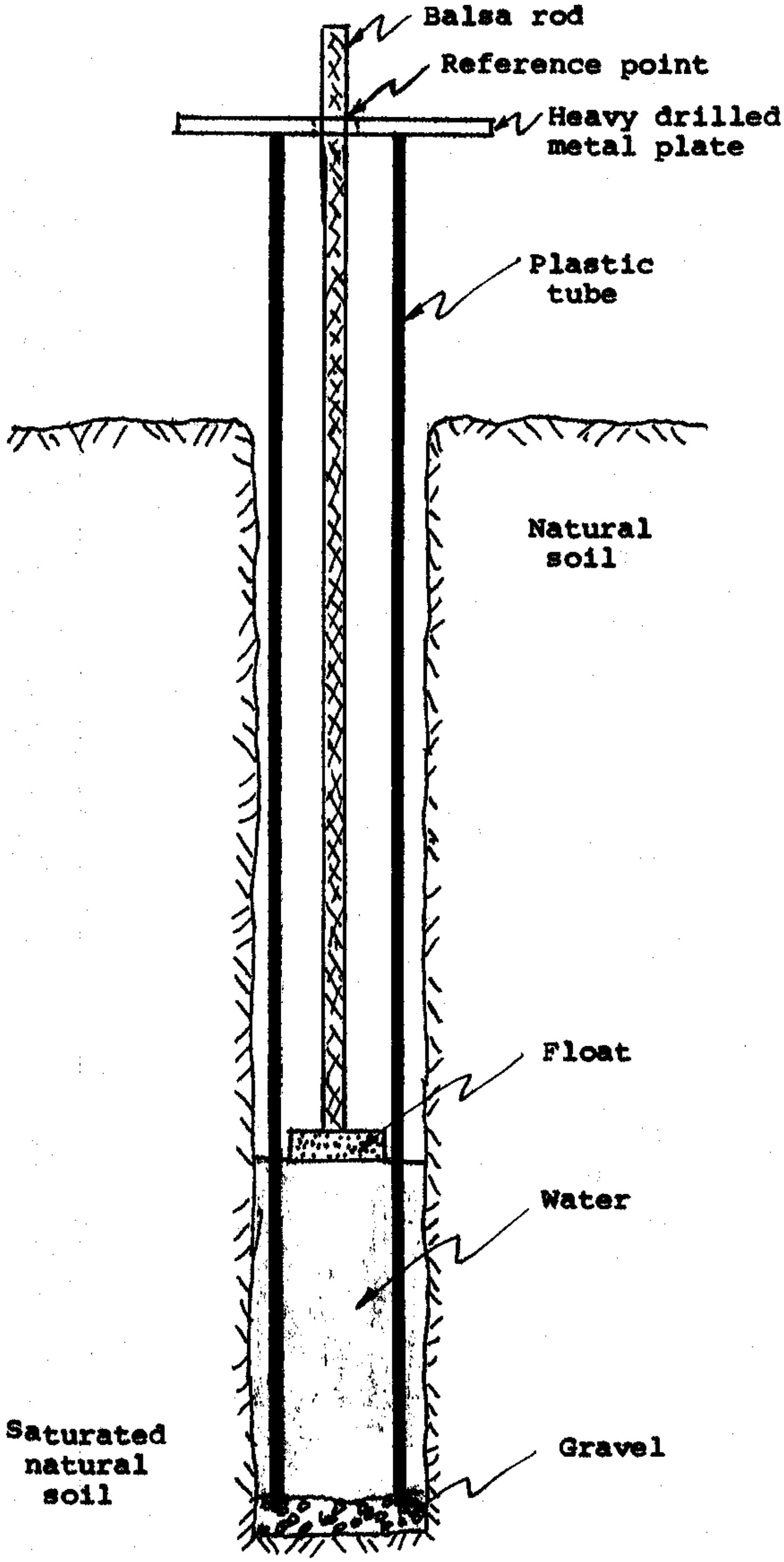


FIGURE 13 DEVICE USED FOR PERCOLATION TESTS

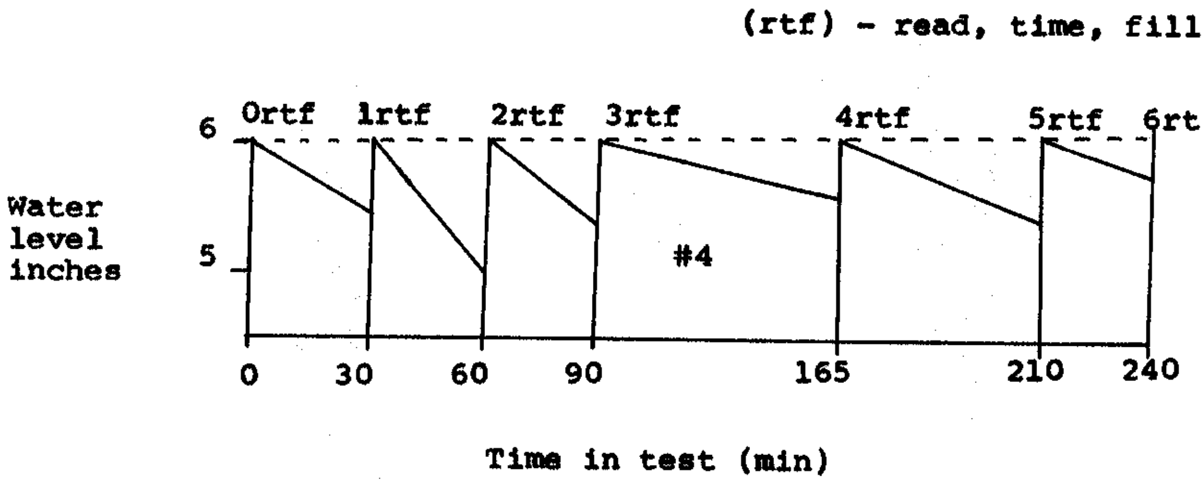
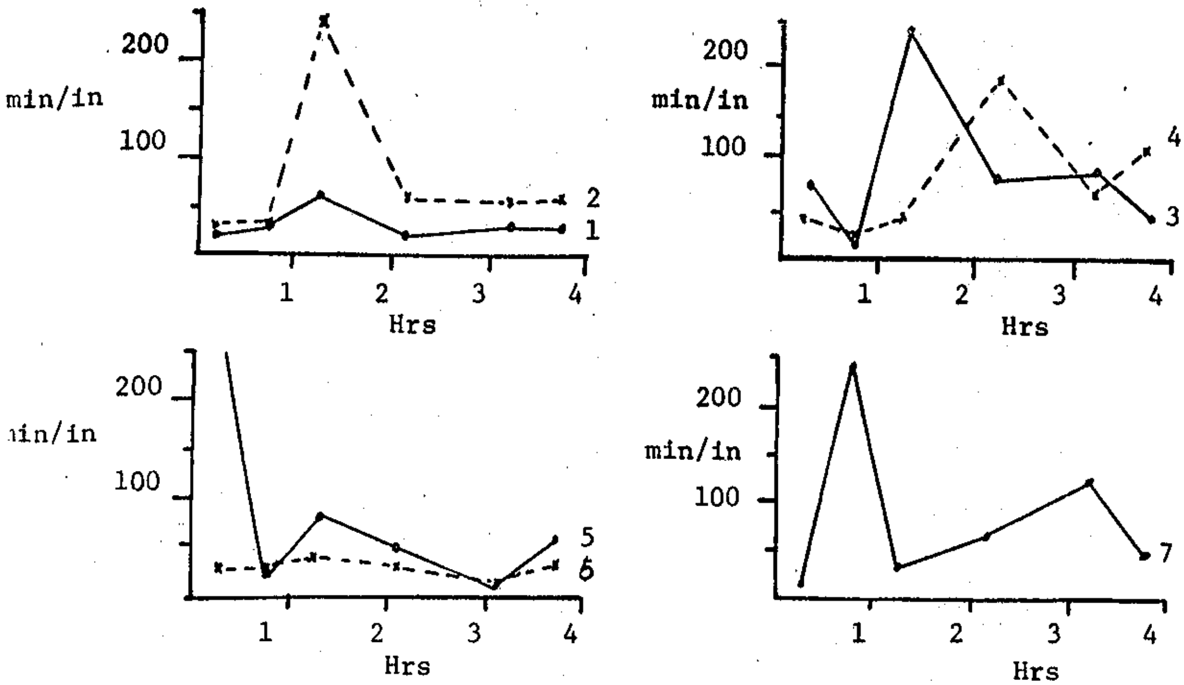


FIGURE 14 PERCOLATION TEST PROFILE

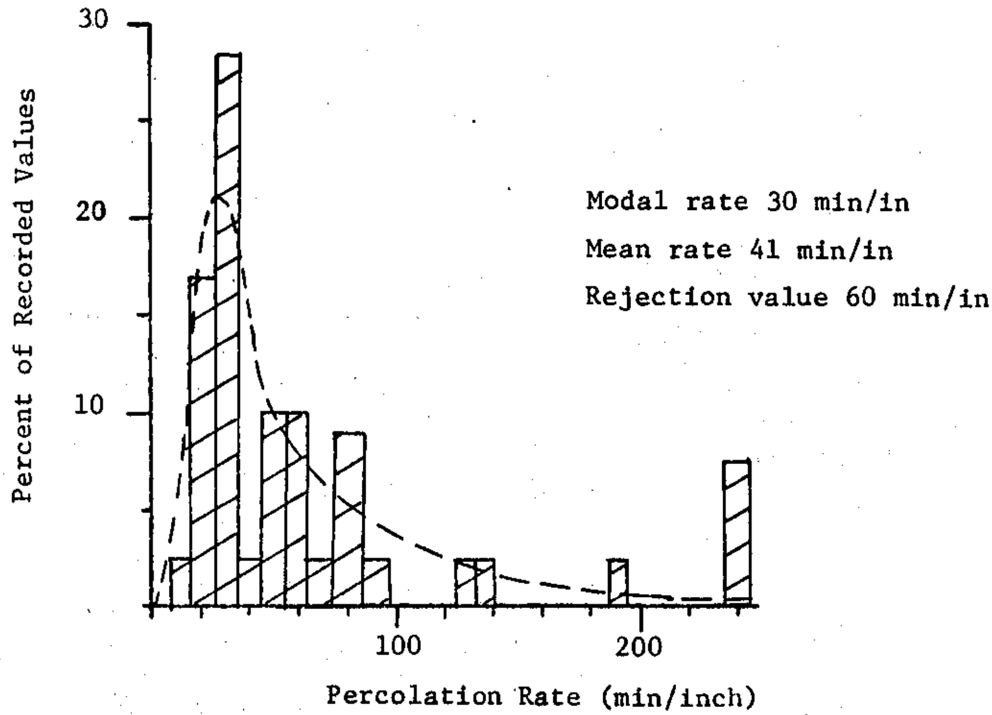
The results of the percolation tests of the seven holes are shown in Figure 15, as well as a distribution of the percolation times obtained. It can be noted that a rather wide statistical distribution of percolation rates resulted. The distribution is skewed due to the zero boundary. The modal value was found to be 30 minutes per inch and the mean (based on inches per minute) was 41 min. per inch. It is interesting that 16 values (38%) were 60 minutes per inch or greater and would have resulted in apparent rejection of the area for use of a leaching field. The range of values for the 7 tests, over a four hour period, was 26-69 minutes/inch and for the 30 minute measurement the range was 14 to infinity minutes/inch. The State of Colorado requires that the percolation test should be run on three test holes at each site for a period of ninety minutes. This procedure helps to minimize the measurement variations.

The wide range of values should not be unexpected for results of very low head permeameter studies. Other authors[30,31] have also reported wide ranges of variation in results for percolation tests for individual sites.

The correlation between the results of the percolation test and the actual infiltration capacity of the soil after a period of use as a leaching bed for sewage effluent has been a subject of study and speculation. McGauhey and Winneberger[31] have shown that the build up of a slime layer of organics, micro-organisms and ferrous sulfate at the interface of the trench material and the natural soil controlled the flow rate in an actual system and the infiltration capacity of a functioning system was not directly related to the results of the percolation test. Five soils were



Four Hour Percolation Tests for Seven Holes at the Same Location



Distribution of Percolation Rate

FIGURE 15 PERCOLATION TEST VARIATIONS IN DECOMPOSED SHALE studied and infiltration rates of 0.5 to 5.6 gal/day/ft^2 were found with an average of 2.1 gpd/ft^2 for soils that were used with septic tank effluent for 120 days. The soil with the best percolation test results produced the lowest infiltration rate for the long term tests with sewage effluent. McGauhey and Krone[32] estimated leaching field infiltration values of 2 to 6 gpd/ft^2. From Figure 12, the values taken from Ryon's curve range from 0.25 to 2 gpd/ft^2 for the usually acceptable percolation test range. Kiker[33] has presented a formula that results in the range of 0.44 to 2.6 gpd/ft^2 for the 5 to 60 minute percolation results. Frederick's[34] formula results in a range of 0.65 to 2.3 gpd/ft^2. Ludwig's[35] formulation results in a range of 0.75 to 9 gpd/ft^2. A 30 day test of Bouma, et al.[30] resulted in a steady state infiltration rate of approximately 1.2 gpd/ft^2. One could conclude from these data that a conservative design value for infiltration rate for any soil would be in the range of 0.5 gpd/ft^2 of trench area. No unsatisfactory correlation values are found below this rate on Figure 12 for percolation rates from 5-60 min/inch.

In order to establish any design infiltration value, the presumptions must be made that the septic tank will be adequately designed and properly cleaned to prevent excessive grease and solids from entering the leaching field, and that the flow will be intermittent in the usual fashion occurring in individual home wastewater discharge events.

Several conditions can make a site unsuitable for the use of a septic tank and the standard leaching field. These include loose soils and fissured rock conditions, impermeable soils, shallow soil mantle above bed rock, steep sloping lots, and high water tables. When these situations exist, alternative waste water disposal systems must be designed.

For many of the conditions listed, the application of special techniques for the development of leaching fields may be possible. Importation of suitable soil cover to form a mounded system has been found to be a satisfactory technique. Special site-specific considerations for design must be utilized and many of these have been evaluated by Bouma, et al.[30]

Discussion

The use of the septic tank and leaching field system of individual home wastewater disposal has been a favored system because of the simplicity of operation, economics and the public health advantages of subsurface disposal.

The percolation test has been used to assess the suitability of soils for use in leaching fields. The single test hole, one-half hour test allows for a wide variation in results. The use of three testing holes and a percolation period of ninety minutes has been shown to produce results with less variation.

The percolation test gives an indication as to the hydraulic conductivity of the soil and therefore, its general suitability for use as a leaching field. The existance of a direct relationship between the percolation test results and the infiltration capacity of an actual system after a period of use, is highly questionable. A standard infiltration rate to be applied to all types of soils may be as well justified as that related to the percolation test.

The determination of the design size of a leaching field based on the number of bedrooms in a home does not seem to be justified from the information in Chapter 2, which showed that the amount of total daily household wastewater production did not vary appreciably with family size.

Aerobic Treatment Units

Aerobic treatment units have been proposed in many areas as an alternative to septic tanks. In early applications, these systems incorporated discharge directly onto the ground or into shallow, rock filled trenches. Installations of this type developed rapidly in Colorado until recently when the requirement for subsurface disposal was instituted. The history of their use in one representative county is shown in Figure 16.

