AN EVALUATION OF A DUAL
FLUID ABLUTION SYSTEM

by

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ABSTRACT

The design requirements of a reduced flow shower system were studied. These design criteria were then applied in evaluating a reduced flow shower system. Test showers were taken during the evaluation, and results of these tests are presented.

The reduced flow system was found to be superior both economically and with regard to environmental impact when compared to a conventional shower, while maintaining the same aesthetic and cleansing qualities.

CHAPTER 1

INTRODUCTION

The various level governmental agencies concerned with regulating the quality of our water environment give direction in three areas:

1. Water Supply: Obtaining water, treating it to obtain an acceptable quality, and delivering of potable water to the user.
2. Wastewater: Collecting of the wastewater produced by the user, its treatment to an acceptable quality, and disposal.
3. Environmental Quality: Maintaining the quality of our water resources.

These three facets of the water environment are, however, merely parametric symptoms of a fourth segment which has been given little organized thought and almost no direction: the water use function.

Stream Energy Concept

Vast amounts of energy and resources are expended to supply potable water to the property line or the boundary that defines the user. Energy, as referred to in this text, represents not only work, but structures for treatment, manpower, land use, political bodies, and control agencies, in fact, any entropy increasing function which must be applied to the water from exploration phase through return to the environment in its original form. The use of potable water results in a wastewater being discharged from the boundary. This waste must be collected, transported to a treatment site, and treated in an attempt to minimize the damage to the environment. These processes again increase the energy level of the flow stream. The resulting treated wastewater is returned to the environment through some dispersion technique, (discharge to water ways, spray irrigation, evapotranspiration, etc.) in a form which ultimately degrades the net quality of resources. In many cases, the cycle is closed when this degraded resource is returned to the water environment. Now, subsequent users must expend a greater and greater amount of energy for each pass through the water use stream cycle before use of this water as a potable supply is possible. This closed cycle of water use is shown in Figure 1.

Use Function in the Water Environment

The household use of water and generation of domestic wastewater exists wherever man lives. Even when man lives in great concentrations, where he can pool his efforts and energies to construct huge wastewater treatment plants, he is, more often than not, unable to treat the tremendous volumes of effluent to a quality such that it is

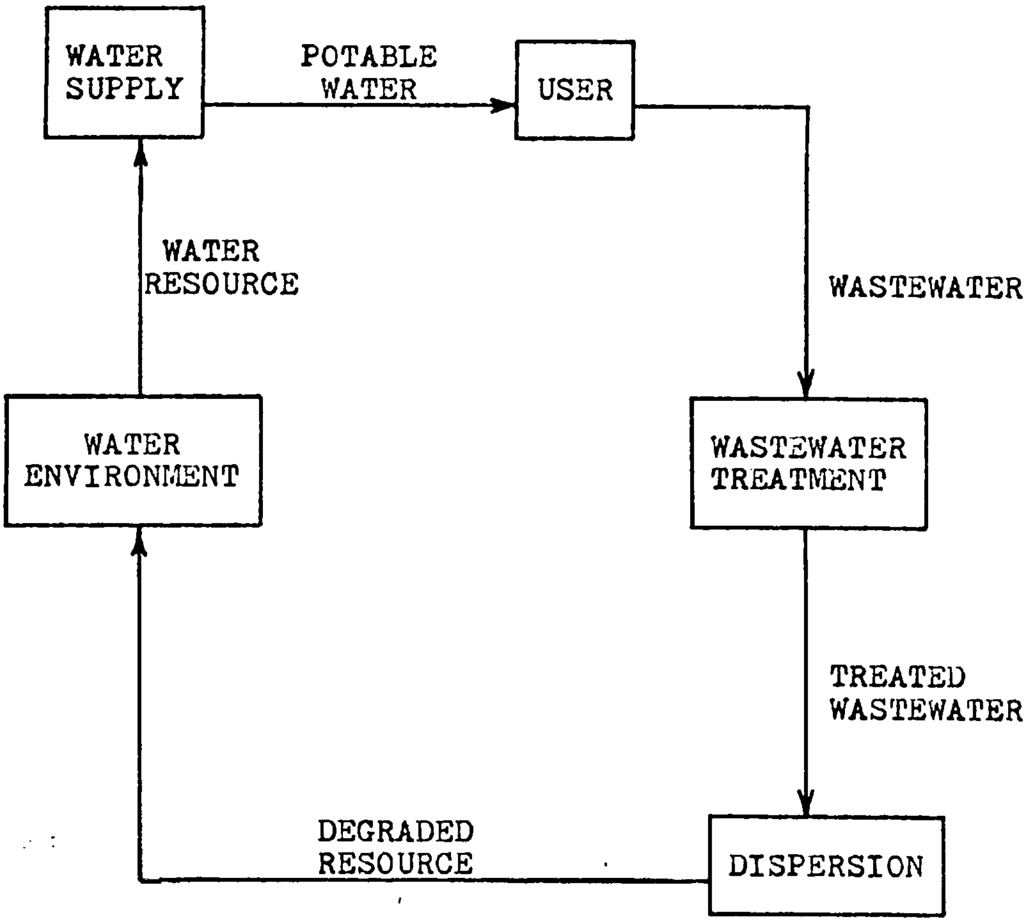

Figure 1. Water Use Stream Cycle

not detrimental to the environment. This problem becomes further exaggerated when the distribution of man's living quarters is further dispersed.

Whether man lives in high density or dispersed communities he can benefit by a reduction in the volume of water he uses. This benefit would be derived by

1. Reducing the drain on this limited resource,
2. Reducing the amount of energy to achieve the water use cycle, and
3. Reducing the environmental impact of the return of the treated wastewater to the environment.

This study is concerned with reduction of the water use rate in the household, and the attendant problems with accomplishing this task.

CHAPTER 2

BACKGROUND

Formerly, in this country, man considered clean water as an endless resource. The primary role of water has changed from that of an essential sustainer of life to that of a vehicle for the removal and disposal of his wastes.

Household Water Use Reduction Methods

The amount of wastewater produced by an average household has been estimated to be between 70 and 100 gallons per person per day (1, 2, 3, 4). These flow rates can be reduced by several means which consider the household as a user entity:

1. The cost of potable water and wastewater disposal can be increased and assessed directly to the user.
2. The pressure to the household can be reduced, resulting in lower use function flow rates.
3. Meters can be installed in unmetered areas.
4. Environmental education programs can be pursued in an attempt to solicit voluntary response for constraint.

In addition to these steps, wastewater flows can be reduced by separating storm drains and sanitary sewers. Further reduction can be achieved by replacing or repairing existing collection systems to achieve low infiltration rates. The use of new materials such as plastic sewer pipe and sealed manholes could make this possible.

The implementation of all of these procedures can only have a limited affect on the flow, because the water use systems will be utilized in the household, at some base rate, which is a function of sanitary requirements as well as aesthetic desires, as long as sufficient water is available.

It becomes apparent then, that if reductions beyond today's base water use amounts are to be accomplished, modifications to existing systems within the household must be made. Knowledge of how the water-wastewater flows are presently generated must be obtained in order to effect a flow reduction.

