RESIDENTIAL INDOOR WATER CONSERVATION STUDY:

EVALUATION OF HIGH EFFICIENCY INDOOR PLUMBING FIXTURE RETROFITS IN SINGLE-FAMILY HOMES IN THE EAST BAY MUNICIPAL UTILITY DISTRICT SERVICE AREA

July 2003

Prepared for and submitted to:

East Bay Municipal Utility District
and
The United States Environmental Protection Agency

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ACKNOWLEDGEMENTS

This research would not have been possible without a grant from the US EPA and the assistance of John Flowers, Director of the U.S. EPA WAVE program. John immediately saw the benefits of this research and moved to support the project.

This project was assisted by EBMUD staff members Richard Harris, manager of water conservation; Richard Bennett, project manager; and Dan Muir, who provided valuable field support.

Thanks go to the following people who contributed to the research effort and offered valuable insight and advice: Al Dietemann, Tim Skeel, John Koeller, John Wright, Tiffany Fulcher, and Leslie Martien.

EXECUTIVE SUMMARY

Residential water conservation retrofits and retrofit rebate programs, often subsidized by municipal water providers, represent an essential element of water conservation planning and programs as well as regional best management practices. While many of these programs have proved popular with customers, questions remain about the actual impact of residential retrofits on per-capita and per household water use – particularly on individual end uses over time. Reliable measurements of water savings are essential for long-range projections of the impacts of conservation projects on urban water demands. As water providers fund water conservation practices, whether voluntarily or by regulatory requirements, the need for precise measurements of actual water savings has intensified.

The EBMUD Indoor Residential Water Conservation Study is the second in a series of three intervention studies that are providing important information on water conserving fixtures and appliances. The first study was conducted in Seattle, Washington and the third is underway in Tampa, Florida. The EBMUD Indoor Residential Conservation Study measured the impact of a variety of water using fixtures and appliances through a before-and-after paired comparison of water use patterns from a sample of 33 single-family homes in East Bay Municipal Water District (EBMUD) service area. EBMUD supplies water and provides wastewater treatment for parts of Alameda and Contra Costa counties on the eastern side of San Francisco Bay in northern California. EBMUD is a publicly owned utility formed under the Municipal Utility District Act passed by the California Legislature in 1921 and currently serves 1.3 million people.

The EBMUD Indoor Residential Conservation Study measured the impact of a variety of indoor water conservation measures on both aggregate and individual water use patterns. Separate meters were installed to measure hot water usage, adding a valuable new dimension to the data obtained. Study participants also rated their old fixtures and appliances while they were still in place, and then rated the new retrofit devices after using them for about six months.

The basic methodology was as follows: two-weeks of specific baseline water use data were obtained from a sample of 33 homes.[1] Next, these homes were retrofit with high efficiency toilets, clothes washers, showerheads, and faucets. Two weeks of flow trace data were collected from these homes about a month after the completion of the retrofit and then a second set of

post-retrofit data was obtained about six months later. All of the pre and post-retrofit flow trace data were disaggregated into relevant end use categories by Aquacraft Inc., using technology developed for the 1999 Residential End Uses of Water study (AWWA 1999). Paired t-test analyses were used to evaluate the demands for each end use measured at the study homes in the pre and post-retrofit periods. This allowed a thorough analysis of the impacts of the retrofits on the end uses of water in the study homes.

Historic water use patterns of the sample selected for this study (from billing data) tended to be higher than those from the general population of single-family homes in EBMUD service area, as shown in Table ES.1. As such, the results should provide a good indication of the impacts of retrofits on customers who use more water to begin with – similar to a targeted retrofit program that focuses on larger water users. It is not possible, nor it is the object of this study to provide conclusive data for the entire nation. The study is a key component in a trio of studies that will be combined in the near future to provide a more national perspective.[2]

Table ES.1 Annual water use in 1999 and 2000, sample frame and study group

Average Annual Water Use	Sample Frame n=1000 (gallons per day)	Study Group n=33 (gallons per day)
1999 Total	290.8	386.5
1999 Indoor	195.5	231.2
1999 Outdoor	95.4	155.3
2000 Total	294.6	387.5
2000 Indoor	204.5	237.5
2000 Outdoor	90.1	150.0

RESULTS

Using data collected with the flow recorders, indoor per household and per capita demand were measured. The logged mean daily indoor demand, which was 191.0 gpd per household during the baseline period, dropped 35.5 percent to 123.3 gpd after the installation of the new

[1] These homes were selected from those customers that expressed a willingness to participate, had not previously performed extensive retrofits, and who had an average daily per capita use higher than 60 gcd.
[2] A similar study was conducted in Seattle, Washington and another is planned for Tampa, Florida.

devices. On an annual basis this equates to an indoor use of 69.7 kgal for baseline conditions and 45.0 kgal with the retrofit.

Per Capita Demand

Indoor water use patterns changed significantly after the conservation retrofit. Average daily per capita use decreased in 31 of the 33 study homes. After the retrofit, leakage (17.1 percent), which had previously been the largest component of indoor use dropped below toilets into fourth place. Toilets (18.6 percent), which have previously been the second largest component of indoor use moved into third place behind faucets. Showers became the largest indoor water use followed by faucets and toilets. Pre and post-retrofit pie charts showing the relative importance of each end use by percent per capita is shown in Figure ES.1. The combination of showers and baths form the largest block of indoor use in the post-retrofit era at 25.5 percent.

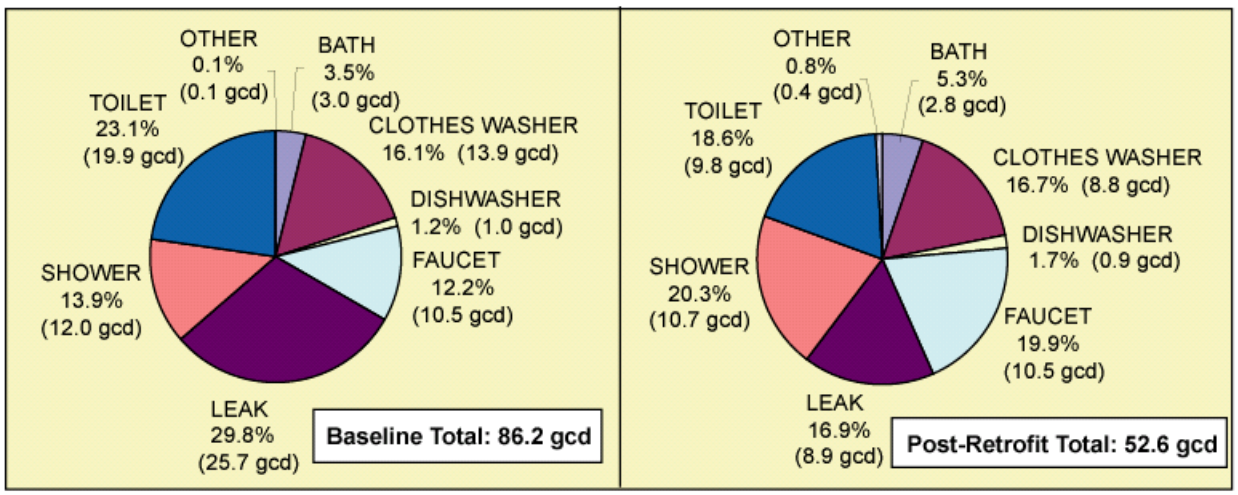

Figure ES.1 Comparing pre-retrofit (on the left) and post-retrofit (on the right) indoor per capita water use percentage including leakage

Table ES.2 presents a comparison of the mean indoor per capita water use from the baseline and post-retrofit data collection periods. Overall, indoor water use decreased by 33.9 gcd – a 39.4 percent drop. A series of unpaired *t-tests* were performed on each end use in these two data sets to determine which changes in water use are statistically significant at the 95 percent confidence level. Statistically significant changes in water use were detected for clothes washers, leaks, toilets, and total indoor use.

More than 30 gallons (or 88%) of the 33.9 gcd average saved through the retrofit was the result of three end uses: toilets, clothes washers, and leaks. Installation of ULF toilets, including some dual flush models saved an average of 10.1 gcd. The new conserving clothes washers saved an average of 5.1 gcd. A reduction in leakage resulted in a surprisingly large savings of 16.8 gcd. The leakage savings were almost certainly the result of the toilet retrofit. Toilet leaks, primarily flapper leaks, are the single largest contributor to household leakage. In this study, replacing old toilets through the retrofit eliminated almost all of these toilet leaks and resulted in substantial savings. None of the other measures implemented through this study (clothes washers, showerheads, or faucet aerators) should have had any impact on the leakage rate.

Statistically significant reductions in water use occurred in most of the end use categories impacted by the retrofits: toilets, leaks and clothes washers. The shower savings was relatively small, 1.3 gcd, and only found to be significant at the 90 percent confidence level. Faucets did not show any significant water use reduction, even though new aerators were installed. The remaining categories not targeted by the retrofit (baths and dishwashers) also showed no change.

Table ES.2 Mean indoor per capita water use, baseline and post-retrofit[3]

Category	Baseline (gcd)	Post-Retrofit (gcd)	Difference in Means (gcd)	% Change	Statistically significant difference?*
Bath	3.0	2.8	-0.2	-6.6%	No
Clothes washer	13.9	8.8	-5.1	-36.7%	Yes
Dishwasher	1.0	0.9	-0.1	-10.0%	No
Faucet	10.5	10.5	0.0	0.0%	No
Leak	25.7	8.9	-16.8	-65.4%	Yes
Shower	12.0	10.7	-1.3	-10.8%	No
Toilet	19.9	9.8	-10.1	-50.8%	Yes
Indoor	86.1	52.2	-33.9	-39.4%	Yes
Other/Unknown	0.1	0.4	0.3	75.0%	Yes
Total	86.2	52.6	-33.6	-39.0%	Yes
Avg. # of Residents per household	2.56	2.52			

*95 percent confidence level

[3] The calculation of per capita per day usage was done on a day by day, house by house basis and then the average of all individual houses was taken to calculate the overall average per capita per day use. This creates a weighted average where the water use in each household is given equal weight. The average number of residents per household was also calculated on a day by day, house by house basis. Multiplying these two weighted averages together to calculate average daily per household use results in a different value than by taking the average of daily use for each household.

Hot Water Use

Water meters were installed on the hot water heaters of 10 of the 33 study homes and flow recorders were attached to these meters so that hot water usage could be monitored alongside overall household usage. Toilet flushing was the only indoor use that had no hot water component. Only 7 percent of the total leaks were composed of hot water. In the post-retrofit period, 30 percent of all water used indoors, 16.5 gcd, was hot water. On a daily basis, the most hot water (83.3 percent) was used for faucets, showers, and baths.

Pre and post-retrofit per capita hot water use are shown in Table ES.3. A statistically significant difference in mean hot water use before and after the retrofit was detected for the following categories: clothes washers, faucets, and total indoor use. The total hot water use dropped by 4.6 gcd after the retrofits, and it appears that nearly all of these savings can be attributed to the retrofit program. Theoretically, the retrofit program could have impacted clothes washers, faucets, showers, and total indoor hot water use. Although hot water use declined in almost all end use categories, the change in shower use was found to be not statistically significant, but the reductions in clothes washer and faucet use were significant. The retrofit had no impact on leaks of hot water.

Table ES.3 Comparison of baseline and post-retrofit per capita hot water use

Category	Baseline Hot Water Use (gcd)	Post-Retrofit Hot Water Use (gcd)	Difference (gcd)	% change	Statistically significant difference?*
Bath	1.7	1.5	-0.2	-11.8%	No
Clothes Washer	1.9	1.0	-0.9	-47.4%	Yes
Dishwasher	1.4	1.0	-0.4	-28.6%	No
Faucet	8.6	6.2	-2.4	-27.9%	Yes
Leak	0.7	0.7	0.0	0.0%	No
Shower	6.9	6.0	-0.9	-13.0%	No
Toilet	0.0	0.0	0.0	0.0%	na
Other/Unknown	0.02	0.01	-0.01	-50.0%	No
Indoor Total	21.1	16.5	-4.6	-21.8%	Yes
Avg. # of Residents per household	2.3	2.3			

*95 percent confidence level

Analysis of Water Savings Excluding Leaks

Because of the high level of leakage found in the study homes both before and after the retrofit, it was decided to examine the water savings exclusive of leakage. One possible explanation for the high leak rate that was found in some of the study participants' homes could be traced to the District's change in its water treatment process. EBMUD converted from treating water with chlorine to chloramines (chlorine and ammonia) in 1998. An August 1993 AWWA Journal article reported study results showing that chloramines have a more deleterious effect on elastomers (products widely used in plumbing distribution, especially for toilet flapper valves) than does free chlorine. When a utility converts from chlorine to chloramine, this negative effect on the elastomers tends to increase incidents of leaks in the home and in the distribution system.

Leakage accounted for 30.3 percent of indoor per capita use prior to the retrofit and 17.1 percent after the retrofit. A specific analysis of leakage is presented later in this report. Pre and post-retrofit pie charts showing the relative importance of each end use by percent per capita, excluding leaks, is shown in Figure ES.2.

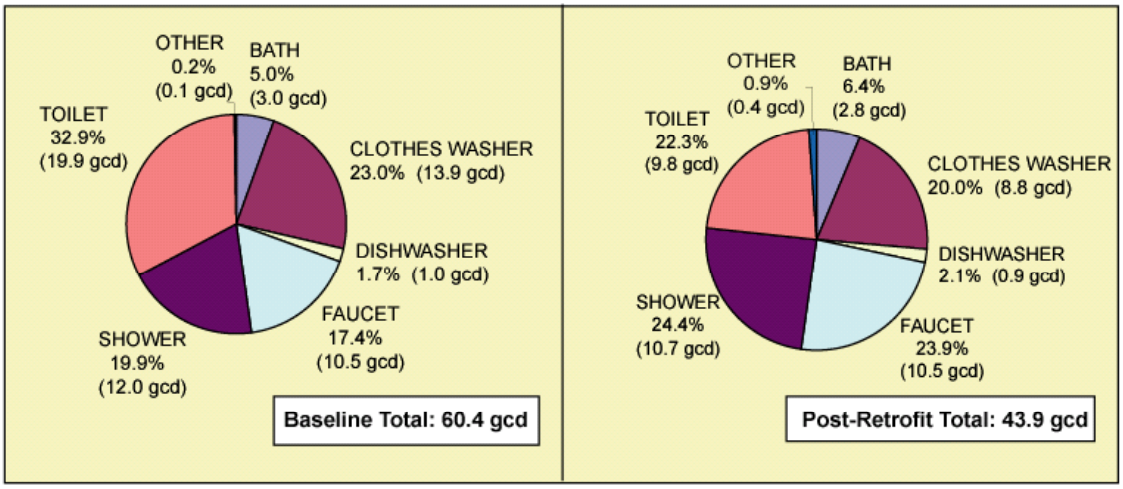

Figure ES.2 Comparing pre-retrofit (on the left) and post-retrofit (on the right) indoor per capita water use percentage excluding leakage

The average baseline per capita per day indoor use – excluding leaks – was 60.3 gcd and the post-retrofit average was 43.5 gcd. By ignoring leaks both in the baseline and post-retrofit

period, the per capita water savings in indoor use becomes 16.8 gcd – a 27.86 percent reduction in demand. Results of the analysis excluding leaks are presented in Table ES.4.

Table ES.4 Comparison of baseline and post-retrofit per capita daily use – excluding leaks

Category	Baseline (gcd)	Post-Retrofit (gcd)	Difference in Means (gcd)	% Change	Statistically significant difference?*
Bath	3.0	2.8	-0.2	-6.6%	No
Clothes washer	13.9	8.8	-5.1	-36.7%	Yes
Dishwasher	1.0	0.9	-0.1	-10.0%	No
Faucet	10.5	10.5	0	0.0%	No
Shower	12.0	10.7	-1.3	-10.8%	No
Toilet	19.9	9.8	-10.1	-50.8%	Yes
Indoor	60.3	43.5	-16.8	-27.9%	Yes
Other/Unknown	0.1	0.4	0.3	75.0%	Yes
Total	60.4	43.9	-16.5	-27.3%	Yes
Avg. # of Residents per household	2.56	2.52			

*95 percent confidence level

Toilet Savings Comparison

A number of studies have measured water savings achievable from installing ULF toilets. The savings found in each of these studies are shown in Table ES.5. The savings found in the East Bay study were similar to the REUWS and Seattle study. The highest savings were found in the statistical models developed for Southern California. The savings from this study were almost twice as much as those found in the 1991 Stevens Institute study also conducted in the EBMUD service area. In the 1991 Stevens study, the average flush volume was found to be 1.8 gallons per flush (gpf) and in this study the average flush volume was found to be 1.48 gpf. The decrease could be attributed to this study's inclusion of newer models and dual flush toilets. In addition, the Stevens study found the number of daily flushes per person to be 3.7 and this study found the number of flushes per person per day to be 5.7. These research efforts each approached the task of calculating savings differently yet their results are reasonably similar.

Table ES.5 Comparison of ULF savings from other studies

Research project	ULF Flush Volume (gal/flush)	Per capita savings from ULF toilets (gcd)	Saturation rate of ULF toilets in study homes
EBMUD Residential Conservation Study (2002)	1.48	10.1	85%*
Seattle Home Water Conservation Study (2000)	1.38	10.9	84%*
REUWS (1999)		10.5	100%
MWD (1992 – 1994)		11.4	73%
Tampa, Florida (1993)		6.1	100%*
East Bay MUD (1991)	1.8	5.3	100%
Boulder Heatherwood (1996)		2.6	50%*

*Saturation rate of ULF Toilets after retrofit

Clothes Washer Savings

A few other studies have measured water savings achievable from installing conserving clothes washers. The per capita per day clothes washer savings found in these studies is compared with the EBMUD results in Table ES.6.

The measurements of per capita savings vary in these six studies, although in the three most recent studies the savings are all quite similar.

The EBMUD and Seattle study both used Frigidaire and Whirlpool clothes washers. The Maytag Neptune was tested in Seattle and the Fisher & Paykel Ecosmart was tested in the East Bay. The SWEEP study used Frigidaire clothes washers exclusively. The similarity in water savings found in the Seattle, SWEEP, and EBMUD studies suggests an approaching agreement on the impact of these specific machines on per capita water use.

Table ES.6 Comparison of clothes washer savings from other studies

Research project	Per capita savings from conserving clothes washers (gcd)
EBMUD Residential Conservation Study (2002)	5.2
Save Water & Energy Program – SWEEP (2001)	5.3*
Seattle Home Water Conservation Study (2000)	5.6
Westminster water wise homes (1999)	4.6
Bern Kansas (1998)	7.2
Boulder Heatherwood (1996)	10.9

*Estimated from % water reduction reported.

Customer Satisfaction Ratings

About six months after installation of the new fixtures and appliances the study participants were asked to rate their performance. Each participating household was asked to complete a nine page, 44 question "New Product Information and Satisfaction Survey" that sought information about customer satisfaction with each of the products installed and with participation in the study. Many of the questions were intentionally made identical to questions asked on the initial Audit Survey so that responses could be compared.

The results of the survey were extremely favorable to the high efficiency fixtures and appliances particularly toilets and clothes washers. This is perhaps surprising given the often repeated assertions (often based on unscientific anecdotal evidence) that these devices are less satisfactory.

Toilets

Table ES.7 shows the results of the questions regarding toilet performance. Two trends are evident in these results: the new ULF toilets were uniformly rated higher in performance than any of the old toilets and second, looking strictly at the old toilets, the customers preferred the ULF models to the standard toilets. With respect to the new ULF toilets used for this study, it should suffice to note that they were rated higher in every category.

Table ES.7 Pre and post-retrofit toilet rating

Rating Category	Pre-Retrofit Non-ULF Toilets	Post-Retrofit ULF Toilets
Bowl Cleaning	3.56	3.70
Flushing performance	3.44	4.00
Appearance	3.26	4.58
Noise	3.41	4.42
Leakage	3.59	4.55
Maintenance	3.52	4.58
Overall Average	3.46	4.31

Rating scale from 1 – 5 where 1 = unsatisfied and 5 = completely satisfied

Clothes Washers

Most of the respondents (70 percent) liked their new clothes washer better than their old one and only 9.1 percent liked it less. Eighty-five percent said they would recommend the

machine to a friend, six percent would not recommend their new machine, and 9 percent were unsure. Nearly half of the respondents (48 percent) agreed that if they were in the market for a washer they would be willing to pay a premium of $150 to get an equivalent quality conserving washer. Thirty-three percent said they would not be willing to pay the extra money and another 19 percent were unsure.

Study participants rated the performance of their existing clothes washers during the initial audit interview. As part of the New Product Information and Satisfaction Survey they were asked to rate their new washer on exactly the same points. The responses to both surveys are shown in ES.8. Participants rated the new clothes washers higher in every single category. Of note were the substantially higher ratings of the new machines for noise and moisture content of the clothes. The new machines scored above 4.5 overall and were particularly praised for cleaning of clothes, moisture content of clothes, and detergent use. The old machines did not score above 4.5 in any category. Respondents also expressed satisfaction with the wash cycle time, cycle selection and reliability of the machines. The new machines scored a 4.33 rating for noise and capacity.

Table ES.8 Comparison ratings of non-conserving and conserving clothes washers

Rating Category	Non-Conserving Clothes Washer (n=33)	Conserving Clothes Washer (n=33)
Cleaning of clothes	4.23	4.70
Reliability	4.43	4.48
Noise	3.17	4.33
Moisture content of clothes	3.57	4.73
Cycle selection	4.11	4.45
Capacity	4.11	4.33
Wash cycle time	NA	4.45
Detergent use	NA	4.61
Overall Average	3.94	4.51

Rating scale from 1 – 5 where 1 = unsatisfied and 5 = completely satisfied

Costs and Benefits

This study was not specifically designed with cost-benefit analysis in mind, but it was possible to utilize the results to calculate cost of each conservation measure fixture and the value

of the water saved. For this analysis three conservation measures were considered: toilets, clothes washers, and showerheads.

The payback time for installing 2 ULF toilets (from savings on water and wastewater charges) was between 3.7 and 6.4 years. The payback time for upgrading to a high-efficiency clothes washer (from savings on water, wastewater, and energy charges) was between 1.1 and 2.9 years. The payback time for installing a new showerhead (from savings on water and wastewater charges) was 3.5 years. Cost and benefit analysis was not performed for faucet aerators.

Conclusions

This study found that significant, verifiable indoor water savings can be achieved through the installation of high efficiency plumbing fixtures and appliances. Not only did these high efficiency fixtures save water, but on average, participants reported that they worked better than their old non-conserving fixtures. An analysis of benefits and costs showed that these products pay for themselves in water and sewer cost savings within the expect life of the product.

Recommendations

The results from this study make it clear that residential retrofits from the customer perspective can be a cost-effective tool for saving water and that customers are quite satisfied with the performance of the new high efficiency toilets and clothes washers currently available. These results provide powerful evidence of the effectiveness of interior water conservation measures and justification for continued support of cost-effective programs across the country.

The effects of conservation retrofits is an important area for future research. Clearly, the more sites that can be included in similar projects, the better and more reliable the results will be for generalizing to wider populations. Examination of the variability in the reductions in water use across several cities is an essential part of determining the ability to make generalizations from the results. A similar study is underway in Tampa, Florida and when that is concluded the results from all three studies will be combined into a single report document published by the US EPA.

Ongoing Research

Tracking the consumption of the EBMUD study group via billing data, and collecting more end use data after 2 years or more time has elapsed is an important to confirm the stability of the savings. The persistence of water savings over time is a critical component in water supply planning that includes water efficiency and more research in this area is needed. There is also interest in conducting more research into the capabilities and accuracy of the flow trace analysis technology used in this study.

Future studies should also include additional water saving technology such as one gpf toilets, instant hot water systems, and hands free faucet controllers. While these may not be economically justified strictly on the basis of water savings, many customers or builders may wish to include them for their convenience, and their water savings should be evaluated.

CHAPTER 2 METHODOLOGY

The EBMUD Indoor Residential Water Conservation Study evaluates the impacts and acceptance of high quality water conservation products in single-family homes. The study was funded by the U.S. Environmental Protection Agency (EPA) and the East Bay Municipal Utility District (EBMUD). Aquacraft, Inc. (the consultant) conducted the study with project management and assistance from Richard Harris, Richard Bennett, and Daniel Muir of EBMUD. Work on the project commenced in December 2000.

In this study, 33 single-family homes were equipped with new water conservation fixtures including toilets, clothes washers, showerheads and faucet aerators. Extensive data were collected before and after the installation of these products so that changes in water use could be measured. Because the data were collected using flow trace technology it was possible to disaggregate them into individual end-uses. This allowed the impacts of each fixture and appliance to be detected directly, including ancillary uses such as leakage. In order to provide input on user satisfaction the participants were asked to rate both their old fixtures prior to retrofit and the new products using a consistent set of criteria for both.

This project is the second of three residential retrofit studies conducted for the EPA. The first was conducted in Seattle, Washington in 1999 and 2000. The third will be conducted in 2002-03 in Tampa, Florida.

The EBMUD Residential Water Conservation Study consisted of five steps:

1. Selection of study participants
2. Initial site visits, audits and data collection
3. Retrofit planning and installation
4. Post-retrofit data collection and customer survey
5. Analysis of results and report writing

This chapter provides an overview of the study group selection methodology used in this project and the planning and installation of the high efficiency plumbing fixtures.

SELECTION OF STUDY PARTICIPANTS

First Team Meeting

Work on the project began with a project kickoff meeting on December 14, 2000. The meeting was held at the EBMUD offices in Oakland and was attended by staff members from Aquacraft, Inc. and EBMUD. A number of decisions were reached at this meeting concerning how the project should proceed including: the project schedule and timeline, the critical path, study group selection methodology, selection of which high efficiency fixtures and appliances to evaluate, and channels of communication. The study team also spoke with Allen Dietemann and Tim Skeel from Seattle Public Utilities who offered suggestions for fine-tuning based on the results of the Seattle retrofit study.

The list of fixtures and appliances to be used for the retrofits was finalized at the meeting. These included 1.5 gpm bathroom faucet aerators, 2.2 gpm kitchen faucet aerators, 2.5 gpm showerheads, and a variety of ultra low flush (ULF) toilets including the Caroma (1.6/0.8) gallon per flush (gpf) dual flush model with vitreous tank, the Sloan 1.0 gpf pressure assist model, and the Niagara flapperless (1.6 gpf) with standard bowl.

An equal number of high efficiency clothes washers were to be purchased from Frigidaire, Whirlpool and Fisher & Paykel. The only other device considered for inclusion in the retrofit program was a hands free activator for the kitchen faucet, called the Aqua Lean™. This device allows the user to turn the sink on and off without use of hands, by leaning on an activating bar mounted on the cabinet face under the sink. It was thought that this product offered the possibility of less continuous faucet use during food preparation and dish washing. However, this product had not received plumbing code approval hence it was impossible to include the Aqua Lean in the retrofit program.

The content of the letter of invitation was discussed at the meeting, and the mechanics of the retrofits were outlined. It was decided to install separate water meters on the supply lines for the hot water tanks in ten of the study homes to provide a way of quantifying the savings in hot water use. (This was not part of the original study plan, but was added to provide some insight into the impacts of retrofits on hot water use.)

Study Group Selection

The goal of the study group selection was to obtain a sample of 33 single-family homes spread across the EBMUD service area. There were a total of 305,000 single-family homes in the EBMUD service area at the time of the study, and their average daily indoor use was 190 gallons per day. To begin the process, EBMUD staff utilized a systematic random sampling procedure to select a representative sample of 1000 single-family accounts from their entire population of accounts. To obtain this random sample each single-family account in the EBMUD billing database was listed in order of their annual water consumption from largest to smallest, and a random number n was chosen between 1 and 305. Starting with customer n and then proceeding in even multiples $2n$, $3n$... a list of customers was selected until the end of the list, at which point customer $1000n$ represented the 1000th member of the list. The use of a random start procedure to the sampling process ensured that all members of the sampling frame had an equal possibility of being selected and hence the list was a true random grouping.

Invitation Letter

An invitation to participate in the retrofit study was sent to approximately 600 of the 1000 selected households in a series of mailings. The invitation packet included a cover letter from project manager, a description of the study, and a brief questionnaire. These documents are included in Appendix A.