The typical aerobic unit, as shown in Figure 17, is usually constructed to function in a manner similar to a small extended aeration, activated sludge treatment plant. Some units have pre-settling chambers, although many do not. Pre-fabricated fiber-glass installations are quite common, but when units are constructed in place, the building material is usually concrete. Design detention time in the aeration chamber is in the range of one to two days. Aeration is generally provided with compressed air, aided by mechanical stirring. A small final settling tank is usually provided incorporating ports or slots for gravity

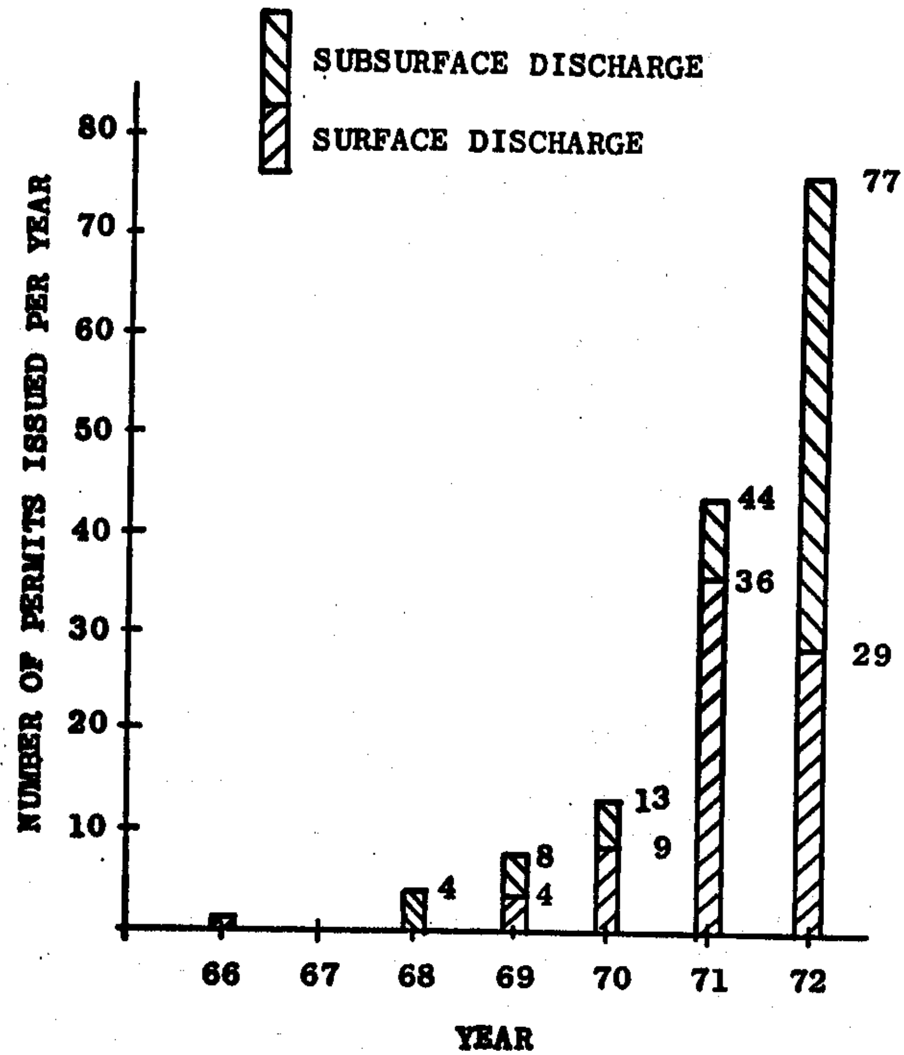


FIGURE 16 NEW PERMITS FOR AEROBIC UNITS IN A COLORADO COUNTY

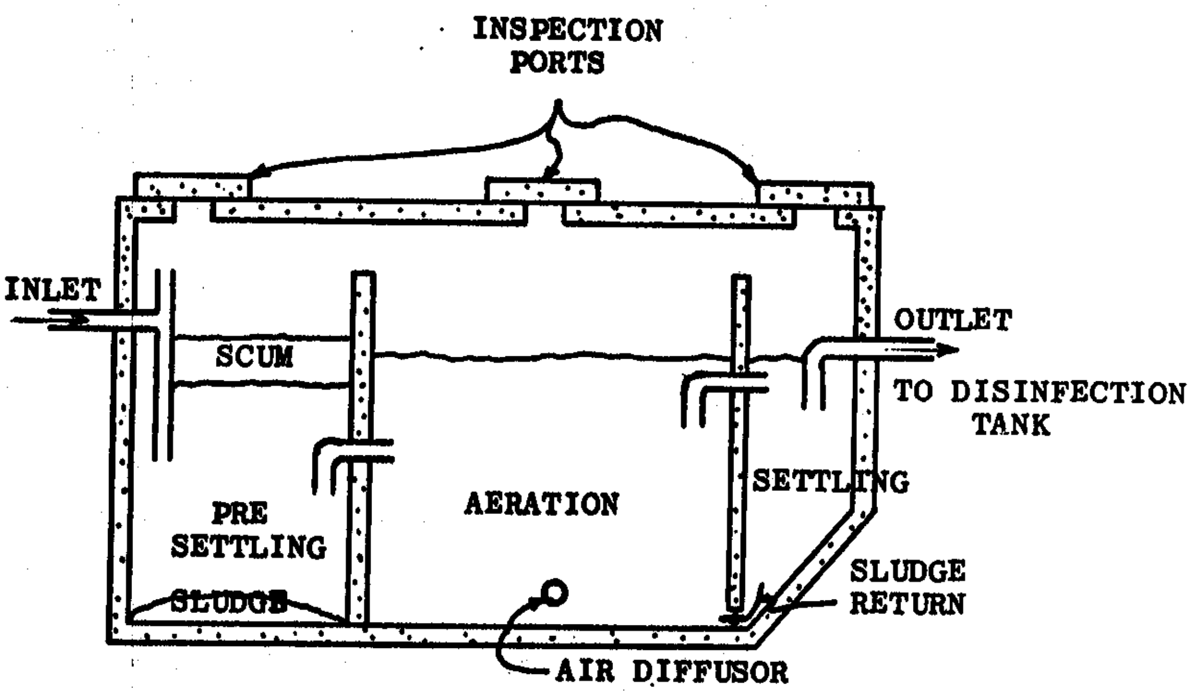


FIGURE 17 TYPICAL AEROBIC UNIT

sludge return to the aeration chamber. Some units are operated in a fill or draw mode with settling occurring in the main tank during the night time.

In an effort to evaluate aeration unit performance, the effluents from several existing, homeowner operated, field units were sampled and evaluated for BOD_5 and suspended solids in the laboratory. The results of the tests were compared with values observed by local health departments during routine monitoring and were found to be similar. A summary of these data is shown in Figure 18 with pollutional parameters of BOD_5 and total suspended solids (TSS) plotted as a function of frequency of occurrence in the effluents. It can be noted that the BOD_5 and TSS values correspond on essentially a one-to-one basis, and that the median BOD_5 and TSS for all of the units grouped together was approximately 150 mg/ℓ. This average performance was found to be only slightly better than that expected from a septic tank.

Two reasons have been identified for the disappointing performance. One important factor is neglect by the homeowner. Many owners will not accept any maintenance responsibility related to their sewage system and, therefore, a successful unit must have a high degree of reliability with minimal maintenance. Another consideration, and one that is substantiated by these studies, is the adverse effects introduced by surge flows. The units observed in this study had secondary settling units with volumes in the range of 30 to 100 gallons. These units are sufficiently small to be adversely affected by the surge flows which characterize individual home discharges. An evaluation of maximum surge flows

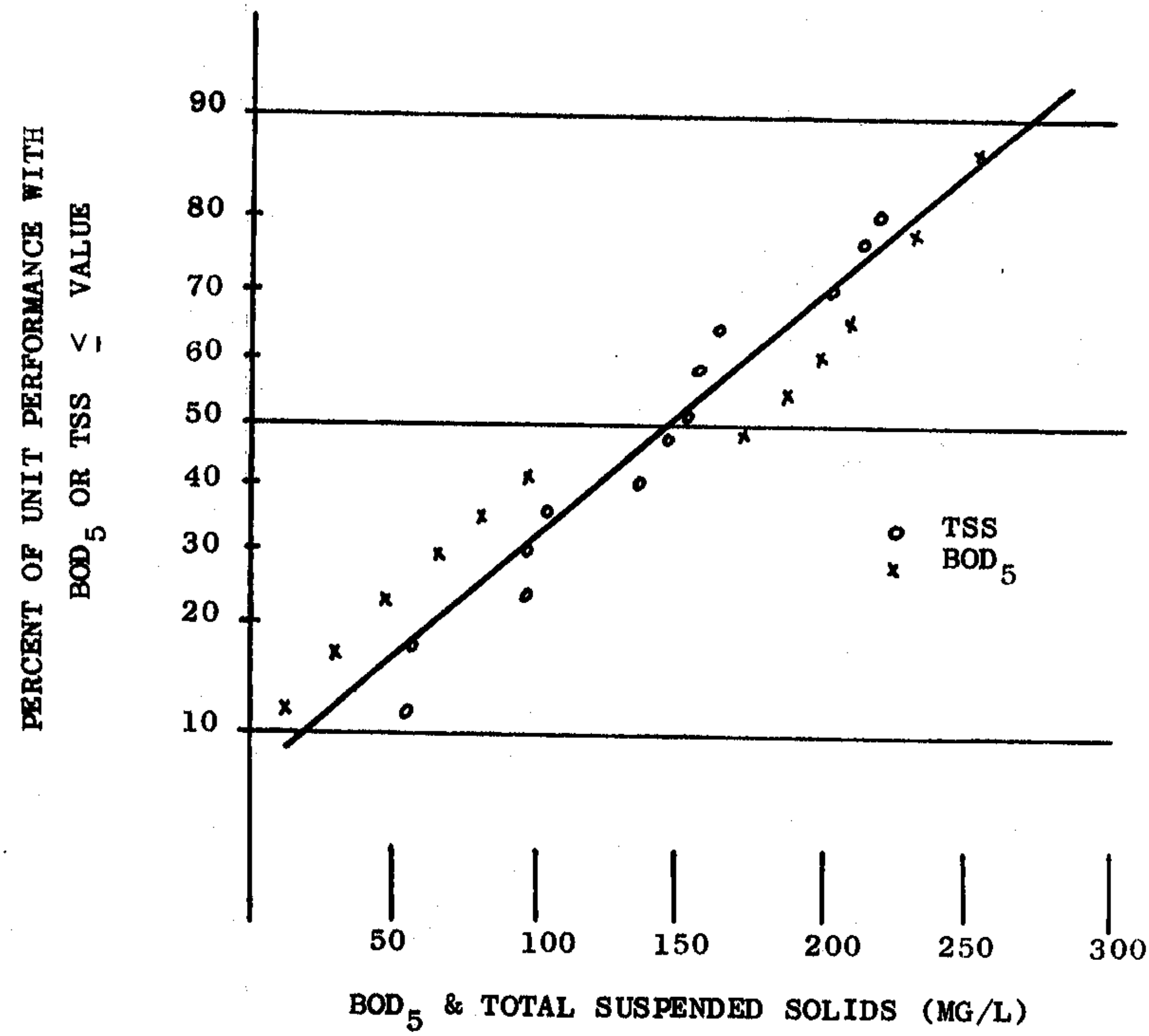


FIGURE 18 SPOT CHECK EFFLUENT QUALITY OF SEVERAL FIELD UNITS

has been developed in Chapter 2. Under normal home use conditions, it was found that a maximum quantity of about 60 gallons could be surged into the unit in a time period of seven to thirty minutes. Field observations have shown that this hydraulic load is sufficient to wash out the settling tank and prevent the build-up of any substantial concentration of organism in the aeration portion of the unit.

In many of the field units tested, the suspended solids concentration in the effluent was essentially the same as in the aeration chamber. This indicated that the units functioned more in the plain aeration mode than as extended aeration units. The combination of the pollutional load surges and the rather short detention time provided for plain aeration treatment may be major considerations in the treatment efficiency achieved by these units. Some of the units evaluated incorporated a cloth filter within the aeration tank to aid in maintaining the biological solids. Homeowner neglect was also a problem for these units. Some were found with the filter clogged and overflowing, and others evidenced that the filter had been cut to prevent overflowing.

Flow surges have also been shown to have an effect on the reliability of the effluent chlorination operation. Effluent discharged during low flow periods tended to be over chlorinated and that discharged during a flow surge was chlorine deficient.

Aerobic units operated in the field under close supervision by research personnel performed at a higher efficiency than those where operation was left to the homeowner.

Evaporation-Transpiration Systems

Evapo-transpiration (E-T) systems are used for disposal of effluent from septic tanks or aerobic units in arid and semi-arid regions where conditions will not permit the use of leaching fields. Site conditions that fall under this classification include surface cover of bare rock, poorly decomposed shale and clay, sites with a high ground water table, or areas with highly permeable materials where the shallow ground water must be protected from all possible contamination. There is a present and growing concern about the effect of septic tank leachate on shallow ground water resources.

The most popular E-T system is the sand filled bed or trench. This system eliminates the dangers associated with an open body of polluted water. A cross-section of a typical E-T bed is shown in Figure 19.

The sand size must be selected so that the pore size will allow for the water to be lifted to the surface by capillary rise. If the water does not reach the surface, evaporation will be severely limited. The sand utilized must be small enough to lift the water by capillary action but large enough to provide for adequate hydraulic conductivity of water up to the surface.

The theory of capillary flow has been described on the basis of idealized laboratory experiments. The ultimate height of capillary rise (h_c) in a circular tube can be calculated from the expression

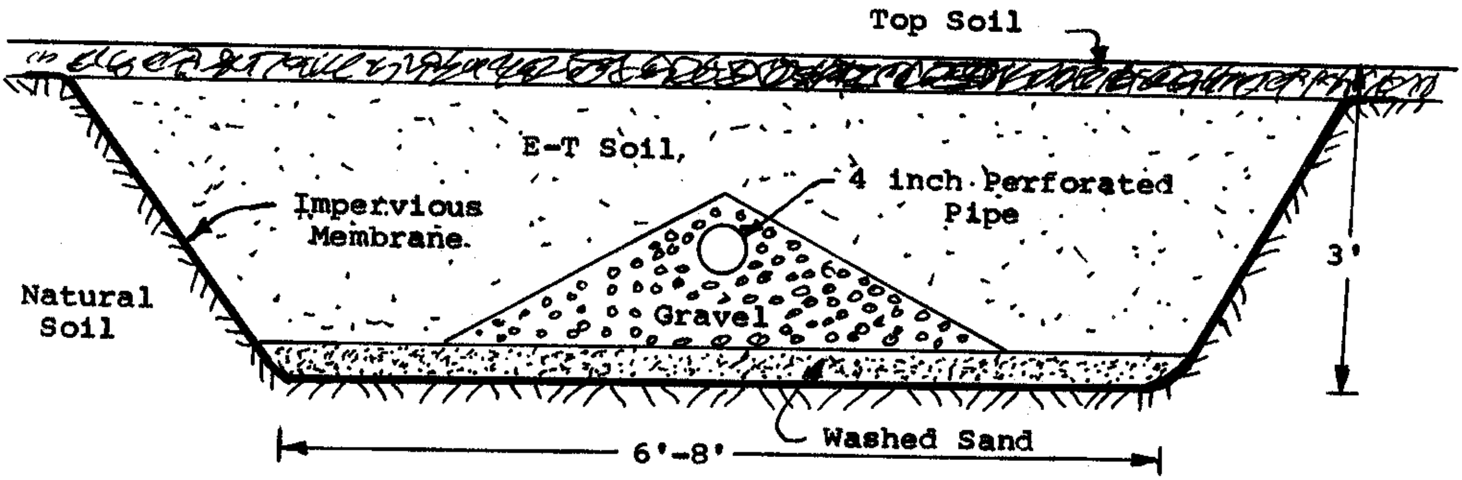


FIGURE 19 TYPICAL EVAPO-TRANSPIRATION TRENCH OF BED

$$h_c = \frac{2T}{r\gamma} \cos \alpha \approx \frac{0.45}{nD_{10}}$$

T = surface tension
γ = unit weight of fluid
n = porosity
r = radius of capillary tube
α = contact or wetting angle
D_{10} = ten percent passing size (cm)

The rate of rise to height y as formulated by Terzaghi[36] can be expressed as:

$$t = \frac{nh_c}{P} \left[\ln \frac{h_c}{h_c - y} - \frac{y}{h_c} \right]$$

n = porosity
P = coef of permeability

For continuous capillary flow at steady state a modification of Darcy's law can be utilized where

$$Q = -K \text{ grad } \psi$$

Q = flow rate
K = capillary conductivity
ψ = capillary potential based on h_c

For real systems, such as E-T sewage disposal beds, the theoretical approach must be heavily supplemented with laboratory and field measurements as well as application experiences. The theoretical model supplies the basis for evaluation of field and laboratory research studies.