Existing Household Water Use Rates

Fair, Geyer and Okun (1) quoting Dorfer and Becker (2), break down domestic water consumption into the uses shown in Table I. The figures were arrived at in a 1962 study of the 100 largest cities in the United States. Haney and Hamann (3) give values resulting from a study for a dual water system where wastes from other functions would be used for the toilet flush, Table II. Bailey et al. (4) propose an "average" home concept based on studies by the Public Health Service and Johns Hopkins University which indicated

TABLE I. DOMESTIC WATER CONSUMPTION PERCENTAGES (1, 2)

Use Function	Percentages
Toilet Flush	41
Washing and Bathing	37
Kitchen	6
Drinking	5
Clothes Washing	4
Watering Garden	3
Car Washing	1

TABLE II. DOMESTIC WATER USE PERCENTAGES (3)

Use Function	Percentages
Toilet Flush	45
Bathing	30
Kitchen	6
Drinking	5
Laundry	4
Cleaning	3
Sprinkling	3
Auto Washing	1
Miscellaneous	3

that certain household water use functions are relatively independent of the number of household occupants. For their average family, two adults and two children were assumed to use water in an "average" way. The quantities listed in Table III resulted.

TABLE III. DOMESTIC WATER CONSUMPTION (4)

Use Function	Gallons Per Day	Percentages
Toilet Flush	100	39
Bathing	80	31
Laundry	35	14
Kitchen*	27	11
Lavatory	8	3
Utility Sink	5	2

*Includes drinking water

It can be seen from these patterns that between 70 and 75 percent of the water used in the household can be attributed to the toilet flush and bathing system.

Existing Reduced Flow Household Water Use Systems

Some domestic flow reduction is referred to in the literature. Most of the emphasis has been on work with the toilet (4, 5, 6, 7, 8, 9, 10).

A Swedish study by Olsson, Karlgren and Tullander (6) quoted by Bailey et al. (4) gives the break down as shown in Table IV.

TABLE IV. DOMESTIC WATER CONSUMPTION WITH REDUCED TOILET FLOW (6)

Use Function	Gallons Per Day	Percentages
Showers and Lavatory	16.4	42
Kitchen	13.5	34
Laundry	2.3	6
Toilets*	7.0	18

*Vacuum toilet 5 flushes

Microphore of California has also developed a reduced flow toilet (11); and various chemical, recycle and incinerator toilets are on the market to fill this need. This indicates that although improvements might be possible in the toilet function, many alternatives are available.

Proposed Household Water Use Flow Reduction

The bathing function consumes almost as much water as the toilet, and would be the next most logical area of flow reduction in the household. Although flow reducing nozzles for showers were referred to in the literature, the lowest acceptable flow noted was 2-3 gpm (4). A significant reduction in this function would far outweigh the impact of any comparable reduction in any other of the use systems mentioned.

It is for these reasons that the subsequent emphasis of this study is placed on the reduction of the flow for the bathing system. An analysis of the design concepts will be presented along with the discussion of the system developed to reduce bathing flows.

CHAPTER 3

DESIGN PARAMETERS FOR A REDUCED FLOW SHOWER

Bailey et al. (4) give a normal shower flow rate of 5-15 gpm for 3-5 minutes, with a reduction to 3 gpm, as an acceptable minimum value utilizing flow reduction hardware.

Metcalf and Eddy (12), quoting Salvanto, (13) found a shower to consume 25-30 gallons per use. Clark and Viessman (14) list a flow rate of 5 gpm for a shower.

With these existing physical parameters in mind, a mechanical starting point is established.

Aesthetic Design Requirements

The design of any new system to replace an existing one, involves much more than just fulfilling the mechanical requirements of the existing device. For instance, aesthetic effects must be considered. The shower, probably more than any other household water use system, has strong aesthetic requirements demanded of it. Kira brings out this point in his work The Bathroom (15). The shower can be used to relax as well as cleanse and therefore would use a disproportionate amount of water when operated in this mode. It is this strong aesthetic requirement that makes design of an acceptable low use shower a more difficult task than is first realized.

The acceptance of a low water use shower device may be brought about by several means. The design criteria depend greatly on the implementation procedures and these procedures are:

1. Direct Appeal: This involves design of a unit which will have the advantages of economics, aesthetics, and functionality over existing systems.
2. Education: This involves the development of acceptance of the unit by conditioning the user to desire a change from the existing system. This could be out of a learned concern from the environment or a strong sell technique.
3. Legislation: Making the unit use mandatory according to public law.

Although any or all of these methods of implementing the acceptance of the reduced flow systems may be used, the first method, direct appeal, would be optimum since acceptance would be voluntary and lasting.

Design Criteria

Based on this assumption of direct appeal as a design philosophy and the physical requirements of a shower system, the following design criteria were established:

1. The new shower system must equal the cleansing ability of the existing shower.

2. The system must allow the same use pattern as the existing shower.
3. The new system must be aesthetically acceptable.
4. Reduction in water consumption must not be offset by increased consumption of other resources, i.e. power, heat, etc.
5. Overall economic superiority to existing shower systems is desirable.

A form of reduced flow shower system is now used in recreational vehicles, and in remote locations as well as on shipboard. This is more of a technique than a system design and follows the pattern of:

1. Water on, wet down,
2. Water off,
3. Soap and scrub,
4. Water on and rinse,
5. Water off.

Although this is a means of conserving water, it would be very hard to enforce in private homes and does not meet the established design criteria.

During the development of the system, all attempts to reduce the flow rate by nozzle configuration changes met with only limited success. These modifications produced a sharp stinging water stream that took longer, and did not produce any significant flow reduction.

The Bathing Function Analysis

For ease of analysis, the bathing process was broken down into four phases:

1. Wetting down,
2. Applying soap,
3. Scrubbing,
4. Rinsing.

Each of these phases was considered separately, in terms of the goal of fulfilling the process requirements involved while maintaining low water usage.

1. Wetting down: The overall man-machine system must be considered. The body area chart illustrated in Figure 2 shows the body area as a function of height and weight (16). The total body area of a 180 pound, 70 inch man, is 2 m^2, and will be used as the base body area in the discussion. One liter applied to a 1 m^2 area gives a film thickness of 1 mm and therefore, 1 liter on 2 m^2 area gives a body water film of 0.5 mm. This indicates that in order to utilize a flow rate of about 1.0 l/min, the water stream must be greatly dispersed to cover the area.

   If a stream of water is atomized, and then moved through the air, the drag force exerted on the large surface area of the droplets slows them down rapidly. This deacceleration rate may be reduced by moving the air cocurrently with the droplets. When this is

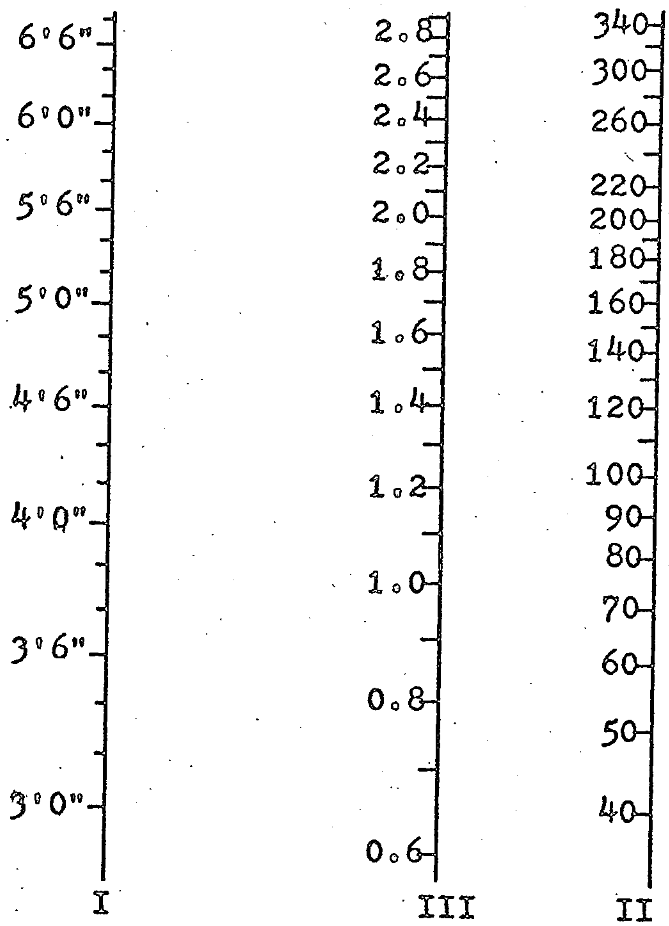

Figure 2. Body Surface Chart (16).