The questionnaire included questions about the number of people in the household and the number of fixtures that had previously been retrofit. Approximately 80 questionnaires were returned to EBMUD. Using the survey data along with historic billing consumption, it was possible to estimate the average daily per capita use for each responding household.

Selection of Participants

Potential participants for the study were selected from those customers that expressed a willingness to participate, had not previously performed extensive retrofits, and who had an average daily per capita use higher than 60 gcd. Initially a group of about 40 potential participants was selected. Each household was contacted by an EBMUD representative to schedule an initial site visit audit and finalize participation. The final group of 33 participants was selected so that all geographic regions in the EBMUD service area were equally represented.

DATA MANAGEMENT

Creation of Retrofit Database

To assist with the collection and analysis of the large amounts of data required for this study, the consultant created a database of participants[4]. This database contains several important tables, queries and forms that allow input of information about the customers and extraction of data needed to meet specific criteria for the selection or analysis processes. All information generated in the study including the audit surveys and results of the pre and post-retrofit data collection periods were entered into the database, and it serves as the main repository of information about the project.

Billing Data

EBMUD provided historic water consumption data from billing records for the 999 homes in their service area selected as the initial sample frame for the study. These billing records included the name of the current occupant/bill payer, bi-monthly consumption for the household from January 1999 through February 2001 in gallons, meter read dates, and other water billing information.

These billing data were organized into a single record per household format to assist with analysis and the table was included in the EBMUD retrofit database described above.

INITIAL SITE VISITS

The initial site visit was a crucial part of the study. A number of important tasks were accomplished during these visits. The goals of the visit were to:

- Explain the study and the responsibility of participation to the participants
- Secure signatures on the participation agreement contract
- Complete a detailed customer questionnaire
- Inventory all existing water using appliances and fixtures in the house
- Determine suitability for installation of new fixtures and appliances
- Measure flow rates
- Install hot water sub-meters (in 10 of the 33 homes)
- Install flow recorders and collect baseline water use data

Visit Protocol

There were at least two people present from the study team for each site visit: one representative from Aquacraft, one from EBMUD. During the first few days, the visits were frequently attended by an additional representative from Aquacraft and a plumber hired to install water meters on the hot water tank.

Audit Questionnaire

An audit questionnaire form was developed by Aquacraft and was based on the survey form used in the Seattle study. Slight changes were made to obtain additional information and improve the results. The questionnaire contained approximately 40 questions about the size and composition of the household – number of adults, teens, and children, year of construction, the existing water using fixtures in the house, typical water use habits of the residents, satisfaction ratings of existing fixtures, etc. The questionnaire was reviewed, edited by EBMUD staff. A copy of this questionnaire is included in Appendix A.

Data Logger Installation

The site visits began on Friday, February 9, 2001. One important goal was to begin collecting two weeks of pre-retrofit baseline water use data from each participating household. Upon homeowner agreement a flow recorder (data logger) was placed on the water meter and set to begin recording water use. These recorders were scheduled to be in place for a total of 15 days each. EBMUD arranged for the old water meter at each home to be replaced with a new standard magnetic drive meter in order to insure the maximum accuracy of the consumption data[5]. Each logger had previously been initialized for local time and synchronized closely to the auditor's watch. Each data logger was removed only at the conclusion of the 15-day logging period.

Once the logger was in place, the team began to collect the information from the home. The Aquacraft staff member administered the audit questionnaire, which involved sitting down with the customer and asking approximately 40 questions about the home. Each questionnaire took approximately 20 minutes to complete.

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[4] Microsoft Access™

[5] The data loggers are no more accurate than the water meters, so having new meters helped insure that the consumption data would be as accurate as possible.

Hot Water Data Collection

At ten homes, the plumber located the hot water tank and installed a 5/8th-inch water meter on the cold water feed line during the audit. This turned out to be a fairly simple process, and in all cases the meter was installed in line above the tank with a few standard fittings. Normally, the installation of the meter was completed at approximately the same time as the audit. Each hot water meter was then fitted with a data logger so that simultaneous water use data could be obtained for both hot and cold water in the home prior to the retrofit.

Collection of Fixture Traces

After completing the survey, the auditor from Aquacraft walked through the home and operated each fixture in the home and noted the time of each operation. This was intended to provide a signature trace of each fixture to be captured by the logger. The key to obtaining good signature traces was to operate each faucet or shower or bath for a long enough time to get a good sample with the logger that records flow in 10-second intervals. Each fixture was operated individually for at least 1-3 minutes and each toilet was flushed individually. The next important step was to allow at least 30 seconds between the operation of each fixture to allow for clear, discreet water use events. The focus of this process was to get accurate maximum flow rates for each sink, bathtub and shower so that during the analysis it would be easier to assign fixture designations for individual events. For example, if the maximum flow rate of the kitchen sink is 2.5 gpm then this fixture can be confidently excluded as the source of any event with peak flows significantly above 2.5 gpm, even if the volume of the event is comparable with a kitchen sink. Generally, the more accurate the flow information available the easier it becomes to obtain accurate disaggregation of water use events.

As a check, the analyst also measured the flow of the fixtures using a calibrated pitcher that converted a volume captured in 15 seconds to a gallon per minute flow rate. This type of device can provide flow estimates up to 6 gpm since *n* quarts per 15 second is equal to *n* gallons per minute and one can usually easily handle a 6 quart volume in a calibrated pitcher. It is important to note, however, that it is not absolutely necessary to perform an in-house audit to perform the disaggregation. An experienced water use analyst can normally identify the various fixtures in houses without any flow signatures since they do not vary significantly from house to house. The audit data and flow rate information from the hand measurement, however, provided useful information that simplified the analysis.

Participant Agreement

Another task accomplished during the visit was for the EBMUD staff person to explain the participation agreement to the customer and execute signed contracts. The terms and conditions of participation in the study were carefully explained to each customer before the conclusion of the site visit. The key terms included agreement to:

- Maintain a log of water use during data collection periods
- Not move during study period
- Accept fixtures installed for study

It was critical that customers understand and feel comfortable with the participation agreement to ensure their full participation in the study. A copy of the participation agreement is included in Appendix A.

The entire audit process typically took between 45 and 90 minutes per household.

Audit Data Entry and QA/QC

Audit data from each household were entered into the database using a customized data entry form. This form contained numerous data quality checks and data restrictions to prevent inadvertent data entry errors. Data entry accuracy was independently checked for each household at the conclusion of the process to ensure the quality of the database.

Retrieval and Verification of Initial Data

The retrieval of the data loggers began 15-days after their installation. EBMUD staff retrieved the loggers and shipped them back to Aquacraft to be downloaded. As each logger was retrieved, the ending water meter reading was recorded on a form and the logger was turned off to end the recording session.

Aquacraft staff members downloaded all the data stored in the loggers to a PC. Each file was checked for accuracy against the water meter reading to ensure it was operating properly. If a logger failed to record data or did not record accurate data, a replacement flow trace was obtained by installing a new data logger on the house and collecting another two weeks of data.

Pre-Retrofit Logging Report

During the first pre-retrofit logging period a total of 43 data loggers were installed at 33 homes – 33 loggers on the main water meter outside the home, and 10 loggers on new hot water meters installed above the hot water tank. From these 45 installed loggers, accurate data were obtained from 29 of 33 main meter loggers and seven of ten hot water meters. The traces that could not be used were caused by complete logger failure due to water damage or from electrical interference in the case of one hot water logger[6]. These homes were re-logged until good data were obtained from each home.

Re-Logging Effort

A total of 9 data loggers were installed as part of the re-logging effort. Six loggers were installed at the homes where good data were not obtained during the first logging period. Because three homes had also been equipped with hot water meters, three additional loggers were installed on the hot water meters there, bringing the total to nine.

After the re-logging effort, flow traces were obtained from the main meter at all 33 participating study homes and from the 10 hot water sub-meters. All flow traces included in the final database met critical accuracy standards (within 5 percent of metered volume).

Pre-Retrofit Flow Trace Analysis

Recorded flow traces from the 33 participating homes (33 main meter traces and 10 hot water traces) were disaggregated into specific end uses by Aquacraft[7]. A more detailed description of the software and the flow trace analysis process is presented in Appendix B.

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[6] During this logging period there were several heavy rainfalls which caused flooding of most of the meter pits. Several of the data loggers had developed small leaks, which caused them to fail to record when immersed. These loggers were repaired by the manufacturer. The electrical interference was remedied by wrapping the sensors in aluminum foil, which acted as a shield.

[7] Using the program "Trace Wizard" which was developed by Aquacraft specifically for this purpose.

During the flow trace analysis process, the recorded water use flow traces are disaggregated into water use events using signal processing technology and then fixture designations are assigned to these events using a pattern recognition algorithm. Specific statistics are calculated for each individual water use event including its use type, volume, start time, stop time, duration, peak flow rate, and mode flow rate.

Water use in each flow trace is shown on an interactive graph in Trace Wizard. The analyst must visually inspect each portion of the trace to ensure proper identification of all water use events. Analysis for each 15-day flow trace took approximately two hours to complete. Each analyzed flow trace was reviewed by a senior engineer to ensure accuracy of the analysis process.

Once the analysis of each trace was completed, two separate water use tables were created in the database – one for water use recorded from the main water meters and a second for the water use recorded from the hot water meters. Each water use event (toilet flush, faucet use, dishwasher cycle, etc.) is included in the database and is associated with a unique keycode number which identifies the house from with the water use was recorded. An example of this database is shown in Table 2.1.

Table 2.1 End use data table example

KEYCODE	USETYPE	DATE	START	DURATION	END	PEAK	VOLUME	MODE	MODE NO
22010	DISHWASHER	2/25/01	1:02:06 PM	50	1:02:56 PM	2.19	1.56	1.79	2
22010	DISHWASHER	2/25/01	1:05:46 PM	90	1:07:16 PM	1.69	2.35	1.66	3
22010	LEAK	2/25/01	1:07:16 PM	10	1:07:26 PM	0.20	0.03	0.2	1
22010	DISHWASHER	2/25/01	1:25:46 PM	90	1:27:16 PM	1.79	2.29	1.66	3
22010	DISHWASHER	2/25/01	1:30:46 PM	90	1:32:16 PM	1.79	2.29	1.59	4
22010	LEAK	2/25/01	1:32:16 PM	10	1:32:26 PM	0.20	0.03	0.2	1
22010	FAUCET	2/25/01	2:23:36 PM	140	2:25:56 PM	1.99	3.71	1.59	7
22010	TOILET	2/25/01	2:24:56 PM	60	2:25:56 PM	3.98	2.89	1.79	2
22010	LEAK	2/25/01	2:25:56 PM	10	2:26:06 PM	0.20	0.03	0.2	1
22010	FAUCET	2/25/01	2:26:16 PM	10	2:26:26 PM	1.00	0.17	1	1
22010	LEAK	2/25/01	2:39:26 PM	20	2:39:46 PM	0.20	0.07	0.2	2
22010	TOILET	2/25/01	2:49:26 PM	60	2:50:26 PM	3.98	2.99	3.98	2

Quality Assurance and Quality Control

Numerous quality assurance and quality control measures were taken during the data collection and analysis process to ensure the quality and accuracy of the data obtained in this study. These measures included:

- Data logger preparation
- Water meter calibration
- Field verification of data logger operation
- Water meter readings upon installation and removal of the data logger
- Fixture signature traces
- Customer log sheets
- Flow rate calibration
- Alignment of flow traces with calibrated flow rates
- Systematic quality checks of analyzed flow traces
- Database integrity testing

These measures are described in detail below.

- **Data logger preparation** - Each data logger/flow recorder was charged, initialized, and tested prior to installation in the field. Loggers were bench tested by Aquacraft by running a known quantity of water (usually 10 or 20 gallons) through a test meter. This verified proper operation of the logger and ensured recording accuracy. Loggers that failed any portion of the testing regime were returned to the manufacturer for repairs. Only fully charged, fully functional data loggers were installed in the field.
- **Water meter calibration** – The data obtained from the flow recorders is only as accurate as the water meter it is attached to. EBMUD understood this concept and replaced all water meters used in that study with brand new Trident T-10 or Badger 25 meters. These new water meters are tested by the manufacturer and offer high-resolution magnetic pulse output to the flow recorders.

- **Field verification of data logger operation** – The Meter-Master flow recorders used in this study have a special sensor which is strapped to the water meter using a heavy-duty Velcro strip. Once the sensor and logger are in place it is important to verify that the logger is installed properly and is picking up the magnetic pulses from the water meter. This was accomplished by running water through an outside hose bib once the logger was installed. The Meter-Master logger has an indicator light that flashes after a specific number of magnetic pulses have been recorded. This flash is repeated 12 times at which point the light shuts down to conserve battery power. The flashing indicator light signals that the logger is installed properly and it recording flow through the meter. This proper functioning was verified during each data logger installation.
- **Water meter readings upon installation and removal of the data logger** – A key to verifying the accuracy of the data recorded with the Meter-Master flow recorders is to compare the volume of water measured by the water meter with the volume measured by the data logger. These volumes are compared when the data stored in the flow recorder is downloaded to a PC at the conclusion of the logging period. Careful, accurate water meter readings were taken when the data logger is installed and again when it is removed. These readings are recorded on a log sheet and then used as a check against the volume recorded by the data logger. Agreement between the meter and logger within 5% is the goal.
- **Fixture signature traces** – To improve the accuracy of the flow trace analysis process, fixture signatures were obtained during the audit process in each home. The Aquacraft auditor intentionally operated each faucet, shower, bath, and toilet fixture individually during the audit, allowing a minimum of 30 seconds in-between each fixture, and noted down the time of each operation. During the analysis process these fixture signatures are carefully examined and used to help identify regular fixture usage during the 15-day logging period.
- **Customer log sheets-** Each customer was left with a log sheet on which the number of persons staying at the house each day was recorded along with the times at which the clothes washer and dishwasher were operated. This provided better information on occupancy for calculating per capita consumption, and assisted with recognition of the two appliances.

- **Flow rate calibration** – During the audits, a special calibrated vessel was use to measure the maximum flow rate in faucets, showers, and baths or all participants. To use this device, water is run into the vessel for exactly 15 seconds. The resulting volume collected in the vessel is then translated into a flow rate in gallons per minutes using graduated markings. An attempt was made to measure the maximum possible flow rate from each faucet, shower, and bath in the audited study homes. These flow rates were noted on the audit form and entered into the Access audit database.
- **Alignment of flow traces with calibrated flow rates** – As a check on the accuracy of the flow traces, the logged flow rates from the signature draws were compared against the physical measurements of flow made with the calibrated vessel. Any discrepancy between the data logged flow rate and the measured flow rate was carefully investigated and if necessary the flow trace was scaled to match the measurement.
- **Systematic quality checks of analyzed flow traces** – The process of flow trace analysis with Trace Wizard contains some subjective components. To ensure the accuracy of the flow trace analysis, two different analysts examined each flow trace in its entirety. The results from each analysis were compared by summarizing the fixture volumes and calculating the differences. If any significant discrepancies existed, the traces were re-examined and finalized in consultation with both analysts.
- **Database integrity testing** – Once all the water use events were assembled into the database, sorting queries were performed to examine peak flow rate, maximum volume, and duration for each end use category. A screen for obvious errors is performed (toilets with a volume of more than 8 gallons, flow rates exceeding meter capacity, etc.). Any database errors are noted and investigated by reviewing the analyzed flow trace data in Trace Wizard. Appropriate corrective action is taken.

PLAN RETROFITS AND INSTALL CONSERVING FIXTURES

The goal of the retrofits was to select and install effective high quality indoor water fixtures on existing housing to determine the water savings that might be available from the use of these products.

Draft Retrofit Plan

The basic retrofit plan was developed by EBMUD in conjunction with Aquacraft, Inc. during the initial team meeting in Oakland.

Results from the AWWARF Residential End Uses of Water Study showed that toilets, clothes washers, showers, and faucets comprise more than 80 percent of indoor water use in a typical single-family home. Because these are the primary end uses of water it was decided to focus the retrofits on reducing water use in the following four categories: toilets, clothes washers, showers, and faucets. This was the same approach taken in the Seattle Home Water Conservation Study.

The widest variety of conservation options is available for reducing toilet water use. All toilets currently manufactured in the United States must conform to the Federal Energy Policy Act standards that mandate a maximum flush volume of 1.6 gallons (6.0 liters). These ultra low-flush (ULF) toilets represent a substantial reduction in water usage over previous 3.5 and 5.0 gallon per flush (gpf) models. There are toilets on the market that use even less water than the standard 1.6 gpf ULF models. These include dual flush toilets that offer two flushing modes – one at 1.6 gpf and one at 0.8 gpf, super high-efficiency dual flushing models that flush at 1.0 and 0.5 gpf, and pressure assisted toilets that can flush using 1.1 gpf. Composting toilets that do not use water are also available, but these are primarily designed for houses without central plumbing, campers, and boats.

In the 1990s a number of manufacturers began offering high efficiency clothes washers that use less water and energy than traditional models. Originally, most of the high efficient washers operated on a horizontal axis (h-axis) and opened on the front of the machine instead of the top. Manufacturers that offer h-axis machines include Maytag, Frigidaire, and Asko. In the past few years several companies have entered the high efficiency washer market with top loading models. Whirlpool and Fisher-Paykel both offer top loading clothes washers that purport to offer significant water and energy savings. The washers selected for this study are shown in Figures 1.1 – 1.3.[8]

[8] Photos printed with permission courtesy of Frigidaire, Fisher & Paykel, and Whirlpool

Figure 2.1 Frigidaire Gallery clothes washer

Figure 2.2 Fisher & Paykel Ecosmart

Figure 2.3 Whirlpool Super Capacity Plus Resource Saver clothes washer

Showerheads and faucets, like toilets, are now regulated under the Federal Energy Policy Act. Showerheads must restrict flow to 2.5 gpm and faucets must restrict flow to 1.5 gpm. A wide variety of products are available from numerous manufacturers in the U.S.

The list of fixtures and appliances to be used for the retrofits was finalized by EBMUD staff after researching the availability and price of different products. These included 1.5 and 2.2 gpm faucet aerators, 2.5 gpm AM Conservation Group showerhead, Niagara Spray Massage hand held showerhead, 1.6 gallon per flush (gpf) Niagara ™ flapperless toilets, and 1.6/0.8 gpf

dual flush Caroma ™ toilets. Several other toilets were also installed for this study, but not in sufficient number to use in any meaningful analysis. These included the Sloan Flushmate 1 gpf pressure assist toilet assembly, the Toto Drake ULF toilet, and the Gerber Ultra-Flush pressure assisted ULF toilet. Caroma and Niagara toilets – the primary fixtures tested in this study, are shown in Figure 1.4 and Figure 1.5.[9] Clothes washers were provided by Frigidaire, Fisher & Paykel, and purchased from Whirlpool.

Figure 2.5 Caroma Caravelle dual flush ULF toilet

Figure 2.4 Niagara Flapperless 1.6 GPF toilet

Final Retrofit Plan

A final retrofit plan for each of the participating households was developed based upon the physical requirements of the home (some houses could only have a specific make and model toilet installed because of space limitations), requests from the homeowners (some people expressed a product preference), and the availability of various fixtures. EBMUD was in charge of ordering the products for the retrofit and finalizing the list of products to be installed.

[9] Photos printed with permission courtesy of Niagara and Caroma.

Some study participants were particularly sensitive about the fixtures they wanted installed in their home. The staff at EBMUD worked hard to accommodate as many requests as possible, but in a few cases it proved impossible to get all items required (such as wall mounted toilets).

During the course of the retrofit, two of the participants withdrew from the study, leaving 33 participants.

Perform Retrofits

EBMUD contracted with a plumber to remove old fixtures and install new ones for this study. Plumbers were responsible for installing toilets, faucets, and showerheads in study homes. The appliance dealer who sold the conserving clothes washers also performed the installation.

Table 2.2 shows the number and make and model of all fixtures installed for this study.

Validate and Tabulate Retrofits

Audit Installation Quality Assurance and Quality Control

To ensure that the proper fixtures were actually installed at the final 33 study homes, EBMUD completed a product installation form for each house. This survey specified the exact fixtures (make and model) installed at each home. Initial audit data included a detailed list of existing fixtures in each study home.

In the follow-up retrofit satisfaction survey, participants were asked to verify the products installed at their home as part of the study. They were also asked to report on the survey any installation problems or dissatisfaction.

As a final check, the toilet, faucet, and clothes washer installation was inspected by a project team member during installation of the hot water meter data loggers. This took place in only 10 of the 33 homes.

Table 2.2 Conserving fixtures installed in 33 study homes

Product	Quantity	Make	Model
Showerhead	57	AM Conservation Group	Spoiler Showerhead 2.5 gpm
Bathroom faucet aerator	79	New Resources Group	1.5 gpm
Kitchen faucet aerator	20	New Resources Group	2.2 gpm
Clothes washer	13	Fisher & Paykel	Ecosmart (GWL10)
Clothes washer	9	Frigidaire	Gallery (FWT449)
Clothes washer	11	Whirlpool	Super Capacity Plus (LSW9245BQ)
Toilet	35	Caroma	Caravelle 305 (0.8/1.6 gpf dual flush)
Toilet	32	Niagara	Ultimate Flush flapperless 1.6
Toilet	2	Sloan	Flushmate 1.1 gpf (St. Thomas Creations pottery)
Toilet	5	Toto	G Max

Post Retrofit Logging Quality Assurance and Quality Control

There were two post retrofit logging sessions. Each involved the same procedures for installation and calibration of the data loggers. The only homes that the study team entered, however, were those with the hot water meters. A postage paid mail-back log sheet was left at the home similar to the initial log sheets. The customers were asked to note some example operation times of all of the new fixtures and appliances in the home to assist with the post retrofit analysis.

CHAPTER 3 BASELINE WATER USE

To determine the effect of the conservation retrofit on water use in the study homes, baseline water use data were collected from the study group. Obtaining high quality baseline use data was critical for this study because all impacts of the retrofit were measured by comparing baseline use patterns against water use after the retrofit. Historic billing data were obtained so that the overall impacts of the retrofit could be measured. Disaggregated flow trace data from the residential end use study, and a new two-week set of flow trace data were obtained so that the impacts on each specific end use could be evaluated, a task that would be impossible with only billing data.

EBMUD provided historic water consumption data from billing records for the 1000 homes in their service area that were selected (as described in Chapter 1) for the initial sample frame. This random sample was selected to be representative of single family households in the EBMUD service area. The billing records provided included the name of the current occupant/bill payer, bi-monthly consumption for the household from January 1999 through February 2001 in gallons, meter read dates, and other water billing information.

ANNUAL WATER USE

Using the data from the random sample of 1000 homes and the sample of 33 homes selected for the retrofit study, annual use frequency distributions for the years 1999 and 2000 were developed and plotted on the same axis. These results are shown in Figure 3.1. These distributions show clearly that annual water use in the retrofit sample was higher than in the sample frame. This is exactly what the researchers were aiming for because it was desired to retrofit homes with higher indoor water use to determine the potential for water savings. It can be seen in Figure 3.1 that water use in the sample frame remained quite consistent over the two-year period. Average daily water use in the study group[10] fluctuated more between 1999 and 2000, but the overall shape of the distribution remained essentially the same.

The average daily demand in the sample frame over the two years was 106.8 kgal (142.8 ccf) or 292.6 gallons per day (gpd) and the average annual demand differed by less than 2 percent between 1999 and 2000. The consistency in demand of this group is important because

[10] Calculated as total annual use per household divided by 365 days

the homes that did not participate in the conservation retrofit will be used as a control group. The control group will be used to test if the expected changes in water use in the study group are in fact due to the retrofit and not some other factor affecting all households in the East San Francisco Bay area. Water use in the sample group was also remarkably consistent from 1999 to 2000, differing by less than 1 percent. The average annual demand for the sample group over the two years (1999 and 2000) was 141.3 kgal (188.8 ccf) or 387.1 gpd.

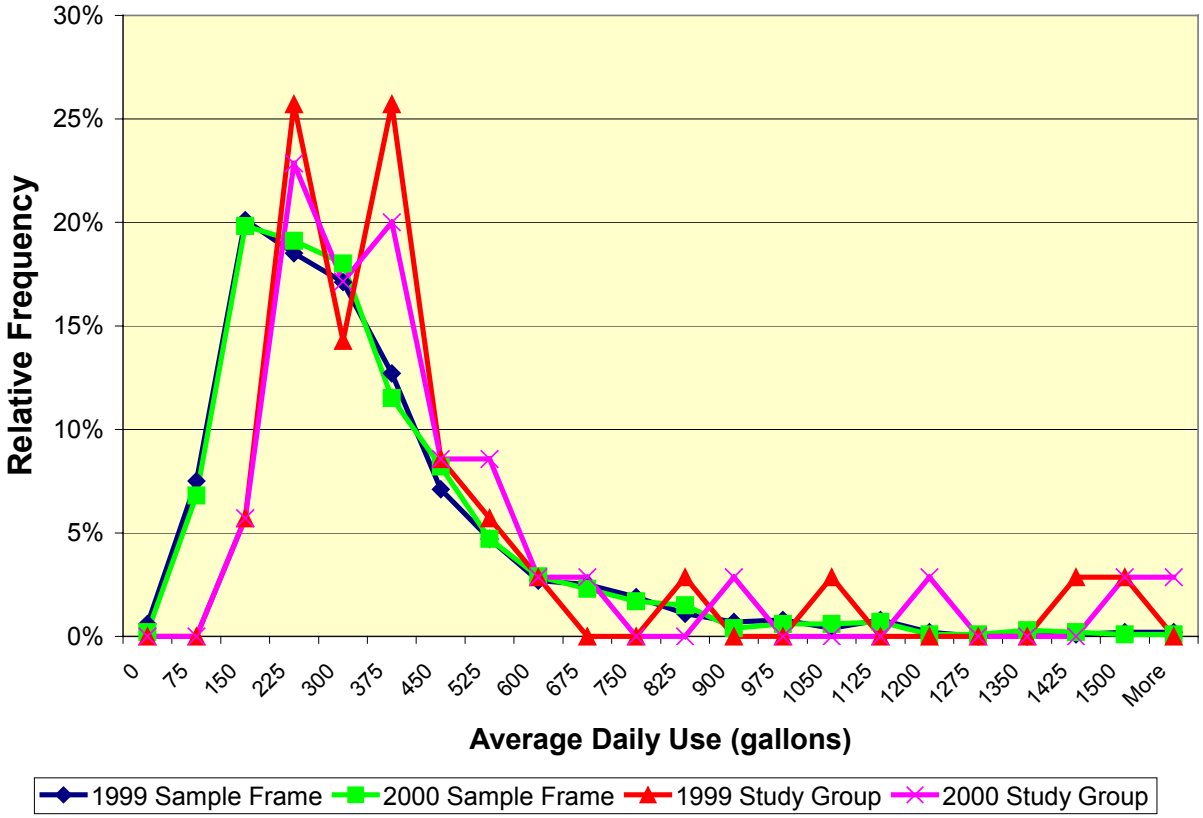


Figure 3.1 Average daily use distributions for 1999 and 2000, study group (n=33) and sample frame (n=1000)

The group of 33 homes, which received new fixtures and appliances in this study (the study group), was selected from the population of homes that expressed a willingness to participate in the study. These homes were also selected because they used more than 60 gallons per capita per day (gcd) for indoor use, as calculated from billing data and survey response information. Table 3.1 compares the total annual, indoor annual, and outdoor average water use, over two years of the sample frame (n=1000), the study group (n=33).

Table 3.1 Annual water use per household in 1999 and 2000, sample frame and study group

Average Annual Water Use	Sample Frame n=1000		Study Group n=33	
	(gallons per year)	(gallons per day)	(gallons per year)	(gallons per day)
1999 Total	106,155	290.8	141,073	386.5
1999 Indoor	71,347	195.5	84,374	231.2
1999 Outdoor	34,808	95.4	56,698	155.3
2000 Total	107,528	294.6	141,436	387.5
2000 Indoor	74,629	204.5	86,683	237.5
2000 Outdoor	32,899	90.1	54,754	150.0

Seasonal Water Use

Seasonal variations in billed consumption provide an indication of the amount of water that is used for indoor and outdoor uses. Seasonal water use estimates for the sample frame and study group in 1999 and 2000 are shown in Table 3.1. Indoor use in this table was calculated using the minimum bi-monthly billing period for the year and multiplying this value by six to extrapolate across the entire year. This methodology assumes that all water use in the minimum bi-monthly billing period is used for indoor purposes. Outdoor use is then calculated by subtracting indoor use from the total billed consumption for the year.