In general the major considerations are height of capillary rise, rate of water rise (hydraulic conductivity) and removal rate of the raised water by evaporation and transpiration. Height of rise is dependent on grain size, uniformity, and packing pattern. Rate of rise is dependent predominantly on the grain size and moisture content of the unsaturated soil. Bodman and Colman[37] have shown that moisture content in the capillary zone is somewhat variable with depth and in a continuous capillary flow system, the fraction saturation would be at field capacity, about midway between pore space saturation and the moisture equivalent. It can be shown from the work of Wyckoff and Botset[38] that the specific permeability of a soil is greatly diminished in unsaturated flow and that the specific permeability can be expressed as a function of the moisture content of the capillary regime in the form:

$$f(k) = [f(sat)]^{3.5}$$

f(k) = fraction of specific permeability compared to saturated pore space permeability

f(sat) = fraction of pore space that is water

Because of the large exponent in this equation, it is very difficult to utilize theoretical equations to accurately predict numerical values in real systems.

It has been found that sand in the D_{50} size range of 0.12-0.18 mm was satisfactory. A uniformity coefficient of four or less has also been found to be desirable. The bed layout should allow for the sand to furrow down into the gravel to provide a wick for raising the water. Wind blown deposits and gravel washings have been found to be adequate materials for evaporation-transpiration bed construction. Grain size distributions for two of the sand materials that have been successfully used in

E-T beds are shown in Figure 20.

Evaporation potential can be determined from weather data for each specific area. Rainfall data for the average and critical wet years should be determined. Evaporation potential for each month of the year can be established from many methods including: energy budget, mass transport, emperical methods (Blaney Criddle,[39] Penman,[40] Thornthwaite,[41] Lowry-Johnson[42]), equations (Rohwer[43]), or pan evaporation data. A typical curve for a semi-arid area is shown in Figure 21. A mass diagram technique can be applied to the critical design year curve to establish the average yearly excess E-T rate in gallons per day per square foot of E-T bed surface area. The amount of water to be evaporated can be established from the sum of the sewage flows rate and the excess precipitation over the bed area for those months that produce rainfall greater than evaporation. Sizing of the unit is based on matching the annual evaporation potential with the total amount of water to be evaporated. Water storage volume must be provided in the rock filled base of the unit to carry it through the low evaporation winter months without creating saturated conditions. For the lower front range areas of Colorado, the design technique has resulted in surface areas of 5000-7000 ft^2, and storage depths of about three feet.

The units must be designed for the climatic conditions of the location. Underdesign or overloading will result in complete saturation of the bed, surfacing of water, a very soft surface, and possible backing up of water in the house plumbing.

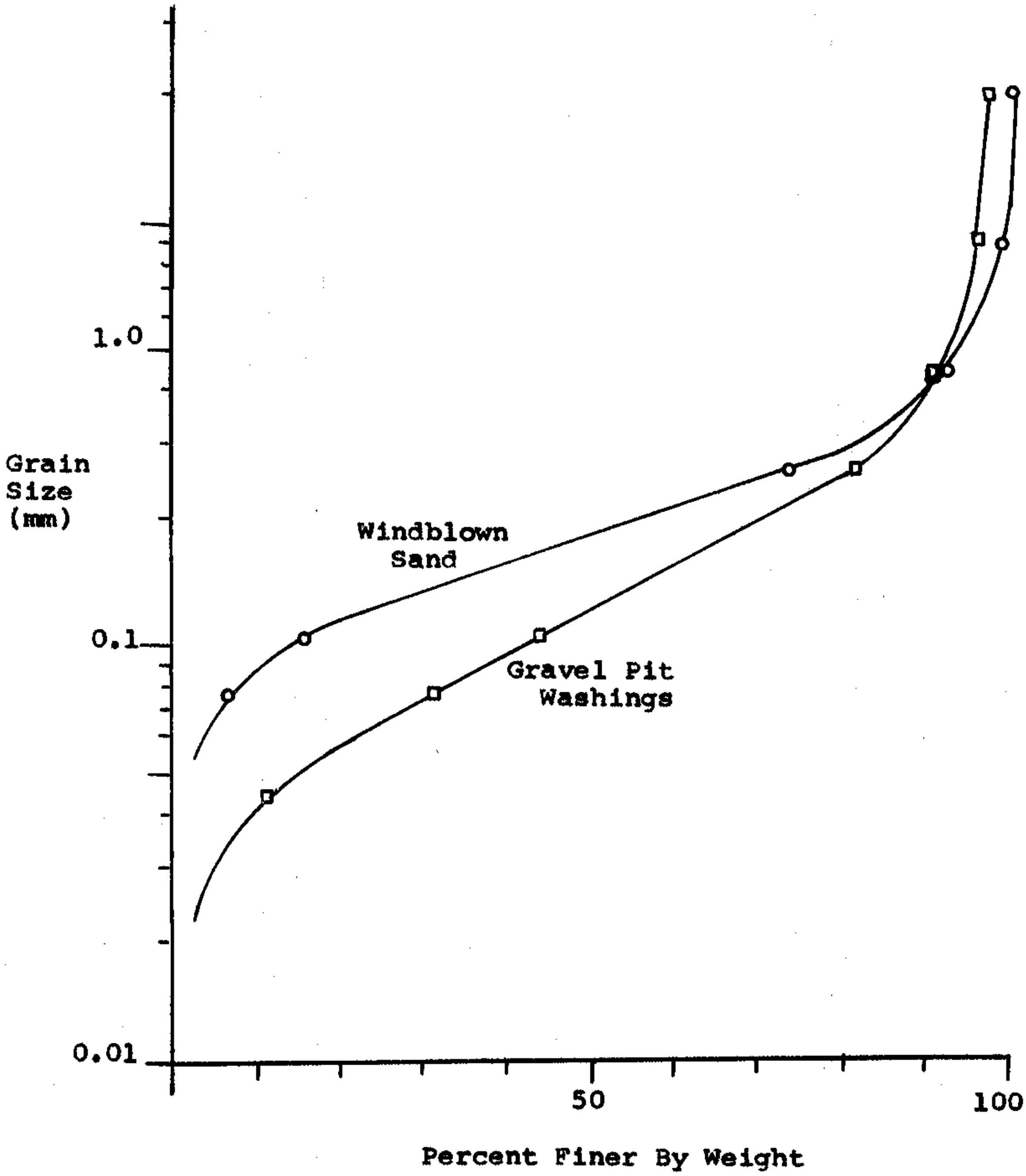


FIGURE 20 E-T SOIL SAND SIZE SIEVE ANALYSIS

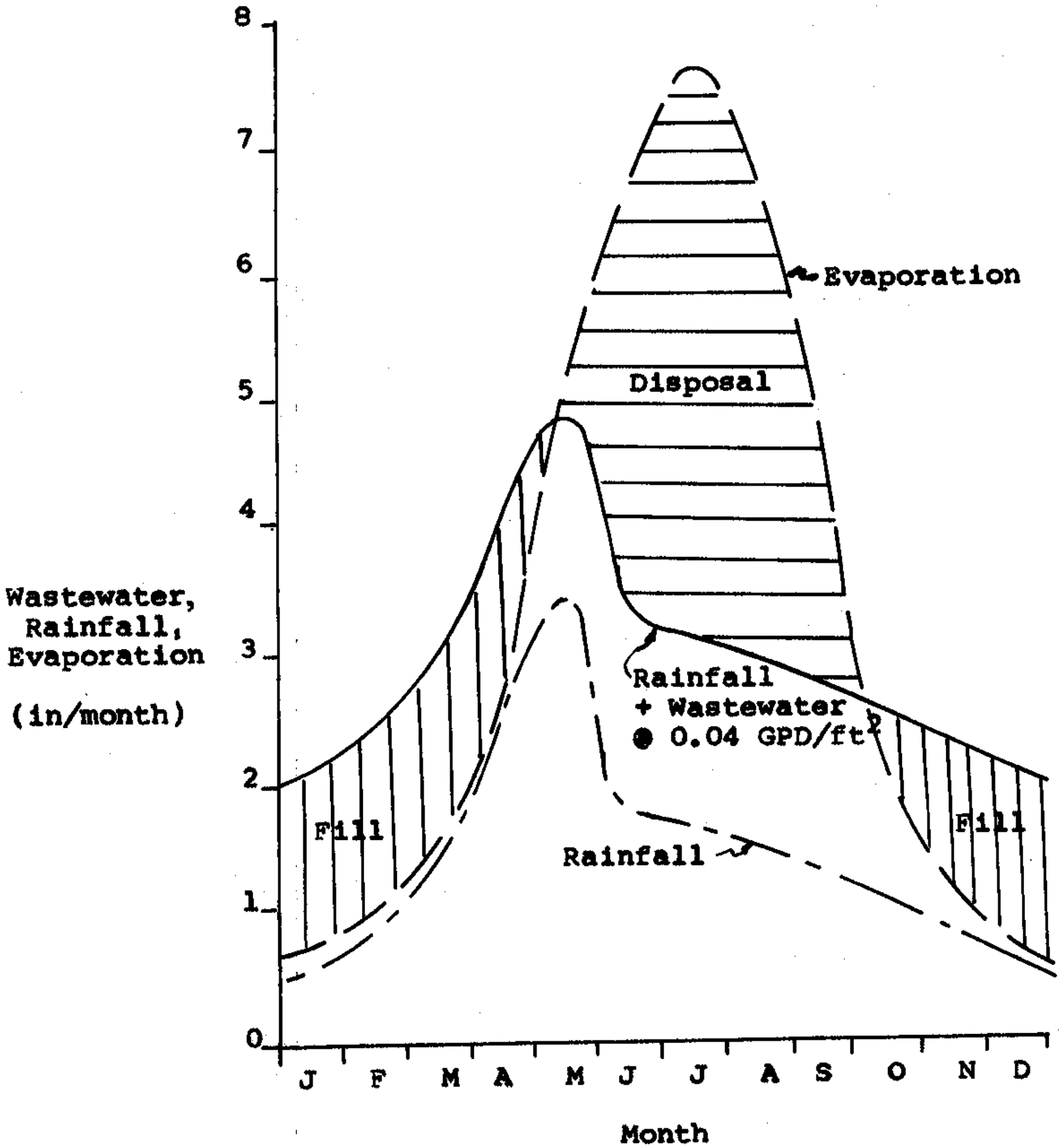


FIGURE 21 TYPICAL E-T POTENTIAL CURVE

Studies on the E-T method of sewage disposal are being initiated at the University of Colorado.

<u>Water Saving Appliances and In-Home Reuse</u>

Most fixtures and appliances in the home are designed to provide maximum convenience for the user with little regard for water savings. The reason for this is the low cost of water and sewage disposal for a large segment of the population. The average cost for water and sewer service for populations residing in established urban and suburban areas is between one and two dollars per thousand gallons. A large reason for the low cost lies in the fact that a large portion of the water treatment and distribution system, and the sewage collection and treatment systems were constructed twenty or more years ago at very low cost in terms of today's dollars. Constructing new systems today results in costs that are two to three times higher. This is shown schematically in Figure 22.

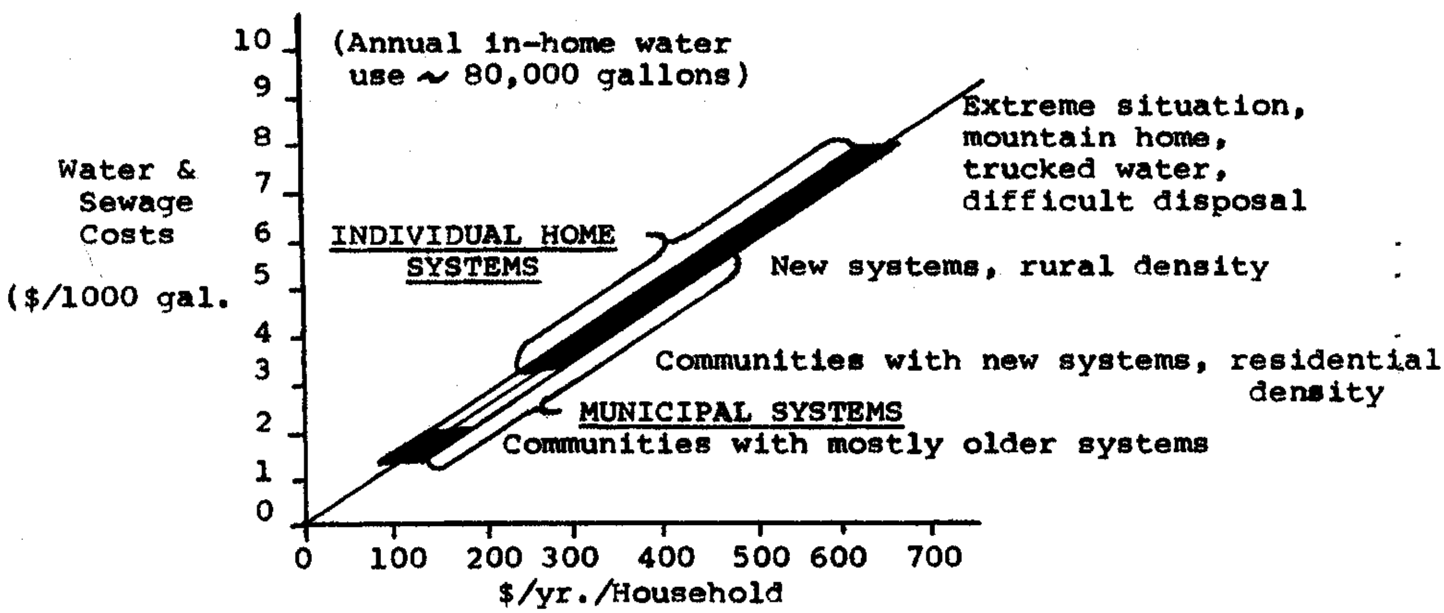


FIGURE 22 APPROXIMATE COST FOR HOME WATER AND WASTEWATER

Construction costs of individual home systems are usually somewhat higher but they must be considered in present cost values since they do not involve additions to older existing facilities. New water and sewage systems for individual homes generally result in costs of four to eight dollars per thousand gallons, and in extreme cases may range even higher. Some people are willing to pay two to three times the normal costs for water, fuel and transportation to have the privacy and environment provided by an isolated mountain home.