To find body surface of an individual, locate the height in inches on Scale I and the weight in pounds on Scale II and place a straight edge between these two points which will intersect Scale III at the individual's surface area in m^2.

done, in practice, the small droplets are well dispersed in the air flow and a small amount of water can be transferred to the varying geometry of the human body and be effectively deposited. This is not the case for a typical shower system operating with the same flow rate. An additional benefit of the mixture is a large water flow feel.

2. Applying soap: The same mechanism is used for both showers.

3. Scrubbing: This action is also carried out in the same manner as in a conventional shower.

4. Rinsing: The waste on the skin surface is partially solubilized, and the particulate matter suspended, by the soap or detergent and water mixture. This waste, consisting of the water-soap mixture, must then be removed from the surface. The bulk of this removal is carried out through direct bulk transfer accomplished by the shear force exerted by the rinsing flow. The remaining film removal is a mass transfer process where the concentration difference between the skin surface water and rinse water coupled with the surface water boundary layer thickness form a concentration gradient. The rate of transfer of the surface waste from the skin is directly proportional to this concentration

difference and inversly proportional to the boundary layer thickness.

The air-water system increases this transfer rate by two mechanisms.

1. The rapid moving air-water mixture replaces the outer boundary layer water with clean water at a rapid rate, increasing the driving force to mass transfer. This mechanism also supplies the shear force to accomplish the bulk waste removal.
2. This fast moving spray reduces the boundary layer thickness by the shear force of the air flow, which also increases the mass transfer driving force.

Theoretically, a system with these properties should give a cleansing shower. This system will be referred to as a Dual Fluid Ablution System (DFAS). The two fluids, air and water, are used to ablute or cleanse the body.

CHAPTER 4

DFAS SHOWER FUNCTIONAL EVALUATION

In order to evaluate the DFAS shower, a test unit was constructed. This experimental unit consisted of a shower stall with a conventional shower head on one side of the stall and the DFAS nozzle on the other.

Test Equipment

In the experimental apparatus as shown in Figure 3, a gauge and valve were installed on the outside of the stall to monitor and control the water flow rate to the nozzle of the DFAS shower. Temperature gauges were installed in each of the shower nozzle feed lines to record the water temperature to each nozzle. The waste flow from the shower was collected from the drain in the shower for quantity and quality analysis.

Test Procedures

Initial tests, by the author, on the system were conducted at a water flow rate of 1 l/min. At this flow rate, the shower would perform the cleansing function and allow the same use pattern as the existing shower, but the flow had to be increased to 1½ l/min to achieve a feeling comparable to a conventional shower. At this point it

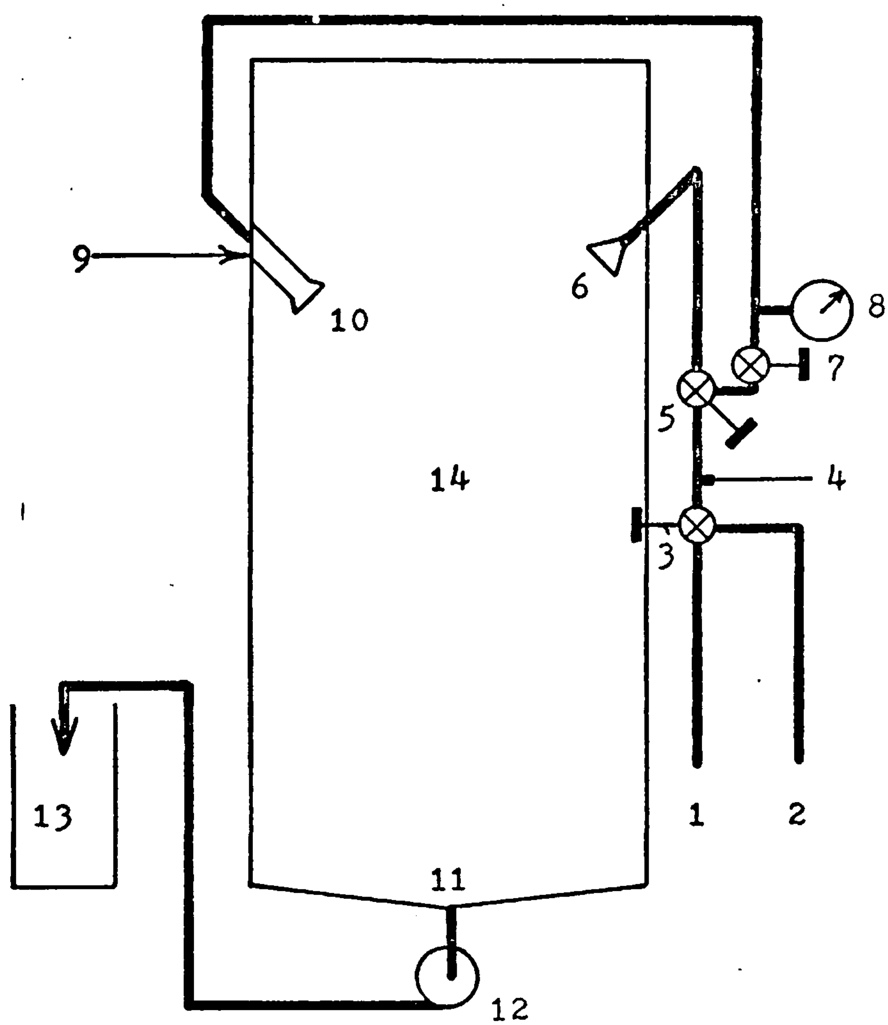

Figure 3. Shower Test Apparatus for DFAS and Conventional Shower Data Collection

1-Hot Water
2-Cold Water
3-Water Mixing Valve
4-Thermometer
5-Directional Control Valve
6-Conventional Shower Nozzle
7-DFAS Flow Rate Control Valve
8-DFAS Flow Rate Control Gauge
9-Air Input
10-DFAS Nozzle
11-Shower Drain
12-Wastewater Collection Pump
13-Wastewater Collection Tank
14-Shower Stall

appeared that the shower was acceptable functionally and aesthetically. To evaluate this system, a number of individuals were asked to use it.

During this experimentation phase of the system evaluation, 32 showers were taken with data being collected on the shower system, and on the individuals taking the showers. Table V is a compilation of these data. Hair length is given, in this table, if the individual washed his hair during the trial.

Each of the subjects was asked to write a short statement on their impression of the shower. They were also asked to note what differences they perceived between this system and a conventional shower. This approach was used, rather than a questionnaire, in an attempt not to prejudice their responses.

