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Residential End Uses of Water

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Residential End Uses of Water

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EXECUTIVE SUMMARY

Where is water used in single-family homes? How much water is used for toilets, showers, clothes washers faucets, dishwashers, and all other purposes? What component of total use can be attributed to each specific water using device and fixture? How does water use vary across single-family homes? What are the factors that influence single-family residential water use? How does water use differ in households equipped with conserving fixtures? *The Residential End Uses of Water Study* (REUWS) was designed to help answer these and other questions and to provide specific data on the end uses of water in single-family residential settings across North America.

The "end uses" of water include all the places where water is used in a single-family home such as toilets, showers, clothes washers, faucets, lawn watering, etc. Accurately measuring and modeling the residential end uses of water and the effectiveness of conservation efforts has been the Achilles heel of urban water planning for many years. Understanding where water is put to use by the consumer is critical information for utilities, planners, and conservation professionals. Empirical evidence of the effectiveness of specific conservation measures can be used to improve the design of conservation programs and can provide justification for continued support of conservation efforts.

RESEARCH OBJECTIVES

The American Water Works Association Research Foundation (AWWARF) and 22 municipalities, water utilities, water purveyors, water districts, and water providers funded this study. Goals of this research included:

- Providing specific data on the end uses of water in residential settings across the continent.
- Assembling data on disaggregated indoor and outdoor uses.
- Identifying variations in water used for each fixture or appliance according to a variety of factors.
- Developing predictive models to forecast residential water demand.

This report represents a time and place snapshot of how water is used in single-family homes in twelve North American locations. Similarities and differences among "end uses" were tabulated for each location, analyzed, and summarized. Great care was taken to create a statistically significant representative sample of customer for each of the twelve locations. However, these twelve locations *are not* statistically representative of all North American locations.

Although a concerted effort was made to recruit a representative sample of households at each location, some households chose not to participate. While this may place some limits on the statistical inferences and generalizations which can be drawn from the data, it does not diminish the contribution made by these data to improving understanding of residential water use.

Analyses are presented for each of the participating cities individually and for the pooled sample of 1,188 households. Creating national water use "averages" was not an objective of this study. The pooled results are presented for summary and comparative purposes alone. Two major contributions of this study are demonstrating the feasibility of identifying and measuring the different ways households use water and describing and analyzing variations in water used for specific purposes between different households. Armed with this insight, individual water utilities interested in reducing water demands in single-family homes now have a better tool to assess their own conservation potential.

The diversity of the water use data found over the twelve locations illustrates the importance of utility specific information on how individual behavior influences home water use. However, a striking conclusion of this report is in the *similarities* between these twelve locations in the amount of water fixtures and appliances use. The range in the amount of water used by hardware such as toilets, washing machines, showerheads, dishwashers, faucets, and fixture leaks is now documented and surprisingly similar - suggesting that this portion of the data has significant "transfer" value across North America. The predictive models developed as part of this study to forecast indoor demand significantly increase the confidence in explaining the water use variations observed. The major benefit of modeling is to provide a predictive tool with a high transfer value for use by other utilities.

PROACH

The project team developed a multifaceted approach to accomplish the research jectives set out for this study. After invitations were sent to utilities and water providers ross the United States and Canada, 12 study sites volunteered to participate and partially fund is research. These 12 study sites were: Boulder, Colorado; Denver, Colorado; Eugene, regon; Seattle, Washington; San Diego, California; Tampa, Florida; Phoenix, Arizona; Tempe nd Scottsdale, Arizona; the Regional Municipality of Waterloo, Ontario; Walnut Valley Water District, California; Las Virgenes Municipal Water District, California; and Lompoc, California.

A detailed and rigorous workplan to obtain data from each study site was developed by the project team. Data collected from each study site included: historic billing records from a systematic random sample of 1,000 single-family detached residential accounts; household level information obtained through a detailed mail survey sent to each of the selected 1,000 households; approximately four weeks of specific data on the end uses of water collected from a total of 1,188 households (approximately 100 per study site), data collection was divided into two, two-week intervals spaced in time to attempt to capture summer (peak) and winter (off-peak mostly indoor water use) time frames; supplemental information including climate data and information specific to each participating utility.

In this study, water consumption for various end uses was measured from a significant sample of residential housing across North America using compact data loggers and a PC-based flow trace analysis software. A flow trace is a record of flow through a residential water meter recorded in 10 second intervals which provides sufficient resolution to identify the patterns of specific fixtures within the household. The flow trace analysis software disaggregates this virtually continuous flow trace into individual water use events such as a toilet flush or clothes washer cycle and then an analyst implements signal processing tools to assign fixture designations to each event.

The data assembled for this research effort include: A sizable residential water use database containing nearly one million individual water use "events" collected from 1,188 residences in the 12 study sites; extensive household level information obtained through the mail survey completed by approximately 6,000 households, and historic water billing records from 12,000 residences. All of this information was collected to provide answers to many long standing questions about how much and where water is used in the residential setting and to provide estimates of the savings available from various conservation measures.

In addition to presenting the findings from the data collection effort, the project team also developed predictive models which incorporated the detailed end use information and household level socioeconomic data.

A research study of this magnitude must rely on a variety of assumptions which are taken as "givens". It is recognized that changes in some of these assumptions could impact the results, but the limits of the project scope and funding did not allow exploration of some of the following factors:

1. The accuracy of the billing consumption histories provided by participating utilities
2. The accuracy of mail survey responses
3. The timeframe of monitoring capturing "representative" indoor water use for each home
4. Capturing the precise weather related use within the monitoring timeframe needed to analyze the variables associated with outdoor use

RESEARCH FINDINGS

The primary goal of this study was to provide specific data on the end uses of water in residential settings across the continent. The accomplishment of this and the other stated goals of the REUWS are summarized in the findings below.

Annual Use

Average annual water use, based on historic billing records from approximately 1,000 accounts in each of the 12 study sites, ranged from 69,900 gallons per household per year in Waterloo and Cambridge, Ontario to 301,100 gallons per household per year in Las Virgenes MWD. The mean annual water use for the 12 combined sites was 146,100 gallons per household per year with a standard deviation of 103,500 gallons and a median of 123,200 gallons (n=12,075). Across all study sites 42 percent of annual water use was for indoor purposes and 58 percent for outdoor purposes. This mix of indoor and outdoor was strongly influenced by annual weather patterns and, as expected, sites in hot climates like Phoenix and Tempe and

;cottsdale had a higher percentage of outdoor use (59 – 67 percent) while sites in cooler, wetter ·limates like Seattle and Tampa and Waterloo had much lower percentages of outdoor use (22 – 38 percent). The net annual ET requirement for turf grass ranged from 15.65 inches in Waterloo ·o 73.40 inches in Phoenix, Tempe, and Scottsdale.

Daily Per Capita Use

Per capita daily indoor water use was calculated for each study site and for the entire study using data logging results from 28,015 complete logged days to calculate water consumption and mail survey responses to count the number of people per household. Across all 1,188 study homes in the 12 study sites the mean per capita indoor daily water use was 69.3 gallons (including leakage). Results are shown in Figures ES.1. Toilet use was calculated at 18.5 gallons per capita per day (gpcd), clothes washer use was 15.0 gpcd, shower use was 11.6 gpcd, faucet use was 10.9 gpcd, leaks were 9.5 gpcd, baths were 1.2 gpcd, dishwasher use was 1.0 gpcd, and other domestic use was 1.6 gpcd. Mean indoor per capita use in each study site ranged from 57.1 gpcd in Seattle, Washington to 83.5 gpcd in Eugene, Oregon.