Indoor water use accounted for 69 percent of total use for the sample frame group and 61 percent of total use for the study group. The bi-monthly consumption records for the retrofit study group are shown in Figure 3.2 for the period from 1999 to 2000. These data show that the average bi-monthly minimum demand for the 33-home study group was 14.3 kgal (235.2 gpd). If one assumed that all use above this was used outdoors, then it establishes an estimate for indoor use of 85.8 kgal per year (235.1 gpd). Outdoor use is estimated at 55.5 kgal per year (152.1 gpd). Outdoor water use in the East Bay area can occur in almost any month of the year, depending upon the weather. Most frequently there is little or no outdoor use in January and February, which are typically the rainiest months.

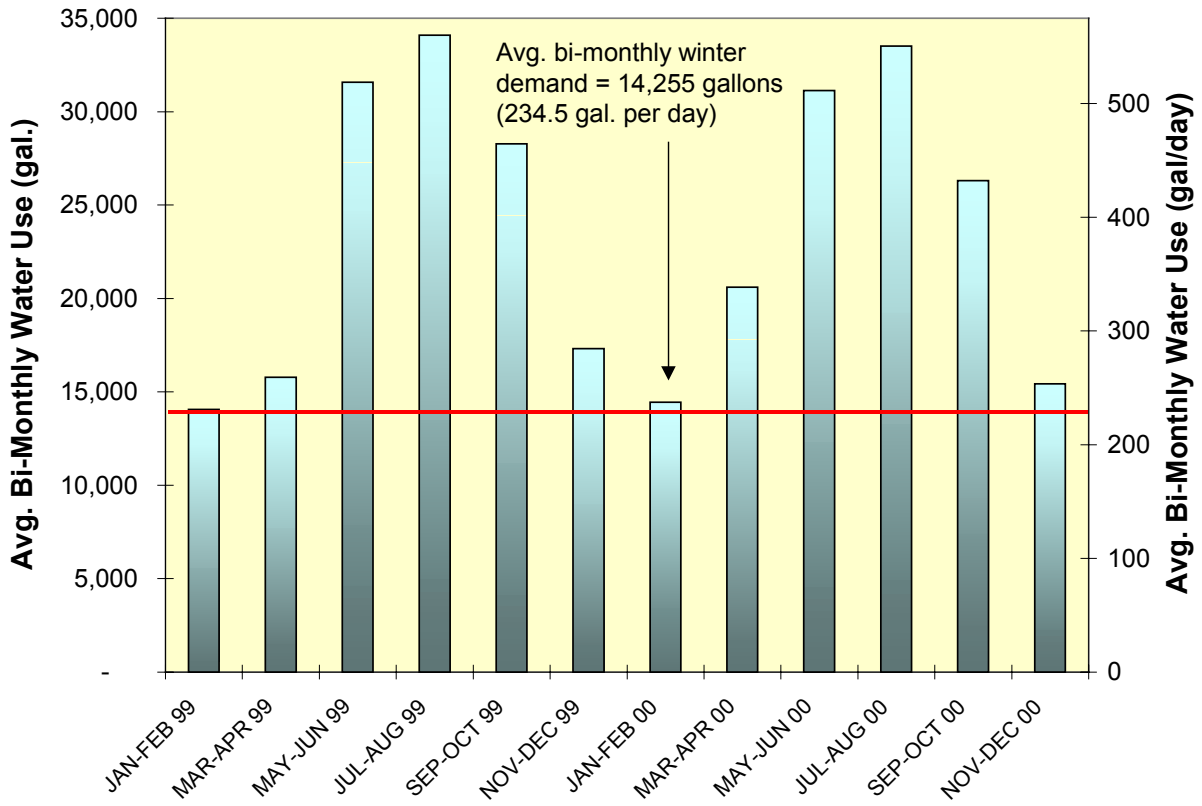


Figure 3.2 Bi-monthly water use in retrofit study group (n=33)

DEMOGRAPHIC INFORMATION

During the site audits that were performed on the retrofit study group a limited amount of household level demographic data were collected. These data help describe the households participating in the study and place them in the context of the population of single family homes in the EBMUD service area and across the United States.

Number of residents per household

Initial audit survey results indicated that the households in the retrofit study had an average of 2.74 full time residents. There were an average of 2.20 adults, 0.37 children (0-12 years old), and 0.17 teens (13-19 years old). Figure 3.3 shows the frequency of different numbers of adults, teens, and children in the 33 retrofit homes. Five households (14 percent) had teenagers, and nearly 26 percent of the households had children. Only one of the study homes

had more than two children. About 23 percent of the households had more than 2 adults residing full time. None of the houses had more than four adults.

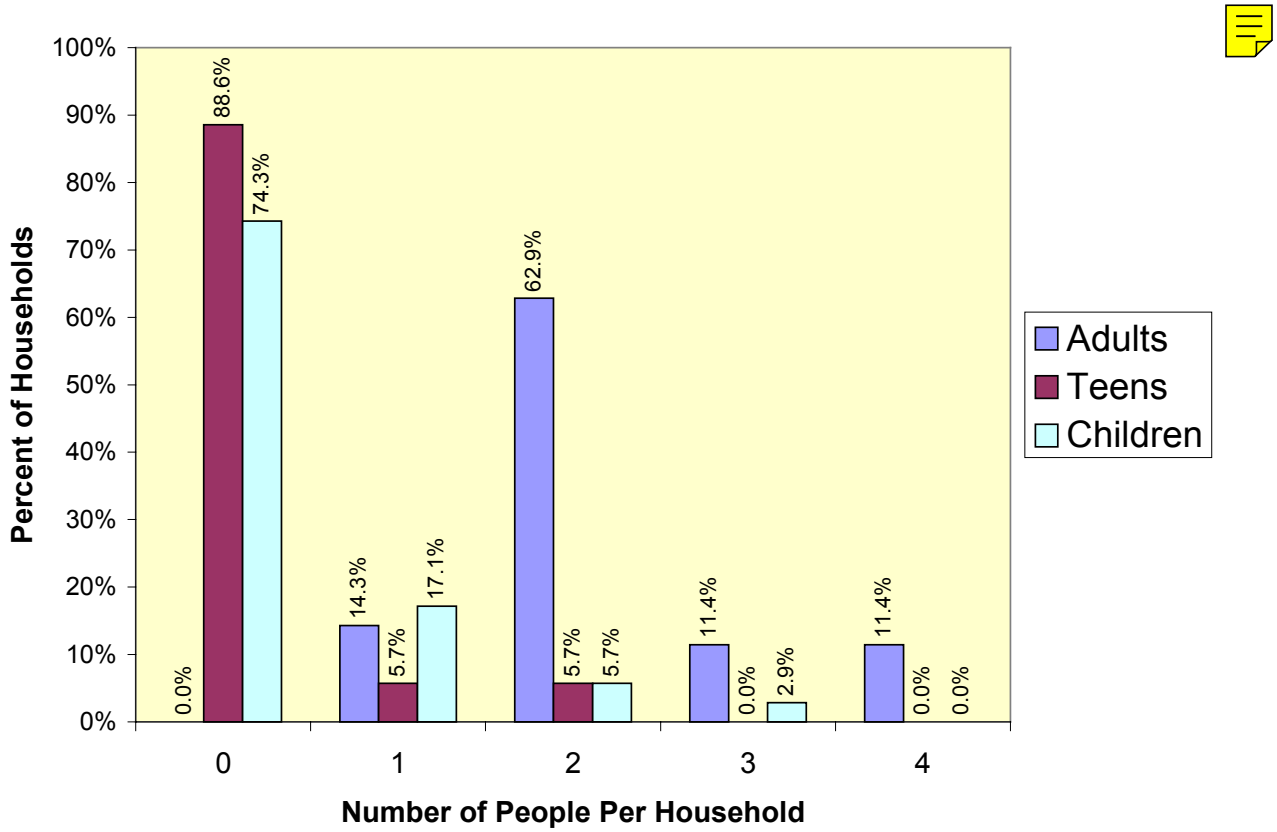


Figure 3.3 Household size distribution, (n=37)

During the data logging period each household was asked to report the number of people staying at the house during each day. This was done so that more accurate measurements of per capita water use could be made. The average number of people per household during the baseline logging period was 2.56.

Household Information

Study participants have lived in their current house about seventeen years on average. The average move in date was 1984. The earliest reported move-in date was 1950 and the most recent was 1997. The houses themselves are a mix of older and newer homes. The median age of the houses was 44 years old (build in 1957). The oldest house was built in 1911 and the newest house was built in 1990. Since many newer houses are already equipped with conserving

fixtures, it is perhaps not surprising that the owners of older houses volunteered to participate in the study.

The average floor area of the study houses was 2054 square feet (sf). The minimum size was 900 sf and the maximum was 6000 sf. The typical study house was 2 stories tall, had a 2-car garage, 4 bedrooms, one full bathroom, and one ¾ bath. Five of the houses had more than 3 bathrooms. Four of the houses (14 percent) already had one ULF toilet installed. Eight of the houses (22.8 percent) had hot tubs and four (11.4 Percent) had a swimming pool.

Twenty-seven houses (77 percent) had automatic sprinkler systems, and eight of the households indicated that they intended to irrigate during the two-week logging period. Five houses (14 percent) had home offices that were used for telecommuting and other work from home activities. None of the households reported doing laundry outside the home from time to time.

Fixture Performance

As part of the audit, homeowners were asked to report on and describe problems with their existing toilets. They were also asked to rate their primary toilet and clothes washer on the same performance measures as would be applied to the ULF retrofits later.

Twenty-four households (69 percent) reported experiencing a problem with their primary toilet within in the past 6 months. Twenty-eight households (80 percent) reported experiencing a problem with their toilet in the past 2 years. The problems reported ranged from leaking flapper valves to broken chains to clogs. Only two households reported never experiencing a problem with their toilet.

Twenty-nine percent of the households reported that their toilets never required plunging. Fifty-four percent reported infrequent plunging ranging from every other month to every other year. Seventeen percent of the households reported that more frequent plunging was required for their toilet.

Double flushing once per week or more was reported by ten households (29 percent). Another 10 households said they double flushed a few times a year. Ten households indicated that they never need to double flush their toilets.

Homeowners were asked to rate their non-ULF toilets in the following areas on a scale of 1 to 5 (1 = unsatisfied and 5 = completely satisfied): bowl cleaning, flushing performance, appearance, noise, leakage, and maintenance. The results of this rating are presented in Table

3.2 and compared against similar baseline ratings from the Seattle retrofit study. It can be seen from this analysis that the study participants were not particularly enthusiastic about their existing toilets. The ratings in the East Bay were similar, but slightly lower overall than in Seattle.

Table 3.2 Pre-retrofit toilet rating, Non-ULF toilets in EBMUD and Seattle

Rating Category	EBMUD Non-ULF Toilets (n=54)[11]	Seattle Non-ULF Toilets (n=37)
Bowl Cleaning	3.56	3.76
Flushing performance	3.44	3.54
Appearance	3.26	3.70
Noise	3.41	3.32
Leakage	3.59	3.70
Maintenance	3.52	3.89
Overall Average	3.46	3.65

Rating scale from 1 – 5 where 1 = unsatisfied and 5 = completely satisfied

Using the same rating system (1 = unsatisfied and 5 = completely satisfied), homeowners were asked to rate their current non-conserving clothes washer in the following areas: cleaning of clothes, maintenance/reliability, noise, moisture content of clothes, cycle selection, and capacity. The results of this rating are presented in Table 3.3 and again compared with the results from Seattle. The results from both study sites were virtually the same. Homeowners appear to be satisfied for the most part with their existing clothes washers. Respondents were particularly pleased with the reliability of the machines, the capacity and the selection of wash cycles available. They were less satisfied with the noise the machines make and the moisture content of the clothes after washing.

The participants in this study had the following selection of clothes washer brands: 12 Whirlpool (34 percent), 10 Maytag (29 percent), 7 Kenmore (20 percent), 2 GE (6 percent), 2 Hotpoint (6 percent), 1 Admiral (3 percent), and 1 Norge (3 percent). The average age of the machines was 11 years old (purchased in 1990). The oldest machine was purchased in 1970 and the newest in 2001.

Table 3.3 Pre-retrofit rating of non-conserving clothes washers, EBMUD and Seattle

Rating Category	EBMUD Non-Conserving Clothes Washer (n=33)	Seattle Non-Conserving Clothes Washer (n=37)
Cleaning of clothes	4.23	3.86
Reliability	4.43	4.44
Noise	3.17	3.32
Moisture content of clothes	3.57	3.50
Cycle selection	4.11	4.06
Capacity	4.11	4.30
Overall Average	3.94	3.91

Rating scale from 1 – 5 where 1 = unsatisfied and 5 = completely satisfied

END USE DATA

The water use data collected and analyzed using the flow recorders and Trace Wizard software contains specific information on the use of water in each study home over the two week data collection period. These data were analyzed in a variety of ways so that the impacts of the retrofit can be measured by comparing water use after the retrofit with the baseline demand patterns. The baseline water use analyses included daily use, daily per capita use, per capita use for different fixtures, the frequency and intensity of use of various fixtures, and the variability of water use. Where useful, these baseline results are compared to the findings from the AWWARF Residential End Uses of Water study national sample.

Daily Household Use

A total of 513 complete days of end use data were recorded from the 33 study homes in the EBMUD service area for an average of 14.7 days of data per household. A minimum of 14 days of data was collected from each study house, and more than 14 days of data were obtained from a few houses. Baseline end use data were recorded from February 10th through May 10th, 2001, but the majority was obtained between February 10th and April 7th, 2001.

[11] A total of 54 toilets were rated by homeowners.

The total daily use (including indoor and outdoor uses) from each logged day is plotted as a scatter diagram in Figure 3.4. The average daily use for all houses was 210.4 gallons per day (gpd) and the standard deviation was 162.8 gpd. The median daily use was 182.5 gpd. The maximum observed daily use during the logging period was 2241.3 gpd, which is actually fairly low when considering that the maximum *average* daily use from the REUWS was more than 9000 gpd. These results suggest that there was some outdoor use during the baseline logging period, but there were also many days without any outdoor use.

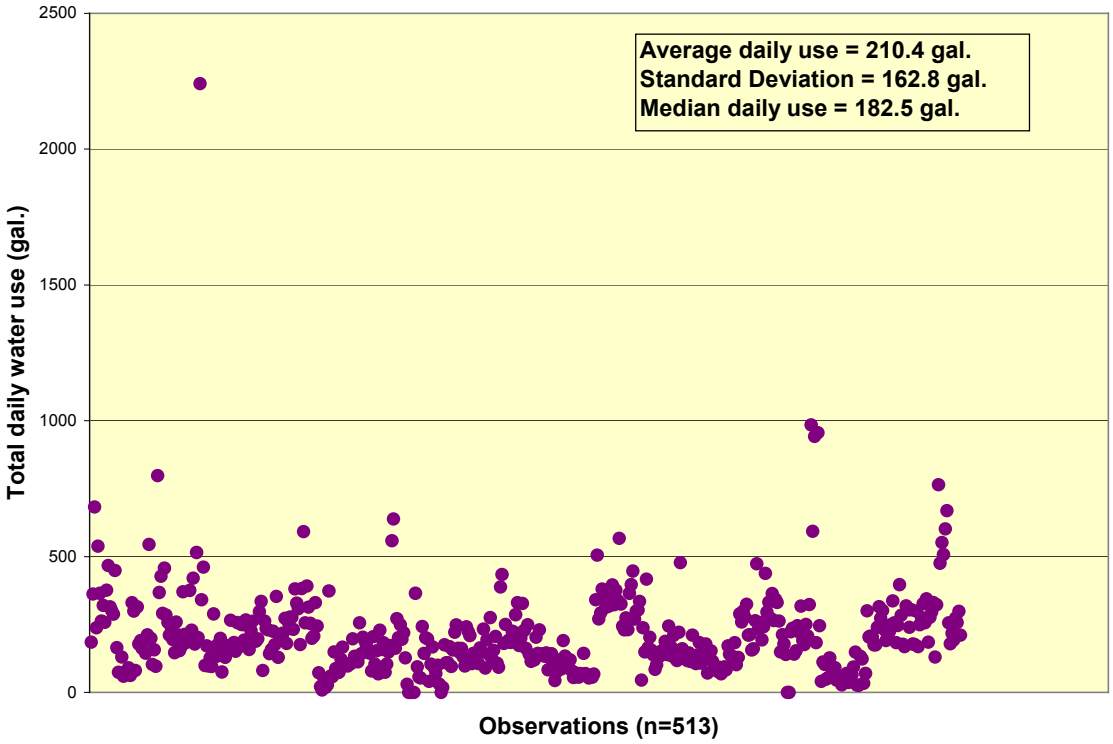


Figure 3.4 Scatter diagram of study group pre-retrofit daily household water use

These same daily use data were used to develop a frequency distribution (histogram), Figure 3.5. Figure 3.5 shows that nearly 50 percent of daily water use was less than 175 gallons per day and 90 percent of daily use was less than 350 gallons per household per day.

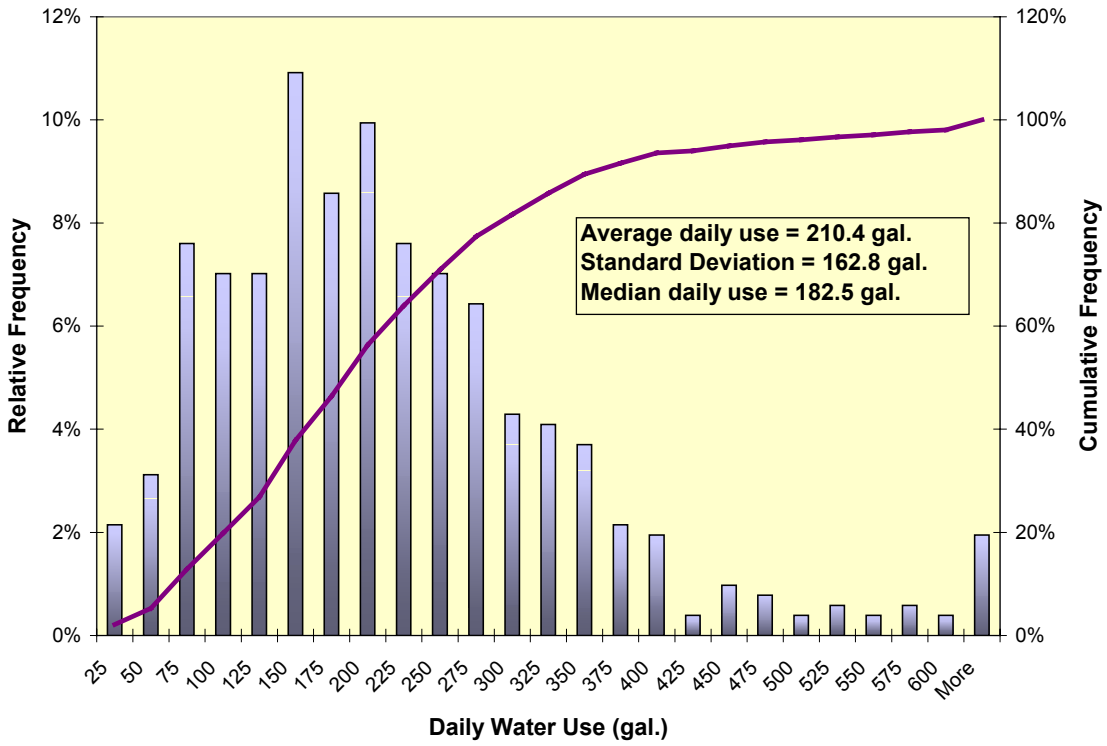


Figure 3.5 Baseline frequency distribution--total daily household water use for pre-retrofit study group

INDOOR PER CAPITA USE

Per capita indoor water use was calculated daily for each individual study home using the daily indoor water use obtained from the flow trace analysis and the day by day reported number of residents in each house from the log sheets. Averages of per capita indoor use for the group were made from the individual daily per capita use values calculated for each identified end use. Days where it was reported that no one was at home were excluded from the set reducing the number of observed days from 513 to 507.

Leakage was the largest component of baseline indoor per capita water use among the 33 study homes, accounting for 30.3 percent of indoor demand. Toilets were the second largest component of indoor use at 22.7 percent followed by clothes washers at 16.0 percent, showers at 13.5 percent, faucets at 12.1 percent, baths at 3.9 percent, dishwashers at 1.3 percent, and

other/misc. use at 0.1 percent. Figure 3.6 shows the percentage breakdown of all indoor water uses collected form the 33 study homes.

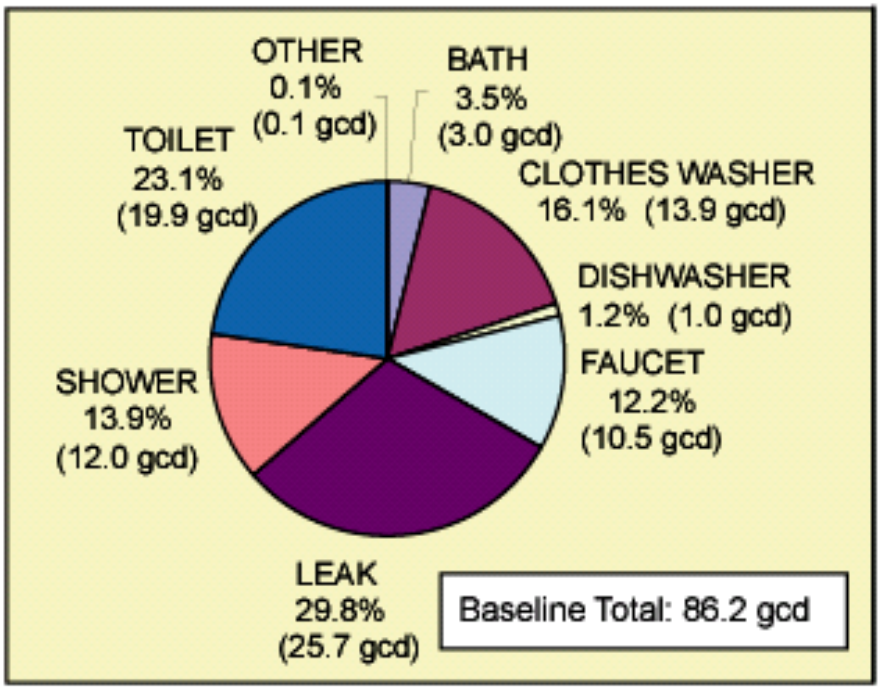


Figure 3.6 Baseline indoor per capita water use percentage including leakage

Mean Per Capita Indoor Use

The baseline average indoor per capita indoor water use in the EBMUD study homes was 86.2 gallons per capita per day (gcd) and the median was 70.2 gcd. The average for the EBMUD retrofit group was 17 gcd more than was found in the REUWS national sample which was 69.3 gcd.[12] Most of the difference was the result of the high leakage rate in the EBMUD study group, but a significant portion is also attributable to higher toilet use. This can be seen in Table 3.4 which presents the average per capita water use from the EBMUD retrofit study (pre-retrofit), the Seattle retrofit study (pre-retrofit), and the REUWS national sample.

[12] It should be noted that the number of people per household information from the REUWS is much less reliable than the data collected for the EBMUD retrofit study.

Table 3.4 Indoor Per Capita Water Use Comparison[13]

	EBMUD Retrofit Baseline		Seattle Retrofit Baseline		All REUWS	
	Average gcd	Percent	Average gcd	Percent	Average gcd	Percent
Bath	3.0	4.0%	3.7	5.8%	1.2	1.7%
Clothes Washer	13.9	16.0%	14.8	23.3%	15.0	21.6%
Dishwasher	1.0	1.3%	1.4	2.2%	1.0	1.4%
Faucet	10.5	12.1%	9.2	14.4%	10.9	15.7%
Leak	25.7	30.3%	6.5	10.3%	9.5	13.7%
Shower	12.0	13.6%	9.0	14.2%	11.6	16.7%
Toilet	19.9	22.7%	18.8	29.5%	18.5	26.7%
Other	0.1	0.1%	0.2	0.3%	1.6	2.3%
Indoor Total	86.2	100.0%	63.6	100.0%	69.3	100.0%
Sample size	*33*		*37*		*1188*	
Avg. # of residents	*2.56**		*2.54**		*2.8*	

*Number of residents during logging period

The indoor water use in the EBMUD group of 33 homes in the retrofit study was higher than the indoor use in the Seattle REUWS sample and the REUWS national sample primarily because of the high rate of leakage. Leaks aside, water use in the EBMUD and Seattle retrofit groups were quite similar. Combined shower and bath usage was higher in the EBMUD retrofit study group (15.6 gcd) than the Seattle retrofit group (12.7 gcd), and the entire REUWS study group (12.8 gcd). Clothes washer, faucet, and dishwasher usage were quite similar between the groups. The toilet use was slightly higher in EBMUD. The average number of residents per household in the EBMUD and Seattle retrofit groups were almost identical (2.55 vs. 2.54), but was higher in the REUWS group (2.8). With the exception of leakage, the per capita usage in the retrofit group appears quite typical of the demand patterns observed in the earlier REUWS research, suggesting the group is fairly typical of single family homes in the EBMUD service area and in other cities across the country.

[13] The calculation of per capita per day usage was done on a day by day, house by house basis and then the average of all individual houses was taken to calculate the overall average per capita per day use. This creates a weighted average where the water use in each household is given equal weight. The average number of residents per household was also calculated on a day by day, house by house basis. Multiplying these two weighted averages together to calculate average daily per household use results in a different value than by taking the average of daily use for each household.

Confidence intervals were calculated for each of the per capita end uses at the 95% level. These results are shown in Table 3.5. Confidence intervals are calculated using the equation:

$$C = \pm Z\left(\sigma / \sqrt{n}\right)$$

Where Z = confidence value from z-distribution table (1.96 for 95% confidence interval)

σ = the standard deviation

n = sample size

This analysis gives a measure of the range within which the true mean occurs. While not a perfect measure, because it does assume a normal distribution around the mean, the ability to perform this allows one to estimate the likelihood that changes in the mean are significant or not.

Based on this analysis the tightest confidence intervals were found for toilets, faucets, showers, and total indoor use. In all three of these categories the confidence interval was less than 8 percent of the mean. Not surprisingly these were also the most frequent end uses of water and occur virtually everyday there are people at home. End uses such as dishwashers, clothes washers, and baths that do not occur everyday are likely to have wider confidence interval measures because the standard deviation of demand is higher.

Table 3.5 Average baseline per capita use and 95% confidence intervals

	Average gcd	**95% Confidence Interval gcd**
Bath	3.0	±0.63
Clothes Washer	13.9	±2.04
Dishwasher	1.0	±0.17
Faucet	10.5	±0.63
Leak	25.7	±5.74
Shower	12.0	±0.91
Toilet	19.9	±1.02
Other	0.1	±0.08
Indoor Total	86.2	±6.83

Baseline Hot Water Usage

An innovative aspect of this study was the logging of both hot and cold water on a portion of the study group. Water meters were installed on the hot water heaters of 10 of the 33 study homes and flow recorders were attached to these meters so that hot water usage could be monitored alongside overall household usage. The hot water flow traces were disaggregated into end uses using Trace Wizard and the data were stored in the EBMUD database.

There was an average of 2.49 residents in the 10 so-called "hot water" homes during the baseline data collection period, and their average daily per capita use was 70.9 gcd. Over 21 gcd or 30 percent of the total indoor use was made up of hot water in these homes.

Overall per capita indoor use in the 10 hot water homes was significantly lower than that of the study group as a whole. Much of this was due to the lower leakage rates, however, the hot water homes used less water in all categories except toilets, faucets, and dishwashers. A comparison with the average gcd found in the entire 33 home study group is presented in Table 3.6. We attribute this use pattern to the normal variations in the group since the hot water houses were chosen in a random manner.