Individual Reactions

The following comments were extracted from the written statements obtained from the individuals after the DFAS shower tests. Some of the duplicate statements are not included.

Shower No. 1, 11

These showers were taken by a 25 year old male with long hair and a beard.

No. 1 (1 l/min). The shower felt a little cool at first but warmed up in a couple of minutes. He stated

TABLE V. TEST DATA FOR DFAS SHOWER

Shower no.	Sex	Age	Ht. in.	Wt. lb.	Hair in.	Flow l/min	Water °F	Time min.	Soap	Shampoo
1	M	25	70	150	7 B	1	112	5	Dial	Prell
2	M	27	69	150	- B	1½	118	5	Ivory	-
3	M	31	69	185	-	1½	118	3	Ivory	-
4	M	26	75	175	3	1½	120	3½	Ivory	Prell
5	M	32	70	170	4	1	118	4	Ivory	Prell
6	M	10	57	75	4	1½	119	15	Ivory	Prell
7	F	6	48	50	-	1½	119	3	Ivory	-
8	F	31	64½	128	-	1½	119	5	Ivory	-
9	F	21	63	103	15	1½	118	13	Sgrd.	Breck
10	M	25	70	175	4	1½	118	8	Ivory	Ivory
11	M	25	70	150	7 B	1½	119	6	Ivory	Prell
12	M	29	71	150	5	1½	118	6	Dial	Prell
13	M	25	69	125	4	1½	119	5	Dial	Prell
14	M	27	69	150	7	1½	119	5	Ivory	Prell
15	M	28	68	181	-	1½	119	5	Ivory	-
16	M	32	73	185	4	1½	119	4½	Dial	Prell
17	F	30	62	150	-	1	119	3	Dial	-
18	F	31	64½	128	5	1	119	6	Dial	Prell
19	M	24	70	165	-	1	112	4	Ivory	-
20	M	24	70	165	-	1½	118	3	Ivory	-
21	M	27	76	205	3	1½	118	5	Dial	Prell
22	M	27	69	150	-	1½	119	3	Ivory	-
23	M	27	69	150	-	1½	119	3	Ivory	-
24	M	27	69	150	-	1	112	3	Ivory	-
25	F	24	69	135	12	1½	120	19	J/Baby	Breck
26	F	19	67	126	15	1½	118	14	Lux	Milk G.
27	F	6	48	50	-	1	118	4	Dial	-
28	M	10	57	75	4	1	118	10	Lux	Prell
29	F	31	64	128	5	1½	118	10	Lux	Prell
30	M	42	70	175	½	1½	118	2	Ivory	None
31	M	27	69	150	-	1½	-	3	Dial	-
32	M	24	-	-	-	1½	-	3	-	-

B-beard washed

that his hair was pretty dirty but was cleaned as well as at home. He also stated that he had less trouble with soap in his eyes than with a normal shower.

No. 11 (1.5 l/min). He stated that this shower felt warmer and rinsed his hair faster.

Shower No. 2, 14, 22, 23, 24

These showers were taken by a 27 year old male with long hair and a beard. The number of tests was an attempt to reduce the novelty of the system and to achieve a better comparison of varying parameters.

No. 2 (1.5 l/min). The water near the nozzle seemed almost hot and gave a slight stinging sensation. His beard was easily wetted and rinsed.

No. 14 ($1\frac{1}{2}$ l/min). It took more time to wash and rinse the hair than a normal shower. However, it seemed to get the soap out.

No. 22, 23, 24 ($1\frac{1}{2}$, $1\frac{1}{4}$, 1 l/min). This was a series of showers which closely followed each other for comparison.

The $1\frac{1}{2}$ liter flow rate seemed to have a lot of water. There was very little stinging sensation. The $1\frac{1}{4}$ liter rate seemed to lack water and some stinging was noticed. Rinsing was satisfactory. The 1 liter rate made rinsing more difficult and was more stinging. Getting soap out of a wash cloth was almost impossible.

The overall comment was made that the skin felt dryer for up to 24 hours after these DFAS showers than with a normal shower.

Shower No. 3 ($1\frac{1}{2}$ l/min)

This shower was taken by a 31 year old male with short hair. Although this was his only recorded test, several previous showers at 1 l/min had been taken. This higher flow rate gave a softer, warmer shower similar in feel to a normal shower.

Shower No. 4 ($1\frac{1}{2}$ l/min)

This 26 year old male commented that at first there didn't seem to be much water coming from the nozzle, but surprisingly it was very adequate. "Plenty to rinse off the soap with no noticeable difference in overall temperature (in comparison with a normal all-water shower)." During the washing of his hair he noted that the rinse seemed to take the same time or less to remove the soap.

Shower No. 5 (1 l/min)

This 32 year old male commented that the air-water flow was a pleasant substitute for water. This flow rate did take longer for hair rinsing than a normal shower though.

Shower No. 6, 7, 27, 28

These DFAS showers were taken by two children. They said they liked the shower, but further more definitive comparisons could not be made.

Shower No. 8, 18, 29

This was a 31 year old female with medium length hair.

No. 8 (1.5 l/min). "Shower felt good. It felt like a regular shower. Rinsed the soap off well." The temperature was a little too warm very close to the nozzle.

No. 18 (1 l/min). At first a slight stinging sensation was felt, but it soon left. The water flow was adequate to get clean, but she preferred more water. She washed her hair, but it took considerable time to rinse out the soap. She stated that she entered the shower tired and felt very much awake afterward.

No. 29 (1½ l/min). She stated, "This time it felt like a normal shower; there was plenty of water; I could get by with less. My hair got wet fast and rinsed very well. Noticed no difference in the length of time it took to shampoo from a normal shower."

Shower No. 9 (1½ l/min)

This 21 year old female had very long hair which she washed in the shower. The following statement was made in regard to washing her hair: "First I had to wet it down before I applied the shampoo. It took a little longer, maybe because it was so dirty and maybe because there was less water. The rinse and re-shampoo was the same as in a regular shower, except there wasn't a lot of soapy water running down my face."

Shower No. 12 ($1\frac{1}{2}$ l/min)

This 29 year old male stated, "I enjoyed washing my hair in this shower more than in a conventional one. This may be partly due to the closeness of the shower head provided by the adjustable head but also I believe that the stream penetrates the hair better than a conventional shower does. Soap was cleaned off very well from both body and hair and there was no apparent soap residue or 'scummy' feeling."

Shower No. 13 ($1\frac{1}{2}$ l/min)

This 25 year old male stated, "The environment presented inside the shower is satisfactory from temperature, flow rate, etc. standpoint. After shower noted feeling of being exceptionally clean. Did a good job on hair."

"Had a tendency to get up to close to shower to get wet but found that I didn't have to to get rinsed."

Shower No. 15 ($1\frac{1}{2}$ l/min)

This 28 year old male did not wash his hair, but commented: ". . . it felt just as if I had taken a shower at home. The water and air impinging on me felt relaxing. It was surprising to find later the amount of water I actually used during the 5 minutes."

Shower No. 19 ($1\frac{1}{2}$, 1 l/min)

The comment received from this 24 year old male in comparing the $1\frac{1}{2}$ and 1 l/min flow rate showers was: "The lower rate was abrasive, higher rate approximated the more luxurious feel of conventional showers."