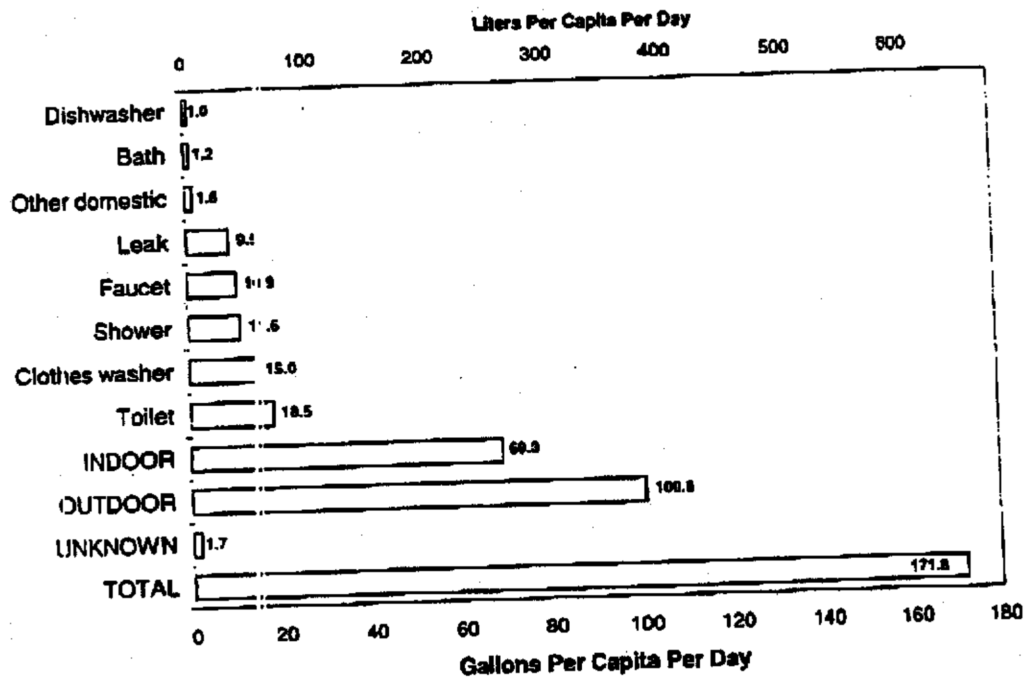

Figure ES.1 Mean daily per capita water use, 12 study sites

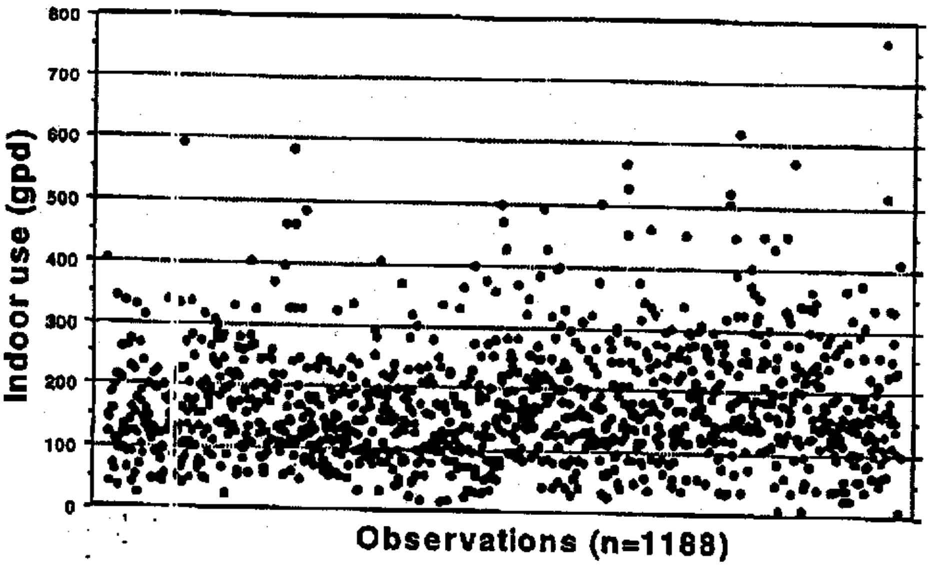

Figure 5.3 Scatter diagram of average daily indoor water use, 1,188 study homes

Figure 5.4 is a box diagram, using the same plotting conventions as in Figure 5.2, but showing the average daily *indoor* water use from the study homes. It is noteworthy that ninety percent of the daily indoor use was below 300 gpd on average. The highest observed average daily indoor use was 769 gpd. The median use is approximately 150 gpd, which is equivalent to 54,750 gallons per year or 4560 gallons per month for each household.

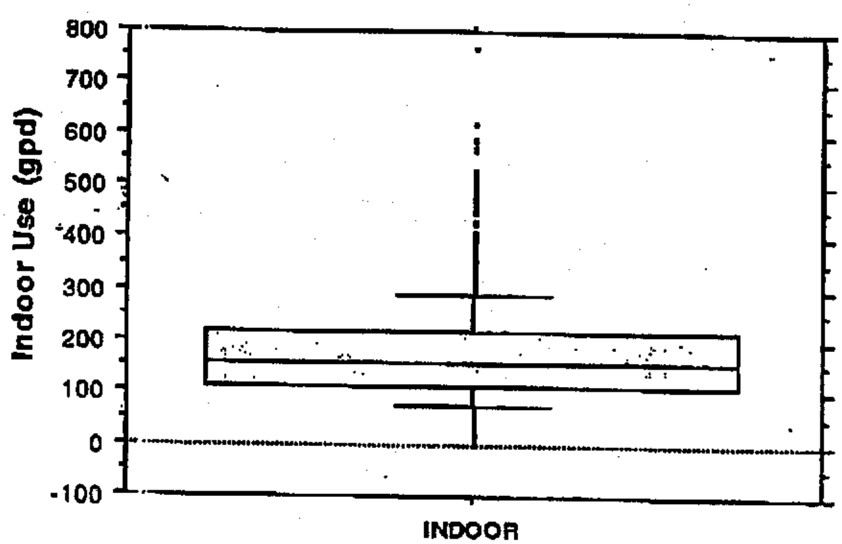

Figure 5.4 Box diagram of average daily indoor water use, 1,188 study homes

INDOOR PER CAPITA USE

Per capita water use was calculated for each individual study home using the daily water use obtained from the flow trace analysis results and the reported number of residents during the summer and winter from the mail survey. Averages of per capita use were made from the daily per capita use calculated for each household. Toilet flushing was the largest component of indoor per capita water use among all data logged homes in the REUWS study. Toilets accounted for 26.7 percent of indoor water use. Figure 5.5 shows the percentage breakdown of all indoor water uses collected from the logged homes in the REUWS project. Clothes washers were the second largest component of indoor use at 21.7 percent followed by showers and baths at 18.5 percent, faucets at 15.7 percent, and leaks at 13.7 percent. This figure is based on the per capita water use calculated for each indoor end use category from the 1,188 data logged homes in all 12 study sites.

For comparison, the 1984 HUD study found comparable indoor water use rates in homes which had similar mean per capita per day consumption. The HUD study found toilets to be 28 percent, clothes washers 22 percent, showers and baths 28 percent, faucets 13 percent, and leaks 7 percent of indoor water use in homes which used an average of 68.4 gpcd for indoor purposes.

Leaks are included in as an indoor use category in the REUWS although it is not known precisely where the leakage occurred. During analysis it was not possible to accurately determine if estimated leakage occurred inside a home or not. However, in homes with particularly high leakage rates it appeared that faulty toilet flapper valves were frequently the cause. Leaks are discussed in more detail later in this chapter.

Mean Per Capita Daily Water Use

In the REUWS, the average total daily per capita usage was found to be 172 gpcd with 69.3 gpcd coming from indoor uses, 101 gpcd coming from outdoor uses, and 1.7 gpcd from unknown or unidentified indoor or outdoor use. Figure 5.2 shows the average gallons per capita per day measured during the REUWS. Outdoor use was calculated using a combination of flow trace data collected and analyzed during the study and historic billing data provided by each study site. Billing data were used to calculate outdoor use because the data logging equipment was not in the field long enough to accurately measure average outdoor use over an entire irrigation season. The measured indoor use for each participating house was pro rated to an annual amount which was subtracted from their total annual consumption to arrive at the annual outdoor use figure. As per capita per day usage is not a particularly useful way to study outdoor water consumption, outdoor use is more closely examined in subsequent sections of this report.

The "unknown" category includes water use that could not be assigned any specific use category during the flow trace analysis process. Because of this uncertainty this use category has not been included in either indoor or outdoor per capita per day totals, but is added into the total per capita per day usage.

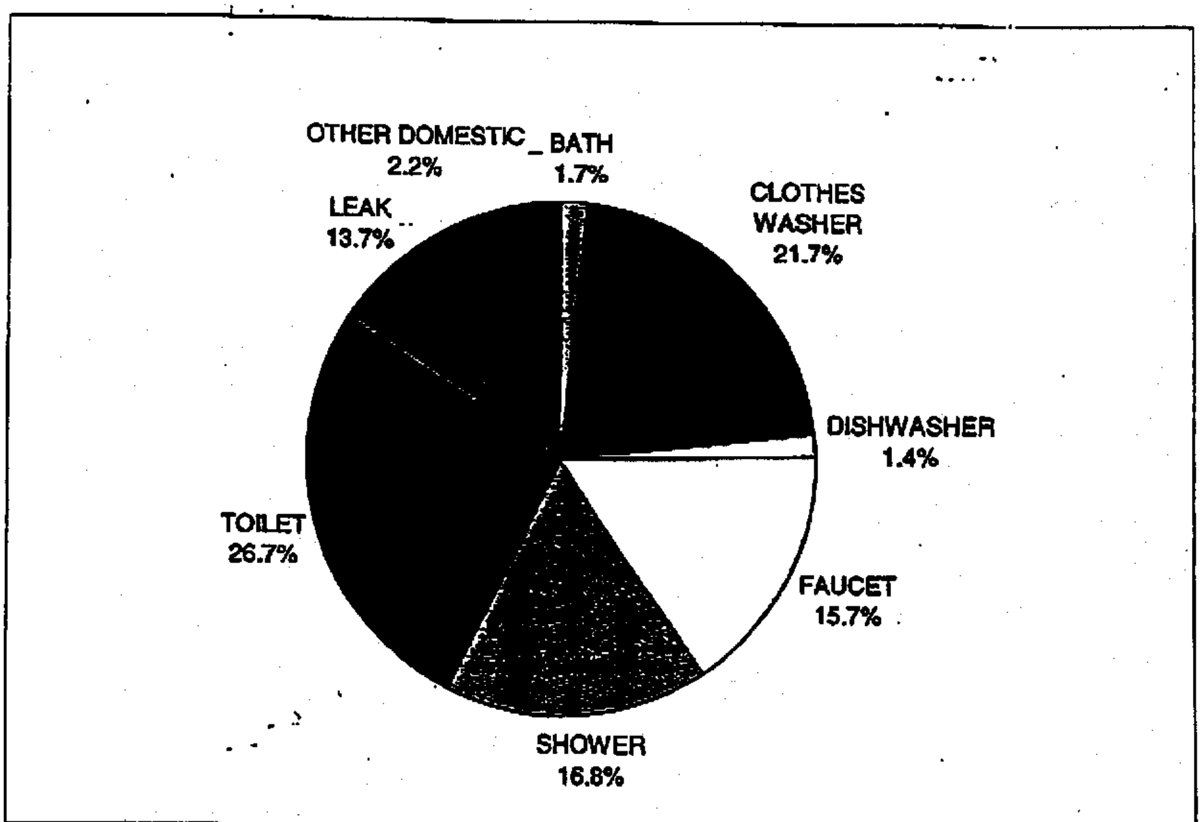

Figure 5.5 Indoor per capita water use percentage including leakage, 1,188 study homes