Table 3.6 Baseline per capita hot water use

	Baseline Hot Water Use		**Total Use in Hot Water Homes**	**EBMUD Retrofit Group**
	Average gcd	**Percent of Use Type that is Hot Water**	**Average gcd**	**Average gcd**
Bath	1.7	89.5%	1.9	3.5
Clothes Washer	1.9	15.3%	12.4	14.3
Dishwasher	1.4	100.0%	1.4	1.2
Faucet	8.6	65.2%	13.2	10.8
Leak	0.7	6.3%	11.2	27.1
Shower	6.9	71.9%	9.6	12.1
Toilet	0.0	0.0%	21.4	20.3
Other	0.02	66.7%	0.03	0.1
Indoor Total	21.1	29.8%	70.9	89.3
Sample size	*10*	*10*	*10*	*33*
Avg. # of residents	*2.49**		*2.49*	*2.55*

*Residents in homes with hot water monitoring during logging period

Not surprisingly, 100 percent of dishwasher use is made up of hot water – this is the only indoor use that is entire made up of hot water. Only 15.3 percent of clothes washer usage was hot water while 89.5 percent of baths and 71.9 percent of showers were hot water.

These results suggest that on an annual basis each person in the hot water homes is using approximately 7,702 gallons of hot water. It is calculated that the annual cost in gas and electricity charges of heating 7,702 gallons of water is approximately $28.60.[14] The calculated cost of heating 1000 gallons of water with gas is $2.82 and the cost of heating 1000 gallons of water with electricity is $7.32.

Confidence intervals were calculated for each of the per capita hot water end uses at the 95% level. These results are shown in Table 3.7. The tightest intervals were for faucets, leaks and total indoor per capita daily use. Because of the smaller sample size, the confidence intervals for the hot water group were somewhat larger than for the entire study group

Table 3.7 Confidence intervals for baseline

	Baseline Hot Water Use		Total Use in Hot Water Homes	
	Average gcd	**95% Confidence Interval gcd**	**Average gcd**	**95% Confidence Interval gcd**
Bath	1.7	±0.69	1.9	±0.78
Clothes Washer	1.9	±0.57	12.4	±3.01
Dishwasher	1.4	±0.33	1.4	±0.35
Faucet	8.6	±0.93	13.2	±1.52
Leak	0.7	±0.10	11.2	±2.55
Shower	6.9	±1.23	9.6	±1.62
Toilet	0.0	NA	21.4	±1.83
Other	0.02	±0.01	0.03	±0.03
Indoor Total	21.1	±1.98	70.9	±5.95

Leaks

The leakage rate in the EBMUD retrofit group was substantially above the average found in the REUWS, and leakage was the largest use of water in the study group. The leakage data showed a strong positive skew. That is, the mean value is greater than the median, and

consequently, there are more values less than the mean than greater. In this case, the mean per capita leakage rate was 25.7 gcd and the median leakage rate was only 4.2 gcd. It was found that 10 houses (29 percent) in the study were responsible for more than 86 percent of the total per capita leakage during the baseline period and four houses (11 percent) were responsible for an astonishing 64.5 percent of the leakage. The top two leaking homes by themselves were responsible for nearly 43 percent of the total leakage. These homes each leaked approximately 210 gcd! While leakage is clearly a major problem in this group of homes as a whole, it is really only significant problem in a small number of homes. This result is quite similar to the findings from all other study sites in the REUWS – a small number of houses are responsible for most of the leakage.

The first high leakage homes (296 gcd) had two substantial leaks. The largest was a persistent flapper leak shown in Figure 3.7. It is believed that this leak was the result of improperly seated flapper valve on a toilet in a back bathroom that is seldom used. As shown in Figure 3.8, the leak stops when the toilet is flushed about halfway through the logging period. The second leak in that home (also evident in Figure 3.7 and Figure 3.8) is a low flow-rate leak that continues throughout the flow trace. The source of this leak is not known, but a running toilet, open faucet, leaky sprinkler valve, or even a slow leaking water pipe could cause it.

The second high leakage home also had a continuous low flow leak between 0.07 and 0.11 gpm. This leak resulted in the loss of approximately 144 gallons per day. A distribution of daily per household leakage is shown in Figure 3.9.

[14] Assumptions: 80 percent of the homes heat water with gas and 20 percent heat with electricity; the water starts out at a temperature of 55 °F and is heated to 105 °F; gas costs $0.44 per Them and electricity costs $0.06 per kWh.

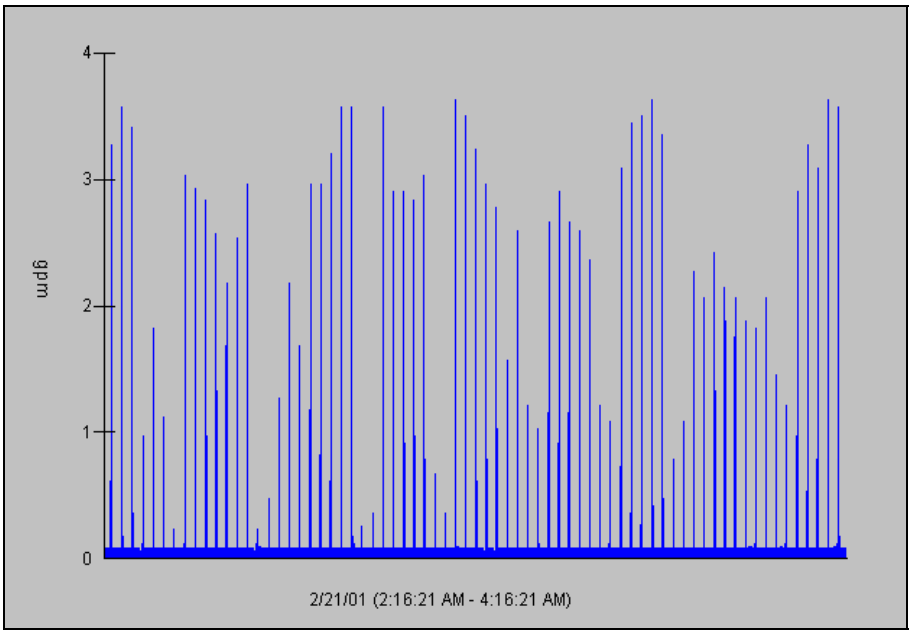


Figure 3.7 Persistent flapper leak

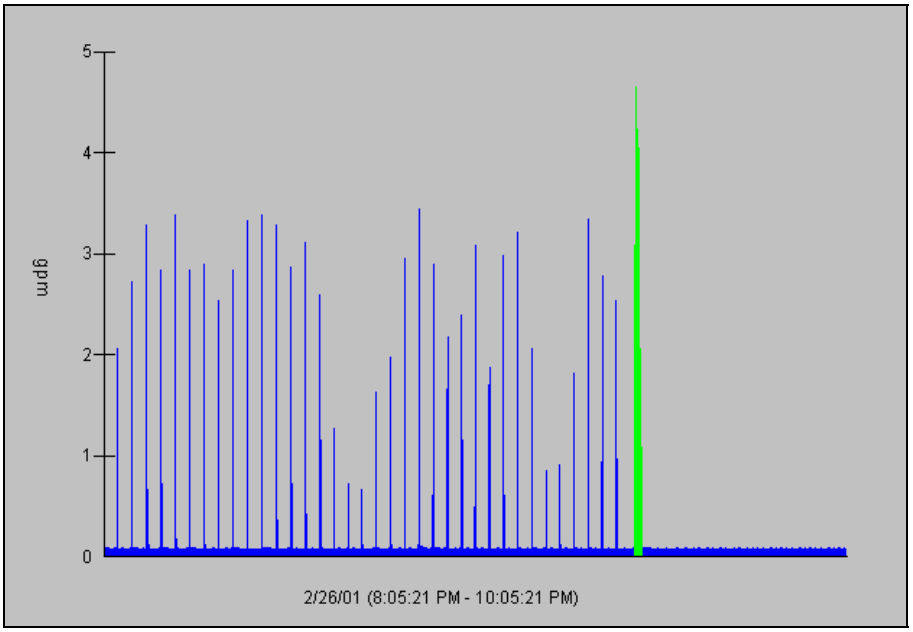


Figure 3.8 End of flapper leak with toilet flush (green)

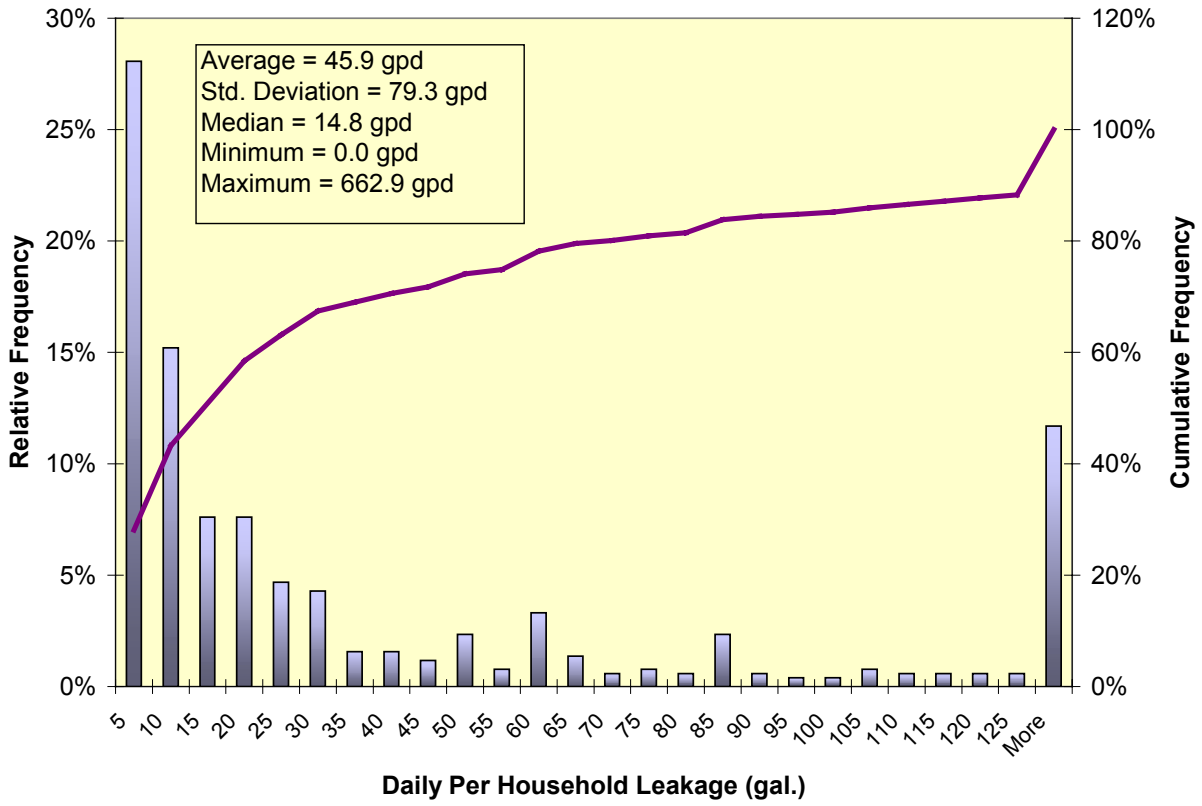


Figure 3.9 Daily per household leakage distribution, pre-retrofit study group

One possible explanation for the high leak rate that was found in some of the study participants' homes could be traced to the District's change in its water treatment process. EBMUD converted from treating water with chlorine to chloramines (chlorine and ammonia) in 1998. An August 1993 AWWA Journal article reported study results showing that chloramines have a more deleterious effect on elastomers (products widely used in plumbing distribution, especially for toilet flapper valves) than does free chlorine. When a utility converts from chlorine to chloramine, this negative effect on the elastomers tends to increase incidents of leaks in the home and in the distribution system. The plumbing industry has responded to this problem by marketing elastomer products with compounds resistant to attack by chloramines.

FIXTURE USAGE

Toilets

The data set developed for this study made it possible to calculate the number of times per day each fixture was used and the volume of use per fixture. It is important to compare these results against the fixture utilization measured after the retrofit to ensure that increased utilization is not diminishing efficiency savings, which is a commonly expressed concern.

During the baseline data collection period a total of 6,051 individual toilet flushes were recorded from the 33 study homes on 513 days for an average of 11.7 flushes per household per day and 5.14 flushes per capita per day.[15] The average flush volume across the 33 study sites was 3.88 gallons per flush (gpf) with a standard deviation of 1.28 gpf. The distribution of toilet flushing volume of all recorded flushes is shown in Figure 3.10. This distribution shows the range of flushing volumes found during the baseline data collection period. Only 7 percent of the baseline recorded flush volumes were in the low flow range (below 2 gpf). About 60 percent of the flush volumes were above 3.5 gpf and 15 percent were above 5 gpf.

The median value of flushes per capita per day (fpcd) was 4.78. A daily per capita flushing distribution for all 507 days on which toilet flushes occurred is presented in Figure 3.11. This distribution shows that 80 percent of the study homes flushed an average of seven times per person per day or less.

[15] The value of 5.14 flushes per capita per day was derived by averaging the flushes per person per day determined for each home on each day of the study. This is not the same as dividing the 6051 total flushes by the 513 days of observation and 2.55 persons per home (which gives 4.63 flushes per person per day).

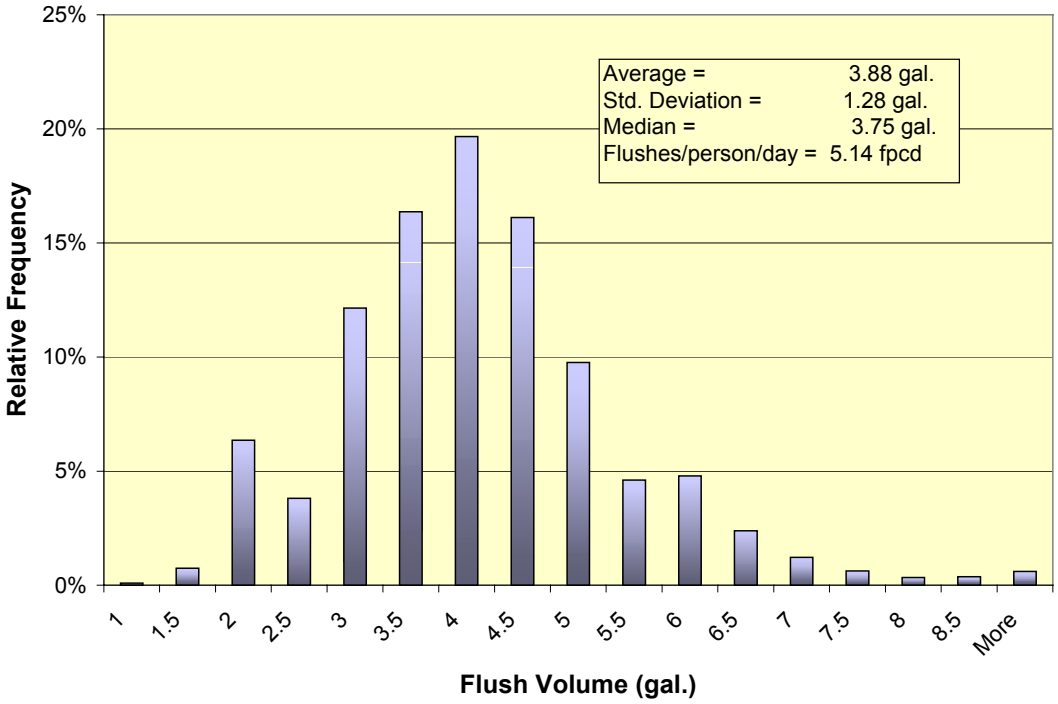


Figure 3.10 Baseline toilet flush volume distribution, pre-retrofit study group

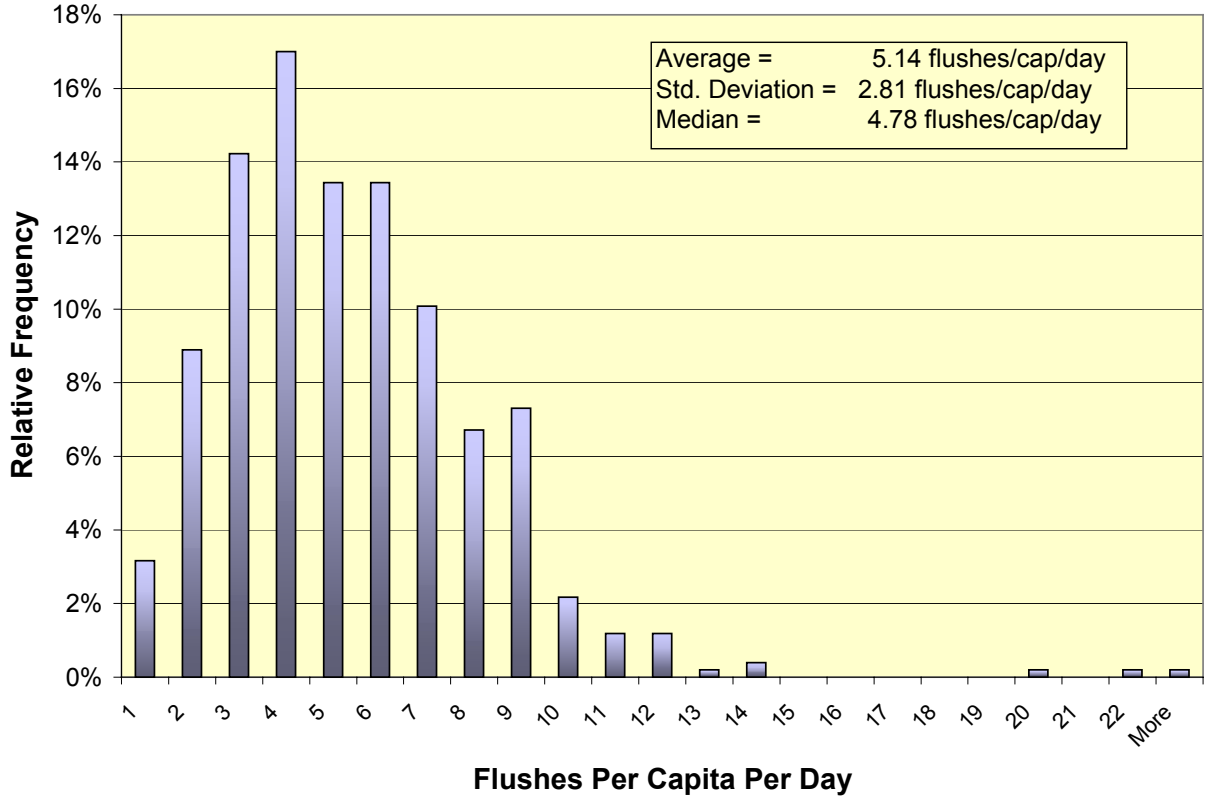


Figure 3.11 Baseline toilet flush frequency distribution, pre-retrofit study group

Showers

Showering accounted for 13.6 percent of the average per capita indoor water use during the baseline period. A total of 806 individual shower events were recorded during the baseline period for an average of 0.65 showers per person per day. In the hot water study homes (n=10) 71.9 percent of the shower water was hot water. The average shower used 18.4 gallons, lasted for 8.9 minutes, and was taken at an average flow rate of 2.0 gallons per minute (gpm). This indicates that on average, the people in the study group already shower at a flow rate substantially below the national plumbing code standard of 2.5 gpm. A similar result was found in the Seattle retrofit study and in the REUWS. This suggests that the actual water savings achievable through a showerhead retrofit may be less than has been traditionally estimated using standard engineering techniques.

The distribution of showering volumes is shown in Figure 3.12. This distribution shows that most showers (81 percent) used between 7.5 and 27.5 gallons. These results are quite similar to the showering volume calculated in the REUWS. In that study the average shower volume was 17.2 gallons and the average duration was 8.2 minutes.

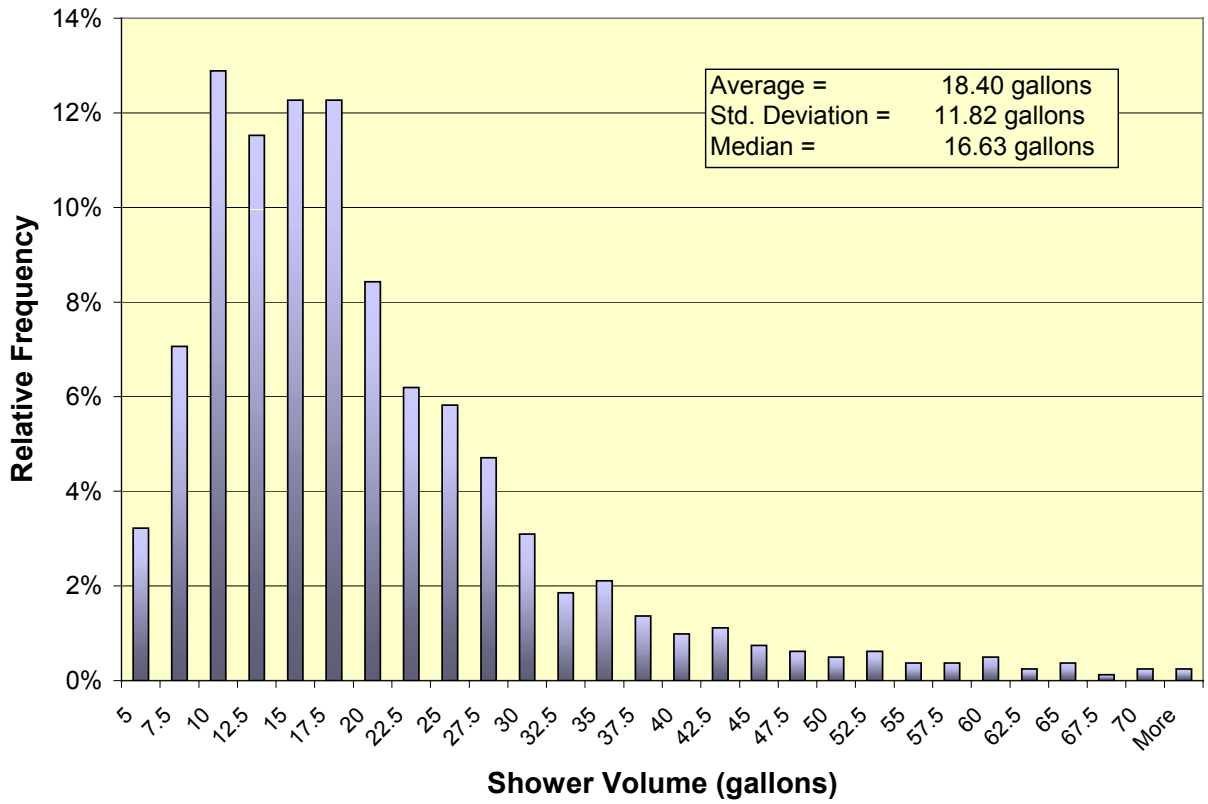


Figure 3.12 Baseline shower volume distribution, pre-retrofit study group

The distribution of shower durations for all recorded shower events during the baseline period is shown in Figure 3.13. In this figure, 77.51 percent of all showers were between 3 and 12 minutes in length with a mean of 8.9 minutes and a standard deviation of 4.4 minutes. Less than 10 percent of all showers were longer than 15 minutes in duration.

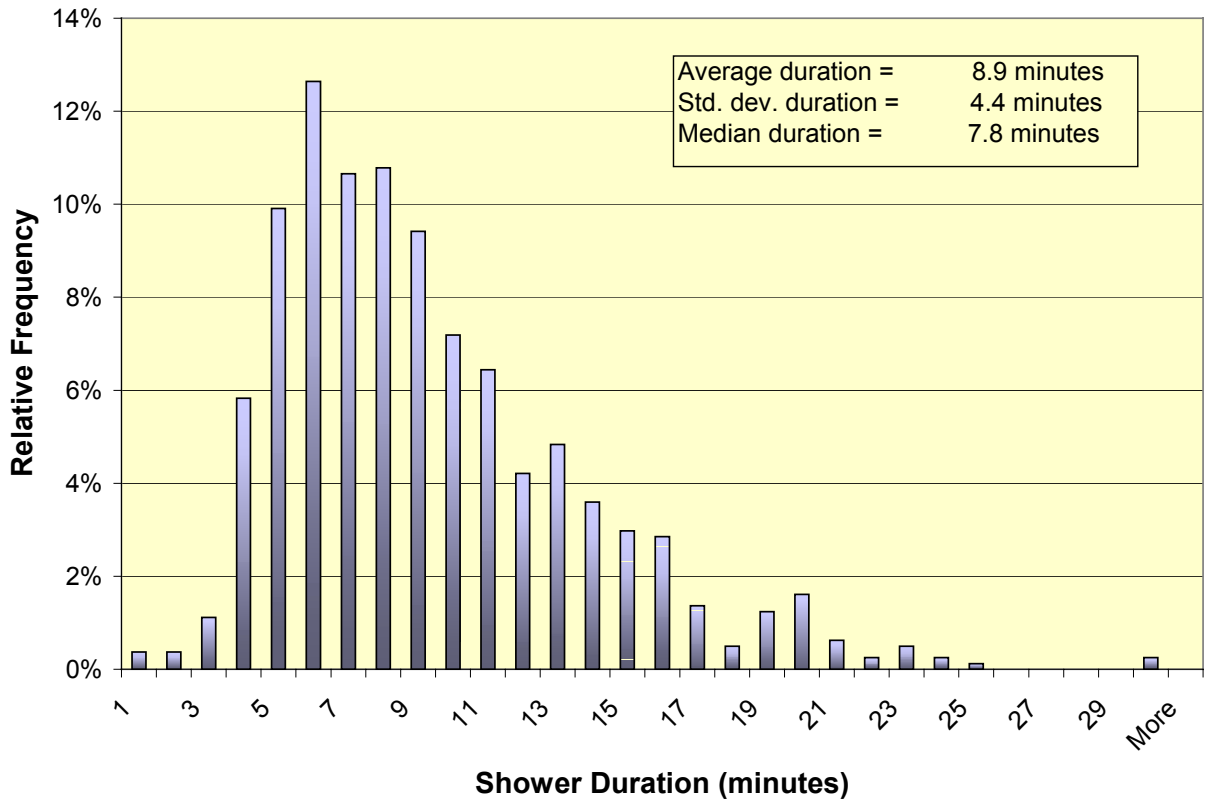


Figure 3.13 Baseline shower duration distribution, pre-retrofit study group

The distribution of shower flow rates for all recorded showers during the baseline period is shown in Figure 3.14. 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 is 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 during the baseline period was 2.0 gpm with a median of 1.89 gpm and a standard deviation of 0.96 gpm. The distribution of shower flow rates drops off sharply after the 2.25 gpm flow rate and appears less regular than either the distribution of shower volumes or the distribution of shower durations. More than 84 percent of the showers recorded during the baseline period were taken at a flow rate below 2.5 gpm, which suggests that flow rate reductions may only be accomplished on roughly 16 percent of the showers as a result

of the showerhead retrofit. All of the shower distributions shown in this section are compared against post retrofit distributions later in this report.