Shower No. 25 ($1\frac{1}{2}$ l/min)

This 24 year old female had long hair and took her normal long shower with washing and treating of her hair. Her comments were: "Cleansed my hair very nice. Also enjoyed the spray on my face. It may be just my imagination, but I do feel cleaner; and my skin does not feel as dry as it usually does after showering. The temperature was very nice."

Shower No. 30 ($1\frac{1}{2}$ l/min)

This test shower was taken by a 42 year old male with short hair. His comment was: "Rather a different sensation; however not at all unpleasant. More difficult to 'suds' unless turn away from impacting water-air mixture but end result as to rinsing etc. equal to ordinary type of home shower."

All of the subjects stated that, while using the same techniques for bathing, the DFAS shower cleansed them as well as a conventional shower based on past experience. This indicates the shower satisfies the first two design criteria as outlined in Chapter 3. These criteria were that the replacement shower system was to provide the same cleansing ability while allowing the individual to use the same bathing procedure as with the conventional shower.

In evaluating test results for the aesthetic acceptability of the shower it was found that a lower limit of $1\frac{1}{2}$ l/min had to be set on the flow rate. Although flow rates down to 1 l/min gave an acceptable cleansing shower, the lower rate resulted in an unacceptable stinging sensation and a feeling of a lack of water. These problems were reduced at $1\frac{1}{4}$ l/min, but $1\frac{1}{2}$ l/min was finally determined to be the point where the system could be considered a truly acceptable bathing substitute, both aesthetically and physically.

CHAPTER 5

ENVIRONMENTAL ASSESSMENT

The environmental assessment of the DFAS shower was made by comparing the magnitude of resources utilized and degraded through the use of the proposed DFAS shower system as opposed to a conventional shower system. The procedure used was to analyze the resources involved from potable water acquisition through waste water disposal.

Before, however, the comparison of the overall flow streams from source to disposal could be made, the differences in the streams at various points had to be identified. The physical, chemical and biological characteristics of the waste flows from the DFAS shower are shown in Table VI. This analysis was completed using the methods outlined in 13th edition of *Standard Methods for the Examination of Water and Wastewater* (17).

In order to have a comparison with these data, five conventional showers were taken, using the conventional nozzle referred to in Figure 3, and the waste from these showers analyzed. The results of this analysis yielded an average flow rate of 12.26 l/min (3.24 gpm). Table VII is a compilation of the basic shower parameters, while the wastewater analysis of these tests are shown in Table VIII.

TABLE VI. DFAS SHOWER WASTEWATER CHARACTERISTICS

Shower no.	COD*	BOD_5*	$\frac{BOD_5}{COD}$	Filtered* COD	TS*	SS*
1	1965				1300	465
2	2730	1770	.649	908	1700	520
3	-				2892	670
4	3225			953	2154	600
5	-				2595	790
6	1230	900	.731	300	908	390
7	1080	650	.594	488	914	250
8	3255				1800	560
9	1095	680	.620	473		160
10	1500					370
11	2850				1634	560
12	1800	1410	.785	638	1218	550
13	2025	1260	.674	788		470
14	1410	870	.618	600	962	300
15	3195			840	1758	510
16	2895				1816	600
17	2745	1830	.666	867	1528	570
18	2490	1500	.603	1050	1216	420
19	-				2270	480
20	2100				1160	530
21	2490				1230	450
22	1185				972	170
23	2730			353	692	180
24	-					
25	2505	1470	.589	1748	1280	230
26	1020				710	150
27	990				762	190
28	1755				1100	350
29	975				1318	320
30	3600			1373	2080	750
31	-					
32	-					

*Values in mg/l

TABLE VII. TEST DATA FOR CONVENTIONAL SHOWER

Shower no.	Sex	Age	Ht. in.	Wt. lb.	Hair in.	Flow l/min	Water °F	Time min.	Soap	Shampoo
33	M	31	69	190	1	11.4	104	3	Safgrd.	Prell
34	M	25	69	125	4	10.5	108	4½	Safgrd.	Prell
35	M	24	72	185	-	11.2	98	2½	Safgrd.	-
36	M	25	70	150	7	16.6	106	4	Safgrd.	Prell
37	M	25	70	175	5	11.4	110	4½	Dial	Dial

TABLE VIII. CONVENTIONAL SHOWER WASTEWATER CHARACTERISTICS

Shower no.	COD*	BOD_5*	$\frac{BOD_5}{COD}$	TS*	Soap	Shampoo
33	1140	685	.601	822	Safeguard	Prell
34	383	203	.529	428	Safeguard	Prell
35	578	300	.511	538	Safeguard	–
36	453	245	.541	546	Safeguard	Prell
37	500	257	.514	488	Dial	–

*Values in mg/l

In order to ascertain the effects that the various brands of soaps and detergents that were used in the showers had on the wastewater characteristics, samples of the soaps used were analyzed and the results are presented in Table IX.

Figure 4 shows the relationship between COD and TS for the DFAS and conventional showers, as well as the soap sample. This linear relationship would indicate that either the major contributor to the shower COD is the soap used, or that the body waste has a COD/TS ratio similar to the soap.

Another interesting relationship, shown in Figure 5, is the apparent increase in COD per shower minute with increased water flow rate. It is from this relationship and the reduced water use by the system, that a projection was made that the use of the DFAS shower reduces the total oxygen demand on the system receiving the wastewater from the shower for treatment and disposal.

As a starting point for the comparative analysis, representative shower systems with the parameter values shown in Table X were assumed. These were based on both literature review and experimental results.

An average family of 3.5 capita is assumed, and the data from Table X was applied to this family over a one year period. It is assumed that the family lives in an area which has a no discharge requirement and spray irrigation is the only means of disposal. The disposal period is confined to 6 months out of the year at an application rate of 6,000

TABLE IX. DETERGENT AND SOAP CHARACTERISTICS

Sample no.	COD*	BOD*	$\frac{BOD_5}{COD}$	TS*	$\frac{COD}{TS - TS\ TAP}$	Sample
38	2109	1470	.695	1160	2.61	Dial
39	2124			1170	2.60	Dial
40	2046			1152	2.56	Dial
41	1999					Dial
42	1968			1212	2.29	Dial
43	2281	1725	.766	1364	2.25	Ivory
44	3468			1806	2.39	Ivory
45	2374	1710	.748	1284	2.55	Lux
46	3436			1752	2.45	Lux
47	2281	1485	.650	1262	2.51	Safeguard
48	3405			1738	2.46	Safeguard
49	828			548	4.22	Prell
50	1125	640	.569	636	3.96	Prell
51				352		TAP water