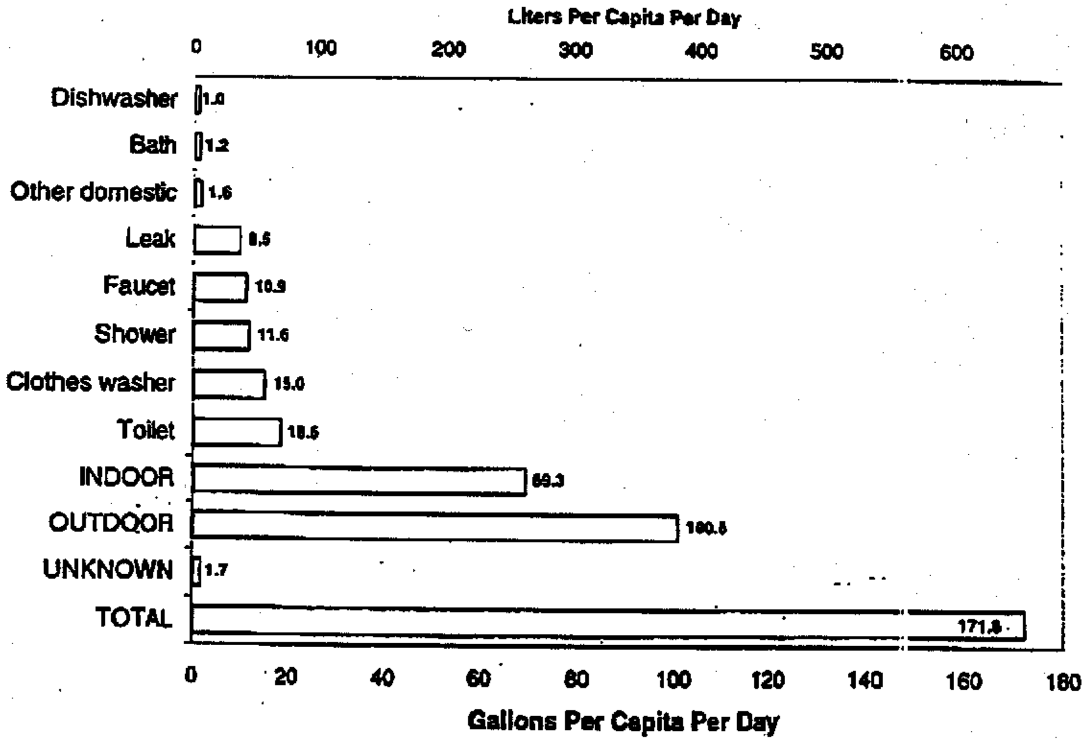

Figure 5.6 Average per capita per day usage (gpcd), 1,188 data logged homes

The distribution of mean household daily per capita indoor water use is shown in Figure 5.7. Based on the mean indoor gpcd calculated for each of the 1,188 data logged homes, the distribution is focused around homes which used between 40 and 90 gpcd for indoor purposes. As shown in Figure 5.6, the mean daily per capita indoor water use for the sample was 69.3 gallons. As evidenced by the variability shown in the distribution in Figure 5.7, the standard deviation of mean daily per capital indoor use was 42.6 gpcd. The median indoor use was 60.1 gpcd.

As would be expected, indoor water use increase as household size increase, but use per person decreases. This result is shown in Figure 5.8. Per capita use in households with only one occupant is 97.4 gpcd, but this amount decreases to 44.7 gpcd in households with eight occupants. There appear to be efficiencies associated with an increase in the number of occupants in a household which could be related to the age of the occupants and/or the amount of water needed for cleaning, washing clothes and dishes, and general maintenance.

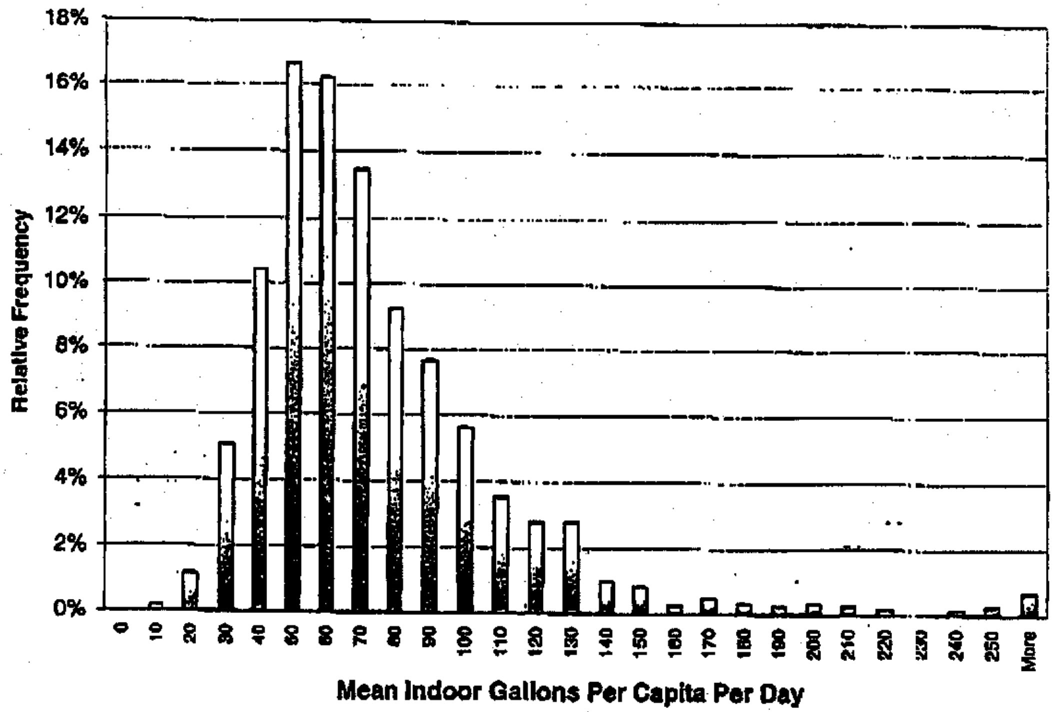

Figure 5.7 Distribution of mean household daily per capita indoor water use, 1,188 study homes

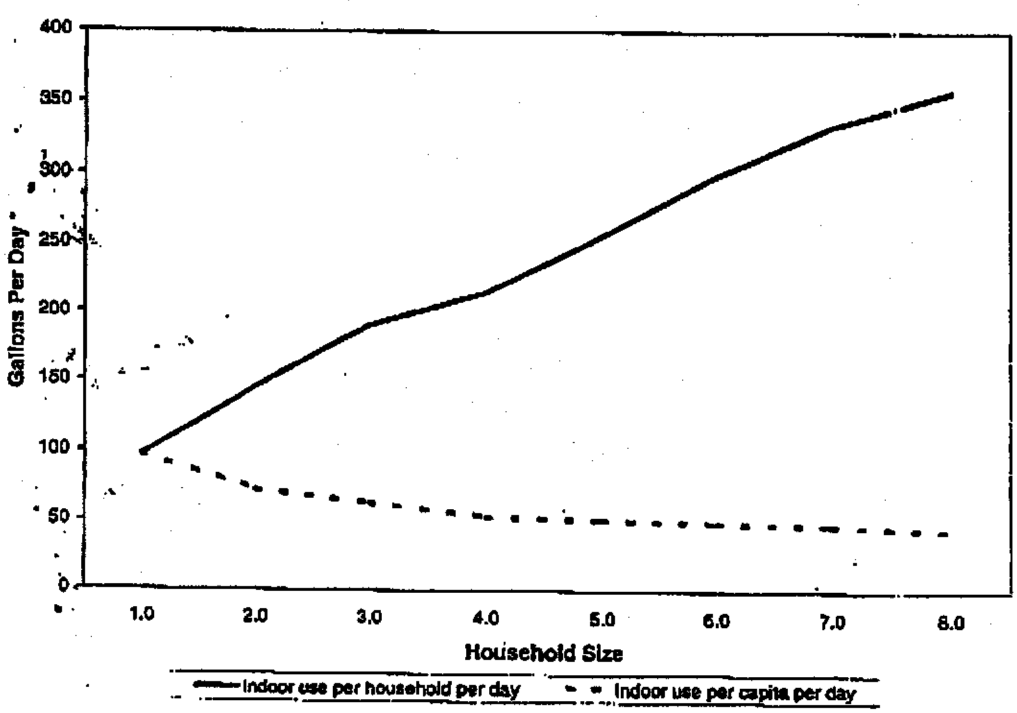

Figure 5.8 Indoor water use by household size

In order to quantify the increase in total indoor water use with household size, a least squares regression line was fit to the indoor per household per day data and equation 5.1 was obtained. The coefficient of determination (R^2) for this equation is 0.9944 indicating an excellent fit.

$$y = 37.2x + 69.2 \qquad (5.1)$$

where y = indoor use per household per day and

x = the household size (number of people per household)

This equation indicates that there is an increase of approximately 37 gallons per day for each extra person in the household with a "threshold" water use of about 69 gallons per day.

Study Site Comparison

Mean indoor use patterns in the 12 study sites differed by up to 26.4 gallons per capita per day (gpcd). The average per capita per day indoor usage ranged from 57.1 gpcd in Seattle to 83.5 gpcd in Eugene, Oregon with a mean for the entire study of 69.3 gpcd. Results for all 12 study sites are presented in Table 5.1. The median use was less variable, with only a 12.9 gpcd difference between the extremes. This result is important because the calculation of the median avoids the right hand tail effect from outliers. The importance of outliers is shown by the large difference between the mean and median for each city. The standard deviation of daily per capita indoor use ranged from 23.4 in San Diego to 68.9 in Eugene. The Tempe/Scottsdale and Eugene, Oregon study sites had the highest daily per capita indoor water use and standard deviation because of a small number of outliers who used considerably more water due to excessive leakage and the possibility that additional persons may have been staying at the home during one of the logging periods.

Leaks

The mean per capita rate of leakage (9.5 gpcd) should be of concern to utilities, water providers, and consumers. This is not the first study that has found residential leakage rates in this range. The 1984 HUD study found leakage rates ranging from 5 to 13 percent of indoor use (Brown and Caldwell 1984). The Boulder Heatherwood Studies found leakage to be 11.5 percent of indoor use, but this was reduced to 5.5 percent after a significant ULF toilet retrofit in each participating home (DeOreo et al. 1996c). In the REUWS, leakage comprised 12.7 percent of indoor use.

To put the 9.5 gpcd leakage rate in world-wide perspective, studies in Turkey, Indonesia, Egypt, and Hong Kong found that the entire indoor domestic consumption among lower income groups ranged from 12.4 to 18.5 gpcd (Twort, et. al., 1994).