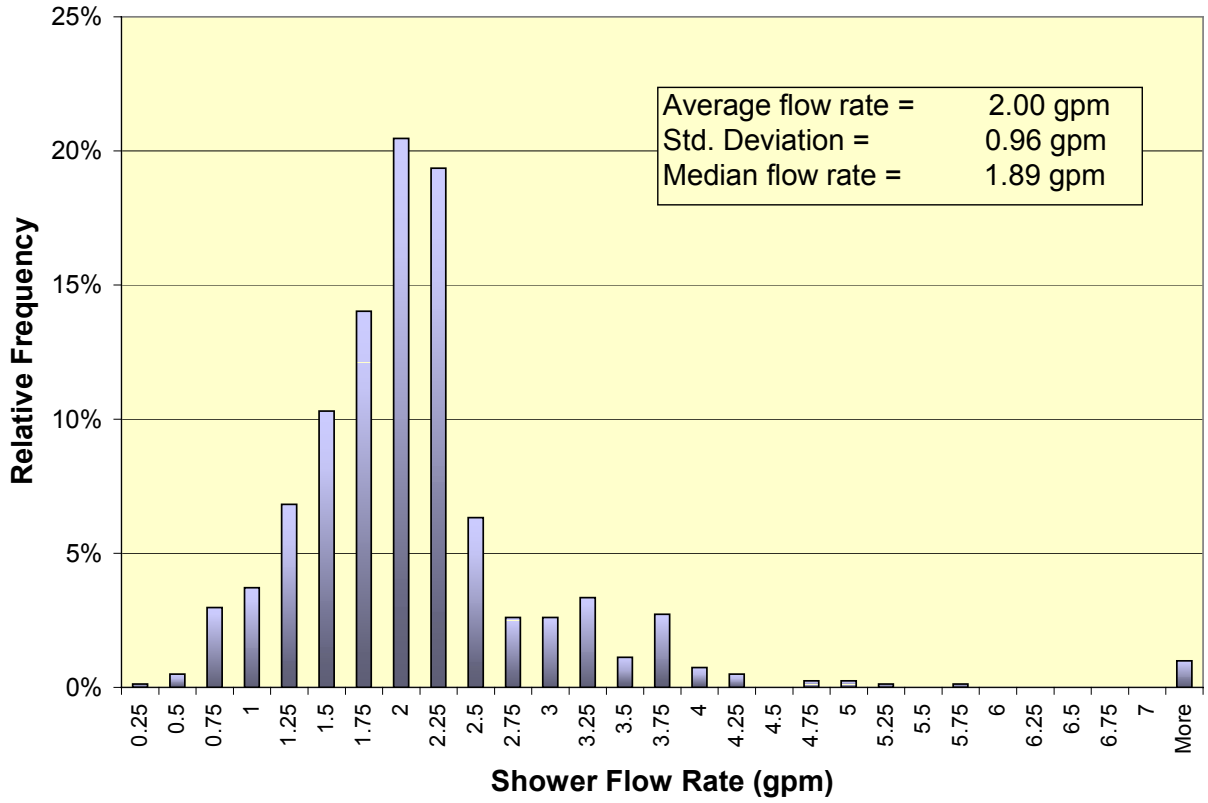


Figure 3.14 Baseline shower flow rate distribution, pre-retrofit study group

Clothes Washers

All of the homes in this study had to have a washing machine as a requirement of participation. A total of 425 loads of laundry were washed in the 33 study homes during the baseline period for an average of 0.36 loads of laundry per person per day, a use rate which is quite consistent with previous findings.

The average volume used to wash a load of clothes was 40.7 gallons with a standard deviation of 9.8 gallons. Nearly 89 percent of the washer loads used 50 gallons of water or less and 99 percent of the washer loads used less than 70 gallons of water. In the three loads that used more than 70 gallons it appeared that one or more extra rinse cycles were used. The largest individual cycle (wash or rinse) observed was approximately 38 gallons.

A few sample clothes washer flow traces from Trace Wizard are presented below. Figure 3.15 shows a 1995 Maytag Super Capacity washer. The total volume for this load of clothes was 45.0 gallons. The four cycles shown include the wash cycle, two rise cycles, and a spin cycle. This machine often operated with only a single rinse cycle.

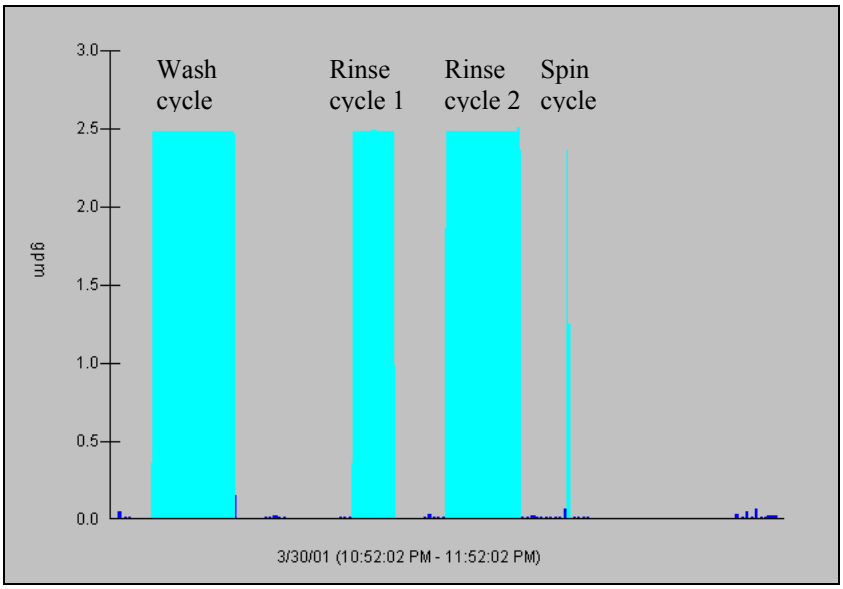


Figure 3.15 Sample clothes washer flow trace, 1995 Maytag Super Capacity

Figure 3.16 shows a 1990 Whirlpool Heavy Duty model clothes washer. The total volume for washing this load of clothes was 40.6 gallons. The two sets of short spike-like cycles are spin cycles.

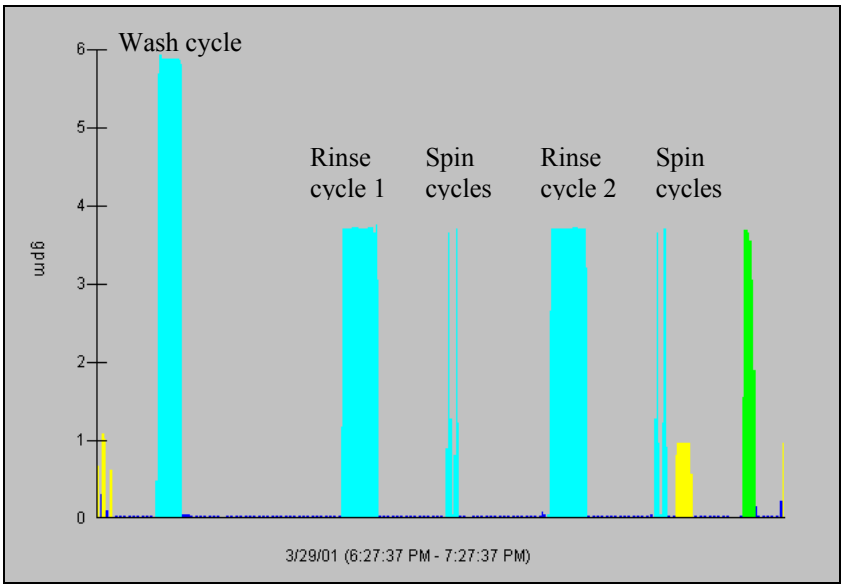


Figure 3.16 Sample clothes washer flow trace, 1990 Whirlpool Heavy Duty

Results from the hot water homes show that 15.3 percent of the water used for clothes washing is hot water. This was substantially lower than the 27.8 percent found in the Seattle retrofit study. From the 10 hot water flow traces, it appears that the first cycle (the wash cycle) is typically the only cycle to contain any hot water. Subsequent cycles (rinse and spin cycles) are almost exclusively cold water with a few exceptions. In the EBMUD homes many of the clothes washer cycles contained no hot water at all.

Given the average volume per load of clothes found during the baseline period there appears to be considerable opportunity for conservation savings with the new conserving machines if they actually meet their advertised usage of no more than 30 gallons per load.

Dishwashers

A total of 155 loads of dishes were washed by machine during the baseline study period. On average, dishwashers were used 0.13 times per person per day – about 0.9 times per person per week. The average load of dishes used 8.9 gallons of water. The maximum amount of water used by any dishwasher was 18.2 gallons. More than 80 percent of the dishwashers in the study homes used between 6 and 12 gallons per load.

All of the water used in the dishwashers was hot water. So, while the volume of their use is relatively small they are significant energy users.

Faucets

Faucet use accounted for 12.1 percent of the total indoor water use during the baseline study period and 65.2 percent of faucet use was made up of hot water. A useful means of evaluating faucet utilization is to calculate the duration faucets are utilized per capita per day. During the baseline period it was found that faucets were used an average of 10.4 minutes per person per day. In the REUWS, faucet use averaged 8.1 minutes per person per day.

The typical baseline faucet flow rate was 1.2 gpm, based on an analysis of the mode faucet flow rates calculated using Trace Wizard. Typical peak baseline faucet flow rate was 2.9 gpm. Similar to the situation with showers, it appears that many of the homes in this study either

already have faucet flow restrictors or simply throttle their faucets below the 2.2 gpm federally establish low flow rate.

Baths

Because baths require a fixed amount of water, this conservation retrofit program is not expected to reduce bath water usage. With the increasing popularity of larger Jacuzzi tubs in the past decade, it seems likely that there could be an increase in per capita bath water usage.

During the baseline period, the average bath used 28.5 gallons of water. The maximum bath usage was 89.9 gallons[16]. Baths in the hot water homes were 89.5 percent hot water and 11.5 percent cold water. Study residents took an average of 0.12 baths per person per day or 0.84 baths per person per week. The nine households with children were responsible for more than half of the baths recorded during the baseline period. Average per capita bath usage in households without any children under the age of 13 was 3.03 gcd; in households with one child the bath average was 4.52 gcd; and in households with two or more children the bath average was 6.17 gcd.

Twenty of the 33 study homes (57 percent) took at least one bath during the baseline data collection period. Information on bathing habits (time and frequency) was collected during the audit portion of the study and this information proved useful during the flow trace analysis process enabling baths to be identified with greater confidence. The hot water traces were also helpful in accurately identifying baths.

MAXIMUM DAY DEMANDS

Maximum demands are often the driving factor for facility expansions and facility design. While interior retrofits are not designed with the intention of reducing peak instantaneous and peak day demand they may achieve this goal anyway.

The maximum day water use for each household in the study was calculated and plotted from the highest to lowest in Figure 3.17. The average maximum day during the baseline data collection period was 445 gallons. The largest maximum day household was 2241 gallons.

Because the baseline data collection period extended from winter into spring, outdoor use began to become more frequent at the end of the data collection period. Typically it is outdoor demand that drives peak day usage in the single-family sector.

The peak instantaneous demand distribution of all 531 baseline logged days is shown in Figure 3.18. The average peak instantaneous demand was only 6.1 gpm and the maximum peak demand was 13.0 gpm. In the REUWS, the average peak instantaneous demand was 8.2 gpm and the maximum peak was 64.6 gpm. The flows in the EBMUD retrofit study group were considerably smaller primarily because demand during the baseline period was primarily indoors. High peak flows are typically observed during automatic irrigation. Baseline peak flows in the Seattle retrofit study were slightly lower because there was even less outdoor use during that logging period.

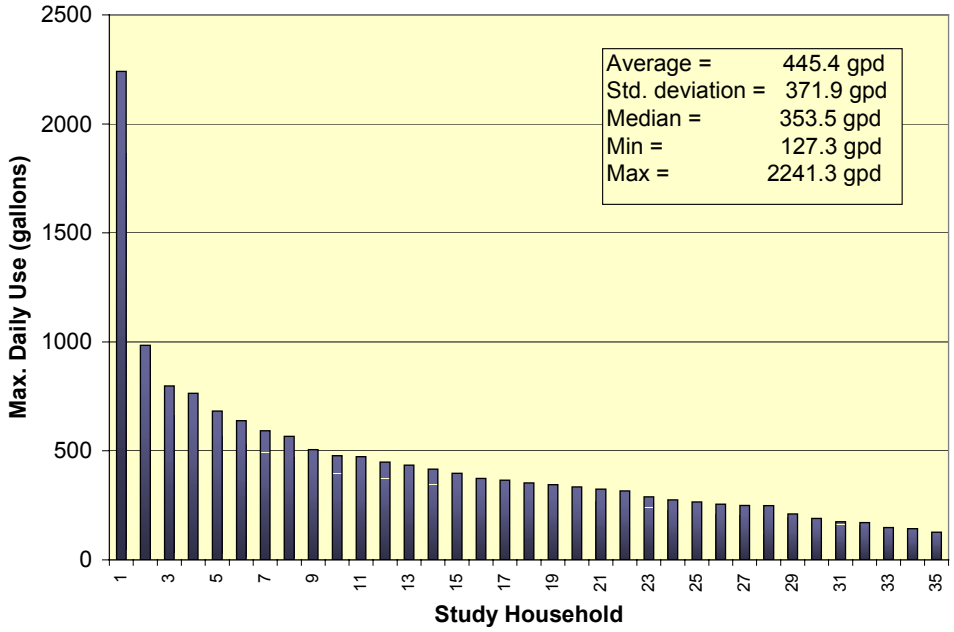


Figure 3.17 Baseline pre-retofit peak day demand for each study house

[16] This house was equipped with a large Jacuzzi tub and water was added several times during the bath.

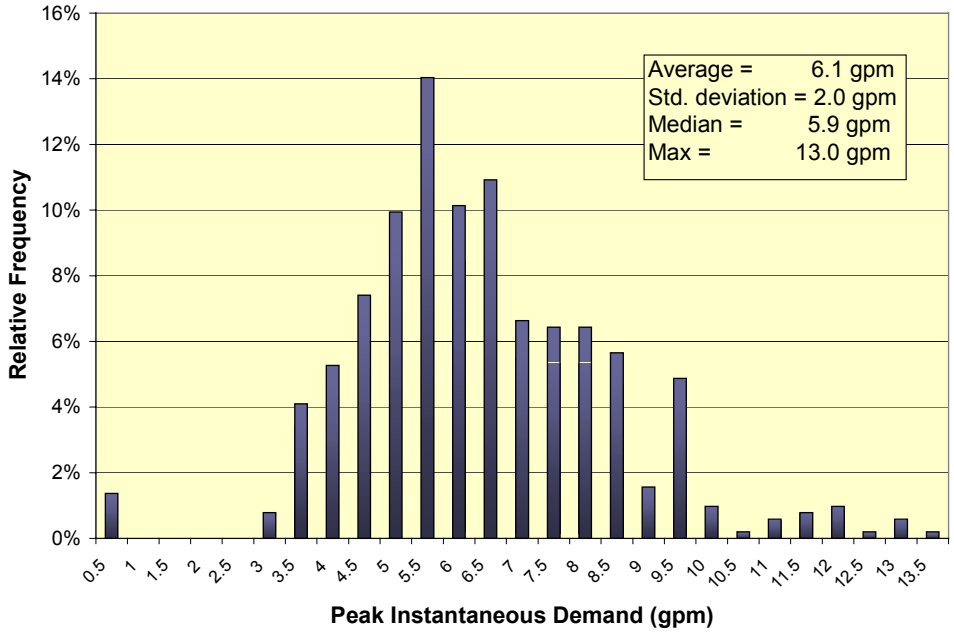


Figure 3.18 Baseline pre-retrofit peak daily instantaneous demand distribution

CHAPTER 4 POST-RETROFIT RESULTS

The installation of conserving fixtures in 34 of the 35 participating study homes was begun in June 2001 and completed in stages by December 2001 and the first set of post-retrofit end use data was collected during the period from August 8, 2001 to January 10, 2002.[17] In June 2002, the participants completed a detailed opinion survey about their experience with the conserving fixtures and the second and final set of post-retrofit data was collected from May 29 to July 23, 2002. By the conclusion of the study two homes opted to drop out, leaving the final study group size at 33. Additionally, billing data from the entire sample of 1,000 homes were obtained through the August 2002 billing period. Aquacraft analyzed all of these data and the results are presented below.

COMPARISON OF WATER USE DURING LOGGING PERIODS

It was clear that the data analysis would be greatly simplified if the data from the two post-retrofit logging periods could be combined into a single group. Consequently, one for the key analyses involved a comparison of the two post-retrofit logging sessions against each other. If the results of this showed that the two were similar statistically, then it would possible to combine them for the comparison against the baseline use upon which the assessment of the retrofits would then be performed.

Table 4.1 shows a comparison of the mean daily indoor per capita water use during the three logging periods. After the installation of the conserving fixtures, the mean daily indoor per capita water use dropped from 89.3 gcd to approximately 52 gcd, which represents a 42 percent reduction. This is based on one baseline and two post-retrofit logging periods in which end use data were obtained from all 33 participating households for a total of 910 days. It should be noted that the per capita water use was determined for each home based on the number of people in the home each day of the study. Days in which no one was home, i.e. days with 0 occupants, had to be excluded from the data set to avoid the mathematical impossibility of dividing by zero.

[17] The residents in one household (Keycode #22014) moved during the retrofit period and subsequently this home was excluded from all aspects of the study.

In order to test whether the observed variation in means is significant, the per capita daily use from the three data collection periods were compared through a series of paired *t-tests* at a 95 percent confidence level. The null hypothesis in each test was that the mean daily per capita indoor use in the compared logging periods were equal; the alternate hypothesis was that they were not equal. The t-test results are shown in Table 4.2.

The difference between the baseline and post-retrofit water use was found to be significant at the 95 percent confidence level. This result indicates the observed reductions in per capita demand were not due simply to random chance. On the other hand, the difference between the two post-retrofit logging periods was found to be *not significant* at this confidence level. This result indicates that there was no statistical difference between the water use during the two post-retrofit logging periods, and allowed the data sets to be combined into a single data set, which was used to compare pre and post-retrofit water use.

Table 4.1 Mean daily indoor per capita use comparison – 3 logging periods

	n (logged days)	Mean daily indoor per capita use (gcd)	Variance	Standard Deviation	95% Conf Int
Baseline	481	89.3	6156.0	78.5	6.85
Post-Retrofit 1	455	50.3	843.4	29.0	2.70
Post-Retrofit 2	451	54.1	1346.9	36.7	3.32

Table 4.2 Comparison tests of baseline and post-retrofit indoor per capita water use

	Mean difference in indoor daily per capita use (gcd)	Degrees of Freedom	t-Value	P-Value	95% Lower Limit	95% Higher Limit	Statistically significant difference?
Baseline vs. Post-Ret. 1	39.3	934	9.35	<.0001	28.8	44.1	Yes
Baseline vs. Post-Ret. 2	35.2	930	8.07	<.0001	24.7	40.6	Yes
Post-Ret. 1 vs. Post-Ret. 2	3.8	904	-1.73	0.0841	-8.1	0.5	No

Demographic Information

In order to improve the accuracy of the per capita measurements each household was asked to report the number of people in residence during each logging day. The average number of people per household during the baseline logging period was 2.56, which is lower than the 2.74 full time residents reported during audits. During the post-retrofit logging periods the

average number of people per household was 2.52 – similar to the number reported during the baseline logging period.

DAILY HOUSEHOLD USE

When the post-retrofit data were used to compare water use before and after the retrofits a clear pattern of reduction was noted. Figure 4.1 shows a scatter diagram of total indoor water use before and after the retrofit for each logging day. The figure shows that there were more high demand days during the baseline period. The mean daily indoor demand, which was 191.0 gpd per household during the baseline period, dropped 35.5% to 123.3 gpd after the installation of the new devices. On an annual basis this equates to an indoor use of 69.7 kgal for baseline conditions and 45.0 kgal with the retrofit.

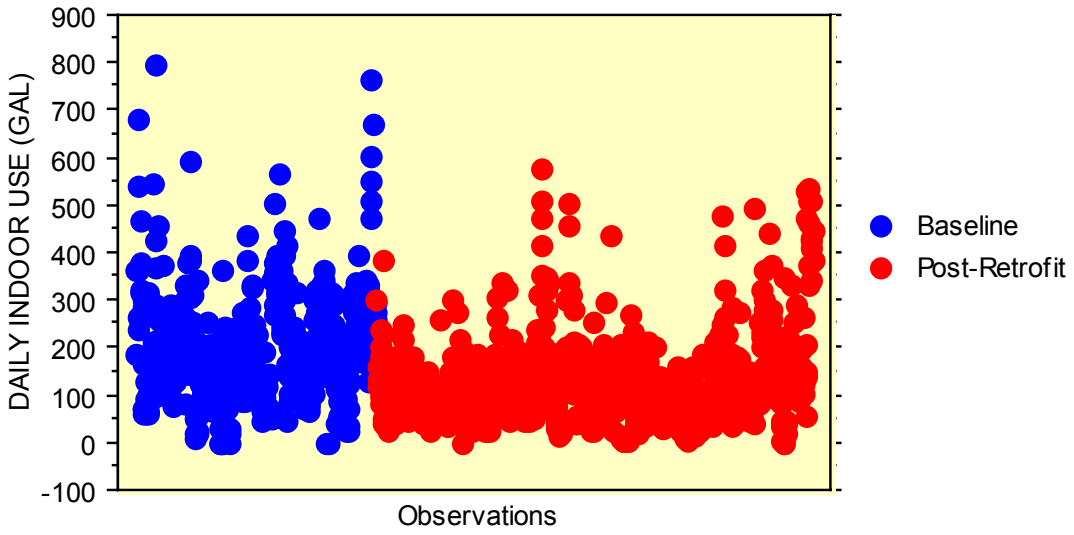


Figure 4.1 Scatter diagram of daily indoor per household use, pre and post-retrofit

These data are plotted as a histogram (frequency diagram) in Figure 4.2. Here the change in demand brought about by the retrofit can be seen in the shift of the demand distribution to the left. The effectiveness of the retrofits in reducing daily demand can be seen from the fact that while during the baseline period indoor use fell below 300 gallons 85 percent of the time, in the post-retrofit period it fell below this level 95 percent of the time.

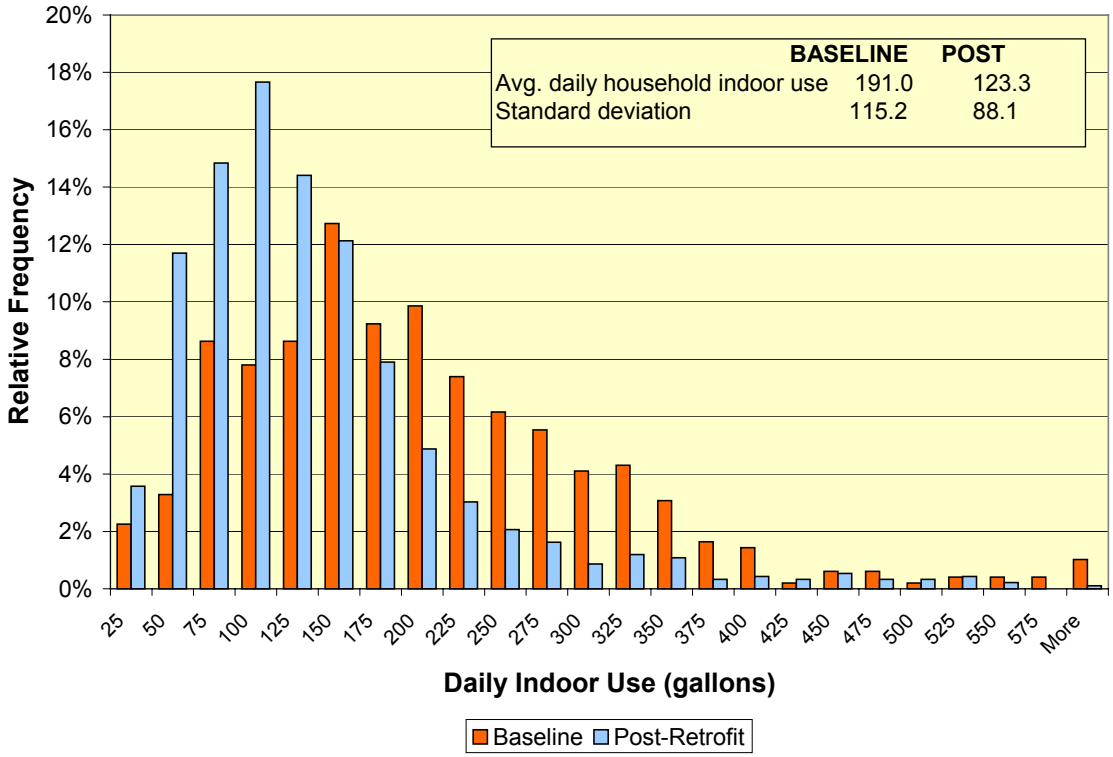


Figure 4.2 Daily per household indoor water use distributions, pre and post-retrofit

INDOOR PER CAPITA USE

Indoor water use patterns changed dramatically after the conservation retrofit. Average daily per capita use decreased in 31 on the 33 study homes. In the two homes where per capita use increased, the change was less than 2.2 gcd in each case. A comparison of the baseline and post-retrofit average per capita daily use is shown in Figure 4.3. In this figure the data are sorted from highest to lowest baseline per capita use. This result shows that a good portion of the water savings came from a relatively few participants.

After the retrofit, leakage (17.1 percent), which had previously been the largest component of indoor use dropped below toilets into fourth place. Toilets (18.6 percent), which have previously been the second largest component of indoor use moved into third place behind faucets. Showers became the largest indoor water use followed by faucets and toilets. A pie chart showing the relative importance of each per capita end use is shown in Figure 4.4. The combination of showers and baths form the largest block of indoor use in the post-retrofit era at 25.5 percent.

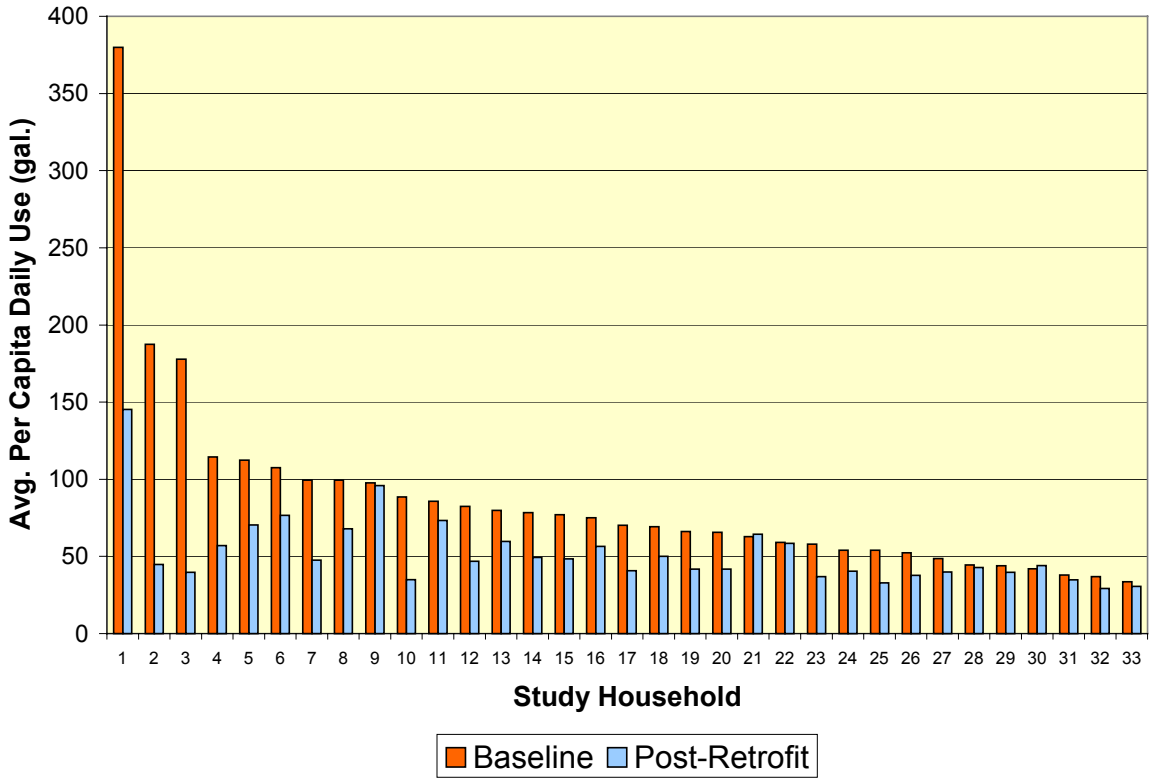


Figure 4.3 House by house average per capita daily use comparison, baseline and post-retrofit

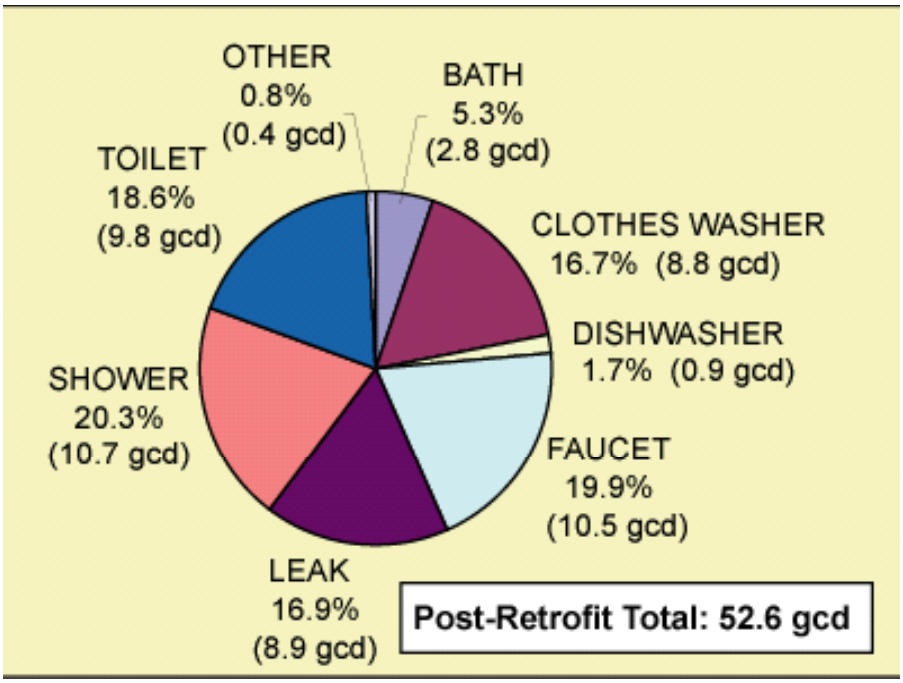


Figure 4.4 Post-retrofit indoor per capita water use percentage including leakage

Table 4.3 presents a comparison of the mean indoor per capita water use from the baseline and post-retrofit data collection periods. Overall, indoor water use decreased by 33.6 gcd – a 39.0 percent drop. A series of paired *t-tests* were performed on each end use in these two data sets to determine which changes in water use are statistically significant at the 95 percent confidence level. The results of this analysis are also presented in Table 4.3 as the t-Value and P-Value from the t-test. In order for a difference in means to qualify as statistically significant, the P-Value must be less than the alpha level of 0.05, the 95 percent confidence level. Statistically significant changes in water use were detected for clothes washers, leaks, toilets, indoor use, miscellaneous other use, and total indoor use.