Water saving devices do not provide appreciable cost advantage when used in conjunction with municipal systems because of the low price of services and because the costs are not very elastic. Water sub-mains are sized to provide fire fighting flow. Often, in the design of water treatment plants, lawn watering demands far overshadow home use demands. Sewerage laterals are designed on a minimum size to prevent clogging. Sewage treatment plant flows consist of a significant portion of industrial flows and infiltration water.

For these reasons, reductions in household water usage cannot be reflected in proportional savings in water and sewage utility bills. The only immediate application of water saving devices for homes on municipal systems relate to the short term condition where new taps are not permitted until inadequate facilities can be expanded. A separate consideration is that in order to achieve a long term goal of conserving water resources, new fixtures and appliances should be designed to provide convenience while using a minimum of water.

The situation for individual home systems is quite different. Water savings can produce more nearly proportional cost savings in pumping costs and in the reduced size and cost of leaching fields or E-T beds. Non-availability of adequate water and limitations on disposal areas may also be important aspects. The use of water-saving devices should be a consideration in the planning of any individual home water and sewerage system.

Several techniques are available for home water savings. These have been studied by others[13,44-48] and will only be briefly reviewed here. The major water using functions, as established in Chapter 2, are bathing, sink, toilet, and clothes washing.

Bathing and Sink - The amount of water used in bathing can be reduced from 27 gallons to 5 gallons for each bath with the use of a flow reducing shower head. Most newer home showers are equipped with an adjustable shower head. A satisfactory shower can be taken with a flow rate of 3/4 gpm to 1 gpm but it is very difficult to blend the hot and cold water to the proper temperature when ½" valves are installed. The use of 3/16" valves and plumbing for the shower and lavatory sinks, and the use of adjustable spray nozzels would reduce household water use by 20 percent. If bathtubs were made slightly smaller, five gallons of water would be adequate for tub bathing. Another effective control that could be used in conjunction with the valves and shower head devices would be a small (6-8 gal.) extra fast recovery, water heater for the normal house system that would heat water to bathing temperature. This type of system is prevalent in European hotels. The 50 gallon water heater common to most U.S.

homes today is a convenience device for use with the washing machine. If a large water heater were plumbed so as to serve only the washing machine, it could be operated only prior to use. This system would conserve water and fuel as well. Home water heating has been estimated by the U.S. Energy Office to consume fifteen percent of home energy costs.[47]

Toilet - Reductions in the amount of home water use caused by the toilet can be achieved in several ways. Dual cycle water closets with reduced flush volume on the urinal cycle could save 6 to 9 gallons per capita per day or approximately 13 to 20 percent of the total water use. Utilization of a soap related wastewater renovation process and reuse in the toilet would reduce water use by about 33 percent. The same approximate reduction would be accomplished with a waterless toilet such as the multrum or oil flush type units. These concepts are in the development and review stage. The use of shallow trap, batch flush, toilets, that are common in Europe, would probably not be aesthetically acceptable in the U.S. due to the odor problems.

Washing Machines - There are several ways that washing machine water use could be reduced somewhat. The old-fashioned method of using rinse water from one wash as wash water for the next, when multiple loads are washed, would be somewhat inconvenient for use in modern washing machines. It would save water for large families where multiple loads are common. A water level control device that meters water to the wash on the basis of weight of clothes being washed would produce a water savings, but approximately the same advantage is available for most washing machines with the multiple load size selector. It was found in this study that most people either use the load size selector or wait until they have a full load before they wash. The use of the permanent press load cycle should be discouraged where water savings is being practiced. Selection of a washing machine with a low water intermediate rinse cycle should save approximately six percent of the total daily water use as compared to the average machine. It can be noted that home water use can be reduced from thirty to forty percent without causing undue inconvenience, for situations where it is needed.

Cost Considerations

The cost of individual home wastewater disposal systems is dependent upon the type of system required, site conditions, distance from supplies, engineering requirements and contractor availability. A very general estimate of costs for comparing different components of wastewater systems is given in Table 15.

It can be noted that the septic tank and leaching field result in the lowest cost and account for their widespread use where suitable soils exist. Where conditions do not permit the use of leaching fields, sub-surface filters and E-T beds are selected. Aerobic systems provide no cost advantage unless disinfection and surface release of the effluent is permitted. Generally, the surface release of home wastewater effluents is discouraged in Colorado. It should be noted that the cost of leaching fields, sub-surface filters, and E-T beds can be reduced nearly proportionately to the flow reduction accomplished with water saving fixtures and appliances.

Table 15

Individual Home Wastewater Cost Estimates

	Size	Installed Cost	Total Annual Cost	Total Annual Cost/1000 Gal.
Septic Tank	750 gal	$500	$50 Clean. 15 $65	$0.80
Leaching Field				
Soil Permeability				
Good	280 ft^2	$ 300- 450	$ 30- 45	$0.50
Fair	500 ft^2	500- 750	50- 75	0.80
Poor	1330 ft^2	1330-2000	130-200	2.00
Sub-Surface Filter	variable	$1500-4000	$150-400	$3.25
E-T Bed - Boulder area	5000-7000 ft^2	$3000-5000	$300-500	$5.00
Aerobic Unit	750 gal	$1000-1600	$100-160 Elec. 25-100 Serv. 30- 50 $155-310	$2.60
Disinfection		$ 150- 250	$ 15- 25 Chem. 20- 50 $ 35- 75	$0.65
Soap Related Water Reuse System		$ 500-3800	Chem? $ 50-380 Elec 15-120 $ 65-500	$2.00-$10.00

* 80,000 gal/house/year
Capitol recovery at 20 years and 7½% interest rate

New construction of municipal sewerage systems and sewage treatment facilities results in a cost range of two dollars per thousand gallons for residential density areas to as high as six dollars per thousand gallons for rural density locations. The use of individual home sewage disposal systems for suburban subdivisions is a practice that should be discouraged.

CHAPTER V - RECYCLING POTENTIAL OF HOME WASTEWATER STREAMS

Isolated individual homes are often located in areas that have problems of low water supply availability, high water cost, and inadequate areas for wastewater disposal. Under those conditions, reduction of volume of water used in the home through recycling may be highly desirable.

Based on the results of the studies related to flow quantities and pollutional strengths of the wastes from the individual water fixtures and appliances, it was decided to evaluate the potential for renovation of the less polluted waters from the bath, washing machine and dishwasher with the aim of recycling the treated effluent for toilet flushing or possibly lawn watering purposes. In this way the water use in the home could be reduced by one-third. The objective of the research was to evaluate the efficacy of three treatment devices for the renovation of the less polluted wastewaters.

One of the first considerations was that of desired quality of the renovated water. Little exploration has been made into the water quality requirements of individual household uses. The primary reason is that household water supplies have been considered to originate from one source and, thus, all water had to be of drinking quality. From this the public has generally taken water quality for granted, despite its usage. Public acceptance of lower grade water for secondary uses can only be estimated prior to introduction of such a system. Water used for toilet flushing merely acts as a medium for transporting wastes and does not entail body contact. "Reasonable criteria for toilet flushing are minimum odor, minimum staining properties, and prevention of serious health hazards."[44] Where color and turbidity do not affect the above parameters, acceptance is dependent on the public's attitude which forces adoption of acceptable quality standards.

Bailey, et al.[44] have presented the list of suggested toilet water standards that is shown in Table 16. Turbidity and color limits are relaxed from those given by the U.S. Public Health Service but the other criteria are equivalent values. Turbidity and color are primarily caused by the presence of suspended solids. Odor originates from organic compounds, detergents and microbial activity. This parameter is therefore related to the organic concentrations found in the water. Staining results from the precipitation of metals on the toilet bowl. Microbiological quality, as stated by Bailey, et al.[44] should be equivalent to the Public Health Service standard to prevent any possible health hazard. This value is less than one coliform per 100 ml. Thus, disinfection may be required depending on the bacteria removals in the renovation processes.

Lawn irrigation water is similar to toilet flushing water in that very little body contact occurs. However, the quality of the water must not be injurious to plant life or the physical, chemical and biological properties of the soil. Table 17 comprises the values suggested by the same author for irrigation water standards. The table stresses physical characteristics for

Table 16

Suggested Toilet Flushing Water Standards*

A. Physical Characteristics

Turbidity	20 Units
Color	30 Units
Odor	6 Units

B. Tentative Limits of Staining Agents

Mn	0.5 mg/ℓ
Cu	1.0
Fe	1.0
Fe + Mn	1.0

C. Disinfection May be Desirable

* After Bailey, et al[44]

Table 17

Suggested Irrigation Water Standards*

<u>Physical Characteristics</u>

Turbidity	10 Units
Color	15 Units
Odor	3 Units

<u>Chemical Characteristics</u>

Alkyl Benzene Sulfonate (ABS)	1.0 mg/ℓ
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chloride (Cl)	500
Chromium (Cr)	0.05
Copper (Cu)	1.0
Carbon Chloroform Extract (CCE)	0.4
Cyanide (CN)	0.2
Fluoride (F)	6.0
Iron (Fe)	1.0
Lead (Pb)	0.05
Manganese (Mn)	0.5
Iron and Manganese	1.0
Nitrate (NO_3)	180.0
Phenols	0.05
Selenium (Se)	0.01
Silver (Ag)	0.05
Sulfates (SO_4)	500
Total Dissolved Solids (TDS)	1000
Zinc (Zn)	10.0
Boron (Bo)	1.0

* After Bailey, et al.[44]

aesthetic control and chemical characteristics for control of toxic substances. Not included in the table are microbiological standards which the author stated that he considered as equal to that of drinking water.

In order to evaluate the renovation methods as sewage treatment processes, standards for the common pollutional parameters of BOD, COD and suspended solids (TSS) needed to be considered. The Colorado Department of Health[2] has set discharge standards which are applicable to any privately owned, non-municipal, non-septic, domestic waste treatment system that utilizes surface discharge. A listing of these follows:

Parameter	Effluent Standard
BOD_5	20 mg/ℓ
TSS	30 mg/ℓ
COD	85 mg/ℓ
Coliforms	2/100 mℓ

Although more work needs to be done on characterizing the quality of waters to be reused within the home, the values given above were considered as the upper limits for the evaluation of feasibility of the renovation processes studied.

Experimental Procedures and Results

The investigation into the treatment potential of soap-related wastewater was segmented into two phases. Phase 1 involved a study of the biological degradation of soap-related wastewater, while Phase 2 included implementation of the results of Phase 1 in the design and construction of a bench scale biological treatment system. In addition, during Phase 2 the treatment capability of dual media filtration and carbon adsorption were assessed. Each treatment process was studied both separately, and in sequence with the other processes.

Phase 1

Each of the wastes from the soap-related sources was evaluated separately and in combination to establish its amenability to biological degradation. The wastes studied were washing machine, bathroom sink, kitchen sink, dishwasher, bath-shower, and a combination of these wastes proportioned to normal daily flow (bath-shower 35%, sinks 20%, washing machine 40%, and dishwasher 5%). The kitchen sink wastewater event was found to be highly variable and significantly higher in pollutional strength relative to the other events.

The wastes were placed in one gallon batch reactors. One set of waste samples was aerated so that the dissolved oxygen content of the reactor was maintained above one mg/ℓ throughout the testing period. An identical set was evaluated without any external oxygen source. All of the samples that were non-aerated were void of dissolved oxygen in a period of slightly less than one day.

It was thought possible that some of the individual wastes would not contain the proper bacterial cultures to stimulate biological action. An initial set of tests was run with duplicate samples, one with the waste and a small amount (10 ml) of seed bacteria (activated sludge mixed liquor), and the other with unseeded wastewaters. It was found that the seeding did not appreciably affect either the rate or the extent of the biological reaction.

During the tests, the wastes in the batch units were periodically analyzed over a time span of 300 hours for the major pollutional parameters of COD, BOD and total and dissolved solids.

All of the wastes degraded in a very similar manner. A set of typical curves for the results of the combination wastes are shown in Figures 23 and 24. Some sedimentation occurred in all units but this was more pronounced in units with the non-aerated samples. Test aliquots were taken without stirring the units, as this was felt to represent realistic effluent conditions for prototype treatment units. The curves for all of the wastes resulted in nearly the same shape. Reductions in pollutional parameters occurred rapidly in the aerobic units for a period of about four days and after that time the rate was greatly reduced.

Table 18 is a presentation of the results of all units tested which shows the percent reduction in pollutional parameters at a period of four days. It can be noted that, with aeration, most of the wastes were degraded to the extent of approximately sixty percent within four days. In fact, the curves for BOD removal were similar to an inverted form of the familiar BOD progression curve. The dishwasher pollutants were mostly soluble