Table 5.1 Comparison of daily per capita indoor water use, 12 study sites

Study site	Sample size	Mean persons per household	Mean daily per capita indoor use (gpcd)	Median daily per capita indoor use (gpcd)	Standard deviation of per capita indoor use (gpcd)
Seattle	99	2.8	57.1	54.0	28.6
San Diego	100	2.7	58.3	54.1	23.4
Boulder	100	2.4	64.7	60.3	25.8
Lompoc	100	2.8	65.8	56.1	33.4
Tampa	99	2.4	65.8	59.0	33.5
Walnut Valley	99	3.3	67.8	63.3	30.8
Denver	99	2.7	69.3	64.9	35.0
Las Virgenes	100	3.1	69.6	61.0	38.6
Waterloo & Cambridge	95	3.1	70.6	59.5	44.6
Phoenix	100	2.9	77.6	66.9	44.8
Tempe & Scottsdale	99	2.3	81.4	63.4	67.6
Eugene	98	2.5	83.5	63.8	68.9
12 study sites	1188	2.8	69.3	60.5	39.6
Range	5	1.0	26.4	12.9	45.5

Table 5.2 shows the mean daily per capita leakage rates for all 12 study sites. Leakage varied from 3.4 gpcd in Boulder, Colorado to 17.6 gpcd in Tempe and Scottsdale, Arizona. The three sites with the highest mean daily per capita leakage rate (Eugene, Phoenix, Tempe, and Scottsdale) were also the same three sites with the highest overall mean per capita indoor use, indicating to what extent leaks can contribute to daily water use patterns.

One of the limitations of the flow trace analysis technique used in this study was impossible to determine the exact source of the leakage in each study house. However, it was apparent during the analysis of the recorded flow trace data that toilet flapper leaks (which appear in Trace Wizard as regular spikes of water use following toilet flushes) were the primary contributor followed by continuous faucet/hose bib leaks in homes with exorbitant leakage. In some homes with automatic irrigation systems it appeared that there may have been leaks in irrigation valves. Lacking an adequate method to apportion leaks between indoor and outdoor uses, it was decided to include leaks with indoor use for several reasons: (1) Flow trace analysts agreed that the majority of the leakage appeared to be from indoor sources such as faulty toilet flappers and faucets; (2) Including leaks with indoor use more effectively shows the significance of water lost to leakage; and (3) Leaks were included with indoor use in the 1984 HUD study making for easier comparisons.

Table 5.2 Comparison of daily per capita leakage rates, 12 study sites

Study site	Sample size	Mean daily per capita leakage (gpcd)	Median daily per capita leakage (gpcd)	Standard deviation of per capita leakage (gpcd)
Boulder	100	3.4	1.3	6.0
San Diego	100	4.6	1.5	7.9
Denver	99	5.8	1.2	11.6
Seattle	99	5.9	1.2	20.1
Walnut Valley WD	99	7.6	3.0	10.8
Waterloo & Cambridge	95	8.2	3.3	16.1
Lompoc	100	10.1	3.3	23.6
Tampa	98	10.8	1.7	20.2
Las Virgenes MWD	100	11.2	2.7	17.9
Eugene	98	13.6	2.5	46.6
Phoenix	100	14.8	5.8	23.3
Tempe & Scottsdale	99	17.6	5.5	40.3
12 study sites	1188	9.5	2.7	20.4

Figure 5.9 is a histogram of the average daily leakage measured from each of the 1,188 study homes. In the REUWS it was found that a small number of homes were responsible for the majority of the leakage. While the average daily leakage per household was 21.9 gallons, the standard deviation was 54.1 indicating a wide spread in the data. The median leakage rate was only 4.2 gallons per household per day. Nearly 67 percent of the study homes leaked an average of 10 gallons per day or less, but 5.5 percent of the homes leaked an average of more than 100

gallons per day. Saying it another way, 10% of the homes logged were responsible for 58% of the leaks found.

In the 100 logged homes with the highest average daily indoor water use, leaks accounted for 24.5 percent of average daily use. These top 100 homes averaged 90.4 gallons per day (gpd) of leaks compared with 21.9 gpd for the entire 1,188 home data logged group.

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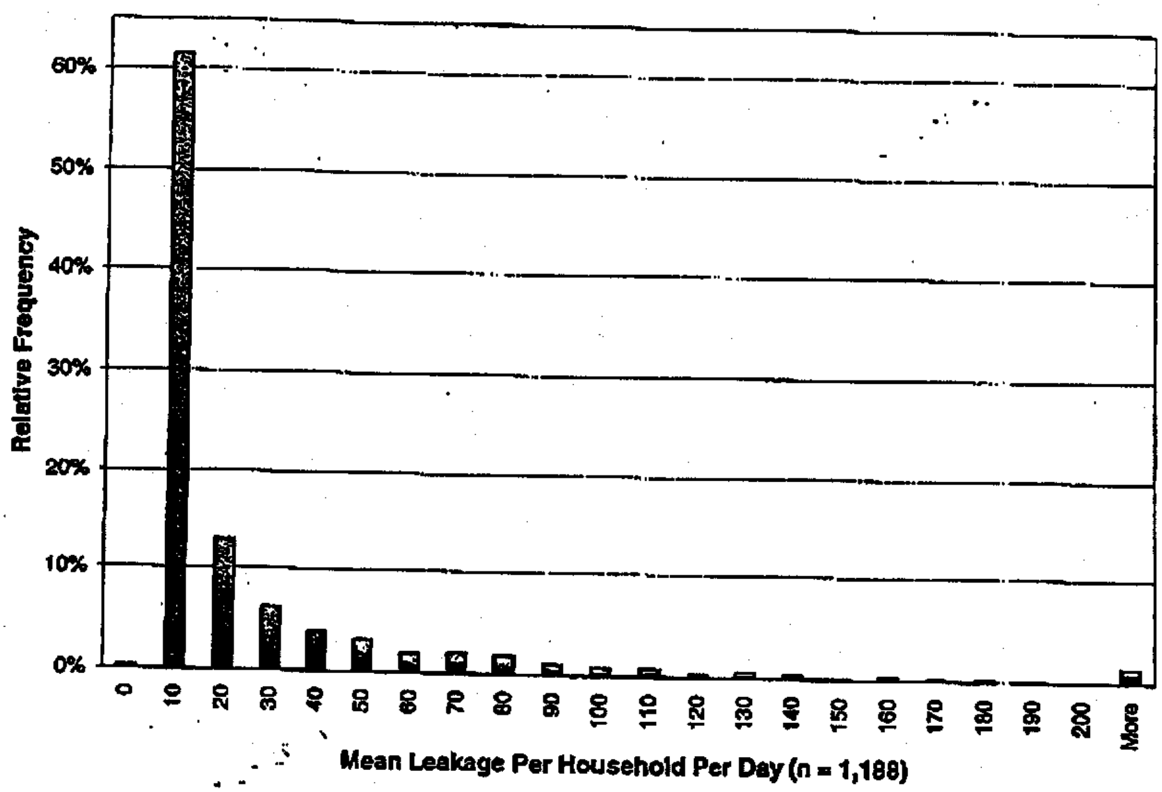

Figure 5.9 Distribution of mean daily leakage, 1,188 study homes

Although not a stated objective of this project, this result suggests that identifying and repairing leaks in the top 5 to 10 percent of leaking homes would provide greater benefit in terms of water savings than a general non-targeted leak detection and repair program. The difficulty lies in accurately identifying the large leak accounts in an inexpensive and systematic manner. A good approach, suggested by the data, would be to target homes in the top tier of winter water use. For the twelve study sites, the data logging results indicate that there is a 76 percent probability that a single family home occupied by four persons or less having winter water use (essentially indoor use) exceeding 12,000 gallons per month (400 gallons per day) has a major leak problem exceeding 4,000 gallons per month (130 gpd). Water utilities may want to target single family accounts with winter water use exceeding 400 gpd to receive a high consumption notice accompanied by suggestions of searching for and repairing leaks.

Fixture Utilization Per Capita Per Day

The data set developed for the REUWS made it possible to calculate the number of times per day each fixture was used in each study home. For toilets, baths, showers, clothes washers, and dishwashers the count of uses per day is a meaningful value.. For faucets, it is more instructive to examine the duration of usage per day. Results are shown in Table 5.3.

The average number of toilet flushes per capita per day ranged from 4.49 in Seattle to 5.62 in Eugene with a study-wide mean of 5.05. Study participants took an average of 0.75 showers and baths per day. Participants in Eugene bathed the most often while participants in Waterloo and Cambridge bathed least frequently. Clothes washers were run an average of 0.37 times per capita per day across all 12 study sites and dishwashers were run 0.10 times per capita per day on average. A typical family of four in the study ran nearly 1.5 loads of laundry and 0.4 loads of dishes per day. Faucets were utilized for an average of 8.1 minutes per person per day at an average flow rate of 1.34 gpm.

Fixture utilization was an important finding of the 1984 HUD study and the HUD findings are compared with the REUWS results in Table 5.4.

These results on fixture utilization for the REUWS and HUD study are similar for showers and baths, but differ somewhat in mean toilet flushes per capita per day and in clothes washer and dishwasher loads per capita per day. The HUD study did not collect data on duration of faucet utilization.

Table 5.3 Fixture utilization per capita per day, mean and standard deviation, 12 study sites

Study site	Toilet flushes per capita per day		Showers & baths per capita per day		Clothes washer loads per capita per day		Dishwasher loads per capita per day		Faucet minutes per capita per day	
	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Boulder	4.79	2.25	0.81	0.53	0.34	0.22	0.13	0.10	8.4	4.9
Denver	5.10	2.71	0.80	0.48	0.37	0.26	0.11	0.10	7.5	4.4
Eugene	5.62	3.40	0.90	0.65	0.40	0.32	0.13	0.14	9.1	6.6
Seattle	4.49	2.28	0.75	0.51	0.30	0.17	0.10	0.11	6.9	4.4
San Diego	5.20	2.39	0.63	0.32	0.42	0.27	0.10	0.08	8.1	4.0
Tampa	4.85	2.61	0.70	0.54	0.36	0.24	0.06	0.10	9.4	6.5
Phoenix	5.31	3.00	0.77	0.49	0.40	0.29	0.08	0.07	6.7	3.6
Tempe & Scottsdale	5.12	2.67	0.82	0.73	0.36	0.24	0.11	0.08	8.6	7.2
Waterloo & Cambridge	5.51	3.31	0.63	0.64	0.35	0.21	0.08	0.11	8.0	6.0
Walnut Valley WD	4.69	2.50	0.74	0.37	0.34	0.20	0.07	0.07	9.0	6.1
Las Virgenes MWD	4.73	2.38	0.74	0.44	0.40	0.28	0.09	0.07	8.2	5.4
Lompoc	5.19	2.82	0.71	0.43	0.38	0.20	0.09	0.10	7.5	5.1
12 study sites	5.05	2.69	0.75	0.51	0.37	0.24	0.10	0.09	8.1	5.3

Table 5.4 Fixture utilization per capita per day

Measurement	Mean utilization per capita per day	
	HUD Study	REUWS
Toilet flushes	4.00	5.05
Showers and baths	0.74	0.75
Clothes washer loads	0.30	0.37
Dishwasher loads	0.17	0.10
Faucet utilization	-	8.1 minutes

Toilets

According to mail survey results, there were an average of 2.27 toilets per household in the entire REUWS study group. A total of 348,345 toilet flushes were recorded during the 28,015 days for which data were collected for an average of 12.4 flushes per household per day and 5.05 flushes per capita per day. The average toilet flush volume across all study sites was 3.48 gallons per flush (gpf) with a standard deviation of 1.19 gpf. The distribution of toilet flushing volumes of all recorded flushes is shown in Figure 5.10. This distribution shows the range of toilet flush volumes that were be found in the study homes. The majority of flushes fell in the 3 to 5 gpf range but here is a distinct secondary peak in the 1.5 to 2 gpf range indicating that while 3.5 gpf toilets predominate, the data logged group contains a significant number of ULF toilets.