*All values mg/l

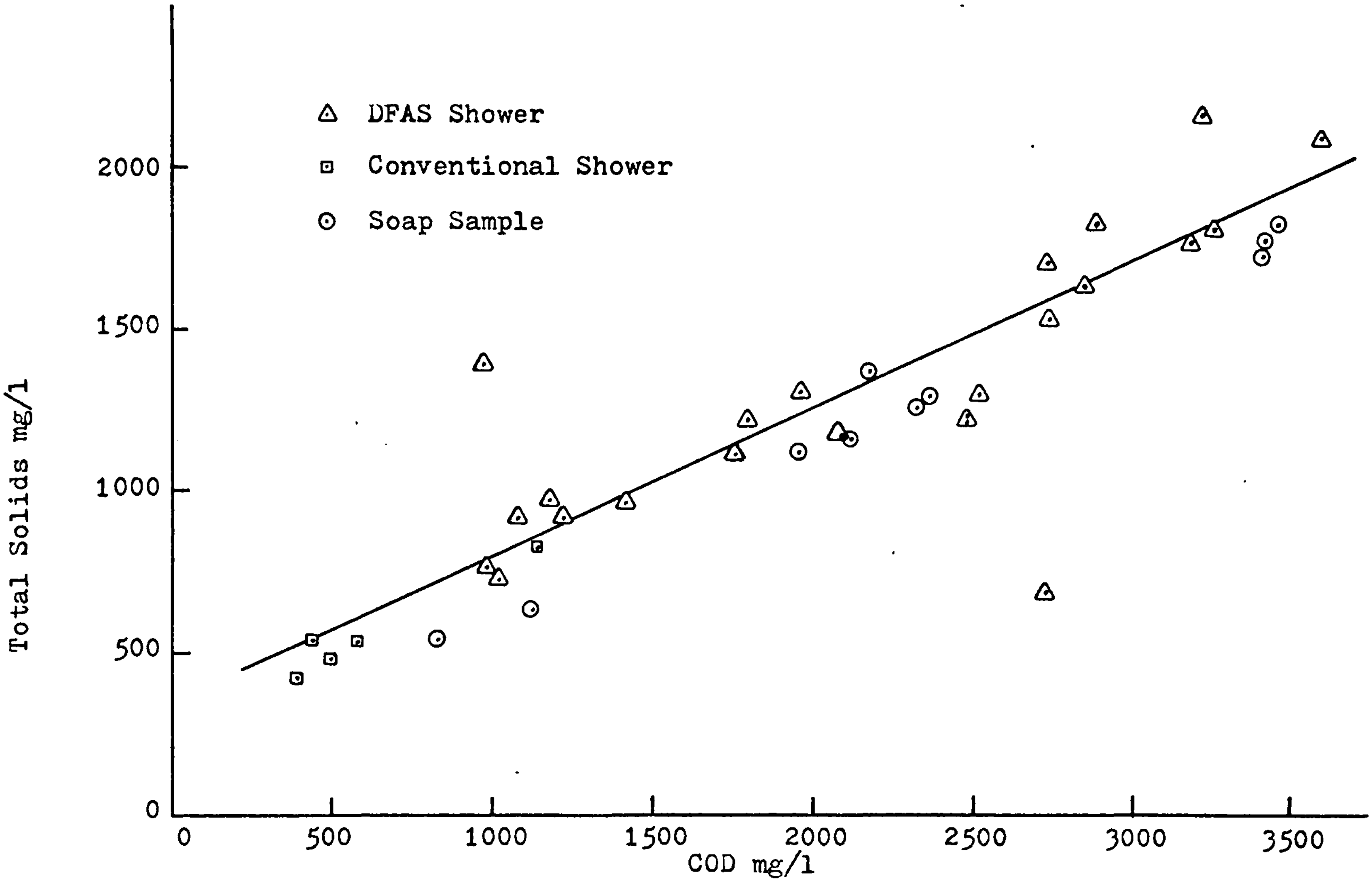

Figure 4. COD vs. TS for Soap Samples, DFAS and Conventional Showers

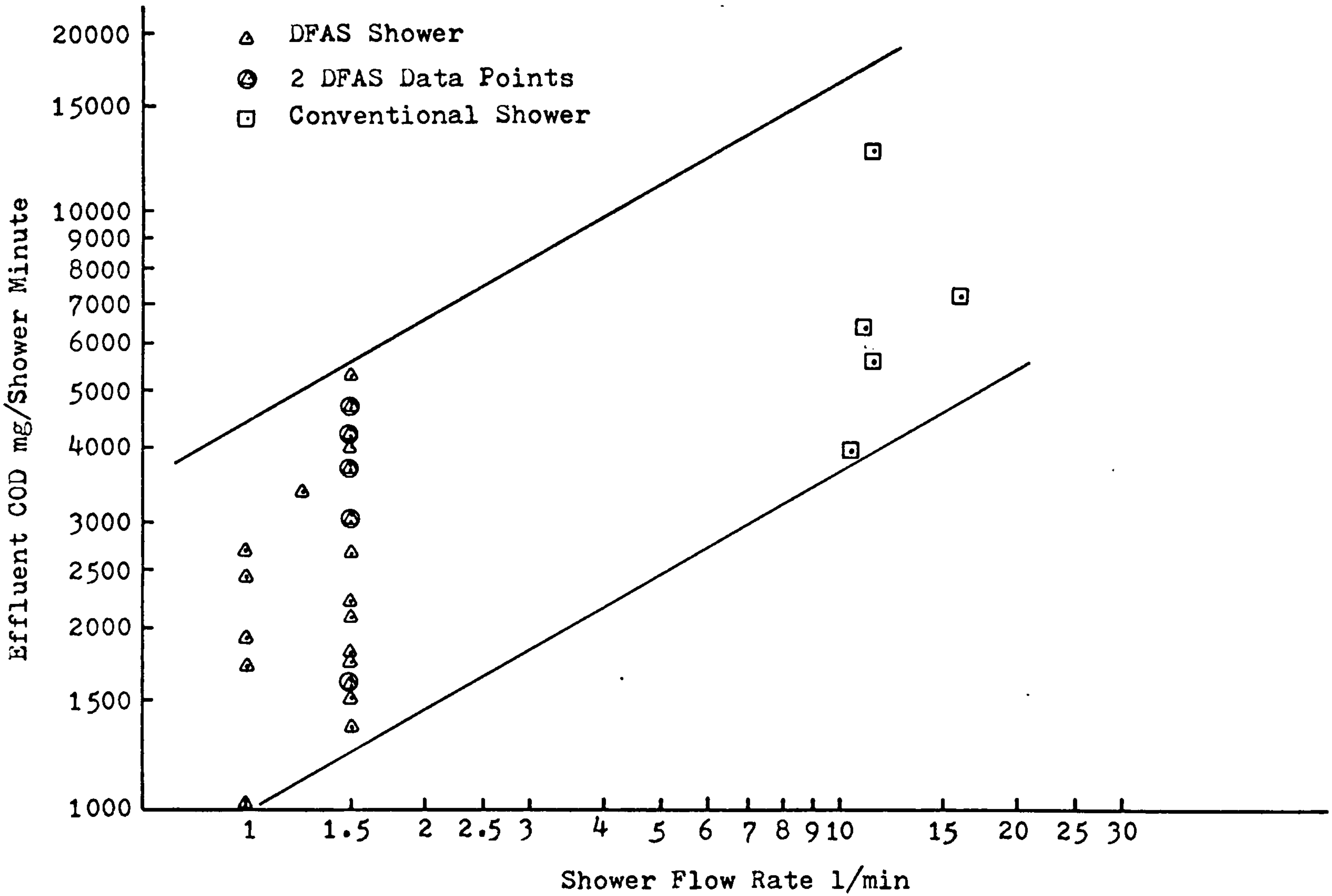

Figure 5. Effect of Shower Flow Rate on mg of COD Per Minute of Shower Time

TABLE X. REPRESENTATIVE SHOWER SYSTEM

Parameter	Shower System DFAS	Conventional
Flow rate	1.5 l/min	15 l/min
Water temp	15°C	15°C
Shower temp	45°C	40°C
Power head	7 amp 110 V	NA
Shower time	7 min	7 min
COD	1911 mg/l	610 mg/l
BOD_5	1234 mg/l	333 mg/l
BOD_5/COD	.645	.546

gallons of effluent per acre day (18, 19). These are realistic values for central and northern California and follow the general guidelines of the California Water Quality Control Board for land disposal application rates (20). The values used to compute treatment plant component sizes are based on the percent of the designed capacity that the given shower system initiates for a 30,000 gpd extended aeration treatment plant.