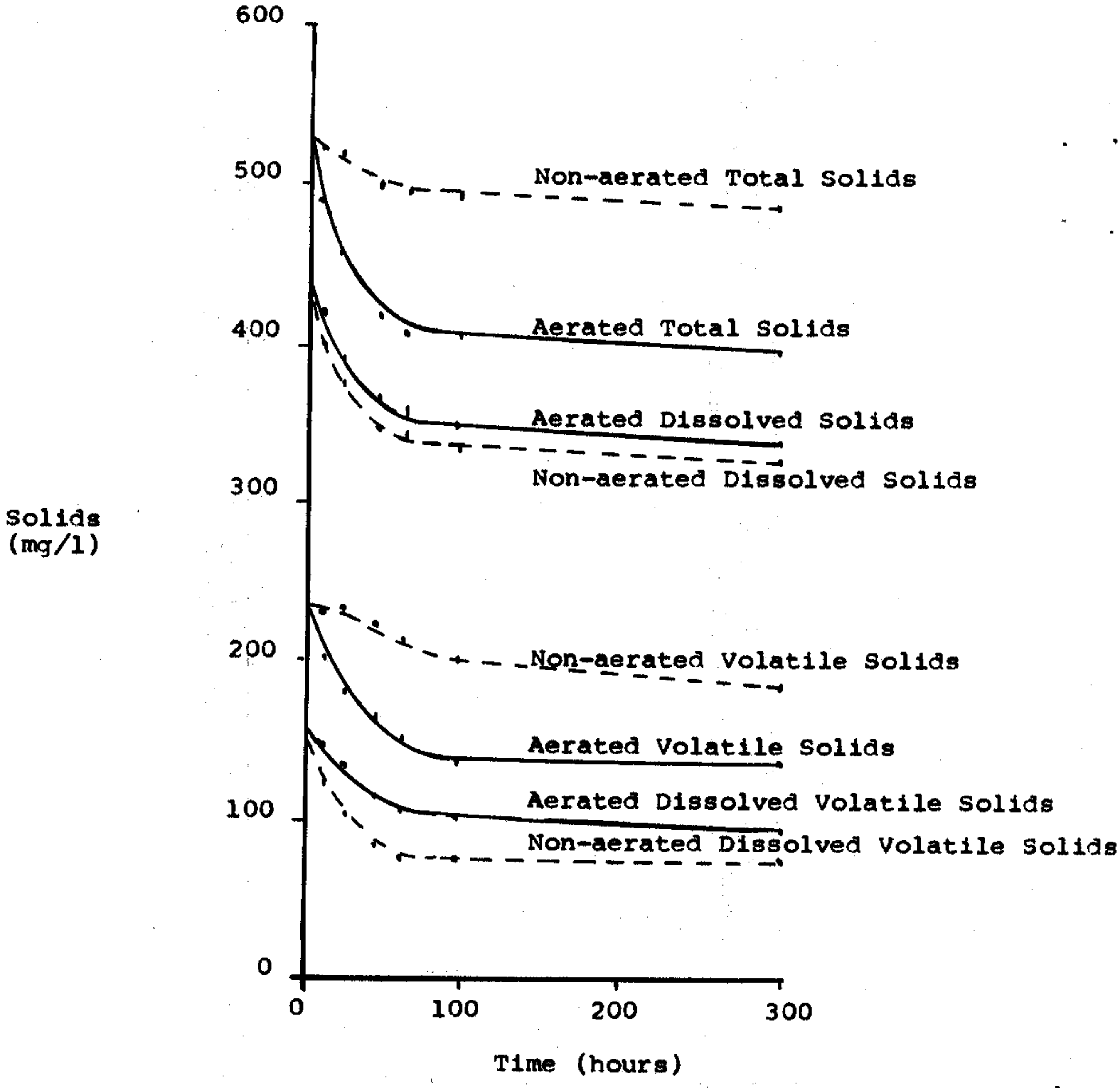


FIGURE 23 COMBINATION WASTES SOLIDS REMOVAL CURVES

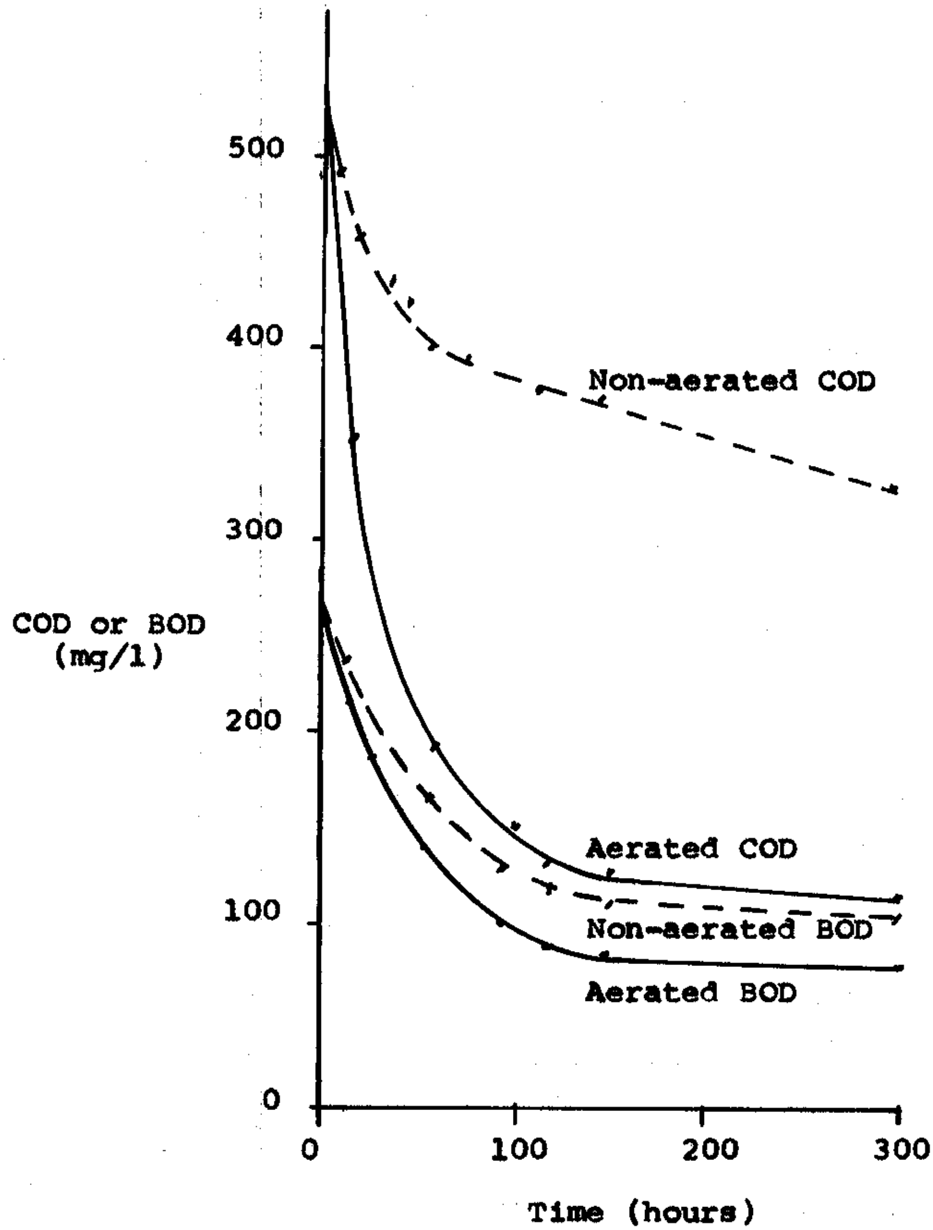


FIGURE 24 COMBINATION WASTES COD,BOD REMOVAL CURVES

Table 18

Results of Batch Test Studies

(all mg/ℓ)

Waste	Reactor Type	Pollutional Parameter	Initial Conc.	Conc. 4 Days	Conc. 20 Days	% Reduction 4 Days
Combination	Aerated	COD	530/135F	120	107/42F	77%
		BOD	250/65 F	95	78/28F	62%
		Total Sol	535	405	390	24%
		Vol Solids	245	135	145	45%
		Dissolved Tot Sol	455	345	369	24%
		Dissolved Vol Sol	170	110	107	34%
Combination	Non-Aerated	COD	530	385	223	27%
		BOD	250	150	93	40%
		TS	535	495	483	7%
		VS	245	200	170	23%
		DTS	455	335	325	26%
		DVS	170	130	115	24%
Washing Machine	Aerated	COD	605/203F	270	144/49F	55%
		BOD	240/82F	82	63/23F	66%
		TS	490	370	334	25%
		VS	220	142	120	35%
		DTS	425	255	245	40%
		DVS	175	70	59	60%
Washing Machine	Non-Aerated	COD	605	465		23%
		BOD	240	145		40%
		TS	490	412		16%
		VS	220	215		2%
		DTS	425	270		35%
		DVS	175	77		56%
Kitchen Sink	Aerated	COD	5200/4650F	2000	405/229F	62%
		BOD	3750/3360F	1450	847/465F	61%
		TS	4050	1200	808	70%
		VS	3600	900	432	75%
		DTS	3650	800	509	78%
		DVS	3150	450	215	86%
Kitchen Sink	Non-Aerated	COD	5200	4200		19%
		BOD	3750	2700		41%
		TS	4050	2900		28%
		VS	3600	2450		32%
		DTS	3650	1950		47%
		DVS	3150	1550		51%
Bathroom Sink	Aerated	COD	330/87F	140	84/37F	58%
		BOD	215/62F	90	57/25F	58%
		TS	225	120	120	47%
		VS	120	75	50	30%
		DTS	165	117	120	29%
		DVS	70	60	54	14%
Bathroom Sink	Non-Aerated	COD	330	245		26%
		BOD	215	110		49%
		TS	225	175		22%
		VS	120	95		25%
		DTS	165	95		42%
		DVS	70	53		24%
Dishwasher	Aerated	COD	1160/281F	1100	651/103F	5%
		BOD	850/197F	700	485/73F	18%
		TS	4950	4150	3762	19%
		VS	1100	900	381	18%
		DTS	4550	3750	3552	18%
		DVS	750	850	671	-13%
Dishwasher	Non-Aerated	COD	1160	1020		12%
		BOD	710	690		18
		TS	4950	4600		7%
		VS	1100	1000		9%
		DTS	4550	4150		9%
		DVS	750	850		-13%
Shower	Aerated	COD	310/60F	125	60/21F	60%
		BOD	220/55F	85	41/16F	65%
		TS	220	142	144	35%
		VS	155	75	75	57%
		DTS	157	105	114	32%
		DVS	90	42	49	53%
Shower	Non-Aerated	COD	310	230		25%
		BOD	240	105		56%
		TS	220	155		30%
		VS	155	97		37%
		DTS	157	95		39%
		DVS	90	42		53%

For some COD and BOD, double values are reported. The first value represents the normal sample and the second value is for a filtered sample (dissolved, COD, BOD).

inorganics and displayed very little degradation. The organics in dishwasher detergents also seemed to be quite resistant. Likewise, bathroom sink wastes contained a significant amount of inorganics, and the organic fraction was not as easily decomposed. For most of the wastes tested under aerobic conditions, two results of decomposition were apparent. With the exception of the combination wastes, the suspended solids were not significantly removed, but the BOD and COD associated with the suspended solids were greatly reduced. The volatile dissolved solids were removed in approximately the same percentage as the result for filtered BOD. The volatile solids data for the combination wastes were somewhat erratic.

The non-aerated wastes were not as completely decomposed, once the dissolved oxygen was depleted. The short time period used and the low laboratory temperature ($\sim 20^\circ C$) did not stimulate active anerobiasis. Slow decomposition occurred and no odors were noted.

Phase 2

It can be noted from the effluent characteristics of the aerated combination wastes that the residual pollutants included approximately 50 mg/ℓ suspended BOD and 28 mg/ℓ dissolved BOD. Since the fraction of suspended BOD with respect to the total was similar to that of the raw waste, it was assumed that the fraction of suspended BOD at four days was in the range of sixty to seventy percent.

From these observations of Phase 1, a bench scale treatment unit was designed, constructed, and analyzed in order to evaluate the efficiency of biological oxidation, sedimentation, filtration, and carbon adsorption in treating soap related wastewater. Figure 25 illustrates the apparatus used in each treatment process and the arrangement of the processes. As can be noted from the diagram, hydraulic flow through the treatment unit could be altered to allow for the analysis of each unit process with varying degrees of pretreatment. Table 19 lists the unit processes evaluated and the degree of pretreatment that preceeded each.

Table 19

Treatment Alternatives

1. Aerobic (biological) and sedimentation
    a. No pretreatment
2. Filtration
    a. Without pretreatment
    b. With pretreatment
        (1) aerobic (biological) and sedimentation
3. Carbon adsorption
    a. Without pretreatment
    b. With pretreatment
        (1) aerobic (biological) and sedimentation
        (2) filtration
        (3) aerobic (biological), sedimentation and filtration

Flow meters, manometers
sampling points, not shown

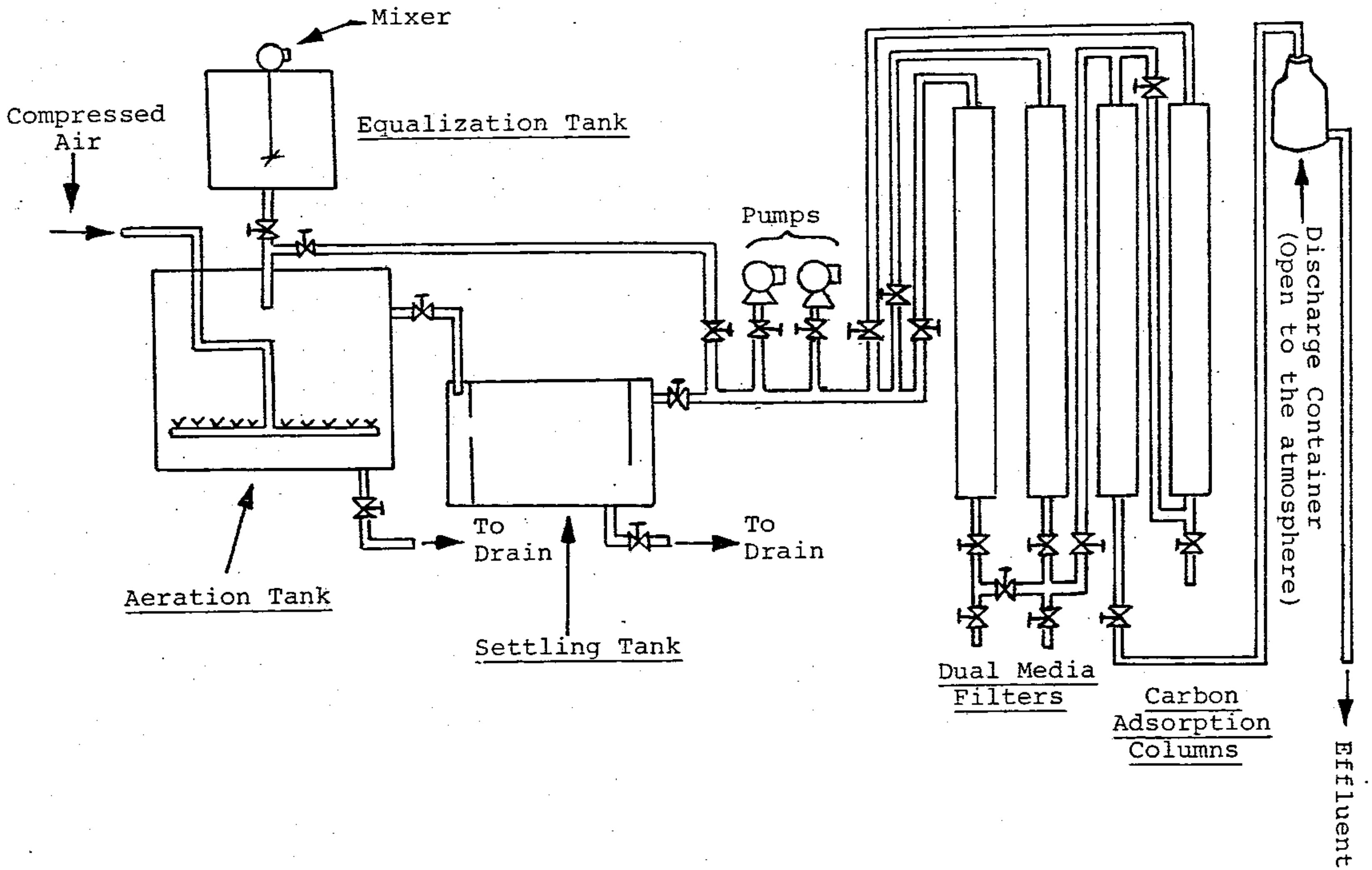


FIGURE 25 DIAGRAM OF BENCH SCALE PILOT PLANT

From the results of Phase 1, it was noted that the kitchen sink wastes contained high BOD levels. Since the objective of Phase 2 was to evaluate treatment units capable of producing a high quality water for reuse, it was decided to eliminate the kitchen wastewater from the flow stream. With this stream excluded the composition of the combined wastewater used in the second phase was as shown in Table 20.

Table 20

Daily Soap-Related Wastewater Flow

Wastewater Event	Household Volume/Day	Percentage of Total Volume	Bench Unit Volume/Day
1. Bathroom Sink	20 GPD	20%	2.0 GPD
2. Bath Tub and Shower	35	35	3.5 GPD
3. Washing Machine	40	40	4.0 GPD
4. Dishwasher	5	5	0.5 GPD
	100 GPD	100%	10.0 GPD

Based on assumption of 4 persons per household.

The flow capacity of the pilot plant was 10 gallons per day. This value was determined by the limited space available for construction of the pilot plant and the required transportation of samples from individual homes to the site of the plant. The resulting volumetric scale ratio of prototype to model was 10:1. The prototype unit represented a treatment system designed to handle the total flow of soap-related wastewater from an individual residence.

Biological treatment in the pilot treatment unit consisted of two units: 1) an aeration reactor and 2) a settling tank. Design of the aeration tank was based on data obtained in Phase 1. The settling tank allowed all settable floc to be removed from the effluent stream.