A comparison of toilet flushing in all 12 study sites is presented in Table 5.5. Included are comparisons of mean flush volume, mean gpcd toilet usage, and mean per capita flushing frequency. The mean toilet usage across all data logged sites was 18.5 gpcd and the mean toilet flush volume was 3.48 gpf. San Diego, Las Virgenes MWD, and Lompoc had the lowest average toilet flush volume. Not surprisingly, these three cities also had the lowest mean daily per capita toilet water use. These cities also have implemented ULF toilet retrofit programs. Differences between usage at these sites is examined in more detail later in this chapter.

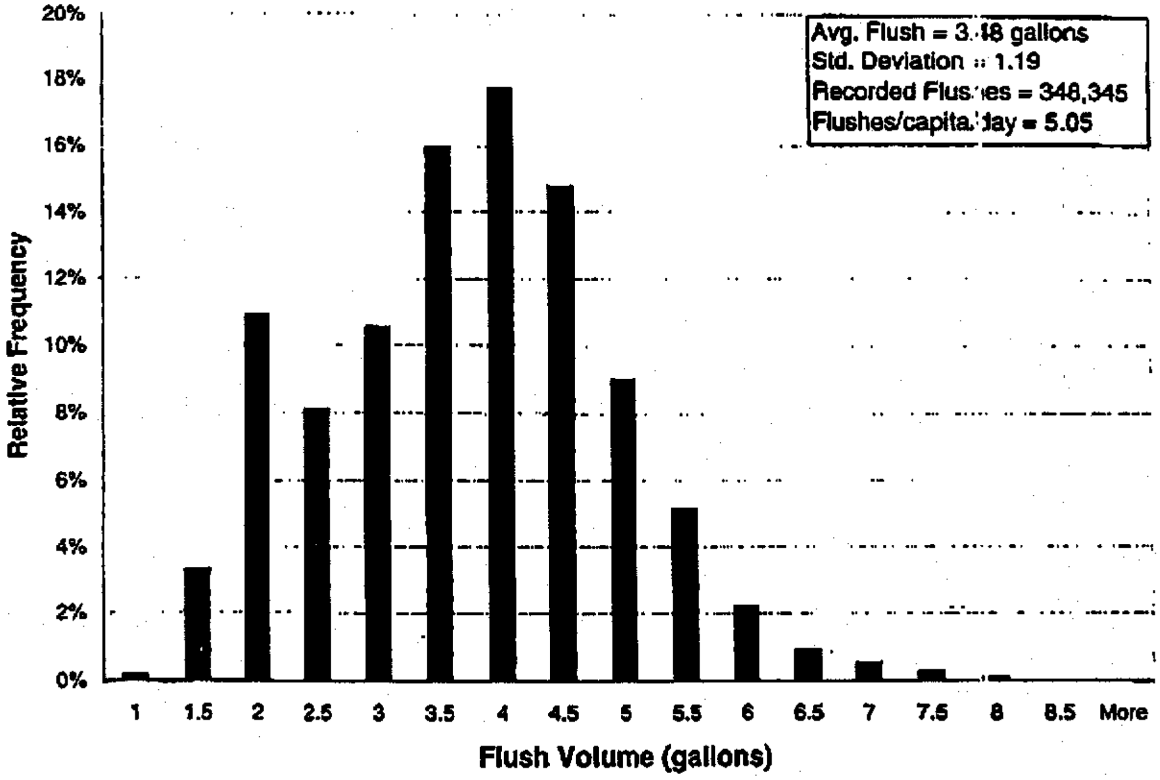

Figure 5.10 Toilet flush distribution, all recorded toilet flushes

Results from this research about the variability of toilet flush volumes indicate that toilets do not flush in neat little intervals like 1.6, 3.5, or 5.0 gpf. A toilet rated to flush at 3.5 gpf or 1.6 gpf will seldom use precisely that amount of water for a single flush, even when the toilet is new. Modifications to toilets such as new flapper valves, toilet dams, displacement devices, and float valve adjustments can also affect the flush volume (Webster, McDonnell, and Koeller 1998; Babcock 1999). Other studies have also found that each toilet is different, even if they are the same make and model (Honold and Ewald 1994; DeOreo et al. 1996c). Further research on the actual flush volumes of toilets in the field is warranted given the variability found in this study and the potential impact of modification to ULF toilets to water planning scenarios.

An examination of ULF toilets, conservation savings, and flushing frequency is presented later in this chapter.

Table 5.5 Toilet flush volume, per capita use, and utilization, 12 study sites

Study site	Sample size	Toilet flush volume Mean (gpf)	Toilet flush volume Std. Dev. (gpf)	Daily per capita toilet use Mean (gpcd)	Daily per capita toilet use Std. Dev. (gpcd)	Toilet flushes per capita/day Mean	Toilet flushes per capita/day Std. Dev.
Boulder	100	3.87	0.97	19.8	9.9	4.79	2.25
Denver	99	3.84	1.34	21.1	13.0	5.10	2.71
Eugene	98	3.91	1.04	22.9	14.5	5.62	3.40
Seattle	99	3.69	1.12	17.1	8.7	4.49	2.28
San Diego	100	2.88	1.17	15.8	7.8	5.20	2.39
Tampa	99	3.32	1.21	16.7	9.4	4.85	2.61
Phoenix	100	3.63	1.06	19.6	12.5	5.31	3.00
Tempe & Scottsdale	99	3.50	1.25	18.4	11.0	5.12	2.67
Waterloo & Cambridge	95	3.49	0.96	20.3	14.3	5.51	3.31
Walnut Valley WD	99	3.65	1.05	18.0	10.8	4.69	2.50
Las Virgenes MWD	100	3.04	1.22	15.7	10.3	4.73	2.38
Lompoc	100	3.09	1.22	16.6	10.8	5.19	2.82
12 study sites	1188	3.48	1.19	18.5	11.1	5.05	2.69

Showers

According to mail survey results, there were an average of 1.98 showers per household in the entire REUWS study group. Of these showers, 1.22 (62 percent) were part of a combined shower-bathtub fixture and 0.76 (38 percent) were stand alone showers. A total of 48,727 individual shower events were recorded over the two year REUWS research effort. The average shower used 17.2 gallons and lasted for 8.2 minutes and the average flow rate was 2.1 gpm. This indicates that on average people shower at a flow rate below the 1993 U.S. national plumbing code standard of 2.5 gpm. The distribution of shower volume is shown in Figure 5.11. This classic binomial distribution shows that most showers used between 7.5 and 20 gallons of water per event.

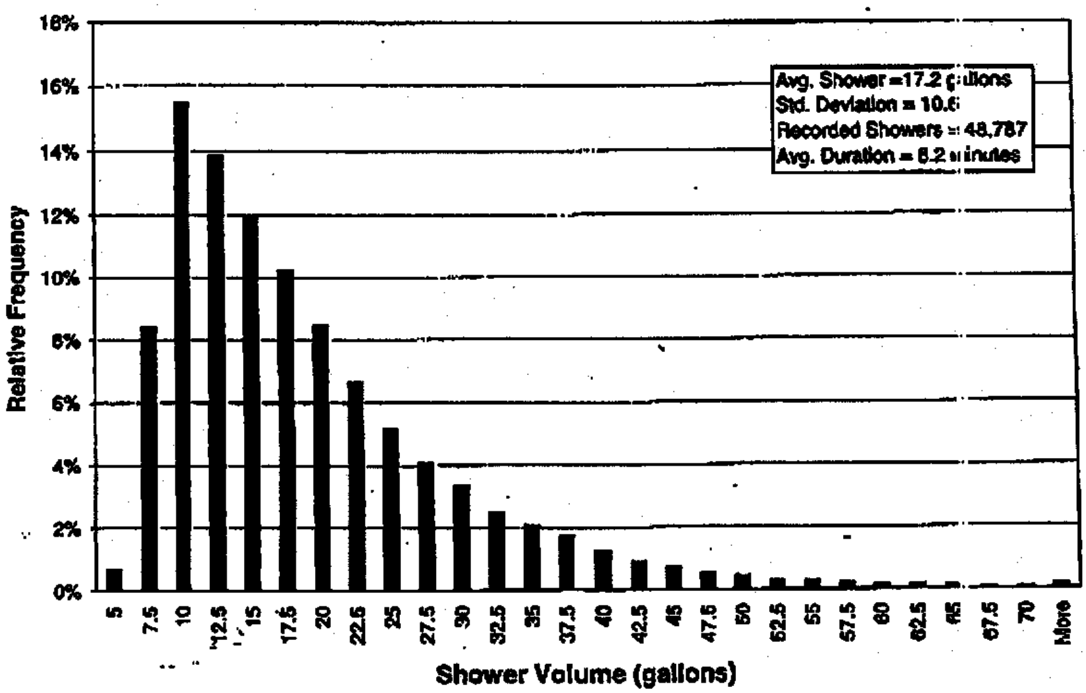

Figure 5.11 Shower volume distribution diagram

The distribution of shower durations for all recorded shower events is shown in Figure 5.12. In this figure, 71.5 percent of all showers were between 4 and 10 minutes in length with a mean of 8.2 minutes, a median of 7.2 minutes, and a standard deviation of 4.5 minutes. Less than 10 percent of all recorded showers were longer than 15 minutes in duration. An analysis of the start time of showers revealed that 36.5% of all showers were taken between 5 a.m. and 9 a.m., 32.7% of all showers were taken between 9 a.m. and 5 p.m., 27.6% were taken from 5 p.m. and midnight, and 3.2% were taken from midnight to 5 a.m.