In order to transform these figures into a usable size, the contribution of the representative family of 3.5 members, using the described systems for a one year period, as shown in Table X, results in the values shown in Table XI.

TABLE XI. SHOWER USE FOR ONE YEAR FOR FAMILY OF 3.5

Parameter	Shower DFAS	Shower Conventional
Water/yr	13,414 l (3544 gal)	134,138 l (35439 gal)
Water heat/yr	402,413 kcal	3,353,437 kcal
Energy/yr (power head)	28,199 kcal (32.79 kwh)	NA
BOD_5/yr	16.55 kg (36.50 lb)	44.67 kg (98.49 lb)
COD/yr	25.63 kg	81.82 kg

The quantities shown in Table XI reflect the difference in the values of various parameters when comparing the use of the DFAS shower and a conventional shower. The water used in bathing is reduced by 90% by the use of the DFAS; while the power consumed to heat the water and supply power to the power head is 12% of that required to heat the water for a conventional shower.

The reduction in the BOD_5 and COD to approximately 1/3 of the conventional values through the use of the DFAS shower is a reflection of the experimental results presented in Figure 5. The explanation of this reduction is only speculative, but it is thought that the bar of soap is scrubbed until it slides freely on the skin; the less water on the skin, the less soap is required to achieve the same feeling.

This was the only logical explanation that could be arrived at by the author.

Realizing this is a very qualitative look at the total effect of reducing the flow, it does, however, give an indication of the relative impacts of each of the systems on the environment.

The difference in quantity alone between these two systems would require 5.32 days of spray disposal to dispose of the effluent at 6,000 gpd/acre on one acre of land.

If stored for the six months of winter, the quantity of waste to dispose of would have increased in proportion to the amount stored, due to the accumulation of rainfall. With a constant pond depth, the more effluent that is stored, the more precipitation that is collected. This results in a greater quantity of wastewater to be disposed of.

This demonstration of an overall reduction in the water used, power consumed, and BOD load on the environment demonstrates the ability of the DFAS system to meet the design criteria No. 4, which was set forth in Chapter 3. This criteria states that the reduction in water consumption achieved in the reduced flow shower system must not be off-set by increased consumption of other resources. The system actually results in an overall resource depletion reduction.

CHAPTER 6

ECONOMIC ANALYSIS OF DFAS VS. CONVENTIONAL SHOWER

The ubiquitous yard stick (0.91 m) that must ultimately be applied to everything is: HOW MUCH DOES IT COST?

The calculated cost of the DFAS unit is $150. This is taking the estimated cost of constructing the unit in a mass production condition.

The comparable conventional shower plumbing that this system would replace is assumed to cost $25. Neither of these costs include the shower stall, doors, etc., which are common to both installations and therefore do not represent a net cost difference.

Assumed Conditions

The general assumptions used to estimate the remaining costs for comparison are:

1. The conventional shower represents 30% of the household water usage
2. 3.5 capita per household
3. Average daily shower usage of 7 min per capita
4. Flow parameters of each of the systems are as shown in Table X in Chapter 5.

5. Water costs of \$6 per 1000 ft^3 or \$0.80 per 1000 gal (5). This figure is given by Howe as being the division between medium and high cost water, and would be the low value expected for areas with water conservation problems. This cost was verified on a limited basis by a California water district (21).
6. Wastewater treatment: Based on 30,000 gpd, the cost of an extended aeration plant is estimated at \$0.50/1000 gal in 1967 dollars for both capital and operating costs (22). This figure was adjusted using the ENR index of 1000 for 1967, and 1789 for 1972 for construction costs. The resulting cost is \$0.90/1000 gal (23).
7. Collection system: For this comparison the collection systems are considered equal due to governmental control.
8. Effluent storage:
    a. 6 months per year (winter).
    b. Assume 24 in. of precipitation during 6 mo.
    c. Evaporation is negligible during the winter.
    d. Precipitation equals evaporation during the summer.
    e. Average storage depth of 10 ft.
    f. Storage construction cost estimate of \$2/yd^3 of storage (21).
    g. Useful life of 40 yr.

9. Effluent disposal:

a. Spray field capital equipment cost \$1500/acre (24, 25, 26).

b. Application rate of 6000 gpd/acre (18, 19, 20).

c. Spray field equipment life assumed to be 20 yr.

d. Disposal time is 6 mo.

e. Assume 1 man-hr/week-acre over a 6 mo. time at \$5/hr + 20% overhead.

f. Monthly cost is then \$75 for capital plus \$156 for labor for a total of \$231/acre-6 mo. or \$1.27/acre-day.

10. Power costs: \$0.02/kwh (8).

11. Water heat: Use electricity at 80% efficiency.

Cost Comparison Calculations

Cost comparison calculations were made utilizing the above assumptions. These calculations follow and the significant results are shown in Table XII.

1. Water quantity

a. DFAS system

Flow x min/shower x showers/day x days/year

1.5 l/min x 7 min x 3.5 x 365

= 13,400 l or 3540 gal at \$0.80/1000 gal

= \$2.80/yr

b. Conventional shower

Flow = 15 l/min = 134,000 l/yr or

35,400 gal @ \$0.80/1000 gal

= \$28.40/yr

2. Water heating energy

a. DFAS shower

(1). Temp rise 30 °C

(2). Water heated 13,414 l

(1) x (2) = 402,000 kcal

80% efficient hot water heater and piping system; input power = 503,000 kcal or 585 kwh @ \$0.02/kwh

= \$11.70/yr

b. Conventional shower

(1). Temp rise 25 °C

(2). Water heated 134,138 l

(1) x (2) = 3,350,000

80% efficient hot water heater and piping system; input power = 4,190,000 kcal or 4870 kwh @ \$0.02/kwh

= \$97.50/yr

3. Power head energy requirements

a. DFAS shower

(1). 7 amp x 115 volt = 805 watt = 0.805 kw

(2). 7 min/shower x 3.5 showers/day x 365 days/yr 60 min/hr = 149 hr/yr

(1) x (2) = 120 kwh @ \$0.02/kwh

= \$2.40/yr

b. Conventional shower

Not applicable

4. Wastewater treatment

a. DFAS shower

(1). 13,400 l = 3540 gal

(2). 3540 gal at \$0.90/1000 gal

= \$3.20/yr

b. Conventional shower

(1). 134,000 l = 35,700 gal

(2). 35,700 gal at \$0.90/1000 gal

= \$32.10/yr

5. Wastewater storage: This section is used to explain how the final disposal quantities are arrived at. A lagoon 10 ft deep = 8 ft effluent storage + 2 ft of precipitation accumulation.

a. DFAS shower

(1). 13,400 l = 474 ft^3 effluent

(2). In ½ yr, 237 ft^3 effluent

(3). 237 ft^3 at 8 ft deep = 30 ft^2 surface

(4). Precipitation accumulated at 2 ft = 60 ft^3

(5). Total annual effluent = sewage + precipitation accumulation = 534 ft^3 = 15,123 l

= 20 yd^3 @ \$0.05/yd^3

= \$1.00/yr

b. Conventional shower

(1). 134,000 = 4740 ft^3 effluent

(2). In ½ yr, 2370 ft^3 effluent

(3). 2370 ft^3 at 8 ft deep = 296 ft^2 surface

(4). Precipitation accumulation at 2 ft = 592 ft^3

(5). Total annual effluent = sewage + precipitation accumulation = 5330 ft^3 = 151,000 l = 197 yd^3 @ \$0.05/yd^3 = \$9.85/yr

6. Wastewater disposal

a. DFAS shower

(1). 15,123 l = 4020 gal

(2). Disposal of 4020 gallons at 6000 gpd/acre = 0.67 acre-days

(3). 0.67 acre days at \$1.27/acre day = \$0.85/yr

b. Conventional shower

(1). 151,000 l = 40,200 gal

(2). Disposal of 40,200 gal at 6000 gpd/acre = 6.69 acre days

(3). 6.69 acre days at \$1.27/acre day = \$8.50/yr

These calculations do not reflect the differences in wastewater collection system size requirements or land cost requirements for disposal.