The capacity of the aeration tank provided a 4 day detention time and allowed for the continuous flow of diffused air into the aerated reactor. The units were operated 24 hours per day. The current of air not only maintained a high dissolved oxygen concentration in the mixed liquor but also provided mixing throughout the unit. Mixing prevented short circuiting in the reactor and did not allow solids to settle out. A rectangular sedimentation tank of two day detention time followed the aeration reactor. This unit allowed the biological floc formed during aeration to settle.

Two dual-media, sand-coal filters, were installed to evaluate the removal of solids by in-depth filtration. The two,2 in. diameter plexiglass columns contained an 11 in. deep layer of approximately 0.9 mm diameter anthracite coal above an 11 in. layer of approximately 0.5 mm diameter silica sand. An underdrain of gravel was placed beneath the sand layer to distribute the flow over the surface area of the column during backwashing operations. When the filters were operated, 10 gallons of wastewater passed through the filter beds every day over a span of four hours. This produced a surface loading rate of ~.2 gpm/ft^2. Sampling was accomplished at the bottom of the coal bed and at the effluent of the filter. Only one filter column was placed on line during operation of the filter system. The second column acted as a standby unit to be used if the column in service became clogged with solids or required other maintenance.

Initially, the clogged columns were backwashed by simply reversing the flow of water through the column. However, this process was not capable of removing the hardened mat of solids which formed on the surface of the filter bed. This layer of solids resisted the abrasive action of countercurrent water flow and since the mat was more dense than the filter media, it could not be washed out of the column without also washing some filter media from the column.

A two step backwash operation was used to solve the problem. In the first step, the column bed was drained until only a three inch depth of water remained above the surface. Air was then introduced into the bottom of the column and the entire filter bed was suspended into violent abrasive action. This agitation caused the solid mat to disintegrate into small pieces. In the second step, these smaller sized solids were washed from the column when the filter bed was backwashed with water.

Two identical columns of activated carbon were installed into the pilot plant. The carbon beds were retained in two, 2.5 in. diameter plexiglass columns. Each column was 5 ft. in length and contained 3.75 ft. of washed virgin activated carbon. The carbon used throughout the study was 8x30 mesh, Calgon Filtrasorb 300.

Flow through the carbon columns was pressurized to allow for the operation of downflow carbon beds. With 10 gallons of wastewater passed through the columns daily over a 4 hour time span, a surface loading rate of 1.2 gpm/ft^2 was maintained on the columns. This loading rate produced 20 minutes of contact time in each carbon bed.

Piping on the carbon columns allowed the columns to be operated either individually or in series. When the two columns were operated in series, a 40 minute contact time was obtained. Sampling portals installed along the depth of the carbon bed produced samples at contact times of 3, 10, and 20 minutes on an individual column and 3, 10, 23, 30, and 40 minutes when the two columns were operated in series.

Method of Operation

The biological unit was operated for a period of two weeks to assure steady state conditions and then sampling and evaluation of all units was accomplished over a five to fourteen day period.

Analyses were made daily for COD, BOD, total, volatile, and dissolved solids. Testing for total and ortho-phosphate, ammonia and organic nitrogen, and total coliforms was accomplished about every third day. All tests were conducted in accordance with Standard Methods[21].

A sidestream system of very small 1" diameter, 8" deep, carbon columns was operated to determine the organic capacity of the activated carbon.

Flow through the aerobic biological reactor was not continuous. Instead, influent was introduced on a once daily basis and effluent was discharged once a day. Thus, the unit simulated a pulse loaded, semi-continuous reactor.

The temperature of the aeration liquor varied between 13°C and 17°C. The reason for depression of the temperature below that of room temperature was believed to be caused by the flow of cool air through the air diffusers.

Results - Biological Oxidation

The results are presented for individual units and then analyzed as sequential treatment systems. The results of the biological aeration unit with sedimentation are shown in Tables 21 and 22.

It can be noted that the influent wastewater strength was considerably less than that in Phase 1. The extent of pollutant reduction was slightly greater than that found in Phase 1 due to the addition of the settling tank and absence of the effects of the kitchen sink wastes. A range of influent pollutional values existed due to the changing nature of household wastes, but the mixing and biological action produced fairly consistent effluent values. Apparently a nitrogen deficiency did not exist, probably because of the low micro-organism level of the plain aeration system. Coliform concentrations were not reduced, in fact, there were indications of growth within the reactor.

Table 21

Summary of Data

Type of Treatment: Aeration and Subsequent Sedimentation

Parameter	Sampling Position	# Data Points	Range	Mean Value	Percent Removal
COD (mg/ℓ)	Influent	9	131-215	168	0
	Aeration Tank	13	65-85	75	55.4
	Settled Eff.	13	57-71	64	61.9
BOD (mg/ℓ)	Influent	6	45-102	66	0
	Aeration Tank	6	13-20	15	77.3
	Settled Eff.	6	10-15	12	81.8
Total Solids (mg/ℓ)	Influent	4	238-389	296	0
	Aeration Tank	5	259-292	280	5.4
	Settled Eff.	5	271-292	280	5.4
Dissolved Solids (mg/ℓ)	Influent	4	180-355	263	0
	Aeration Tank	5	214-277	259	1.5
	Settled Eff.	5	234-264	253	3.8
Turbidity (JTU)	Influent	6	42-53	49	0
	Aeration Tank	6	11-14	13	73.5
	Settled Eff.	6	11-14	13	73.5

Table 22

Pollution Reduction

Type of Treatment: Aeration and Subsequent Sedimentation

Pollutional* Parameter	Influent mg/ℓ	Aeration Tank mg/ℓ	Settled Effluent mg/ℓ
	Sample Point		
COD	168	75	64
BOD	66	15	12
TS	296	280	280
TFS	190	200	197
TVS	106	80	83
DS	263	259	253
FDS	178	186	192
VDS	85	73	61
Total P	15.9	18.4	18.4
Ortho-P	5.3	8.0	18.5
NH_3-N	0	0.1	0.25
Organic N	0.6	2.0	1.4
Turbidity (JTU)	49	13	13
Coliforms ($x10^6$/100ml)	1.6	2.1	2.1

Dual Media Filtration

Evaluation of the treatment potential of filtration in a home treatment system involved two types of treatment. The first phase of the filtration study included analysis of an influent that had received no previous treatment, while in the second and last phase, influent introduced to the filter column had previously been passed through an aeration reactor and a subsequent sedimentation basin. Chemical pretreatment was not investigated since its application in a home treatment system would require a large amount of operation and maintenance by the homeowner. Also, the cost of chemicals could make the system un-economical.

The data from the analyses of filtration of raw wastewater are summarized in Tables 23 and 24.

Solids removal in the filter bed was not significant because the solids in the influent stream were primarily in the dissolved state. Solids that were removed were volatile suspended solids (total volatile solids - volatile dissolved solids). The removal of volatile solids caused a 39.4 percent COD reduction and a 45.9 percent BOD reduction through the filter bed.

Close study of the data contained in Tables 23 and 24 shows that little additional solids removal was achieved in the lower layer of silica sand. The solids that passed through the pores in the 0.9 mm anthracite coal grains were small enough to continue through the pore spaces in the smaller silica sand grains.

Table 23

Summary of Data

Type of Treatment: Dual Media Filtration Without Pretreatment

Parameter	Sampling Position	# Data Points	Range	Mean Value	Percent Removal
COD (mg/ℓ)	Influent	6	171-252	213	0
	11 in. of Anthracite	6	118-176	143	32.8
	Filter Eff.	6	96-157	129	39.4
BOD (mg/ℓ)	Influent	3	62-116	85	0
	11 in. of Anthracite	3	42-65	50	43.8
	Filter Eff.	3	35-66	46	45.9
Total Solids (mg/ℓ)	Influent	4	256-369	299	0
	11 in. of Anthracite	4	219-260	249	16.7
	Filter Eff.	4	235-292	264	11.7
Dissolved Solids (mg/ℓ)	Influent	5	124-274	206	0
	11 in. of Anthracite	5	117-248	189	8.3
	Filter Eff.	5	115-257	197	4.4
Turbidity (JTU)	Influent	4	24-73	46	0
	11 in. of Anthracite	4	14-42	26	43.5
	Filter Eff.	4	16-40	27	41.3

Table 24

Pollution Reduction

Type of Treatment: Dual Media Filtration
Without Pretreatment

Pollutional* Parameter	Influent mg/ℓ	Sample Point: 11" of Anthracite Coal mg/ℓ	Dual Media Filter Effluent mg/ℓ
COD	213	143	129
BOD	85	50	46
TS	299	249	264
TFS	183	173	176
TVS	116	76	88
DS	206	189	197
FDS	151	139	137
VDS	55	50	60
Total P	10.2	9.0	11.0
Ortho-P	3.0	2.8	2.0
NH_3-N	0	0	0
Organic N	1.3	1.3	1.3
Turbidity (JTU)	46	26	27
Coliforms ($x10^6$/100ml)	1.5	---	1.5

During filter column operation, a mat of solids formed on the upper surface of the filter bed. This mat was white in color and appeared to be a conglommeration of soap and detergent grains and fibrous material such as hair and cloth fibers. Undoubtedly, the mat of solids aided the filtration process in removing solids from the influent. Evidence of this was indicated by the increasing depth of the solids above the filter bed with continued filter operation. Filtration within the mat of solids could explain the lack of solids removal within the silica sand layer.

Headloss through the filter column was measured by a differential mercury manometer. The data are recorded in Table 25. An exponentially increasing rate of headloss was obvious in operation of the filter column.

Dual-media filtration of an influent that had previously been passed through biological treatment and subsequent sedimentation was not effective in reducing the pollution present. Analysis of Tables 26 and 27 is evidence of this. For each parameter measured, the quality of the influent and the effluent were nearly identical with the exception of turbidity and organic nitrogen. The pollution in the influent was primarily dissolved and, thus, not susceptible to capture in a dual-media filter. A further indication of the inefficient removal of solids across the filter bed is presented in Table 27, which shows only minor headloss accumulation through 20 hours (5 days) of filter column operation.

Table 25

Headloss Data Through Filter

Type of Treatment: Dual Media Filtration Without Pretreatment

Time Into Run (hours)	Headloss: Inches of Mercury	Headloss: Feet of Water
0	0.13	0.14
1	0.19	0.21
2	0.31	0.35
4	0.56	0.64
6	1.19	1.34
8	1.31	1.48
10	1.94	2.19
Backwashed with water, only, at 10 hours.		
10	0.38	0.42
14	2.19	2.47
15.5	3.31	3.74
17	4.31	4.87
18.5	14.50	16.37
Backwashed with water, only, at 18.5 hours.		
18.5	0.38	0.42
21.5	1.75	1.98
25.5	2.19	2.47
26	4.25	4.80
27.5	6.50	7.34
27.75	8.25	9.32
Backwashed with air and water at 27.75 hours.		
27.75	0.75	0.85
30.5	2.00	2.26
31.5	3.50	3.95
32.5	4.87	5.50
35.25	8.23	9.30
36	12.75	14.40

Run terminated at 36 hours or 9 days.

Table 26

Summary of Data

Type of Treatment: Dual Media Filtration Preceeded by Aeration and Sedimentation

Parameter	Sampling Position	# Data Points	Range	Mean Value	Percent Removal
COD (mg/ℓ)	Influent	13	57-71	64	0
	11 in. of Anthracite	4	49-69	62	3.1
	Filter Eff.	4	53-67	62	3.1
BOD (mg/ℓ)	Influent	6	10-15	12	0
	11 in. of Anthracite	3	10-13	11	8.3
	Filter Eff.	3	9-12	10	16.7
Total Solids (mg/ℓ)	Influent	5	271-292	280	0
	11 in.of Anthracite	2	275-287	281	0
	Filter Eff.	2	271-288	280	0
Dissolved Solids (mg/ℓ)	Influent	5	234-264	253	0
	11 in. of Anthracite	2	263-265	264	+4.3
	Filter Eff.	2	256-268	262	+3.6
Turbidity (JTU)	Influent	6	11-14	13	0
	11 in. of Anthracite	2	7.2-7.3	7.3	43.8
	Filter Eff.	2	6.4-6.7	6.6	49.2

Table 27

Pollution Reduction

Type of Treatment: Dual-Media Filtration Preceeded by Aeration and Sedimentation

		Sample Point	
Pollutional* Parameter	Influent mg/ℓ	11" of Anthracite Coal mg/ℓ	Dual Media Filter Effluent mg/ℓ
COD	64	62	62
BOD	12	11	10
TS	280	281	280
TFS	197	205	204
DS	253	264	262
FDS	192	198	190
VDS	61	66	72
Total P	18.4	19	18.5
Ortho-P	18.5	18	18.8
NH_3-N	0.25	---	0.3
Organic N	1.4	---	0.6
Turbidity (JTU)	13	7.3	6.6
Coliforms ($x10^6$/100ml)	2.1	---	2.1

Table 28

Headloss Data Through Filter

Type of Treatment: Dual Media Filtration Preceeded by Aeration and Sedimentation

Time Into Run (hours)	Headloss	
	Inches of Mercury	Feet of Water
0	0.50	0.58
4	0.75	0.85
8	0.75	0.85
12	0.75	0.85
16	0.75	0.85
20	0.75	0.85

Run terminated at 20 hours or at 5 days.

In both modes of filter treatment, coliforms were not removed in the filter beds. This indicates that the effluent would be a health hazard with direct human contact unless disinfection was first applied.

Carbon Adsorption

Analysis of the potential of utilizing carbon adsorption in the treatment of soap-related wastewater included an investigation of the application of pressurized, downflow carbon columns in four treatment systems. Each system incorporated a different degree of wastewater pretreatment prior to passing the wastes through the carbon bed. The four degrees of pretreatment are listed below:

1. No previous treatment
2. Dual-media filtration
3. Extended aeration and sedimentation
4. Extended aeration, sedimentation, and dual-media filtration

The carbon columns provided a 20 minute contact time within the bed of 8x30 virgin activated carbon. (Surface loading rate of 1.2 gpm/ft^2.) If carbon adsorption was subsequent to dual-media filtration within a treatment system, only one carbon column was applied. However, when dual-media filtration did not preceed carbon adsorption, two columns were operated in series in the treatment system. The lead column, therefore, acted as a filter adsorber.

1. No previous pretreatment.

The efficiency of treating raw wastewater with activated carbon is summarized in Tables 29 and 30. Direct carbon adsorption of the soap related wastewater pollutants was effective in removing primarily the large suspended matter and dissolved organic compounds. Fine colloidal materials were not effectively removed by filtration or adsorption, as noted from the turbidity values. This resulted in effluent BOD values that would be unacceptable for most reuse applications. Most of the removal occurred within the initial few minutes of contact. It can be concluded from the data that, even with greatly extended contact time, highly efficient removals with carbon alone would not be feasible.

2. Pretreatment with dual-media filtration.

The results of carbon adsorption of soap related wastes with filtration pretreatment are shown in Tables 31 and 32. Dual-media filtration was not a very effective means of pretreatment with the results of carbon adsorption only slightly better than those reported without pretreatment.

3. Pretreatment with aeration and sedimentation.

Effluent from the aeration-sedimentation system was used with carbon adsorption. The results are shown in Tables 33 and 34. The high quality effluent from the aeration unit was further treated with carbon resulting in an effluent with a BOD of 6 mg/ℓ, suspended solids of 22 mg/ℓ, and turbidity of 6.1 JTU. The effluent, with disinfection, would be acceptable for many reuse purposes.