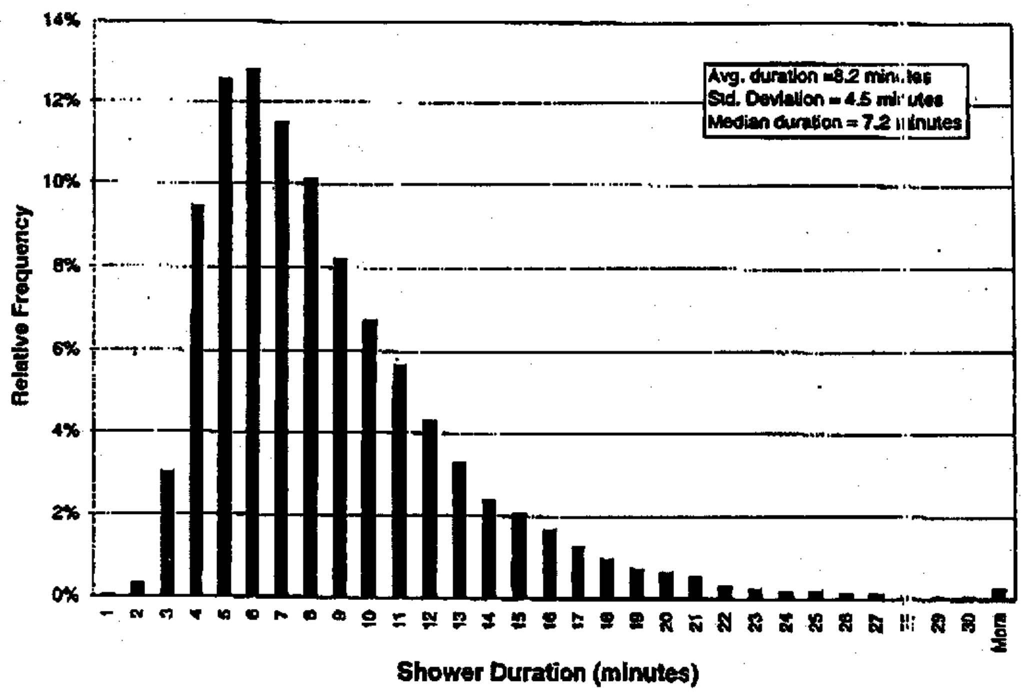

Figure 5.12 Shower duration distribution

The distribution of shower flow rates for all recorded showers is shown in Figure 5.13. For this chart the mode flow rate statistic generated by Trace Wizard during flow trace analysis was taken as the actual shower flow rate because it best represents the flow during the shower itself. An average flow rate might over estimate shower flows because many showers start at a high flow rate as water is run through the bathtub spigot and the temperature adjusted then the flow is restricted when the shower diverter valve is used and flow is constricted through the shower head.

The mean shower flow rate across all 12 study sites was 2.2 gpm with a median of 2.02 gpm and a standard deviation of 0.95. The distribution of shower flow rates appears more normally distributed than either the distribution of shower volumes or the distribution of shower durations. More than 70 percent of the showers recorded during the study were taken at a flow rate below 2.5 gpm although only 50.6 percent of the mail survey respondents indicated that they had installed a low-flow shower head.

An analysis of showering and conservation savings in presented later in this chapter. A comparison of showering and shower usage between study sites is presented in Table 5.6.

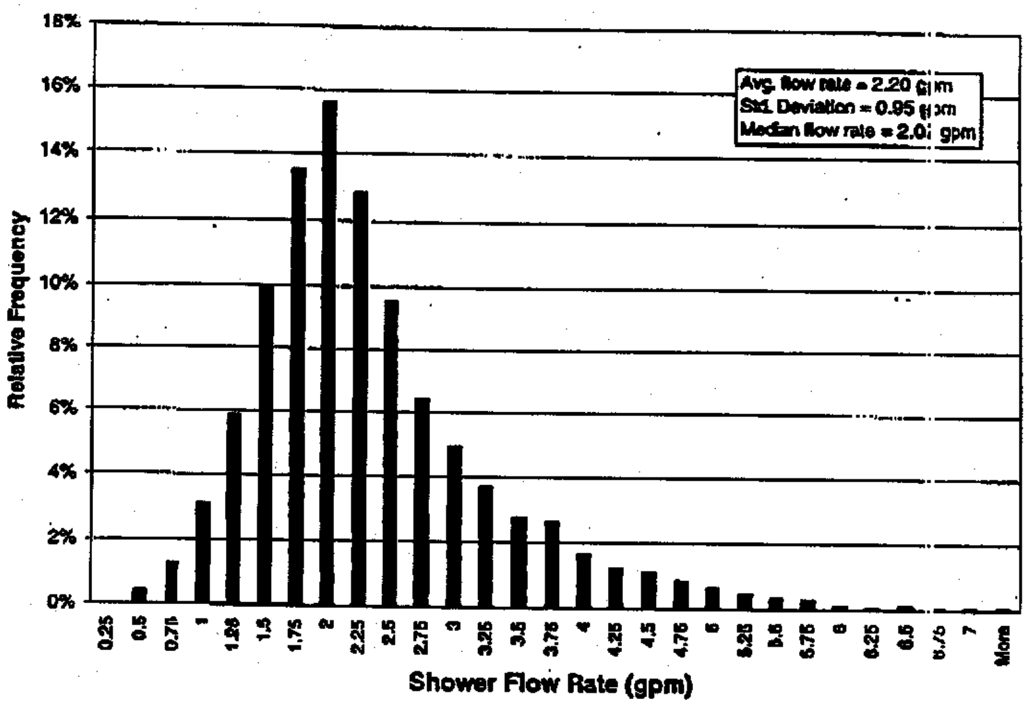

Figure 5.13 Shower flow rate distribution

Table 5.6 Shower per capita use, volume, duration, and flow rate, 12 study sites

Study site	Daily per capita water use for showering (gpcd)			Shower volume (gallons)			Shower duration (minutes)		Shower flow rate (gpm)	
	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Boulder	13.1	11.5	7.4	18.6	18.0	11.3	7.9	4.2	2.44	0.99
Denver	12.9	11.3	7.9	18.4	18.3	11.6	8.1	5.1	2.39	1.00
Eugene	15.1	13.1	11.5	18.3	18.2	10.9	8.1	4.3	2.26	0.96
Seattle	11.4	10.0	7.0	17.1	16.2	12.9	7.9	4.8	2.21	0.94
San Diego	9.0	8.4	5.1	14.9	14.3	9.2	7.9	4.8	1.95	0.92
Tampa	10.2	9.1	7.1	16.2	15.4	8.6	8.2	4.3	2.02	0.84
Phoenix	12.5	11.8	6.8	18.1	17.3	10.5	8.0	4.2	2.32	1.17
Tempe & Scottsdale	12.6	10.3	10.1	17.4	15.6	12.1	7.9	5.2	2.25	1.03
Waterloo & Cambridge	8.3	7.1	6.3	15.4	14.8	8.0	6.8	3.9	2.35	1.04
Walnut Valley WD	11.7	11.1	6.3	16.7	16.2	8.5	8.2	4.4	2.09	0.78
Las Virgenes MWD	11.4	11.1	6.3	17.0	16.2	9.8	8.1	5.0	2.19	0.86
Lompoc	11.1	9.9	7.2	17.2	16.6	9.8	8.3	5.8	2.14	0.81
12 study sites	11.6	10.4	7.4	17.2	16.4	10.6	8.2	4.5	2.22	0.95

Clothes Washers

A total of 26,981 loads of laundry were recorded over the 28,015 logged days during the study. Across all 1,188 logged households in the REUWS, the average loads of laundry per day was 0.96 (this includes the 26 logged homes which reported they did not have a clothes washer on the mail survey). The mean daily per capita clothes washer usage across all households was 15.0 gpcd.

Table 5.7 shows the mean daily per capita usage for each household size ranging from one to eight persons. Also shown are the number of households in each of these groups. Households which did not use a clothes washer during the two logging periods were excluded from this analysis.

Generally as the size of the household increases, the amount of water used for clothes washing decreases. There were a significant number of households with between 1 and 5 residents, but there is much less data from houses with 6, 7, and 8 residents. Nevertheless, it appears that the amount of water used for clothes washing does decrease as the number of residents increases. This trend continues until the household size reaches 4 residents, then levels off. The average daily per capita usage among households with 4 or more residents is 12.6 gpcd (calculated using a weighted average to account for the number of households in each bin).

Table 5.7 Per capita clothes washing use

Household size (# of residents)	Mean clothes washing (gpcd)	Standard deviation (gpcd)	Number of households in the interval
1	18.8	14.4	142
2	16.4	10.5	450
3	14.7	10.0	225
4	12.4	6.2	191
5	13.0	6.3	78
6	12.9	5.6	28
7	14.0	5.3	7
8	12.7	4.6	5

The standard deviation in per capita usage actually decreases as the size of the household increases, perhaps as a result of the increased frequency in use of the washing machine, thus decreasing the number of zero use days.

Figure 5.14 is a frequency distribution of the volume of all clothes washer loads measured during the REUWS. The average volume per load of clothes was 40.9 gallons with a standard deviation of 12.2 and a median volume of 39.8 gallons. The distribution itself looks typically gaussian (normal). Seventy-five percent of the loads were between 25 and 50 gallons. The range in volumes indicates the variety of clothes washers in service which includes extra large top loading machines and low volume horizontal axis washers. Also influencing the distribution is the tremendous number of wash settings available on modern clothes washers. Users are often able to individually adjust the size of the load, the number of cycles, the water temperature, etc.