More than 30 gallons of the 33.9 gcd average saved through the retrofit was the result of three end uses: toilets, clothes washers, and leaks. Installation of ULF toilets, including some dual flush models saved an average of 10.1 gcd. The new conserving clothes washers saved an average of 5.1 gcd. A reduction in leakage resulted in big savings of 16.8 gcd. The leakage savings were almost certainly the result of the toilet retrofit. Toilet leaks, primarily flapper leaks, are the single largest contributor to household leakage. In this study, replacing old toilets through the retrofit eliminated almost all of these toilet leaks and resulted in substantial savings. None of the other measures implemented through this study (clothes washers, showerheads, or faucet aerators) should have had any impact on the leakage rate. A more detailed analysis of leakage is presented later in this report.

It is interesting to note that after the retrofit, statistically significant reductions in water use occurred in many of the end use categories impacted by the retrofits: toilets, leaks and clothes washers. Showers and faucets did *not* show any significant water use reduction, even though new showerheads and faucet aerators were installed. The remaining categories not targeted by the retrofit (baths and dishwashers) also showed no statistically significant change. Specific end uses are examined in more detail in the next section.

Table 4.3 Mean indoor per capita water use, baseline and post-retrofit[18]

Category	Baseline (gcd)	Post-Retrofit (gcd)	Difference in Means (gcd)	% Change	t-Value	P-Value	Statistically significant difference?*
Bath	3.0	2.8	-0.2	-6.6%	0.578	0.5674	No
Clothes washer	13.9	8.8	-5.1	-36.7%	4.762	<0.0001	Yes
Dishwasher	1.0	0.9	-0.1	-10.0%	1.860	0.0720	No
Faucet	10.5	10.5	0.0	0.0%	0.030	0.9759	No
Leak	25.7	8.9	-16.8	-65.4%	2.158	0.0385	Yes
Shower	12.0	10.7	-1.3	-10.8%	1.959	0.0589	No
Toilet	19.9	9.8	-10.1	-50.8%	9.129	<0.0001	Yes
Indoor	86.1	52.2	-33.9	-39.4%	3.987	0.0003	Yes
Other/Unknown	0.1	0.4	0.3	75.0%	-2.614	0.0004	Yes
Total	86.2	52.6	-33.6	-39.0%	3.942	0.0004	Yes
Avg. # of Residents per household	2.56	2.52					

*95 percent confidence level

Post-Retrofit Hot Water Usage

Water meters were installed on the hot water heaters of 10 of the 33 study homes and flow recorders were attached to these meters so that hot water usage could be monitored alongside overall household usage. The hot water flow traces were disaggregated into end uses using Trace Wizard and the data were stored in the EBMUD database created for this project.

There were an average of 2.29 residents in the 10 so-called "hot water" homes during the post-retrofit data collection period, and the average daily indoor per capita use in these homes was 55.8 gcd compared with 52.6 for the larger 33 home retrofit group.

Overall per capita indoor use in the 10 hot water homes was similar to the study group as a whole, differing by 3.2 gcd. A *t-test* test performed on the two data sets found no statistical difference between the means at the 95 percent confidence level.

Toilet flushing was the only indoor use that had no hot water component. Only 7 percent of the total leaks were composed of hot water. These results and a comparison with the average

[18] The calculation of per capita per day usage was done on a day by day, house by house basis and then the average of all individual houses was taken to calculate the overall average per capita per day use. This creates a weighted average where the water use in each household is given equal weight. The average number of residents per household was also calculated on a day by day, house by house basis. Multiplying these two weighted averages together to calculate average daily per household use results in a different value than by taking the average of daily use for each household.

gcd found in the entire 33 home study group are presented in Table 4.4. In the post-retrofit period, 30 percent of all water used indoors, 16.5 gcd, was hot water. On a daily basis, the most hot water (83.3 percent) was used for faucets, showers, and baths.

A comparison of hot water usage during the baseline and post-retrofit periods is shown in Table 4.4. Here it can be seen that in the post-retrofit period, the study participants used an average of 4.6 gcd less hot water than during the baseline period. A series of unpaired *t-tests* assuming unequal variances were performed to compare the baseline and post-retrofit hot water end uses. The results of these tests are presented in Table 4.5. These tests showed that a statistically significant difference in mean water use before and after the retrofit was detected for the following categories: clothes washers, faucets, and total indoor use.

The total hot water use dropped by 4.6 gcd after the retrofits, and it appears that nearly all of these savings can be attributed to the retrofit program. Theoretically the retrofit program could have impacted clothes washers, faucets, showers, and total indoor hot water use. Although hot water use declined in almost all end use categories, the change in shower use was found to be not statistically significant, but the reductions in clothes washer and faucet use were significant. The retrofit had no impact on leaks of hot water.

Table 4.4 Post-retrofit per capita hot water use

	Post-Retrofit Hot Water Use		**Total Use in Hot Water Homes**	**EBMUD Retrofit Group**
	Average gcd	**Percent of Indoor Use that is Hot Water**	**Post-Retrofit Average gcd**	**Post-Retrofit Average gcd**
Bath	1.5	75.0%	2.0	2.8
Clothes Washer	1.0	10.1%	9.1	8.8
Dishwasher	1.0	100.0%	1.0	0.9
Faucet	6.2	50.0%	12.4	10.5
Leak	0.7	7.1%	9.9	8.9
Shower	6.0	60.0%	10.0	10.7
Toilet	0.0	0.0%	11.2	9.8
Other	0.01	50.0%	0.2	0.4
Indoor Total	16.5	29.6%	55.8	52.6
Sample size	10	10	10	33
Avg. # of residents	2.3	2.3	2.3	2.5

Table 4.5 Comparison of baseline and post-retrofit per capita hot water use

Category	Baseline Hot Water Use (gcd)	Post-Retrofit Hot Water Use (gcd)	Difference (gcd)	% change	t-Value	P-Value	Statistically significant difference?*
Bath	1.7	1.5	-0.2	-11.8%	0.209	0.8395	No
Clothes Washer	1.9	1.0	-0.9	-47.4%	3.180	0.0112	Yes
Dishwasher	1.4	1.0	-0.4	-28.6%	1.565	0.1520	No
Faucet	8.6	6.2	-2.4	-27.9%	4.502	0.0015	Yes
Leak	0.7	0.7	0.0	0.0%	-0.165	0.8723	No
Shower	6.9	6.0	-0.9	-13.0%	1.183	0.2673	No
Toilet	0.0	0.0	0.0	0.0%	na	na	na
Other/Unknown	0.02	0.01	-0.01	-50.0%	0.519	0.6164	No
Indoor Total	21.1	16.5	-4.6	-21.8%	2.891	0.0179	Yes
Avg. # of Residents per household	2.3	2.3					

*95 percent confidence level

Analysis of Water Savings Excluding Leaks

Because of the high level of leakage found in the study homes both before and after the retrofit, it was decided to examine the water savings exclusive of leakage. Leakage accounted for 30.3 percent of indoor per capita use prior to the retrofit and 17.1 percent after the retrofit. A specific analysis of leakage is presented later in this report. Results of the analysis excluding leaks are presented in Table 4.6.

The average baseline per capita per day indoor use – excluding leaks – was 60.3 gcd and the post-retrofit average was 43.5 gcd. By ignoring leaks both in the baseline and post-retrofit period, the per capita water savings in indoor use becomes 16.8 gcd – a 27.86 percent reduction in demand. This reduction was found to be significant at the 95 percent confidence level. This analysis does not change any of the specific fixture results discussed earlier.

Evaluating the savings achieved through the retrofit without reference to leakage was recommended by EBMUD utility staff since it is anticipated that leakage of the level discovered in this study group may not be prevalent throughout all single-family customers in the service area. It is important to keep in mind that the retrofit study group was selected specifically because they had a relatively high per capita daily usage compared with other customers, likely

in large part due to leaks. As a result, it may be misleading to suggest that the savings through reduced leakage could be achieved in a more broad-based group of EBMUD residences.

Table 4.6 Comparison of baseline and post-retrofit per capita daily use – excluding leaks

Category	Baseline (gcd)	Post-Retrofit (gcd)	Difference in Means (gcd)	% Change	t-Value	P-Value	Statistically significant difference?*
Bath	3.0	2.8	-0.2	-6.60%	0.578	0.5674	No
Clothes washer	13.9	8.8	-5.1	-36.70%	4.762	<0.0001	Yes
Dishwasher	1.0	0.9	-0.1	-10.00%	1.86	0.072	No
Faucet	10.5	10.5	0	0.00%	0.03	0.9759	No
Shower	12.0	10.7	-1.3	-10.80%	1.959	0.0589	No
Toilet	19.9	9.8	-10.1	-50.80%	9.129	<0.0001	Yes
Indoor	60.3	43.5	-16.8	-27.86%	7.631	<0.0001	Yes
Other/Unknown	0.1	0.4	0.3	75.00%	-2.614	0.0004	Yes
Total	60.4	43.9	-16.5	-27.32%	7.471	<0.0001	Yes
Avg. # of Residents per household	2.56	2.52					

*95 percent confidence level

FIXTURE USAGE

Toilets

During the post-retrofit data collection period a total of 11,859 individual toilet flushes were recorded from the 33 study homes over 923 days; for an average of 12.8 flushes per household per day and 5.74 flushes per capita per day[19]. After the ULF fixtures were installed, the average flush volume across the 33 study sites for ULF toilets only was 1.48 gallons per flush (gpf) with a standard deviation of 0.44 gpf. Since not all toilets in the 33 study homes were replaced there remained a number of non-ULF toilet flushes in the post-retrofit data set. When these flushes are included the average flush volume increased to 1.65 gpf with a stand deviation of 0.87 gpf. For purposes of comparing flush volumes, flushing frequency and per capita use the non-ULF flushes *were included* in the analysis. During the baseline period the average flush

[19] The value of 5.74 flushes per capita per day was derived by averaging the flushes per person per day determined for each home on each day of the study. This is not the same as dividing the 11,859 total flushes by the 923 days of observation and 2.5 persons per home (which gives 5.12 flushes per person per day).

volume was 3.88 gpf, so the new fixtures reduced the average flush volume by 2.23 gpf, a 57 percent reduction.

The distributions of the volumes of all recorded toilet flushes in the baseline and post-retrofit periods are shown in Figure 4.5. These distributions shows the range of flushing volumes found during the baseline and post-retrofit data collection periods. Five households in the study group kept one (or more) of their old non-conserving toilets and these higher volume flushes can be seen in the 3 – 6 gpf range of the post-retrofit distribution.

During the baseline period, only 7 percent of the recorded flush volumes were in the low flow range (below 2 gpf), about 60 percent of the flush volumes were above 3.5 gpf, and 15 percent were above 5 gpf. During the post-retrofit period 87 percent of the toilet flushes were in the low flow range. A *t-test* (two tail) assuming unequal variances was conducted at the 95 percent confidence level to determine with there was a significant difference between the mean flush volume during the baseline period and the post-retrofit period. The t-Value in this test was 118.25 and the P-Value was <0.00001, clearly indicating a statistically significant difference between the two mean flush volumes at the 95 percent confidence level. Thus the conclusion can be made that the installation of the ULF toilets in the study homes resulted in substantial reduction in toilet water usage in these study homes.

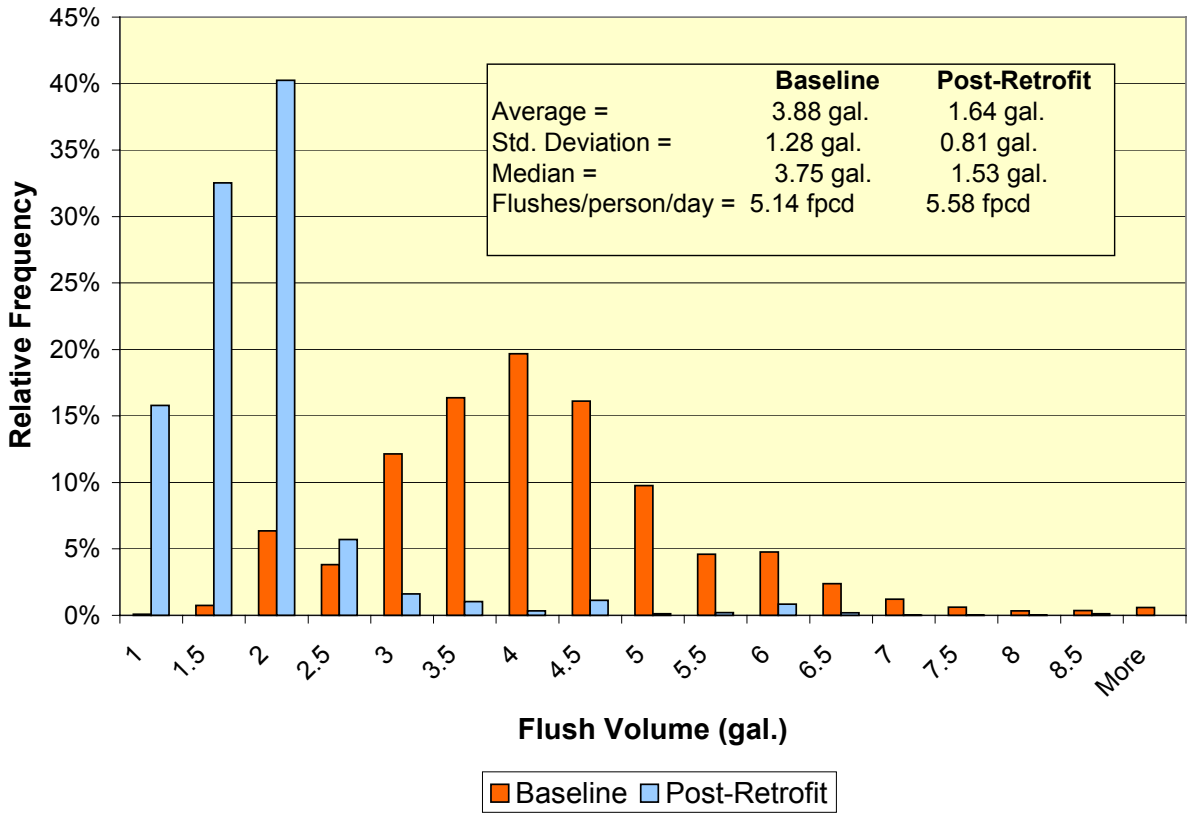


Figure 4.5 Toilet flush volume distribution, baseline and post-retrofit

Flushes per capita per day

Double-flushing has been a concern about ULF toilets ever since they were introduced. Critics have charged that it takes two flushes of a ULF toilet to do the job. The data collected in this study provided another opportunity to test if flushing frequency increases with the installation of ULF toilets[20].

During the baseline period, residents in the EBMUD retrofit study group flushed the toilet an average of 5.14 times per capita per day (fpcd). During the post-retrofit period the average number of flushes per person per day increased to 5.74 fpcd. The daily per capita flushing frequency distributions for the baseline and post-retrofit periods is shown in Figure 4.6.

[20] See Mayer and DeOreo (1999), pg. 131, which discusses the lack of evidence for significant double flushing in the 1188 homes of the REUWS study.

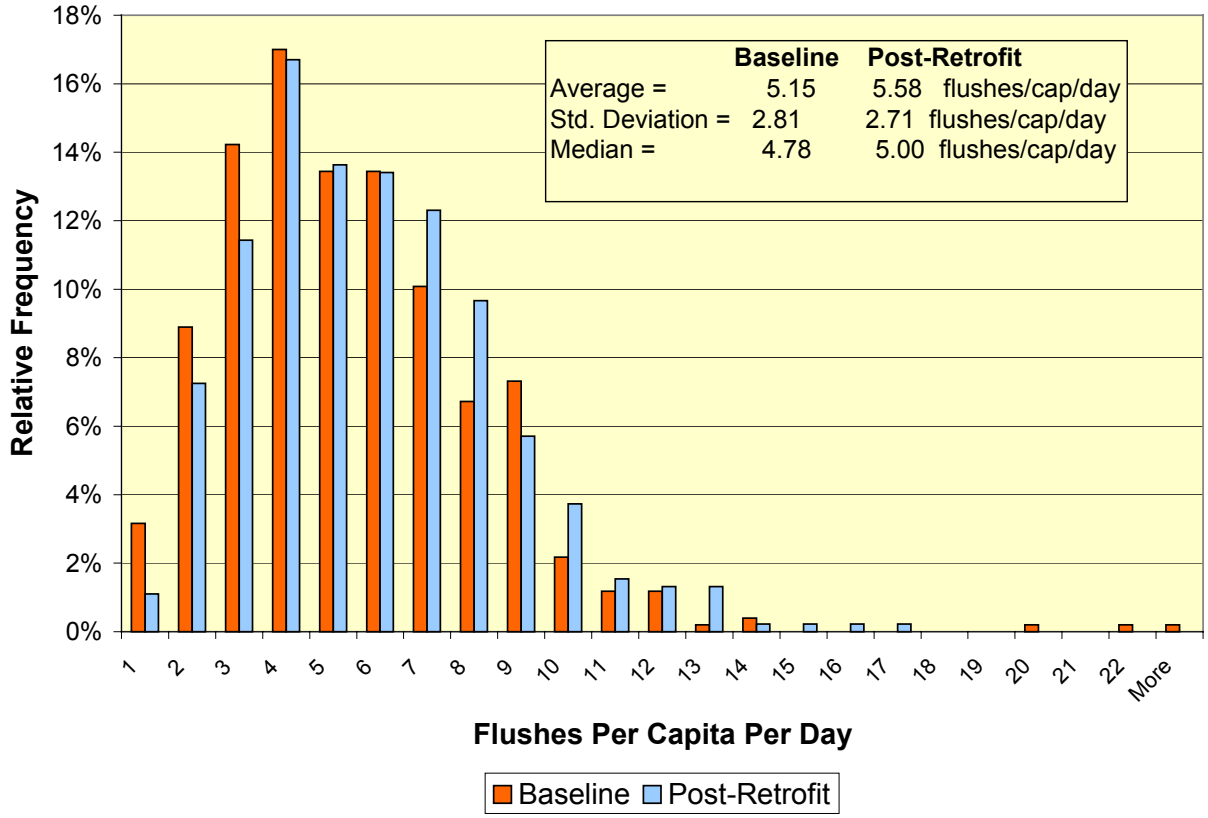


Figure 4.6 Toilet flushing frequency distribution, baseline and post-retrofit

Flushing frequency increased by an average of 0.6 fpcd after the ULF toilets were installed, yet the shape of the flushing frequency distributions are remarkable similar. A *t-test* (two tail) assuming unequal variances was conducted at the 95 percent confidence level to determine of the difference between the baseline and post-retrofit mean flushes per capita per day was significant. This test returned a t-Value of –3.57 and a P-Value of 0.0004. These results indicate that there was a statistically significant increase in flushing frequency after the retrofit amounting to a little more than half a flush per person per day. However, this increase in average flushing frequency did not severely impact the water the water savings accomplished through the installation of the ULF toilets. Per capita use for toilet flushing reduced by 10.1 gcd and this decrease was found to be statistically significant.

Impact of Toilet Make and Model

Four types of ULF toilets were installed as part of this study: the Caroma Caravelle (35), Niagara Flapperless (32), Sloan Flushmate (2), and Toto G-Max (5). The data collected in this

study made it possible to evaluate the impacts of both models of toilet to compare water use, flush volume, and flushing frequency. These results are presented in Table 4.7.

The Caroma Caravelle is a dual flush gravity toilet designed and manufactured in Australia. The unique feature of this toilet is that it offers two different flush options – a full 1.6 gallon (6 liter) flush and a half flush of 0.8 gallon (3 liter). There are two buttons on the top of the toilet tank allowing the user to select the size of flush required. Some dual flush devices have been available in the US, but none offers the reliability and convenience of the Caroma design.

The Niagara Flapperless toilet offers a dramatic departure from standard residential toilets that use a flapper valve to release water from the tank into the bowl. The Niagara Flapperless toilet has a unique "tipping bucket" design that does not use a flapper. Inside the tank is a plastic trough that is filled with water. When the toilet is flushed, the trough tips and dumps the water through a larger opening into the bowl creating a strong flushing action. This design was created to eliminate flapper leaks.

The Toto Drake is a traditional gravity flush toilet with a 3-inch flush valve. This is substantially larger than the traditional 2-inch valve. The tank is designed to hold up to 3 gallons of water, but only 1.5 gallons are used in the flush. The extra water in the tank provides more pressure and during the flush water is rapidly expelled through the 3-inch flush valve into the bowl.

The Sloan Flushmate is a pressurized flushing mechanism that can be installed in a wide variety of existing toilet pottery. For this study St. Thomas Creations pottery was used. The Flushmate vessel traps air, and as it fills with water, it uses the water supply line pressure to compress the trapped air inside. The compressed air is what forces the water into the bowl, so instead of the "pulling" or siphon action of a gravity toilet, the pressure-assist unit "pushes" waste out. This vigorous flushing action is designed to clean the bowl more effectively than other toilets.

In order to test the water using characteristics of these two devices, daily per capita water use for toilets was compared for the homes equipped with each of the four toilet models. A total of 35 Caroma toilets were installed in 17 homes while 32 Niagara toilets were installed in 13 homes. (To avoid confusion, no homes were equipped with both types.) Two Sloan Flushmate toilets were installed in one home and five Toto toilets were installed in two homes. Because of

the small sample size, it was not possible to compare water use of the Sloan Flushmate and Toto toilets with the other brands. Results comparing the Caroma and Niagara toilets are shown in Table 4.7. The homes equipped with Caroma toilets used 9.9 gcd while the homes equipped with Niagara toilets used 9.0 gcd, a difference of 0.9 gallons per capita per day. The difference in means was not found to be significant at the 95 percent confidence level.

Table 4.7 Caroma vs. Niagara toilet water use

	Caroma Homes Avg.	Niagara Homes Avg.	Difference	% Difference	t-Value	P-Value	Statistically significant difference?*
Per capita use (gcd)	9.9	9.0	0.9	9.1%	0.508	0.6158	No
Flush volume (gallons)	1.34	1.70	0.44	32.8%	-46.06	0.00	Yes
Flushing frequency (fpcd)	6.4	5.0	1.4	21.9%	1.782	0.0869	Yes
Sample size (homes)	17	13					

*95 percent confidence level

As shown in Table 4.7, the average flush volume of the Caroma toilets was 1.34 gallons while the Niagara toilets used 1.70 gpf - a difference of 0.44 gpf. This difference in means was found to be statistically significant at the 95 percent confidence level. The lower average flush volume for the Caroma was due to study participants using the 0.8 gpf flush option available on those fixtures.

Residents equipped with the Caroma toilets flushed an average of 6.4 times per person per day while residents equipped with Niagara toilets flushed an average of 5.0 times per person per day. This difference in flushing frequency was found to be significant at the 95 percent confidence level, but the result was not a strong one.

In this study, the Niagara Flapperless toilets appear to offer increased savings over the dual flush Caroma – primarily because on decreased flushing frequency. The average volume per flush for the Caroma was substantially less than the Niagara, but people flushed the Caroma more frequently, thus negating the savings. It must be noted that the samples used for this analysis are quite small and further investigation should be made before making final conclusions about the water saving potential of these two devices.

ULF Toilet Savings from Other Studies

A number of studies have measured water savings achievable from installing ULF toilets. These studies include the Seattle Home Water Conservation Study (Mayer, DeOreo, & Lewis, 2000), the REUWS (Mayer and DeOreo, et. al. 1999), 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; 1994), and Aquacraft's small scale retrofit study in Boulder, Colorado (DeOreo et. al. 1996). The per capita per day toilet savings found in these studies is compared with the EBMUD Indoor Residential Water Conservation Study results in Table 4.8.

The savings found in the East Bay study showed savings similar to the REUWS and Seattle study. The highest savings were found in the statistical models developed for Southern California. The savings from this study were almost twice as much as those found in the 1991 Stevens Institute study also conducted in the EBMUD service area. In the 1991 Stevens study, the average flush volume was found to be 1.8 gallons per flush (gpf) and in this study the average flush volume was found to be 1.48 gpf. In addition, the Stevens study found the number of daily flushes per person to be 3.7 and this study found the number of flushes per person per day to be 5.7.

It should be noted that the REUWS was not a 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 that exclusively used ULF toilets and homes in the study that did not use a ULF. However, from the similarity of the results in the 2002 East Bay study, the Seattle study, the REUWS, and the MWD studies a more accurate picture of the per capita savings achievable from ULF toilet retrofits emerges. These research efforts each approached the task of calculating savings differently yet their results are quite similar.

Table 4.8 Comparison of ULF savings from other studies

Research project	ULF Flush Volume (gal/flush)	Per capita savings from ULF toilets (gcd)	Saturation rate of ULF toilets in study homes
East Bay Residential Conservation Study (2002)	1.48	10.1	85%
Seattle Home Water Conservation Study (2000)	1.38	10.9	84%
REUWS (1999)		10.5	100%
MWD (1992 – 1994)		11.4	73%
Tampa, Florida (1993)		6.1	100%
East Bay MUD (1991)	1.8	5.3	100%
Boulder Heatherwood (1996)		2.6	50%

Showers

During the baseline period, the study participants showered an average of 0.65 times per day. The average shower consumed 18.4 gallons of water, lasted for 8.9 minutes, and was taken at a flow rate of 2.0 gpm. Thirty of the 33 study homes received one or more AM Conservation Group Spoiler (2.5 gpm) showerheads part of the conservation retrofit. In the post-retrofit period, study residents showered an average of 0.74 times per day – an increase of 0.09 showers per day. The average post-retrofit shower used 15.34 gallons, lasted for 8.2 minutes, and was taken at flow rate of 1.8 gpm. In the hot water study homes (n=10) the average shower was 60 percent hot water and 40 percent cold water during the post-retrofit period. The frequency distributions of baseline and post-retrofit shower volumes are presented in Figure 4.7, Figure 4.8 shows the frequency distributions of baseline and post-retrofit shower durations, and Figure 4.9 presents the frequency distributions of baseline and post-retrofit shower flow rates.

From these results, it appears that the LF showerheads installed during the retrofit did reduce the flow rate at which people shower and consequently reduced the volume of showers. However, because of an increase in showering frequency no statistically significant savings were observed in the comparison of baseline and post-retrofit per capita use shown in Table 4.3.

To determine if and how the installation of LF showerheads impacted demand, unpaired t-tests assuming unequal variance were performed on the baseline and post-retrofit shower usage data. The results of these analyses are presented in Table 4.9. The mean shower volume decreased by 3.06 gallons after the retrofit. The change in means in shower volume was found to be statistically significant at the 95 percent confidence level.