TABLE XII. YEARLY COST COMPARISON
DFAS VS. CONVENTIONAL SHOWERING SYSTEM

Parameter	(1) DFAS	(2) Conventional	(2) - (1)
Water	$ 2.80	$ 28.40	$ 25.60
Water Heat	11.70	97.50	85.80
Power Head	2.40	NA	- 2.40
Wastewater Treatment	3.20	32.10	28.90
Wastewater Treatment	1.00	9.90	8.90
Wastewater Disposal	.85	8.50	7.65
Total	$21.95	$176.40	$154.45

CHAPTER 7

PHYSICAL-CHEMICAL TREATABILITY ANALYSIS

The waste collected from the DFAS shower was a very milky liquid. Wastewater from several showers was collected to form the sample used in this phase of the system analysis.

A standard jar test stirring apparatus was used to carry out coagulation, flocculation, adsorption tests in 1 liter beakers. The stirring apparatus speed was increased as far as possible to approximately 100 rpm and the coagulant injected. Rapid mix was continued for 2 minutes, and then the speed was reduced to 5-10 rpm for 15 minutes. The sample was then allowed to settle for 30 minutes. Supernatant was withdrawn with a siphon. This sample was then filtered and COD and total solids analysis were conducted according to Standard Methods (17). The pH of the sample, before and after the test, was measured using a Beckman Expandomatic pH Meter; the temperature of the solution was measured and recorded; the turbidity of the sample was taken before and after the tests, using a Hach Turbidimeter 2100A.

The results of these tests are shown in Table XIII. In Test 1, the alum dosage shown is measured in terms of mg/l of aluminum ion. Test 2 was conducted, using the optimum alum dosage (20 mg/l) found in Test 1, plus the

TABLE XIII. DFAS SHOWER PHYSICAL-CHEMICAL TREATABILITY DATA

Test no.	Sample no.	Additive	Dosage mg/l	pH Start	pH Stop	°F	Turbidity FTU Start	Turbidity FTU Stop	COD mg/l	TS mg/l	%Composite COD Remaining
			Al^{+++}								
1	1	Alum	15	7.3	6.6	78	850	12.0	-	620	-
	2	"	20	"	6.4	"		3.7	225.7	616	11.4
	3	"	25	"	5.8	"		7.0	218.3	648	11.1
	4	"	30	"	5.3	"		8.8	214.6	644	10.9
	5	"	35	"	-	"		12.0	173.9	682	8.8
		Alum(20 mg/l Al^{+++})	Carbon								
2	6	+Carbon	50	"	6.3	72		4.7	199.8	576	10.1
	7	"	100	"	6.3	"		5.2	203.5	574	10.3
	8	"	150	"	6.3	"		4.3	177.6	550	9.0
	9	"	200	"	6.2	"		5.9	166.5	546	8.45
	10	"	250	"	6.2	"		4.7	166.5	546	8.45
	11	"	300	"	6.3	"		5.4	155.4	552	7.9
		Ferric	Fe^{+++}								
3	12	Chloride	50	"	6.1	72		130.	192.4	540	9.8
	13	"	55	"	5.8	"		9.	177.6	540	9.0
	14	"	65	"	5.4	72		5.	181.3	534	9.2
Sample	15	Composite							1970.0	1336	100.
	16	Filtered							321.9	708	16.9

addition of powdered activated carbon. Test 3 was conducted, using ferric chloride as a coagulant. The amount of coagulant added is given as mg/l of Fe^{+++}.

An optimum alum dosage for turbidity and solids reduction was found at 20 mg/l. This dosage resulted in a 54% reduction in total solids and a 89.6% reduction in COD. Increasing this alum dosage beyond 20 mg/l did result in further COD reduction down to 91.2% removal at 35 mg/l of alum, but turbidity and total solids increased.

The use of this 20mg/l dosage of alum in conjunction with powdered activated carbon reduced the total solids and COD from the values obtained for just the alum dosage. The addition of 300 mg/l of powdered activated carbon with 20 mg/l of alum resulted in a 92.1% COD removal and 59% removal of total solids.

Similar COD removals of approximately 90% were achieved using ferric chloride.

These results indicate amenability of this waste to physical-chemical treatment.

CHAPTER 8

SUMMARY AND CONCLUSIONS

Reduction of the amount of water consumed can be accomplished through redesign of the system in which the water is used. The toilet and bathing function account for 70 to 75% of the water use in the home, with the toilet consumption 5 to 10% more than the shower. Many reduced flow toilets have been produced, but no significant reduced flow bathing system.

The bathing system design must meet aesthetic criteria much more stringent than those for less body contacting water use functions, as well as the physical, and economic design requirements. Criteria were established for the advantageous replacement of the conventional bathing system with a system using less water. These criteria were briefly:

1. It must clean.
2. It must not alter habit patterns.
3. It must be aesthetically acceptable.
4. It must not result in other environmental stress increases.
5. It should result in an overall economic savings.

The final design configuration was a DFAS shower. This system was installed in a standard shower stall and individuals were asked to take showers in their normal manner. The results of these tests established that the system fulfilled the first three criteria.

The parameters of water flow rate and water temperature were measured for the DFAS system and a conventional shower. The energy consumed by the power head on the DFAS unit was calculated as an input to this system.

From the results of these tests and data from the literature an average family of 3.5 people was proposed for the basis of comparison of the systems. Each member of this family was assumed to use the shower an average of 7 minutes each day. The savings in water for this family each year was 121,000 l. The energy savings was 3,700,000 kcal for the same time.

The waste from these tests was collected and tested and the resulting data analyzed in terms of the average family for one year. The resulting reduction in BOD, imposed on the environment, was 28 kg per year.

These comparisons indicate a quite substantial reduction in environmental stress imposed by the DFAS system verses the conventional unit.

The $154 savings per year achieved by using the unit will pay for the initial cost of the DFAS system installed in an existing home the first year of use. The components used in the unit are very simple and reliable and have an estimated life of 20 years with no more maintenance costs than a conventional unit. Using these figures, the DFAS system could save the average family about $3000 over the 20 year life of the system.

Savings due to the reduced size required for the water and sewage collection systems are not included in these calculations.

The treatability study indicated that the waste was amenable to physical-chemical treatment. The most significant overriding advantage to be obtained through reduced flow systems use is the ability to take the funds that are normally required to handle the hydraulic quantities of present sewage flows and apply them to improving the quality of treatment of the reduced flow. This will result in a higher quality effluent and less of it to disperse in the environment.

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