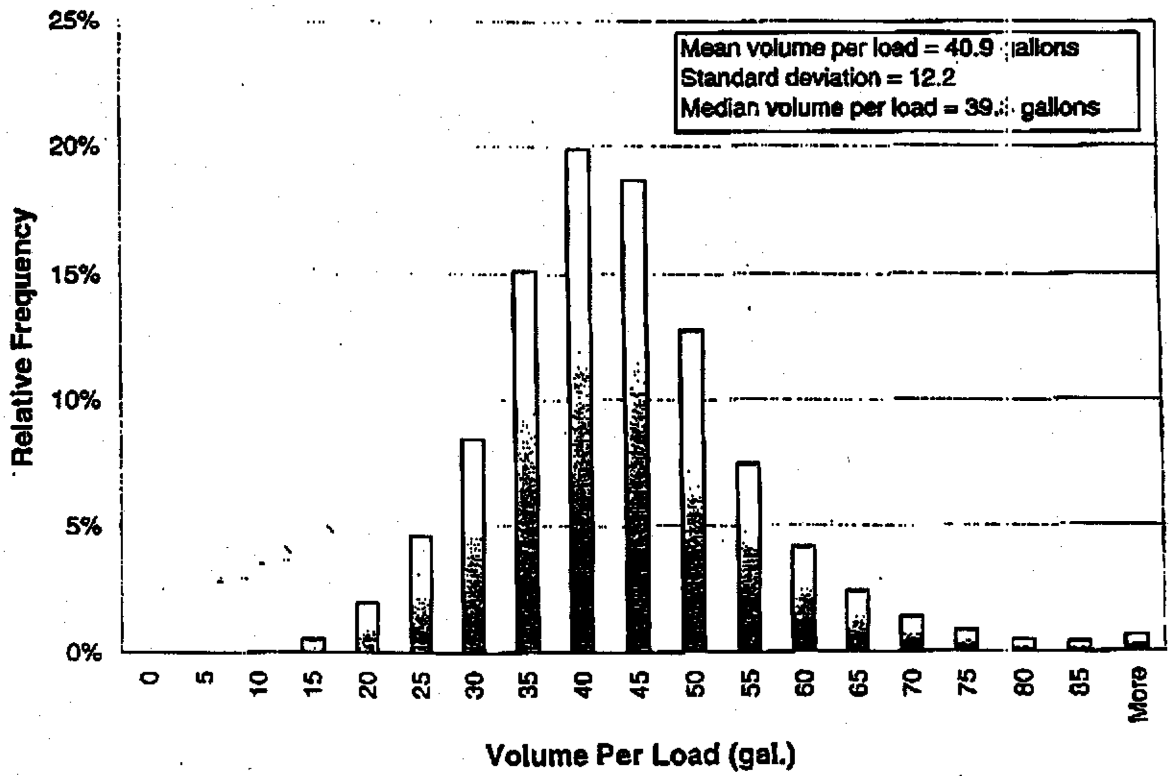

Figure 5.14 Clothes washer volume per load distribution

CONSERVATION EFFECTIVENESS

While the primary purpose of this study was to quantify water use in single family homes, it is possible to use the assembled database to evaluate water use in homes equipped with conserving and non-conserving fixtures. This section presents the observed water savings achieved through the use of ULF toilets and LF showerheads in the 1,188 study homes. While these results are certainly indicative of savings achievable with high efficiency fixtures the sample sizes are too small for them to be considered the final word in the measurement of conservation effectiveness.

Ultra-Low-Flush Toilets

While many studies have documented the water savings achievable from the installation of ultra-low-flush (ULF – 1.6 gallons per flush (6.0 lpf)) toilets (Aher et. al. 1991, Anderson et. al 1993), few studies have physically measured the savings and no study has the quality and sheer volume of real world data of the REUWS. Of the over 289,000 toilet flushes recorded during the two year end use monitoring portion of the REUWS, 14.5 percent of the flushes were less than 2.0 gpf, 34.7 percent of the flushes were between 2 and 3.5 gpf, and 50.8 percent were greater than 4 gpf. A frequency distribution of all recorded toilet flushes was shown in Figure 5.10.

Of the 1188 data logged homes in the REUWS, 101 (8.5 percent) used ULF toilets almost exclusively. This number was determined by first calculating the average flush volume for each study residence. Homes with an average volume per flush of less than 2.0 gallons over the 4 week data logging period were classified as "ULF only" homes meaning that while they may have other units, they use ULF units almost exclusively. The 101 "ULF only" homes used an average of 24.1 gallons per household per day (gpd) for toilet purposes. The residents of these homes flushed the toilet an average of 5.04 times per person per day and used an average of 9.5 gpcd for toilet purposes.

Another 311 study homes (26.2 percent) were found to have a mixture of ULF and non-ULF toilets. These homes were distinguished by counting the number of toilet flushes which used less than 2.0 gallons per flush. Homes that had six or more ULF flushes (and who were not part of the "ULF only" group were placed in the "mixed" toilet group. Homes with a mixture of ULF and non-ULF toilets used an average of 45.4 gpd for toilet purposes. The residents of these homes flushed the toilet an average of 5.39 times per person per day and used an average of 17.6 gpcd for toilet purposes. The remaining 776 study homes we placed in the "non-ULF" group. The "non-ULF" study homes averaged 47.9 gpd for toilets. Residents in these homes flushed an average of 4.92 times per person per day and used an average of 20.1 gpcd. The net potential savings when comparing "ULF only" homes to the "non-ULF" homes is therefore is 10.5 gpcd. These results are shown in Table 5.19.

Table 5.19 ULF and non-ULF toilet use across 12 study sites

Toilet category	Sample size	Toilet use per household (gpd)		Toilet use per capita (gpcd)		Flushes per capita per day	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
ULF only	101	24.2	10.3	9.6	4.4	5.06	2.65
Mixed toilets	311	45.4	18.7	17.6	7.4	5.39	2.72
Non-ULF	776	47.9	19.3	20.1	8.5	4.92	2.50
All homes	1188	45.2	18.4	18.5	7.9	5.05	2.69

A two tailed z-test for significance was performed on the mean daily per capita usage for the ULF and non-ULF study homes with the hypothesis that they were not statistically different. The hypothesis was rejected and the difference between the means of 10.5 gpcd was found to be significant at the 99 percent confidence level. A similar test was performed on the per capita flushes per day and the difference of 0.14 flushes per capita per day was not found to be statistically significant at the 99 percent confidence level.

These findings from the REUWS indicate that a complete ULF retrofit in a single-family detached home without any existing ULF toilet fixtures can achieve a potential water savings of 10.5 gpcd or approximately 8,650 gallons per year. The often hypothesized and reported ULF problem of double flushing was not detected in this study. The average flushes per capita per day for the ULF homes and non-ULF homes were not statistically different, indicating that study homes which exclusively use ULF toilets are not flushing more frequently than homes without any ULF toilets. It appears that double flushing of ULF toilets does not happen any more often than double flushing of non-ULF toilets.

Ultra-Low-Flush Toilet Savings Found in Other Studies

A number of studies have measured water savings achievable from installing ULF toilets. These studies include the Stevens Institute of Technology micro-metering studies for East Bay MUD and Tampa, Florida (Aher et. al. 1991; Anderson et. al. 1993), A&N Technical Service's statistical models developed for MWD (Chesnutt et. al. 1992a, 1992b; Chestnutt 1994), and Aquacraft's small scale retrofit study in Boulder, Colorado (DeOreo et. al. 1996c). The per capita per day toilet savings found in these studies is compared with the REUWS results in Table 5.20.

Table 5.20 Comparison of ULF savings from other studies

Research project	Per capita savings from ULF toilets (gpcd)	Saturation rate of ULF toilets in conserving homes
REUWS	10.5	100%
MWD 1992 - 1994*	11.4	73%
Tampa, Florida 1993†	6.1	100%
East Bay MUD 1991‡	5.3	100%
Boulder Heatherwood 1996§	2.6	50%

Footnotes:
* Chesnutt et. al. 1992a, 1992b; Chestnutt 1994
† Anderson et. al. 1993
‡ Aher et. al. 1991
§ DeOreo et. al. 1996c

The savings found in the REUWS were higher than found in all the other studies except for the statistical models developed for Southern California. It should be noted that the REUWS was not retrofit study and no conserving hardware was installed as part of this research. Rather, the ULF savings estimates were calculated as the difference between the mean per capita toilet usage in homes which exclusively used ULF toilets and homes in the study which did not use a ULF. An intervention study in which the same group of homes are retrofit with conserving fixtures would be a logical next step to better quantify the savings achievable through the installation of ULF toilets.

Low-Flow Showerheads

So called "Low Flow" shower heads are designed to restrict flow to a rate of 2.5 gpm or less. By calculating the modal shower flow rate for each shower at each study residence it was possible to separate homes which always showered in the low-flow range (LF houses), homes which occasionally showered in the low flow range (Mixed houses), or homes which showered exclusively above the low flow range (Non-LF houses). About 15 percent of the study homes showered in the low flow range exclusively, 60.4 percent occasionally showered in the low flow range, and 24.5 percent showered exclusively above the low flow range.

The LF shower homes used an average of 20.7 gpd and 8.8 gpcd for showering, while the non-LF shower homes used an average of 34.8 gpd and 13.3 gpcd. However, the duration of the average shower in the LF shower homes was 8 minutes and 30 seconds, 1 minute and 48 seconds longer than the average shower duration in the non-LF homes which was 6 minutes and 48 seconds. These results are shown in Table 5.21.

Table 5.21 LF and non-LF daily shower use

Shower category	Sample size	Shower use per household (gpd)		Shower use per capita per day (gpcd)		Shower duration (minutes)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
LF houses	177	20.7	14.2	8.8	6.6	8.5	3.4
Mixed houses	712	32.2	20.9	11.8	8.2	8.0	3.8
Non-LF houses	289	34.8	24.7	13.3	10.3	6.8	3.1
12 study sites	1178	31.1	20.8	11.7	8.4	7.8	3.6

A two tailed t-test for significance assuming unequal variance was conducted at an alpha level of 0.05 to determine if there was a significant difference between the mean per capita usage for the LF and non-LF study homes. He null hypotheses was that the two means were equal; they alternate hypothesis was that they were not equal. The difference in per capita use between the LF and the non-LF per capita shower usage was found to be significant (at the 0.05 probability level) given the t-statistic of 6.8 is greater than the critical value of 1.97. The same interpretation can be made by looking at the p-value which is less than 0.05, thus the conclusion that the means are significantly different. A similar test was performed on the average shower duration for the LF and non-LF group and the difference of 1.7 minutes per shower was found to be statistically significant at the 95 percent confidence level.