Table 29

Summary of Data

Type of Treatment: Carbon Adsorption Without Pretreatment

Parameter	Sampling Position	# Data Points	Range	Mean Value	Percent Removal
	Influent	13	165-237	186	0
	3 Minute Contact	13	60-145	102	45.1
	10 Minute	9	59-101	79	57.5
COD (mg/ℓ)	23 Minute	11	45-87	67	64.0
	30 Minute	12	39-81	58	68.8
	40 Minute	13	27-64	43	76.9
	Influent	6	36-65	51	0
	3 Minute	7	16-51	32	37.3
	10 Minute	4	14-32	27	47.1
BOD (mg/ℓ)	23 Minute	6	14-30	26	49.0
	30 Minute	6	13-28	19	62.8
	40 Minute	5	11-28	17	65.7
	Influent	6	236-531	326	0
	3 Minute	6	197-473	282	13.5
	10 Minute	3	182-241	216	33.8
Total Solids (mg/ℓ)	23 Minute	5	177-481	280	14.1
	30 Minute	5	179-485	281	13.8
	40 Minute	6	179-481	269	17.5
	Influent	4	203-474	308	0
	3 Minute	4	175-479	290	6.2
	10 Minute	1	---	177	---
Dissolved Solids (mg/ℓ)	23 Minute	4	156-456	273	12.8
	30 Minute	4	163-470	282	8.4
	40 Minute	4	168-454	275	10.7
	Influent	6	14-58	37	0
	3 Minute	5	8-46	27	27.0
	10 Minute	3	20-35	27	27.0
Turbidity (JTU)	23 Minute	6	6-29	22	40.5
	30 Minute	6	5-33	22	40.5
	40 Minute	6	5-29	20	45.9

Table 30

Pollution Reduction

Type of Treatment: Carbon Adsorption Without Pretreatment

Pollutional Parameter	Influent	Sample Point: 3 Minute Carbon Contact	10 Minute Carbon Contact	23 Minute Carbon Contact	30 Minute Carbon Contact	40 Minute Carbon Contact
COD (mg/ℓ)	186	102	79	67	58	43
BOD (mg/ℓ)	51	32	27	26	19	17
TS (mg/ℓ)	326	282	216	280	281	269
TFS (mg/ℓ)	221	208	154	215	219	211
TVS (mg/ℓ)	105	74	62	65	62	58
DS (mg/ℓ)	308	290	177	273	282	275
FDS (mg/ℓ)	228	222	127	228	234	232
VDS (mg/ℓ)	80	68	50	45	48	43
Total P (mg/ℓ)	14.5	14.5	13.8	13.8	13.4	13.3
Ortho-P (mg/ℓ)	1.8	1.9	2.0	2.4	2.9	3.3
NH_3-N (mg/ℓ)	0	0	0	0	0	0
Organic N (mg/ℓ)	2.0	1.5	---	1.3	1.5	1.5
Turbidity (JTU)	37	27	27	22	22	20
Coliforms ($x10^6$/100ml)	2.4	---	---	2.4	---	2.4

Table 31

Summary of Data

Type of Treatment: Carbon Adsorption Preceeded by Dual-Media Filtration

Parameter	Sampling Position	# Data Points	Range	Mean Value	Percent Removal
COD (mg/ℓ)	Influent	6	96-157	129	0
	3 Minute Contact	6	59-111	80	38.0
	10 Minute	6	44-78	63	51.1
	20 Minute	6	38-59	47	63.5
BOD (mg/ℓ)	Influent	3	35-66	46	0
	3 Minute	3	17-47	30	34.8
	10 Minute	3	7-21	14	69.5
	20 Minute	3	9-15	13	71.7
Total Solids (mg/ℓ)	Influent	4	235-292	264	0
	3 Minute	4	201-236	221	16.3
	10 Minute	4	201-230	213	19.3
	20 Minute	4	185-218	209	20.8
Dissolved Solids (mg/ℓ)	Influent	5	115-257	197	0
	3 Minute	4	124-228	181	8.1
	10 Minute	5	130-208	183	7.1
	20 Minute	5	121-2-4	167	15.2
Turbidity (JTU)	Influent	4	16-40	27	0
	3 Minute	4	10-37	20	35.9
	10 Minute	4	11-24	17	37.0
	20 Minute	4	11-21	15	44.5

Table 32

Pollution Reduction

Type of Treatment: Carbon Adsorption Preceeded by Dual Media Filtration

Pollutional Parameter	Influent	Sample Position: 3 Minute Carbon Contact	10 Minute Carbon Contact	20 Minute Carbon Contact
COD (mg/ℓ)	129	80	63	47
BOD (mg/ℓ)	46	30	14	13
TS (mg/ℓ)	264	221	213	209
TFS (mg/ℓ)	176	168	164	158
TVS (mg/ℓ)	88	53	49	51
DS (mg/ℓ)	197	181	183	167
FDS (mg/ℓ)	137	143	146	139
VDS (mg/ℓ)	60	38	37	28
Total P (mg/ℓ)	11.0	10.7	9.9	9.0
Ortho-P(mg/ℓ)	2.0	2.8	2.8	2.5
NH_3-N (mg/ℓ)	0	0	0	0
Organic N (mg/ℓ)	1.2	1.4	1.4	1.3
Turbidity (JTU)	27	20	17	15
Coliforms (x 10^6/100 ml)	1.5	---	---	1.5

Table 33

Summary of Data

Type of Treatment: Carbon Adsorption Preceeded by Aeration, Sedimentation, and Dual Media Filtration

Parameter	Sampling Position	# Data Points	Range	Mean Value	Percent Removal
COD (mg/ℓ)	Influent	4	53-67	62	0
	3 Minute Contact	4	34-40	38	38.7
	10 Minute	4	30-36	34	46.7
	20 Minute	4	26-30	27	54.6
BOD (mg/ℓ)	Influent	3	9-12	10	0
	3 Minute	3	8-8	8	20.0
	10 Minute	3	6-8	7	30.0
	20 Minute	3	5-7	6	40.0
Total Solids (mg/ℓ)	Influent	2	271-288	280	0
	3 Minute	2	279-285	278	0.7
	10 Minute	2	263-274	267	4.6
	20 Minute	2	255-283	269	3.9
Dissolved Solids (mg/ℓ)	Influent	2	256-268	262	0
	3 Minute	2	259-269	260	0.8
	10 Minute	2	237-260	249	5.0
	20 Minute	2	244-250	247	5.8
Turbidity (JTU)	Influent	2	6.4-6.7	6.6	0
	3 Minute	2	6.2-6.5	6.4	3.0
	10 Minute	2	6.0-6.4	6.2	6.1
	20 Minute	2	5.9-6.3	6.1	7.6

Table 34

Pollution Reduction

Type of Treatment: Carbon Adsorption Preceeded by Aeration, Sedimentation, and Dual Media Filtration

Pollutional Parameter	Influent	Sample Position 3 Minute Carbon Contact	10 Minute Carbon Contact	20 Minute Carbon Contact
COD (mg/ℓ)	62	38	34	27
BOD (mg/ℓ)	10	8	7	6
TS (mg/ℓ)	280	278	269	269
TFS (mg/ℓ)	204	205	196	197
TVS (mg/ℓ)	76	73	73	72
DS (mg/ℓ)	262	260	249	247
FDS (mg/ℓ)	190	197	190	195
VDS (mg/ℓ)	72	63	59	52
Total P (mg/ℓ)	18.5	20	19.3	19
Ortho-P(mg/ℓ)	18.8	18.3	18.3	17
NH_3-N (mg/ℓ)	0.3	---	---	0.3
Organic N (mg/ℓ)	0.6	---	---	0.5
Turbidity (JTU)	6.6	6.4	6.2	6.1
Coliforms ($x10^6$/100ml)	2.1	---	---	2.1

Table 35

Summary of Data

Type of Treatment: Carbon Adsorption Preceeded by Aeration and Subsequent Sedimentation

Parameter	Sampling Position	# Data Points	Range	Mean Value	Percent Removal
COD (mg/ℓ)	Influent	13	57-71	64	0
	3 Minute Contact	6	35-43	38	40.6
	10 Minute	6	26-35	30	53.1
	23 Minute	6	19-34	26	59.4
	30 Minute	6	17-32	23	64.0
	40 Minute	6	12-27	19	70.3
BOD (mg/ℓ)	Influent	6	10-15	12	0
	3 Minute	2	8-9	8.5	29.2
	10 Minute	2	7-8	7.5	37.5
	23 Minute	2	5-5	5	58.3
	30 Minute	2	4-6	5	58.3
	40 Minute	2	3-4	3.5	70.7
Total Solids (mg/ℓ)	Influent	5	271-292	280	0
	3 Minute	3	246-262	254	9.3
	10 Minute	3	239-247	242	13.6
	23 Minute	2	231-242	238	15.0
	30 Minute	3	218-239	230	17.8
	40 Minute	3	194-247	223	20.4
Dissolved Solids (mg/ℓ)	Influent	5	234-264	253	0
	3 Minute	3	241-260	247	2.4
	10 Minute	3	232-240	235	7.1
	23 Minute	3	219-247	231	8.7
	30 Minute	3	183-234	215	15.0
	40 Minute	3	198-237	219	13.4
Suspended Solids (mg/ℓ)	Influent	6	11-14	13	0
	3 Minute	4	6.4-7.0	6.7	48.5
	10 Minute	4	5.6-6.2	5.9	54.5
	23 Minute	4	4.3-5.8	5.2	60.0
	30 Minute	4	3.5-5.4	4.5	65.4
	40 Minute	4	2.5-5.0	4.1	68.5

Table 36

Pollution Reduction

Type of Treatment: Carbon Adsorption Preceeded by Aeration and Subsequent Sedimentation

Pollutional Parameter	Influent	Sampling Position: 3 Minute Carbon Contact	10 Minute Carbon Contact	23 Minute Carbon Contact	30 Minute Carbon Contact	40 Minute Carbon Contact
COD (mg/ℓ)	64	38	30	26	23	19
BOD (mg/ℓ)	12	8.5	7.5	5	5	3.5
TS (mg/ℓ)	280	254	242	238	230	223
TFS (mg/ℓ)	197	193	191	188	178	171
TVS (mg/ℓ)	83	61	51	50	52	52
DS (mg/ℓ)	253	247	235	231	215	219
FDS (mg/ℓ)	192	195	191	186	167	171
VDS (mg/ℓ)	61	52	44	45	48	48
Total P (mg/ℓ)	18.4	20	17.5	15.3	14.3	11.8
Ortho-P (mg/ℓ)	18.5	19	18.3	16.3	13.3	13
NH_3-N (mg/ℓ)	0.25	---	---	0.2	---	0.2
Organic N (mg/ℓ)	1.4	---	---	2.0	---	2.0
Turbidity (JTU)	13	6.7	5.9	5.2	4.5	4.1
Coliforms ($x10^6$/100ml)	2.1	---	---	1.6	---	1.6

4. Pretreatment with aeration-sedimentation and filtration.

The results of this system are shown in Tables 35 and 36. Two carbon columns were used in series to provide a total contact time of 40 minutes.

It can be noted that the carbon acted as both an adsorber and a filter for removing both dissolved and suspended organics, as well as turbidity. Since the dual-media filterwas previously found to be relatively ineffective, the improved results were attributed to the extended depth of granular carbon in contact with the wastewater. The resulting effluent characteristics were found to be, COD = 19 mg/ℓ, BOD = 3.5 mg/ℓ and TSS = 4.1 mg/ℓ.

Work of Other Researchers

Two studies of a somewhat similar nature have been reported. McLaughlin[49] developed an experimental water recycling system that utilized previously used water as a supply for toilet flushing water. Water that had been utilized in washing clothes and bathing was collected in a storage tank, passed through a filter, pressurized and discharged into the toilet. The system was installed in a residence for detailed observation. Two 100 gallon storage tanks with a usable capacity of 50 gallons discharged water to a 20 square foot swimming pool filter. A conventional shallow well pump pressurized the water in a 15 gallon storage tank. From there the water passed through a flow meter and into the toilet reservoir. At the time of installation, the cost of this system was $500.

On June 11, 1967, McLaughlin's system had been in operation for four months when the following observations were made:

1. "The system has worked very well. There has been no major problem in maintaining the water balance between supply and use. The water has a slightly grey color that has not been objectionable. The low sudsing detergents have not caused any problem with foam."

2. "There is no problem with odor or humidity."

3. "There is no indication in the pump suction pressure that the filter requires maintenance at this time."

4. "Plans to continue the project until early 1968 appear practicable."

In 1969 further investigation into the feasibility of household wastewater reuse was conducted by General Dynamics, Electric Boat Division under the guidance of Bailey, Benoit, Dodson, Robb and Wallman.[44] Following the study was another report by Bailey and Wallman.[50] They analyzed the feasibility of wastewater reuse by establishing wastewater reclamation-reuse methods that were plausible within the home and applying costs to each. These methods included: 1) reuse of all wastewater in all daily uses except for drinking; 2) reuse of non-sanitary wastes for toilet flushing and laundering; 3) aerobic treatment and reuse of effluent for lawn watering; and 4) reuse of wash waters for toilet flushing. Cost estimates were made for each method in establishing its economic feasibility. The results indicated that the only reuse method which even approached a practical cost was the reuse of wash waters for toilet flushing. Table 37 illustrates this as it compares the cost of each method

Table 37

Economics of Reusing Household Wastewater

Water Use Method	Water and Waste Cost/Yr/Family of 4
Normal home	$ 90
Reuse of all wastewaters except for drinking	$350
Reuse of non-sanitary wastes for toilet flushing and laundering	$200
Aerobic treatment and reuse of effluent for lawn watering	$150
Reuse of wash waters for toilet flushing	$ 95

Bailey et al[48]

with the cost of the normal water use method. The cost estimates were made for a four member family assuming average per capita water consumption. Costs included all the materials required in treating the water prior to reuse, labor costs of installation of the method, maintenance and power cost, cost of water saved, cost of power saved, and cost of sewerage saved.

In the first three water reuse methods, prohibitive costs arose from expenditures on the treatment required prior to reuse. In reusing all the wastewater for everything but drinking, the authors felt that settling and digestion, filtration, distillation and carbon adsorption treatment had to be incorporated into the treatment system. Reuse of non-sanitary wastes for toilet flushing and for laundry use necessitated a system possessing settling and filtration units prior to toilet reuse, and an additional distillation unit prior to laundry use. Treatment of washwater for toilet flushing was identical to the system used by McLaughlin,[49] with the water passed only through a filter before reuse. Treatment requirements were established by discerning what quality standards had to be met prior to reuse. For example, water used for flushing toilets was not considered to require high standards, since it would not be ingested or would not come into contact with the body. The only quality requirement needed was that the water had to be aesthetically acceptable to the average housewife.

The study by Bailey, et al. was simply a feasibility study and did not encompass the implementation of any of the reuse methods within individual households. However, a two year test program (May 1971 - May 1973) was conducted by General Dynamics, Electric Boat Division under the supervision of Cohen and Wallman [13] in which the results of the 1969 program, where feasible, were applied in the field. Thus, the system of reusing wash waters for toilet flushing was actually assembled in several residences. The method was also expanded to include lawn watering as a reuse alternative of the system. Disinfection was added onto the treatment system to assure that health hazards were prevented.