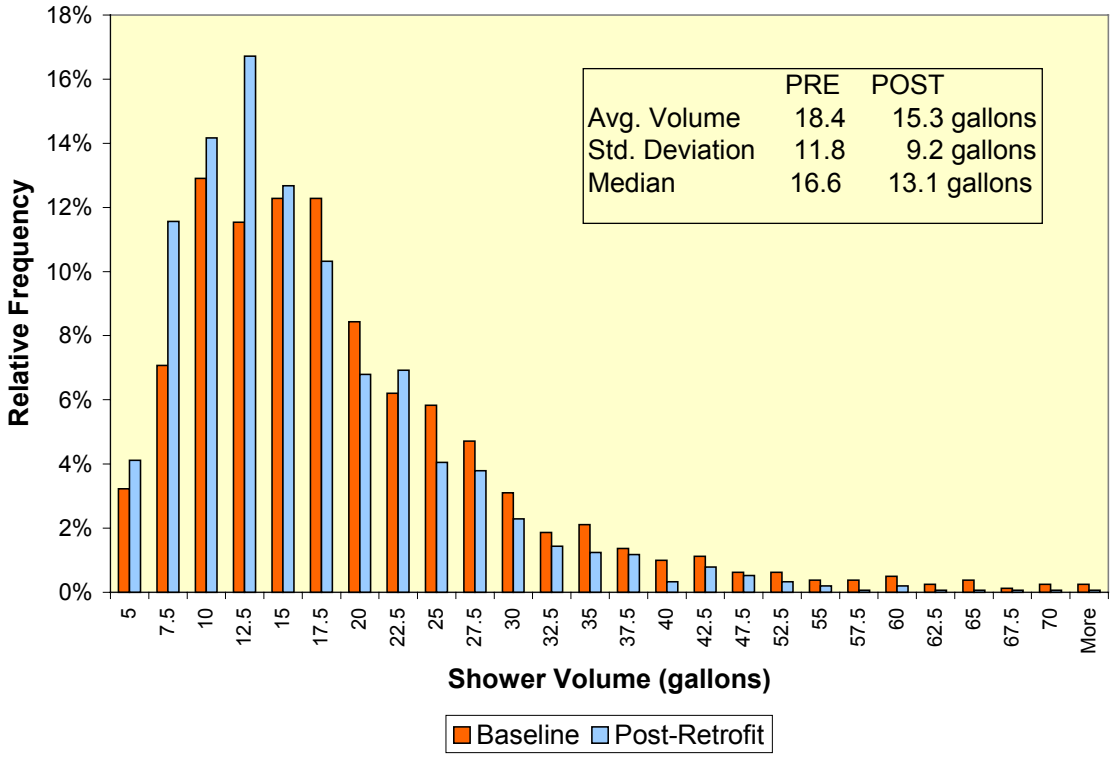


Figure 4.7 Shower volume frequency distributions, baseline and post-retrofit

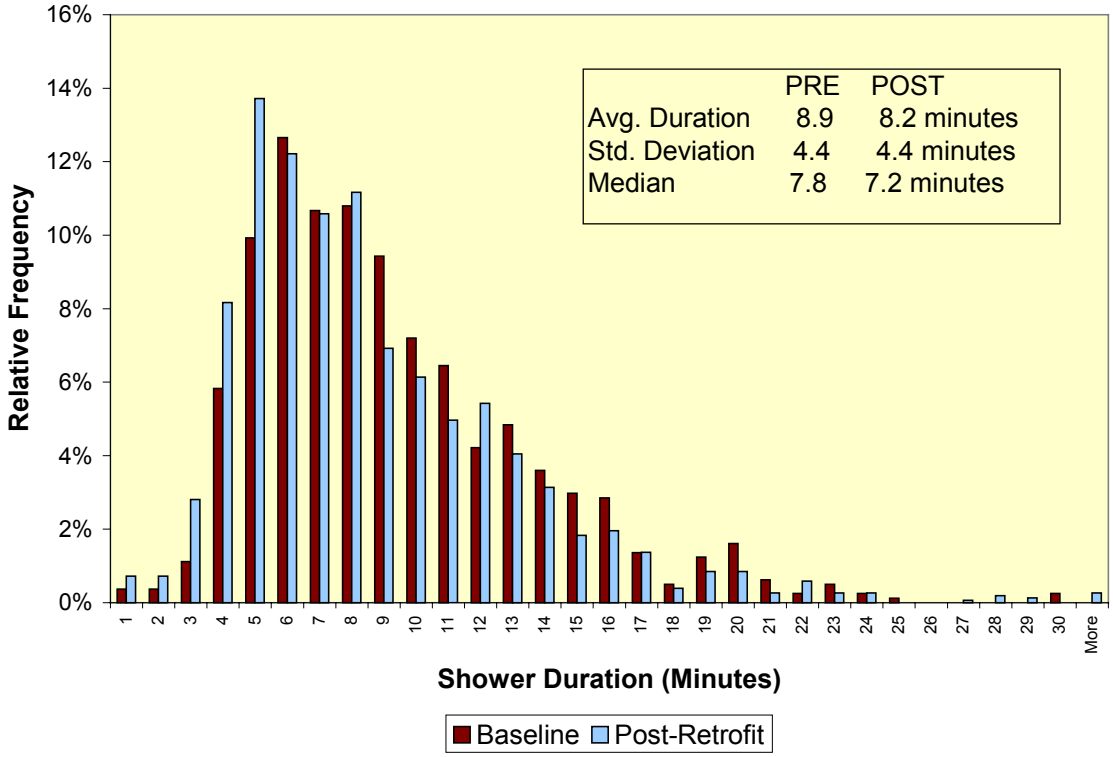


Figure 4.8 Shower duration frequency distributions, baseline and post-retrofit

It has been hypothesized that the introduction of LF showerheads and the subsequent reduction in shower flow rate could cause people to increase the length of time spent in the shower. Results from this study show that the introduction of LF showerheads actually decreased the length of time people spend in the shower. The average shower duration decreased by 41 seconds after the retrofit. Furthermore this change was found to be statistically significant at the 95 percent confidence level.

LF showerheads are expected to reduce the water flow rate during the shower. These new fixtures are designed to restrict the flow of water to 2.5 gpm or less. While this may seem like a low flow rate, results from this study show that most residents showered at a flow rate below 2.5 gpm prior to the installation of the LF fixtures. Many of the participants already had LF showerheads installed in their homes. Others simply chose to throttle their showerheads down, finding that flow rate more comfortable for showering.

After the retrofit, the average flow rate for showers decreased by 0.19 gpm, from 2.00 gpm to 1.81 gpm. The results of the *t-test* conducted on these data show that this change in mean showering flow rate is statistically significant at the 95 percent confidence level. This indicates that the new showerheads successfully reduced shower flow rates in the study homes.

Table 4.9 Shower usage comparison, baseline and post-retrofit

Comparison Category	Baseline avg.	Post-Retrofit avg.	Difference	% change	t-Value	P-Value	Statistically significant difference?*
Shower Volume (gal.)	18.40	15.34	-3.06	-16.6%	6.398	<0.0001	Yes
Shower Duration (min.)	8.88	8.20	-0.68	-7.66%	3.534	0.0004	Yes
Shower Flow Rate (gpm)	2.00	1.81	-0.19	-9.50%	5.269	<0.0001	Yes
Showers per capita per day	0.65	0.74	0.09	13.85%	-3.057	0.0023	Yes
Baths per capita per day	0.12	0.10	0.02	-16.67%	-2.369	0.0180	Yes

*95 percent confidence level

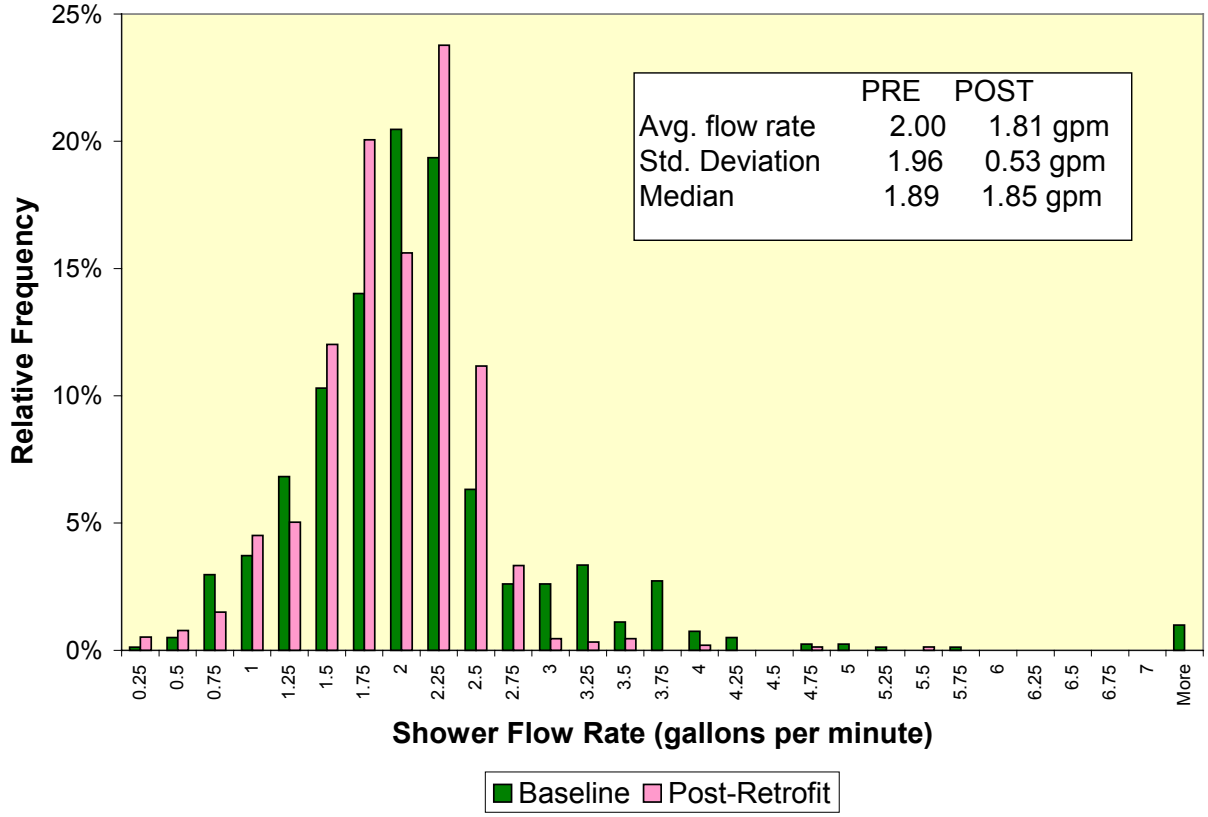


Figure 4.9 Shower flow rate frequency distributions, baseline and post-retrofit

Although these results indicate the LF showerheads accomplished the task of reducing shower flows and volumes, the actual per capita usage for showers decreased by only 1.3 gcd and this change was found to be *not* statistically significant. These somewhat contradictory results are explained by the fact that the frequency of showering by study participants increased in the post-retrofit period. During the baseline period, study participants averaged 0.65 showers per person per day, but during the post retrofit period this increased to 0.74 – nearly a 14 percent increase that was shown to be statistically significant. At the same time, the frequency of baths decreased during the post-retrofit period from 0.12 baths per person per day to 0.10. As shown in Table 4.9 both of these changes in use were found to be statistically significant.

One possible explanation for the change in showering habits is the change in seasons from the baseline to the post-retrofit period. Baseline data were obtained primarily during February and March 2001. The post-retrofit data were obtained during December 2001 and

during June and July 2002. It is possible that different seasonal conditions may have encouraged the switch towards increased showering and decreased bathing. The impact of seasonal changes on showering and bathing is an area for further research.

Regardless of the reason, the increase in showering frequency did substantially reduce the per capita water savings for showering that would have been observed had the number of showers remained constant. If the number of showers per person per day is held constant at 0.65, it is anticipated that the introduction of low flow showerheads would save approximately 2.0 gallons of water per person per day or about 726 gallons per person per year.

LF Shower Savings from Other Studies

A number of studies have measured water savings achievable from installing low-flow shower heads. These studies include the REUWS, 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 1994). The per capita per day shower savings found in these studies is compared with the EBMUD retrofit study results in Table 4.10.

Table 4.10 Comparison of LF showerhead savings from other studies

Research project	**Per capita savings from LF showerheads** (gcd)	**Saturation rate of LF showerheads in study homes**
East Bay Residential Conservation Study (2002)	1.3	94%
Seattle Home Water Conservation Study (2000)	0.3	94%
REUWS (1999)	4.5	100%
HUD (1984)	7.2	NA
Tampa, Florida (1993)	3.6	100%
East Bay MUD (1991)	1.7	100%

The showerhead water savings found in this study are most similar to the savings found in the 1991 EBMUD study. The Seattle study found the lowest level of showerhead savings. 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 a 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.

The disparate results for showerheads suggest that the savings achieved by the devices are uncertain at best. Since showerheads are not expensive it probably makes sense to continue to distribute them broadly, but water planners should be cautious when projecting savings from showerhead retrofit programs. Many homes are already equipped with LF showerheads through natural retrofit and many other people simply throttle their showers down below 2.5 gpm for comfort.

Clothes Washers

As part of the retrofit program, the clothes washer in each of the 33 study homes was replaced with a new water conserving model. There are now several different water conserving clothes washers available in the U.S. In this study, three different models were installed and evaluated: the Frigidaire Gallery, the Fisher & Paykel Ecosmart, and the Whirlpool Super Capacity Plus. The Frigidaire Gallery is a front loading horizontal axis machine while the Fisher & Paykel Ecosmart and the Whirlpool Super Capacity Plus are more traditional top loading washers. In this study 9 Frigidaire, 13 Fisher & Paykel, and 11 Whirlpool machines were installed.

To depict how these machines differ in operation several sample flow traces from Trace Wizard were captured and are presented in Figure 4.10 - Figure 4.14. These figures show the different wash and rinse cycles typical of each machine.

The Frigidaire Gallery used an average of 21.8 gallons per load of clothes with a standard deviation of 4.5 gallons. As shown in Figure 4.10 and Figure 4.11, the Gallery starts with a wash/fill cycle that is a higher flow rate than subsequent wash and rinse cycles. Sometimes the first fill is briefly interrupted and then resumed as shown in Figure 4.10. Usually only the first fill cycle of the Gallery uses any hot water (because most people set the machines to rinse with cold water). There are typically five wash and rinse cycles that complete the load. These cycles may be of different volumes and durations based upon the washer settings. It is also possible to add additional rinse cycles if desired. A single run of the Gallery takes less than one hour.

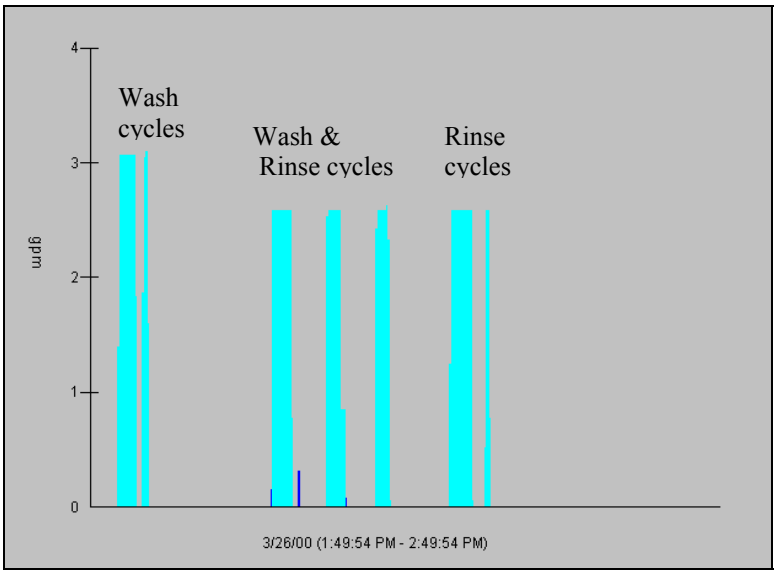


Figure 4.10 Frigidaire Gallery sample flow trace

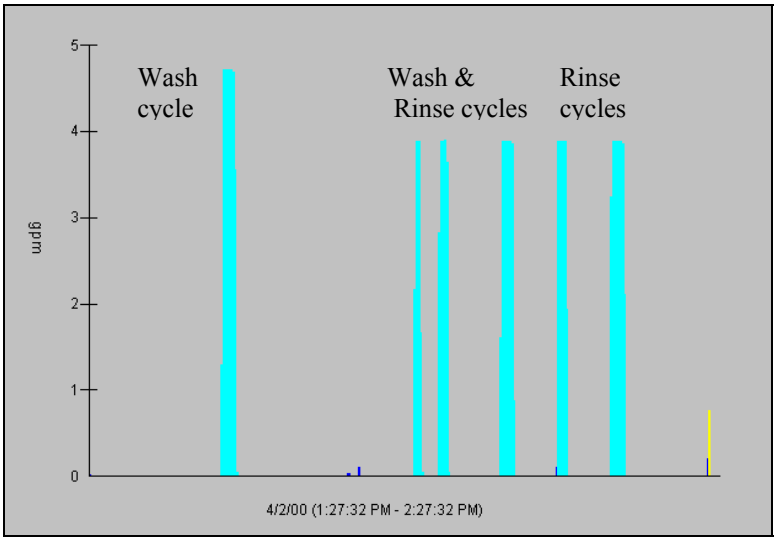


Figure 4.11 Frigidaire Gallery sample flow trace

The Fisher & Paykel Ecosmart used an average of 29.2 gallons per load of laundry with a standard deviation of 8.6 gallons. Examples of the standard water use pattern for this machine is shown in Figure 4.12, and Figure 4.13. This clothes washer has an automatic sensor that adjusts the fill volume depending on the size of the load. The water usage pattern for the Ecosmart varies depending upon the cycle selected and the load size. The wash cycles tend to be at higher flow rates (4 – 6 gpm) and may include some hot water. Typically there are three smaller cold

water rinse cycles at the end that run at a flow rate of approximately 2 gpm. A single run of the Ecosmart takes less than one hour.

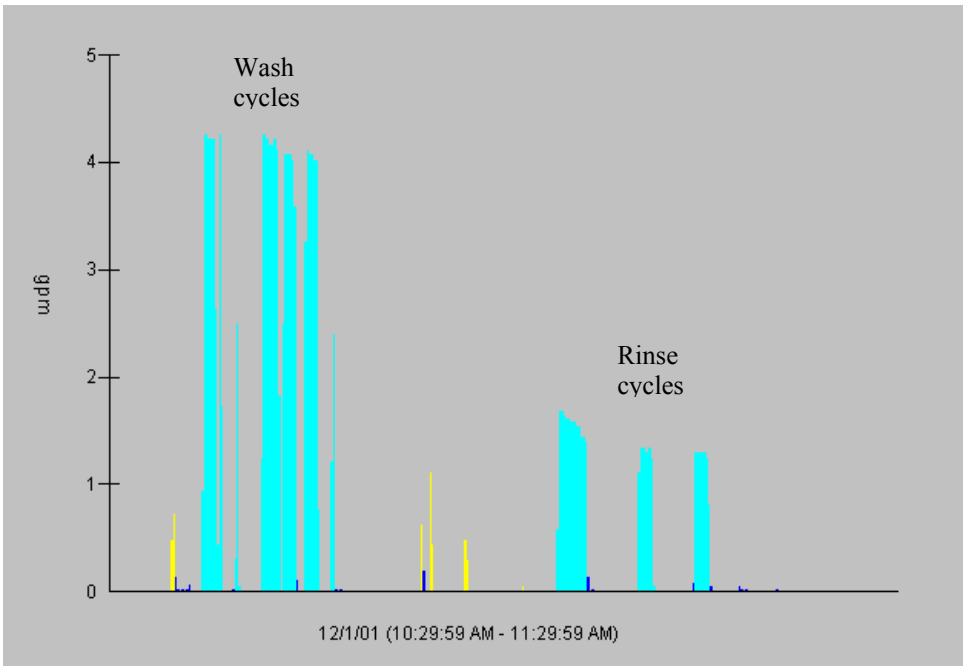


Figure 4.12 Fisher & Paykel Ecosmart wash cycle sample flow trace

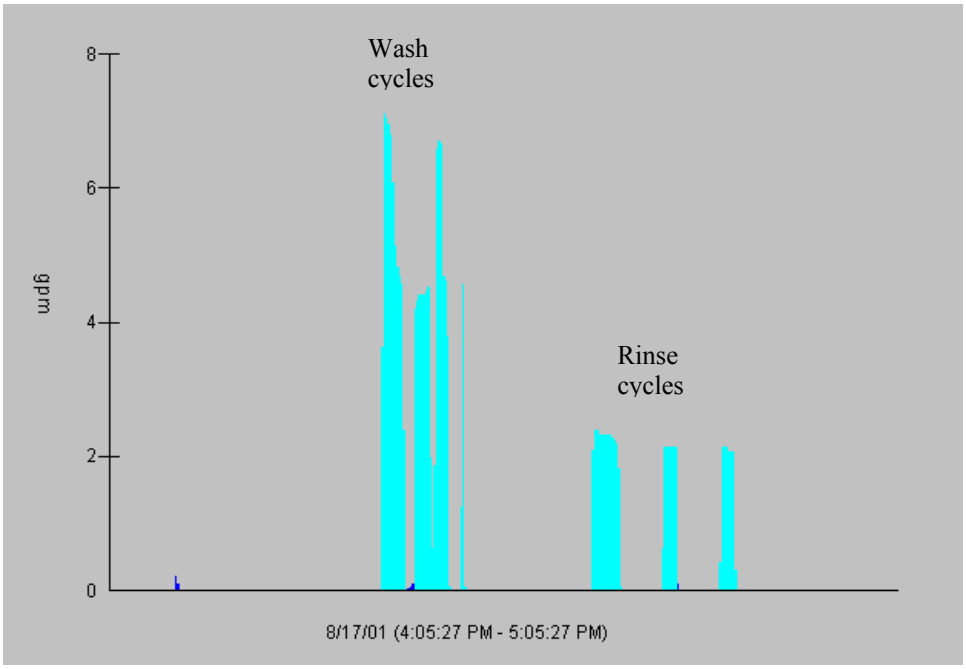


Figure 4.13 Fisher & Paykel Ecosmart wash cycle sample flow trace

The Whirlpool Super Capacity Plus clothes washer used an average of 29.0 gallons per load of laundry with a standard deviation of 7.4 gpl. This machine has a traditional top loading design, but utilizes only one large fill cycle and a series of six short rinse cycles to wash the clothes. A sample for trace from a Super Capacity Plus is shown in Figure 4.14. There is a 15 minute period between the end of the first fill cycle and the first rinse cycle. The first fill cycle typically used about 20 gallons and the subsequent rinse cycles used 1.5 – 2 gallons each. Typically only the first fill cycle included hot water, but there were examples when the rinse cycles also had a hot water component. It is possible to add a second larger rinse cycle with this machine using the "extra rinse" setting. This can effectively negate the water saving benefits of the Super Capacity Plus. An analysis of the hot water consumption of each machine is presented later in this section. A single run of the Super Capacity Plus takes less than one hour.

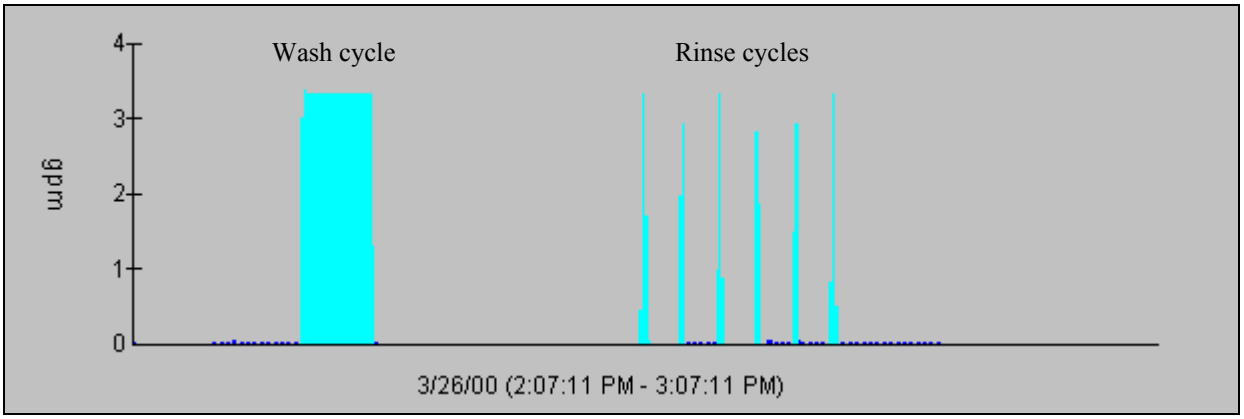


Figure 4.14 Whirlpool Super Capacity Plus sample flow trace

Prior to the retrofit the washing machines in the study homes used an average of 40.7 gallons per load of clothes with a standard deviation of 9.8 gallons. Data from the baseline period indicated that 15.3 percent (6.2 gallons per load) of the water used for clothes washing was hot water. During this period, participants ran an average of 0.36 loads of laundry per person per day. From the analysis shown in Table 4.3 it is known that a statistically significant change in per capita water usage was achieved through the installation of the new conserving clothes washers. Table 4.11 shows the relevant usage statistics for each make and model of washing machine installed for this study.

The clothes washers installed for this study used between 21.8 and 29.2 gallons per load of wash on average. The Frigidaire Gallery averaged 21.8 gallons per load, the Fisher & Paykel Ecosmart averaged 29.2 gallons per load, and the Whirlpool Super Capacity Plus averaged 29.0 gallons per load.

Hot water usage for clothes washing decreased substantially in the post-retrofit period. The Frigidaire used an average of only 3.14 gallons of hot water per load (10.7 percent), the Fisher & Paykel Ecosmart used 3.12 gallons of hot water per load (14.4 percent), and the Whirlpool averaged 2.74 gallons of hot water per load (6.0 percent).

Table 4.11 Clothes washer usage comparison

		Frigidaire Gallery	Fisher & Paykel Ecosmart	Whirlpool Super Capacity Plus	Entire Study Group (post-retrofit)	Entire Study Group (baseline)
Volume Per Load (gal.)	Average	21.82	29.17	29.04	27.20	40.7
	Std. Dev.	4.47	8.57	7.41	7.97	9.8
Hot Water Volume Per Load (gal.)	Average	3.14	3.12	2.74	3.00	6.23
Loads Per Capita Per Day	Average	0.32	0.34	0.30	0.32	0.36
	Std. Dev.	0.48	0.50	0.51	0.50	0.61
Per Capita Daily Use (gal.)	Average	7.53	9.51	9.00	8.78	14.0
	Std. Dev.	11.51	13.67	16.49	14.26	7.1
Number of machines in study		11	13	9	33	33

The frequency of washing machine use decreased slightly after the retrofit. The study households ran their new clothes washers an average of 0.32 times per person per day and during the baseline period they ran their washers 0.36 time per person per day – an 11 percent reduction. This suggests that the capacity of the new machines was sufficient and did not result in any increased use of the clothes washer. The brand of clothes washer present in the home had little effect on the washing frequency. The average loads per capita per day decreased for each of the three brands tested.

All of the clothes washers installed for this study saved water. The mean per capita daily water use for clothes washing was 7.53 gcd for the Frigidaire homes, 9.51 gcd for the Fisher &

Paykel homes, and 9.00 gcd for the Whirlpool homes. None of these differences was significant at the 95 percent confidence level. 14.26 gcd. As shown in Table 4.3, the difference in mean per capita clothes washer usage from the baseline to the post-retrofit period was statistically significant at the 95 percent confidence level.

Clothes washer Savings Found in Other Studies

A few other studies have measured water savings achievable from installing conserving clothes washers. These studies include Aquacraft's 1999 study of water wise homes in Westminster, Colorado (Mayer et. al. 2000), the Bern Kansas study (Tomlinson and Rizy, 1998), and the small scale Heatherwood retrofit study. The per capita per day clothes washer savings found in these studies is compared with the EBMUD results in Table 4.12.

Table 4.12 Comparison of clothes washer savings from other studies

Research project	**Per capita savings from conserving clothes washers** (gcd)
East Bay Residential Conservation Study (2002)	5.2
Save Water & Energy Program – SWEEP (2001)	5.3*
Seattle Home Water Conservation Study (2000)	5.6
Westminster water wise homes (1999)	4.6
Bern Kansas (1998)	7.2
Boulder Heatherwood (1996)	10.9

*Estimated from % water reduction reported.