The difference between the two groups suggests that a retrofit of a non-LF home could result in annual water savings of approximately 4,500 gallons per year. It was also shown that households which shower at a lower average flow rate do tend to take longer showers. A statistically significant difference was observed in the mean shower duration in the LF and non-LF shower homes. This result suggests that greater shower water savings would be available if the LF occupants could reduce the duration of their showers to the level of the non-LF homes.

Low-Flow Showerhead Savings Found in Other Studies

A number of studies have measured water savings achievable from installing low-flow shower heads. These studies include the Stevens Institute of Technology micro-metering studies for East Bay MUD and Tampa, Florida (Aher et. al. 1991; Anderson et. al. 1993) and the 1984 HUD study (Brown & Caldwell 1984). The per capita per day shower savings found in these studies is compared with the REUWS results in Table 5.22.

Table 5.22 Comparison of LF showerhead savings from other studies

Research project	Per capita savings from LF showerheads (gpcd)	Saturation rate of LF showerheads in conserving homes
REUWS	4.5	100%
HUD 1984*	7.2	NA
Tampa, Florida 1993†	3.6	100%
East Bay MUD 1991‡	1.7	100%

Footnotes:
* Brown and Caldwell 1984
† Anderson et. al. 1993
‡ Aher et. al. 1991

The savings found in the REUWS were higher than found in all the other studies except for the HUD study. It should be noted that the REUWS was not retrofit study and no conserving hardware was installed as part of this research. Rather, the LF showerhead savings estimates were calculated as the difference between the mean daily per capita shower usage in homes in which the residents showered exclusively at or below the 2.5 gpm flow rate and homes in which the residents showered exclusively above the 2.5 gpm flow rate. An intervention study in which the same group of homes are retrofit with conserving fixtures would be a logical next step to better quantify the savings achievable through the installation of LF showerheads.

Landscape Measures

W:

The practice of replacing traditional turf grass with low-water-use native plants, commonly know as Xeriscape™, offers potential water savings in the single-family detached sector – particularly in the hot and dry Southwestern United States. A number of studies have found that that a Xeriscape landscape can save a measurable amount of water compared with traditional turf grass landscaping (Nelson 1994).

The REUWS mail survey requested information on conservation landscape measures by asking respondents if they had installed "low-water-use landscaping" and if they had altered their irrigation habits. Of the 1,188 logged study houses, 176 responded that they had installed low-water-use landscaping and 1,012 responded that they had not. A comparison of average annual outdoor consumption between these groups resulted in the finding that the low-water-use landscape group actually used slightly more water outdoors annually than the standard landscape group.

However, when the irrigable areas were taken into consideration (using reported parcel size and percent of landscaped area from the survey) it was seen that the application rates of the low-water-use homes were lower than the standard group. The low-water-use group applied an average of 20.3 gallons of water per square foot of irrigated area over an entire year, while the standard landscape group applied 22.8 gallons per square foot for a difference of 2.5 gallons per square foot. However, a two-tailed z-test performed on these two sets of data found that there was not a statistically significant difference in the two application rates (at a 95 percent confidence interval). As a result it is not possible to draw conclusions about the conservation potential of low-water-use landscaping from this study.

There are several possible explanations for this inconclusive finding. First and foremost is the potential inaccuracy in the reported irrigable areas from mail the surveys. Improved measurements of actual lot size, irrigable areas, and landscape characteristics could greatly improve the accuracy with which estimates of the outdoor use can be drawn from the data set. Secondly, new low-water-use landscaping usually requires additional water to become established. This could be a factor here. Third, this simple analysis comparing application rates did not take into account differences in climate and seasonality among the different study areas.

A more in-depth analysis which corrected for these factors might well detect a measurable difference in water use between the low-water-use and standard landscape groups.

Additional Conservation Potential

Clothes washers

After toilets, clothes washers are the next largest component of indoor water use in the single-family sector. While a great number of studies have documented the conservation effectiveness of ULF toilets and many utilities have implemented toilet replacement incentive programs, clothes washers have received less attention. Beginning in the mid-1990s, cost effective water- and energy-conserving horizontal axis clothes washers have finally made their way to the North American market. These horizontal axis machines, which are often referred to as "front-loaders" because the clothes are placed in the machine through a door on the front rather than the top of the machine, have been popular in Europe for many years. These clothes washers had been prohibitively expensive for the American consumer with machines ranging in price from $800 to $1,200 (substantially higher than the more standard vertical axis top-loading washing machines).

Although generally absent from the residential market, horizontal axis machines have been popular in laundromats and commercial laundries. The horizontal axis design has been around for many years and these machines were popular in the late 1940s and 1950s. Due to patent problems, major U.S. manufacturers stopped making horizontal axis washers even as they continued to be developed, manufactured, and sold in Europe and the rest of the world. These machines use less water than the traditional top loading machines because instead of filling up a large tub with water and agitating the fully submerged clothes, the horizontal axis machines fill up only a small portion of the wash cylinder and then moves the clothes back and forth through this supply of water. Horizontal axis machines also spin at a much faster rate which renders the washed clothes with a much lower moisture content. With a lower moisture content, the drying time for clothes is greatly reduced.

In the past two years almost every major North American manufacturer of clothes washers has introduced a horizontal axis clothes washer for the residential market including

Maytag, Whirlpool, and Frigidaire. The proliferation of these machines in the residential sector could result in significant water and energy savings.

Clothes washer water savings represent one of the greatest potential untapped areas for water conservation. Several recent studies have started to document the impact of the new horizontal axis machines (Hill et al. 1996; Dietemann and Hill 1994). In Bern, Kansas (pop. 204) the Department of Energy monitored the population's water and energy consumption for two months and then replaced every single clothes washer in town with a new Maytag horizontal axis machine (Tomlinson and Rizy 1998). A total of 103 clothes washers were provided free of charge to the citizens of Bern. Average clothes washer water consumption in Bern fell from 41.5 gallons per load at the beginning of the study to 25.8 gallons per load with the new horizontal axis machines, a savings of 38 percent. Energy consumption including washer energy and hot water heating was reduced by 58 percent. A small scale study by Aquacraft, Inc. which retrofit four homes with conserving clothes washers found that clothes washer water savings of 20 to 80 percent were possible with these machines (Aquacraft, Inc., 1996b).

In the REUWS, results on horizontal axis clothes washer savings were inconclusive. Only 24 of the 1,188 logged houses reported owning a "front-loading clothes washing machine" on the mail survey. However, because the survey portion of this study was implemented several months before the widespread introduction the new conserving horizontal axis washing machines so it is unlikely that these 24 households owned any of the new conserving machines. Of these 24 survey respondents, four reported that their front-loading washing machine was manufactured in the 1960s and 70s. Several other respondents indicated that their machines were more recent White Westinghouse front-loaders – one of the few domestically built horizontal axis machines available in the early 1990s. One household reported owning a Swedish built Asko machine and one an older American made Gibson. A few of the 24 respondents reported owning a clothes washer built by a manufacturer who did not make front loading machines during the reported year of purchase such as Kenmore and GE.

An analysis of the average gallons per capita per day used for clothes washing by the 24 front-loading accounts and the accounts who reported owning top loading machines was performed. The top-loading group averaged 14.9 gpcd and the front-loading group averaged 15.2 gpcd, but this difference in water use was not found to be statistically significant. It is suspected that a number of the front-loading washer respondents erroneously answered that question on the survey.

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The conservation potential of clothes washers is an important area for further study. Cities like Boulder, Colorado are starting to offer conservation rebates to encourage purchase of horizontal axis machines. A systematic study of the impacts of conserving clothes washers in the residential setting would be of great value to the conservation community.

Leak Detection

As noted earlier in this report, leakage represents a significant component of residential water consumption. Households in the REUWS averaged 9.5 gpcd in leaks alone. This amounts to nearly 3,500 gallons per person per year wasted due to leaks. Effective leak detection and repair programs could significantly reduce domestic consumption.

In the REUWS it was found that a small number of homes were responsible for the majority of the leakage. While the average daily leakage per household was 21.9 gallons, the median leakage rate was only 4.2 gallons per household per day indicating a definite skewness in the leakage rates across the study homes. Nearly 67 percent of the study homes leaked an average of 10 gallons per day or less, but 5.5 percent of the homes leaked an average of more than 100 gallons per day.

This result suggests that identifying and repairing leaks in the top 5 to 10 percent of leaking homes would provide the most benefit in terms of water savings than a general leak detection and repair program. The difficulty lies in accurately identifying the large leak accounts in an inexpensive and systematic manner. A good approach to this, suggested by the data, would be to target homes in the top 10 percent of winter water use. In the winter when there is little or no outdoor use, high domestic consumption is more likely attributable to high leakage rates.

Another technique for identifying houses with significant leaks is a sorting and filtering routine which operates in a utility's billing database and flags accounts which have dramatically altered their usage patterns – possibly due to a leak.

Once a potential high leakage account has been identified the utility has a variety of options for further investigation. One relatively simple technique is to install a data logger, similar to those used for this study, on the customer's water meter. Data could be collected for 24 or 48 hours and then analyzed using Trace Wizard software. Persistent leaks due to faulty flapper valves or broken pipes are easily identified. When the existence of a major leak has been confirmed, the customers could be notified and encourage to make repairs. The utility might also offer some form of assistance in cases of need.

Other Opportunities

Additional conservation opportunities in the single-family sector include: installation of low flow faucet aerators to reduce miscellaneous faucet usage, recirculating systems for bleedoff water in evaporative coolers, recirculating systems to decrease the amount of water run through faucets and showers while waiting for hot water to arrive; grey-water reuse systems to augment irrigation water, various landscape retrofits and irrigation control devices, and conservation education programs. The REUWS did not specifically examine the savings available from any of these conservation techniques, but other studies in the literature provide information about many of these approaches.