The storage tanks used for two of the homes were 100 gallon tanks and a 150 gallon tank was used in another home. The stored wash water was disinfected prior to filtration. Two different disinfection techniques were used in the systems studied. The first used continuous introduction of diluted laundry bleach (NaOCl) with the use of an air lift feeder. The second approach was utilization of a chlorine tablet feeder which introduced calcium hychlorite tablets or chlorinated isocyanurates into the storage tank. Both approaches provided sufficient disinfection once they were properly adjusted. "As long as measurable chlorine residuals were maintained, no unpleasant odors were detected at the water closet or storage tank location, and the coliform counts were essentially negative ($<$ 11/100 ml)." Three different types of filters were incorporated in the reuse systems. A diatomite filter was one of the experimental units. The septum was made from woven polypropylene and had a filtering surface area of 1.67 square meters. Prior to operation, the filter was precoated with a slurry containing approximately 0.7 Kg of diatomite. Also used were two different cartridge-type filters. One of these filters was an AMF/Cuno CG 4DC-1 stainless steel filter. Two different types of cartridges were inserted into this filter. One type provided nominal solids removal down to 5 to 25 microns while the other type provided removal down to 10 microns. The other cartridge-type filter was a Fram MCM epoxy-coated steel filter. Cartridges used in the filter were also of two types which provided solids removal down to 5 to 15 microns in one case and down to 10 microns in the other. In order to provide fluid transfer and pressurization, a 1/3 HP shallow well jet pump was mounted on either 45 or 115 liter pressure tanks which were provided with an air volume control to maintain sufficient air space inside the tank.

Table 38 summarizes the performances of the different filter systems with regard to effluent turbidity levels and effluent suspended solids levels. The diatomite filter was clearly established to be the most efficient system in both turbidity and suspended solids reduction as well as being the least expensive system to operate. Effluent COD levels discharged from this system ranged from 53 to 85 mg/ℓ. The two cartridge filters also processed 74 to 88 percent less wash water per cycle than did the diatomite filter.

Toilet flushing reuse was a success in all three of the homes in which the reuse systems were controlled. No impairment of flush toilet operation was witnessed and continued chlorination effectively prevented bacterial growth as no unpleasant odors were noticed in any of the bathrooms during normal

Table 38

Filter System Performance Summary*

Filter System	Average Volume Processed (liters/cycle)	Equivalent Filtration Period (Days)	Average Effluent Turbidities (ppm)	Average Effluent Suspended Solids (ppm)	Annual Operating Costs $/year
Diaclear LP-18 Diatomite	17,000	86	23	21	16
Fram MCM 15 Micron Surface-Type	12,600	48	60	31	43
AMF/Curo CG4-DC1 10 Micron Depth-Type	15,000	71	62	43	40

* After Cohen and Wallman

operation. Aesthetic requirements, in terms of clarity and color, were satisfactorily achieved by the diatomite filter. However, the residual suspended solids did produce temporary stains in the toilet bowls which required increased maintenance. No problems with foaming were in evidence.

In two homes located in Southeastern Connecticut, lawn watering reuse systems were installed. The program was conducted over a three month period. Revolving sprinklers distributed the water over the surface of the lawns. "No significant effects, adverse or beneficial, were noted on lawn growth or appearnace throughout the test period or during the next growing season."

Cohen and Wallman[13] found in their study that benefits from the reuse systems not only included water savings but also allowed for more effective operation of the septic tank and soil absorption system. The overall average water saving for toilet or lawn sprinkling reuse was 44.0 liter per capita per day. This was an average percentage reduction in total water consumption of 26 percent. In two homes, the septic tank soil absorption systems performed poorly prior to the installation of the recycle system. During the time of the experimental program, significant improvement in the performance of the septic tank systems was witnessed.

Discussion

Several renovation methods for reuse of in-home wastewaters have been evaluated in the University of Colorado study.

Aerobic biological treatment in the plain aeration mode has been found to be an effective way of reducing the pollutional parameters of soap related wastes. BOD reduction of greater than 80% within four days was experienced with a continuous feed reactor for wastes from a combination of shower, bathroom sink, washing machine, and dishwasher. A somewhat slower reaction rate was observed in batch tests for the same waste. Dissolved organic wastes were consumed in the process. Suspended organic matter was not effectively removed,but the BOD content of the suspended organics was rapidly degraded and that appeared to be a major factor in the overall BOD reduction. The reaction in the aeration units could be approximated with a first order equation for the removal of BOD as a function of time. The reaction rate constant was found to be 0.17 days^{-1} which is greater than that which has been established for municipal sewage. The fact that soap related wastes are more rapidly degraded than human wastes or food preparation wastewaters has been confirmed by others.[26] Higher removals could have been accomplished with an activated sludge system designed to produce a build up of organisms in a more concentrated mixed liquor, utilizing secondary settling and return of the sludge to the aeration chamber. Small individual home sized extended aeration activated sludge units have been found to be difficult for home-owners to control and many eventually operate as plain aeration systems. For this reason, a plain aeration system was evaluated in this study.

Plain dual-media filtration was not found to be as effective as with normal sewage treatment plant effluents.[51] There appeared to be a large fraction of colloidal sized organics in the soap related wastes that were not effectively contacted in the filter. Similar results using other types of filters were found by others. Effective filtration requires that the suspended matter have a high "sticking efficiency" and this apparently does not exist,even after biological treatment. If the process is to be used, coagulating chemicals will be required or a very fine filter media will be required to produce removal by physical straining.

Carbon adsorption for removal of organics was found to be about as effective as it is when applied to sewage treatment plant effluents.[52] Three mechanisms were apparent in the removal of organic matter with activated carbon. Physical straining of large particulate matter occurred at the surface of the carbon bed. Adsorption of dissolved organics took place within the micro-pores of the granules and entrapment of fine particulates occurred in the deep carbon beds. The results of all of the carbon studies are approximated in Figure 26. It represents removal of COD or BOD and shows fraction remaining as a function of carbon bed contact time. The variation bands represent all of the COD data presented. A continuously operated home carbon treatment system would require provisions for periodic backwashing of the carbon beds.

From the results of this study, various other arrangements of treatment methods can be considered. A system was considered for the purposes of cost estimation as shown in Figure 27, that

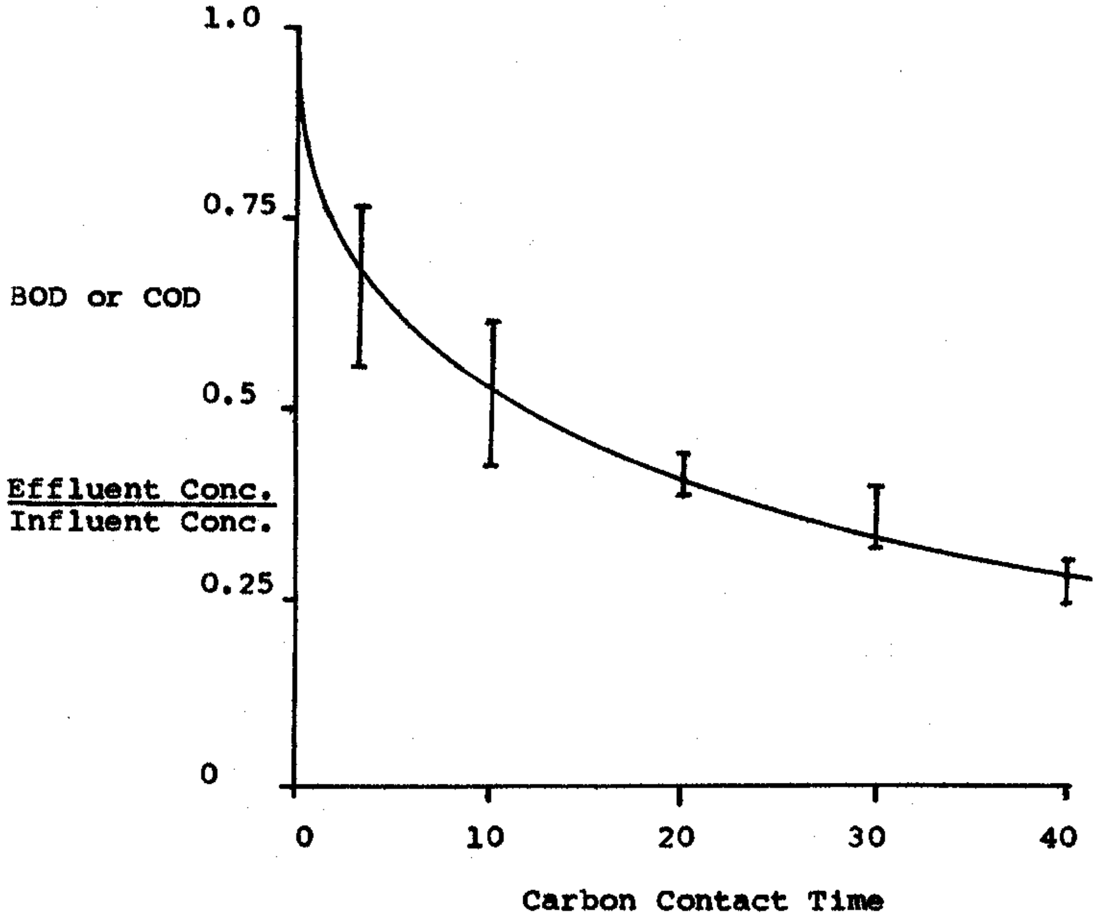


FIGURE 26 BOD AND COD REMOVAL WITH ACTIVATED CARBON

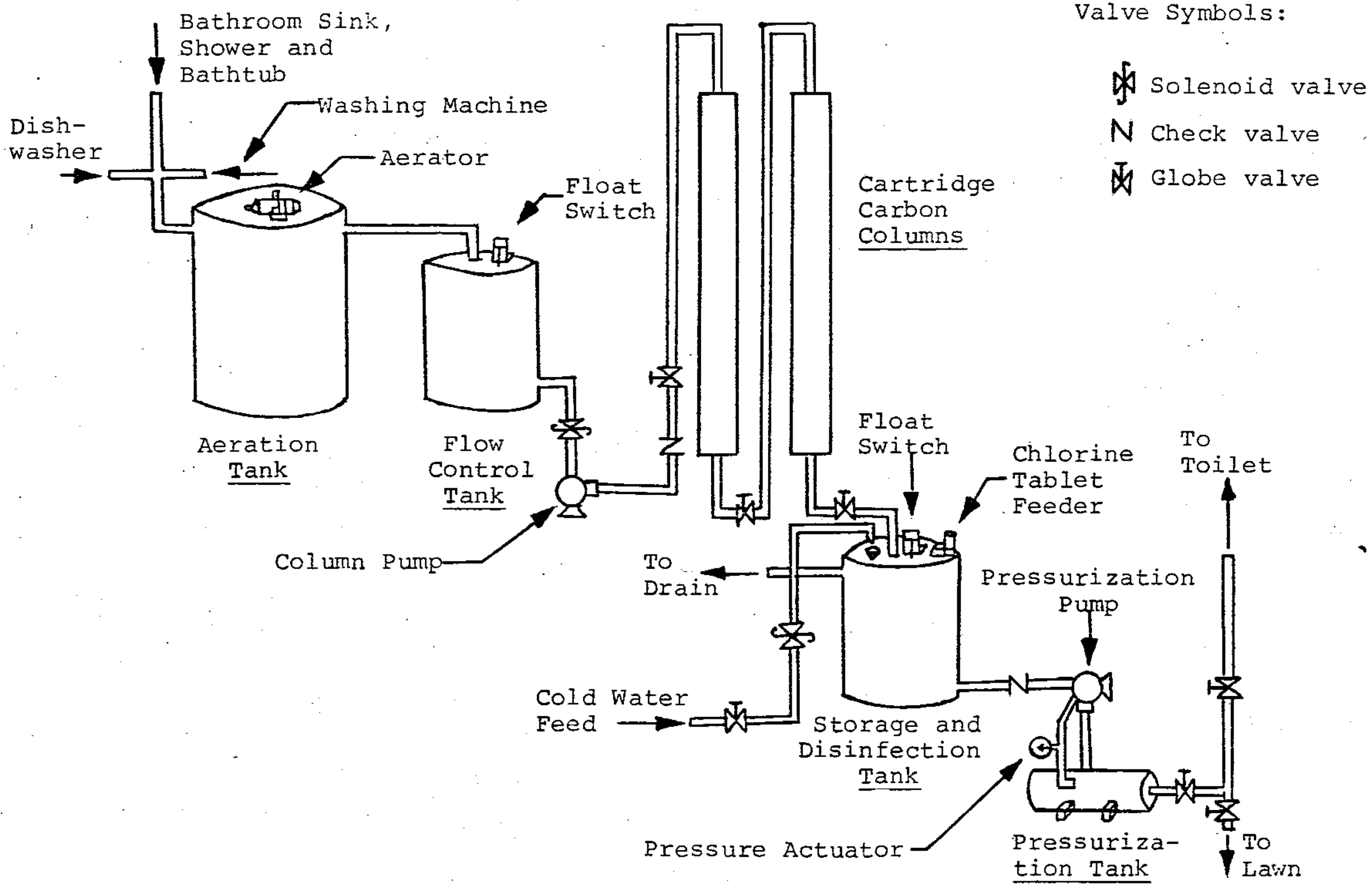


FIGURE 27 AERATION-CARBON ADSORPTION TREATMENT SYSTEM

utilized the unit operations studied. The estimate of cost for renovating water with such a system was found to be approximately ten dollars per thousand gallons. Such a system would be practical only under extreme water cost and disposal conditions.

Simplications of the system may be possible. A batch treatment system may be more feasible. In such a system the flow would be aerated while filling a reaction tank. It could then be treated with polyelectrolytes for coagulation and powdered activated carbon for adsorption of organics. This would be followed with a settling period. Dual tanks would be required so that one could fill while the other was being processed. Sludge could be drawn off and disinfecting chemicals could be added prior to use as a supply water for toilets or lawn watering. Batch systems have been found to be easier to control in small units than flow-through units. This method of treatment was not evaluated.

CHAPTER VI - SUMMARY

An evaluation of individual home wastewater characteristics, reuse and disposal methods has been accomplished utilizing field and laboratory methods and literature sources.

The average per capita daily generation of wastewater in the home was found to be 44.4 gallons of which 33 percent was for toilet use, 17 percent for sinks, 2 percent each for garbage disposal and dishwasher, 20 percent for bathing, and 26 percent for the washing machine. Per capita daily use was found to be greater for small families. The daily design household use for all family sizes was found to be 250 gallons.

Pollutional strength measurements of household wastes were found to be COD = 0.35 lb/day, BOD = 0.11 lb/day, and suspended solids = 0.15 lb/day. Approximately one-half of the pollutional strength was found to be due to toilet wastes, one-fourth due to the garbage grinder, and the remainder due to the soap related wastes from the sinks, bathing, dishwashing, and clothes washing.

A brief evaluation of the treatment methods used in home systems has been presented. A large variation in the results of the standard percolation test was observed and a three hole, ninety minute test was found to be very beneficial in obtaining representative results. The leaching field trench area criteria based on number of bedrooms was questioned.

Aerobic treatment systems were field tested and found to have effluent characteristics similar to those from a septic tank. Median BOD and suspended solids levels in the effluents from homeowner operated units were found to be approximately 150 mg/ℓ.

The theory of evaporation-transpiration systems has been discussed along with some of the considerations for field applications as they apply in the lower front range of Colorado.

Generalized cost analyses for system components for individual wastewater methods are included.

Laboratory studies evaluating several methods for renovating the soap related wastes from individual homes to meet quality criteria for reuse for toilet flushing have been reported. Plain aeration treatment with a four day detention time was found to be an effective method for stabilizing the BOD of soap related wastes. Filtration was evaluated as a process for removing the fine suspended solids in the effluent but the results were not encouraging. Granular carbon adsorption was determined to be partially successful in the removal of both dissolved and suspended organics. Methods for renovation of soap related wastewaters have been demonstrated but the costs of the systems as presented would make the system impractical. Further development could reduce these costs substantially.

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