The measurements of per capita savings vary in these six studies, although in the three most recent studies the savings are all quite similar. The 1996 Heatherwood study only included four homes and two of those homes received the water efficient Asko washer. The Bern Kansas study exclusively used Maytag Neptune washers. Both Heatherwood and Bern were true intervention studies (like EBMUD and Seattle), that measured demand before and after the installation of conserving washers. The Westminster study compared clothes washer use in a sample of standard new homes and sample of "water wise" new homes equipped with high efficiency fixtures including clothes washers.

The EBMUD and Seattle study both used Frigidaire and Whirlpool clothes washers. The Maytag Neptune was tested in Seattle and the Fisher & Paykel Ecosmart was tested in the East Bay. The SWEEP study used Frigidaire clothes washers exclusively. The similarity in water

savings found in the Seattle, SWEEP, and EBMUD studies suggests an approaching agreement on the impact of these specific machines on per capita water use.

Faucets

A total of 79 bathroom faucet aerators and 20 kitchen faucet aerators were installed as part of the retrofit program in the EBMUD service area. These aerators were manufactured by New Resources Group and were designed to limit flows to less than 2.2 gpm in the kitchens and less than 1.5 gpm in the bathrooms. These aerators have a pressure compensating feature so that flow rates can be maintained under a variety of different water pressures.

Mean per capita faucet was unchanged at 10.5 gcd after the retrofit. As shown in Table 4.3, this was the only end use where a retrofit was accomplished but no change was exhibited. During the baseline period, faucet usage accounted for 12.2 percent of all indoor use. After the retrofit it accounted for 20.0 percent of total indoor use because of the large decrease in leaks, toilet, and clothes washer usage.

In the 10 hot water study homes, mean per capita hot water faucet use went from 13.2 gcd in the baseline period to 12.4 gcd in the post retrofit period, but this change was found not to be statistically significant. During the baseline period 65.2 percent of all faucet usage was hot water and after the retrofit the hot water component decreased to 50.0 percent. A summary of results for faucet usage is presented in Table 4.13.

Table 4.13 Faucet use comparisons, baseline and post-retrofit

	Per Capita Daily Use		Typical Flow Rates	
	Volume (gal)	**Duration (minutes)**	**Average (gpm)**	**Peak (gpm)**
Baseline	10.5	10.4	1.2	2.9
Post-Retrofit	10.5	13.3	0.93	2.6**
t-Value	0.030	-6.654	14.123	4.176
P-Value	0.9759	<0.0001	<0.0001	<0.0001
Statistically significant difference?*	No	Yes	Yes	Yes

*95 percent confidence level
**Not all faucet aerators could be replaced.

The faucet results shown in Table 4.13 bear some important conclusions. First, after the retrofit faucet flow rate decreased – both the average and peak. This indicates the aerators did

have an impact. However, the duration of faucet use increased after the retrofit – this increase was found to be statistically significant. Many faucet uses such as filling a glass or a sink should be independent of faucet flow rate, meaning that the volume of water used for these purposes is fixed and that volume will be used regardless of the delivery flow rate of the water. Reducing the flow rate should result in water users spending more time to fill specific volumes. The net result in this study was that the average per capita faucet use did not change from the baseline to the post-retrofit period.

Figure 4.15 shows the baseline and post-retrofit frequency distributions of per capita faucet use durations. The increase in duration of faucet use can be seen in the shift of the post-retrofit distribution to the right of the x-axis.

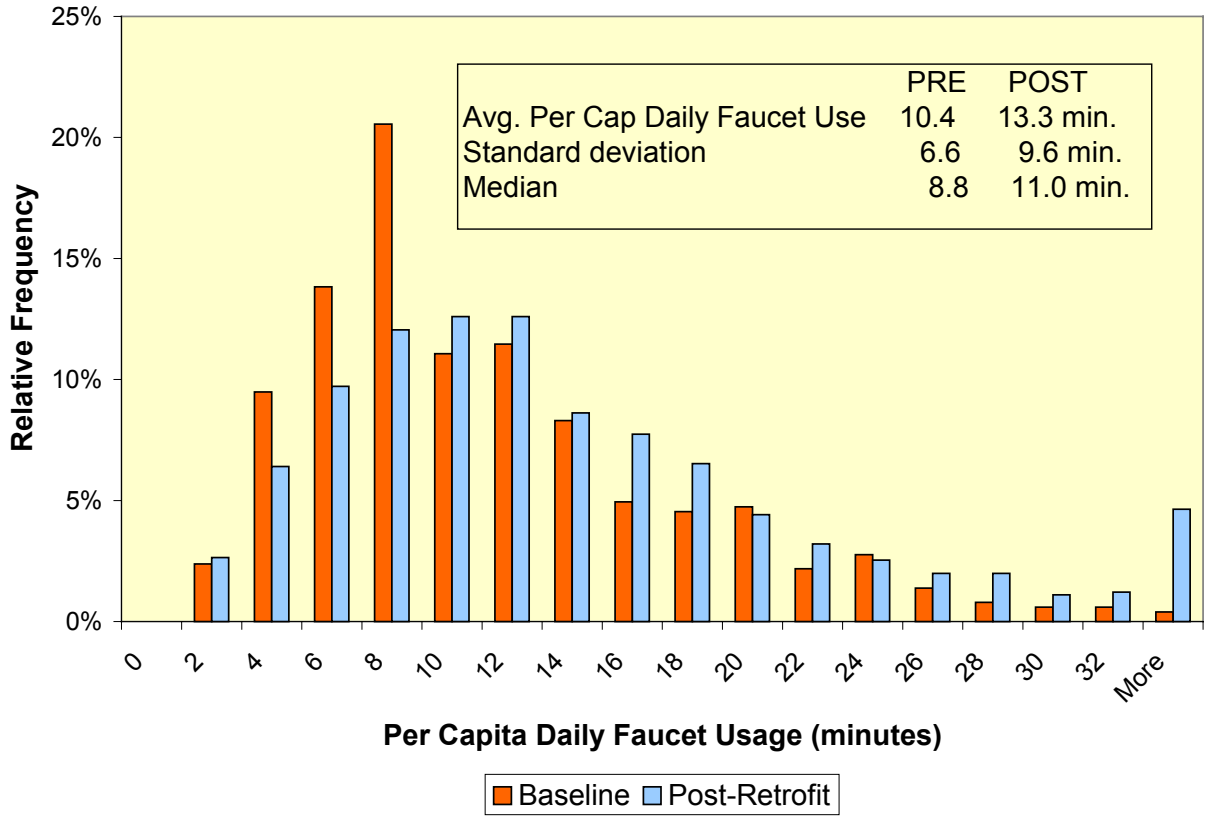


Figure 4.15 Faucet usage comparison, baseline and post-retrofit

Baths

Because baths require a fixed amount of water, this study did not include any bath retrofits and therefore a reduction in bath water usage was not expected. During the baseline period, the average bath used 28.5 gallons of water and during the post-retrofit period the average bath used 27.5 gallons. This difference was found not to be statistically significant. The maximum baseline bath usage was 89.9 gallons and the maximum post-retrofit bath usage was 94.3 gallons.

During the baseline period, baths taken in the hot water homes were 89.5 percent hot water and 11.5 percent cold water. During the post-retrofit period, baths were measured as using 75.0 percent hot water and 25.0 percent cold water.

Study residents took an average of 0.12 baths per person per day or 0.84 baths per person per week during the baseline and 0.10 baths per person per day or 0.70 baths per person per week during the post-retrofit period. Comparisons of baseline and post retrofit bath data are shown in Table 4.14.

Table 4.14 Bath usage comparisons, baseline and post-retrofit

	Avg. Bath Volume (gal.)	Max. Bath Volume (gal.)	Hot Water Component %	Avg. Baths per Capita Per Day
Baseline	28.5	89.9	89.5%	0.12
Post-Retrofit	27.3	94.3	75.0%	0.10
Statistically Significant Difference?*	No	na	Yes	Yes

*95 percent confidence level

Leaks

The reduction and elimination of leaks appears to be one important result of the retrofit program. Mean daily per capita leakage was reduced by 65.4% percent from 25.7 gcd to 8.9 gcd after the retrofit as shown in Table 4.3. Most of the leaks eliminated during the retrofit were the result of replacing toilets that had leaky flapper valves. No other leak repair was performed as part of the retrofit program.

During the baseline period it was discovered that 10 of the households were responsible for roughly 86 percent of the total leakage in the entire study group. As was the case during the

baseline period and in the results of the REUWS, a few houses accounted for most of the leakage during the post-retrofit period. Two houses accounted for more than 50 percent of the total leakage during the two post-retrofit data collection periods and 10 houses accounted for more than 80 percent of the total. Leaks in the top two leaking homes were re-examined using Trace Wizard and in both homes the leaks appeared as continuous water uses with very low flow rates (<0.5 gpm). While it is impossible to determine the exact cause of these leaks, they looked to be caused by leaking faucets or hose bibs or perhaps by a leak in piping. These leaks did not appear to be toilet leaks, which are almost always associated with toilet flushes, nor did they appear to be irrigation leaks, typically caused by broken heads or stuck valves in automatic irrigation systems.

One possible explanation for the high leak rate that was found in some of the study participants' homes could be traced to the District's change in its water treatment process. EBMUD converted from treating water with chlorine to chloramines (chlorine and ammonia) in 1998. An August 1993 AWWA Journal article reported study results showing that chloramines have a more deleterious effect on elastomers (products widely used in plumbing distribution, especially for toilet flapper valves) than does free chlorine. When a utility converts from chlorine to chloramine, this negative effect on the elastomers tends to increase incidents of leaks in the home and in the distribution system. The plumbing industry has responded to this problem by marketing elastomer products with compounds resistant to attack by chloramines.

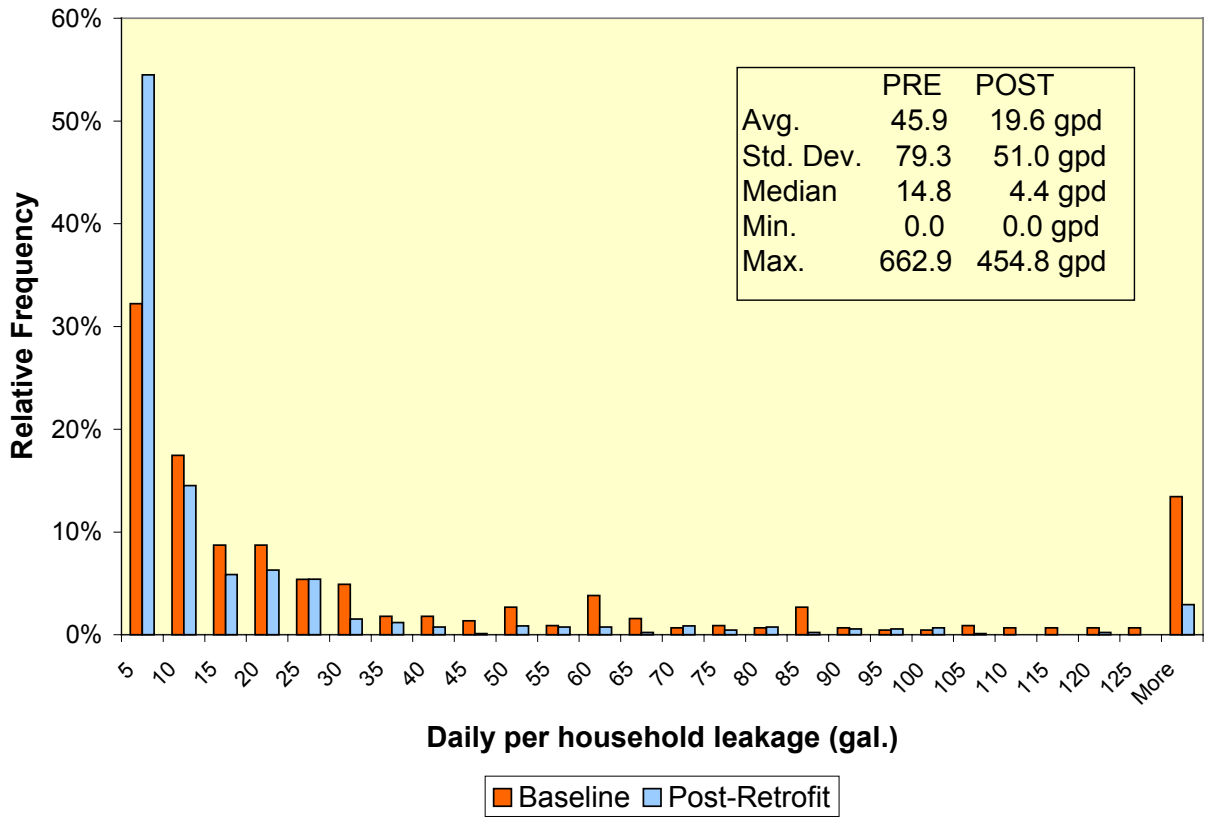


Figure 4.16 Daily per household leakage distributions, baseline and post-retrofit

Figure 4.16 shows the baseline and post-retrofit distributions of daily household leakage. The general shape of these distributions is the same, but in the post-retrofit period there were many more low leakage days. The difference in mean per household leakage (26.3 gpd) was found to be significant at the 99 percent confidence level. It is interesting to note that the median leakage rate in both distributions is substantially lower than the mean, belying the positive skew of the distributions.

MAXIMUM DAY INDOOR DEMANDS

Peak day demands measured for each study house during the post-retrofit period were typically higher than the peak demands measured during the baseline period. This is not surprising since there were twice as many post-retrofit data days and some of these data were collected during the spring and summer when many of the study participants were irrigating

several times per week. Since the retrofit targeted indoor use exclusively it was decided to compare indoor peak day demands before and after the retrofit.

Figure 4.17 shows the maximum daily indoor demands for each study home during the baseline and post-retrofit period. Twice as much daily use data were available from the post-retrofit period, but peak indoor use during the baseline period exceeded peak use during the post-retrofit period 26 out of 33 study homes. In seven homes, the post-retrofit indoor peak exceeded the baseline peak. Overall, indoor peak demand decreased by 16 percent after the retrofit. This reduction was found to be statistically significant at the 95 percent confidence level.

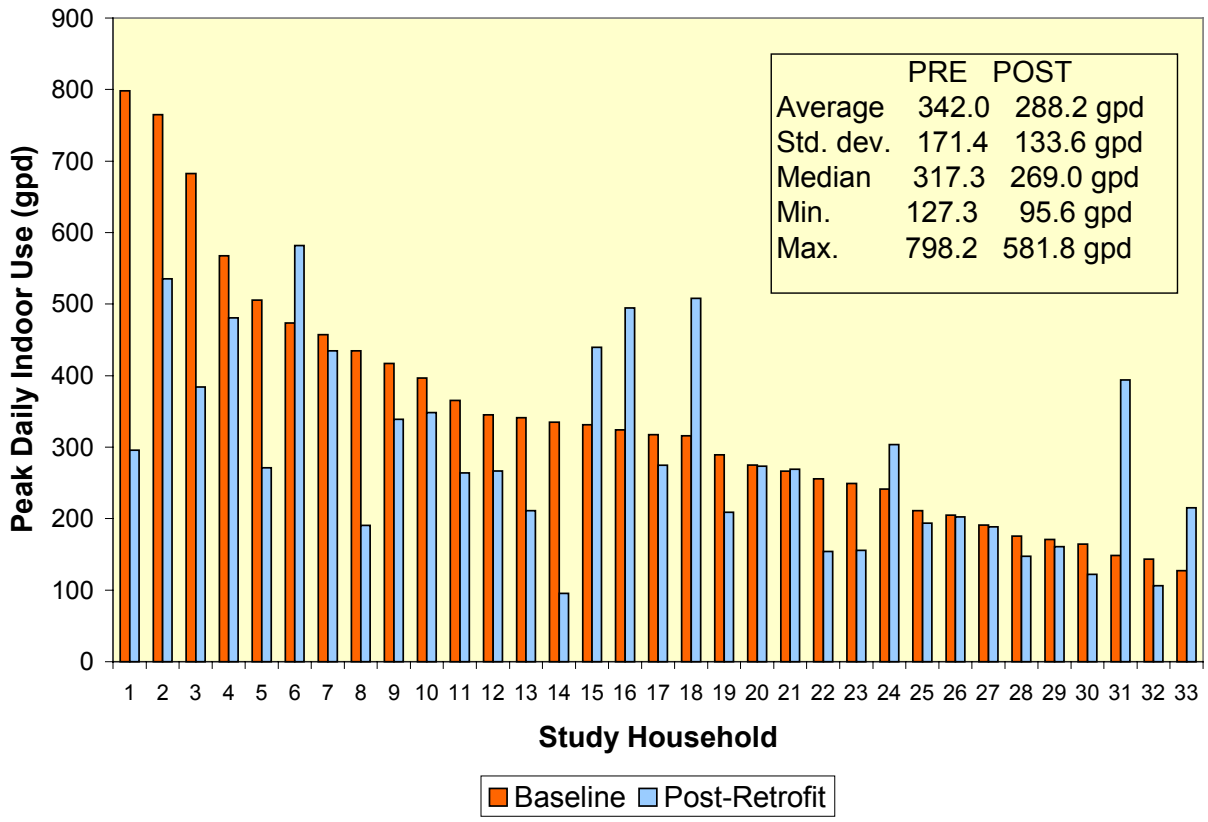


Figure 4.17 Peak daily indoor use comparison, baseline and post-retrofit

For most systems, peak demand during the summer due to outdoor use is the driving factor in sizing treatment plants and distribution lines. Reductions in indoor peak demands are not likely to profoundly impact these design criteria. Nevertheless, a 32 percent reduction in

indoor peak demand will be reflected in a lower demand on the peak day, and will create a benefit from the perspective of peak reduction as well as volumetric demand reduction.

BILLING DATA ANALYSIS

Billing data from the post-retrofit period were obtained from EBMUD staff as one of the final data items for the study. It was hoped that billing data could be used to confirm the savings detected through the flow trace analysis techniques. Ideally such an analysis should be performed with at least one full year to post-retrofit billing data to use to compare against the pre-retrofit billing data described earlier in this report. Because of the project time schedule this was not possible and instead only about eight months of post-retrofit billing data, from January – August 2002, could be obtained. Billing data were obtained for all 999 homes in the original Q1000 sample frame, which includes all 33 homes in the retrofit study and a 966 home control group.

The retrofits in the 33 study homes were begun in June 2001 and completed in stages by December 2001. EBMUD reads customers' water meters on a bi-monthly schedule and different areas of the service area are read at different times of the month. EBMUD keeps good records of the date each meter is read so it was possible to screen the billing data from each household to ensure that billing periods that included both pre and post-retrofit data were excluded.

There are problems inherent in using billing data to evaluate the effectiveness of conservation measures such as those tested in this study. These problems have been well documented and include: unequal billing periods, estimated meter readings, unusual usage levels, meter read errors, rounding of meter reads, changes in customer occupancy, etc. (Dziegielewski 1993a). However, billing data remains a reliable, cheap, and easy way to measure customers' water use and it should be examined in spite of the inherent shortcomings.

In this study, the limited amount of post-retrofit billing data available made a comparison of pre and post-retrofit water use more difficult. Much of the available post-retrofit data included a substantial component of irrigation demand which can easily mask the sought after effect. To minimize the potential impact of unequal billing periods, the average daily consumption for each billing period was calculated for the pre and post-retrofit periods, and the

data were organized so that the meter read dates corresponded. A total of four post-retrofit billing periods were available for use in the analysis these were as follows:

- Period 1. Read dates from February 9 – April 11, 2002, with the typical consumption period from January and February.
- Period 2. Read dates from April 12 – June 7, 2002, with the typical consumption period from March and April.
- Period 3. Read dates from June 8 – August 6, 2002, with the typical consumption period from May -June.
- Period 4. Read dates from August 8 – October 7, 2002, with the typical consumption period from July – August.

Each period contained consumption data from a three-month period, but the data for any given account only covered a period of roughly 60 days. Because of the consistency in meter reading schedules, most customers' meters were read at roughly the same time in 1999, 2000, and 2002. This improved the accuracy of comparison tests that evaluated water use in 1999 and 2000 before the retrofit and data from 2002 after the retrofit. Data from 2001 was ignored because the retrofits were occurring during six months of the year. Results of the billing data comparison for the study group is shown in Table 4.15 and for the control group is shown in Table 4.16.

Table 4.15 Pre and post-retrofit billing data comparison, study group (n=33)

	Avg. Daily Per Household Water Use (gallons)		**Mean Difference** (gal/day)	**t-Value**	**P-Value**	**Statistically Significant Difference?***
	1999 & 2000 Avg. Pre-Retrofit	**2002 Post-Retrofit**				
Period 1 – Jan – Feb	236.6	147.1	-89.5	4.0492	<0.0001	Yes
Period 2 – Mar – Apr	296.7	255.2	-41.5	0.9177	0.18105	No
Period 3 – May – Jun	469.9	420.8	-49.1	0.5716	0.28484	No
Period 4 – Jul – Aug	496.2	493.2	-3.0	0.0287	0.4886	No
ALL – Jan – Aug	374.4	329.0	-45.4	0.7345	0.23271	No

*95% confidence level

For the study group, a statistically significant reduction in water use was observed only the first billing period – January – February – when outdoor use was at a minimum. Although substantial water savings were observed in two other billing periods, because of the variability in the data caused by outdoor use, the savings were statistically masked. Over the course of the 8 month period, demand went down an average of 45.4 gallons per household per day after the retrofit. Although this reduction was not statistically significant at the 95 percent confidence level, it is interesting to note that in the Seattle retrofit study the savings measured from billing data was virtually identical: 45.7 gallons per household per day after the retrofit. In the East Bay, the 45.4 gallons per day reduction equates to a savings of 1,381 gallons per month and 16,571 gallons per year.

Table 4.16 Pre and post-retrofit billing data comparison, control group (n=966)

	Avg. Daily Per Household Water Use (gallons)		**Mean Difference** (gal/day)	**t-Value**	**P-Value**	**Statistically Significant Difference?***
	1999 & 2000 Avg. Pre-Retrofit	**2002 Post-Retrofit**				
Period 1 – Jan – Feb	205.2	190.3	-14.9	2.6170	0.00447	Yes
Period 2 – Mar – Apr	251.1	264.6	13.6	-1.5637	0.05903	No
Period 3 – May – Jun	375.5	376.5	1.0	-0.0701	0.47205	No
Period 4 – Jul – Aug	404.8	406.7	1.9	-0.1217	0.45159	No
ALL – Jan – Aug	309.2	309.5	0.3	-0.0318	0.48732	No

*95% confidence level

For the control group, the only statistically significant change in water use was a slight decrease in average daily use that occurred during Period 1. This was followed by a nearly statistically significant increase in use during Period 2. On average, water use in the control group barely changed at all from 1999-2000 to 2002. Billing data indicate an average daily per household increase of 0.3 gallons per household per day and this was not statistically significant.

These results suggest that the impacts of the retrofit can be detected through the bi-monthly billing data collected by EBMUD, but the savings cannot be verified as statistically significant using the relatively simple techniques employed in this study. The magnitude of the use reduction in the study group (45.4 gallons per household per day) certainly suggests a significant change. This result points out the value of the flow trace data in measuring changes in water use, because it can eliminate the variability caused by outdoor use.

It would be valuable to continue to track demand in this study group over the next several years to evaluate the on-going impacts of the retrofit. It should be noted that the average savings detected via the billing data were not as large as the average savings measured from the flow trace analysis effort. As described earlier in this chapter, the flow trace analysis found an average savings of 67.7 gallons per household per day or 24,711 gallons per household per year. Flow trace results provides an analysis of water use uncluttered by outdoor use, rounded or estimated meter reads. These and other factors could easily explain the different findings from the two methods. In particular outdoor use, which can vary tremendously depending on weather patterns, can easily disguise or enlarge savings from interior retrofit programs measured with billing data.

Despite the limited amount of post-retrofit billing data available at the time this report was written, the results provide strong evidence of water savings achieved as a result of the retrofit. Water use in the control group held constant from 1999 - 2002 while the study group reduced their demand by more than 12 percent.

CHAPTER 5 NEW FIXTURE SATISFACTION RATINGS

In April 2002 the EBMUD study participants were asked to rate the performance of their new fixtures and appliances and their experience with the study. Each participating household was asked to complete a nine page, 44 question "New Product Information and Satisfaction Survey" that sought information about customer satisfaction with each of the products installed and with participation in the study. A copy of the survey instrument can be found in Appendix A and complete summaries of responses to each question along with any written comments can be found in Appendix C. Many of the questions were intentionally made identical to questions asked on the initial Audit Survey so that responses could be compared. Out of 33 participating households, 33 completed the survey, a 100 percent response rate.

RESULTS

Most of the equipment installed during the retrofit was kept in place during the study period however 8 households reported that various faucet aerators or showerheads had been replaced. Three households removed the kitchen faucet aerator and one home removed bathroom faucet aerators. The participant that removed the faucet aerators commented that the aerators installed simply restricted flow too much. Kitchen faucet aerators were removed due to clogging or stiffness. Six households removed showerheads because of "painful" spray, leakage, cracking, and other problems. The overwhelming majority of the fixtures installed were kept in place and used for the duration of the study period.

Toilets

Overall, customers were quite pleased with their new ULF toilets. Seventy percent of the respondents said they would recommend the fixtures to a friend, sixty percent liked their new toilets more than their old ones, and 30 percent liked the new toilets the same as the old ones. Only 10 percent like the new toilet less than their old model. At the same time, the participants had many recommendations for improving the toilets ranging from wanting a larger waters spot to complaints about "plastic parts". Eleven households (33 percent) reported a flushing or performance problem with their new toilet. Many of these problems were related to bowl cleaning and three were related to leakage. Repairs successfully fixed flushing problems in two

cases. Of the 11 households reporting problems, 5 were equipped with Caroma toilets, 4 were equipped with Niagara toilets, 1 was equipped with the Sloan Flushmate, and 1 with a Toto.

Seventy-three percent of the households reported that their new ULF toilets never needed to be plunged during the study period and twenty-seven percent said their toilet needed to be plunged less than once per month. This suggests that the new ULF toilets required *less frequent* plunging than the old toilets removed during the retrofit. Prior to the retrofit, twenty-nine percent of the households reported that their toilets never required plunging. Fifty-four percent reported infrequent plunging ranging from every other month to every other year and seventeen percent of the households reported that more frequent plunging was required for their toilet(s).

The requirement for frequent double flushing (more than once per week) increased after the retrofit from 29 percent to 51 percent. Occasional double flushing (a few times per year) decreased from 30 percent to 27 percent. After the retrofit, 18 percent of the respondents said they never double flush their new toilets while prior to the retrofit 30 percent of the respondents indicated that they never needed to double flush. It is important to keep in mind here that while more homes reported double flushing than before the retrofit, the actual number of extra flushed might only amount to one or two per week per household.

Table 5.1 shows a comparison of the ratings of toilets before and after the retrofit in the following areas: bowl cleaning, flushing performance, appearance, noise, leakage, and maintenance. Participants rated their toilets on a scale of 1 to 5 (1 = unsatisfied and 5 = completely satisfied).

Table 5.1 Pre and post-retrofit toilet rating

Rating Category	Pre-Retrofit Non-ULF Toilets	Post-Retrofit ULF Toilets
Bowl Cleaning	3.56	3.70
Flushing performance	3.44	4.00
Appearance	3.26	4.58
Noise	3.41	4.42
Leakage	3.59	4.55
Maintenance	3.52	4.58
Overall Average	3.46	4.31

Rating scale from 1 – 5 where 1 = unsatisfied and 5 = completely satisfied

The new ULF toilets received substantially higher ratings in every category. The overall average was 0.85 points higher for the new ULF toilets 3.46 vs. 4.31. Study participants were particularly pleased with the appearance, leakage, noise reduction, and maintenance associated with the new toilets. The new toilets received their lowest score for bowl cleaning, but the average rating of 3.70 equates between "neutral" and "somewhat satisfied". This score was higher than any score the old toilets received in any category. It is important to remember that these ratings of the old fixtures were done while those fixtures were still in place during the audit.

The customer satisfaction survey also asked participants to compare their new toilets to their old toilets in a number of ways. The results are shown in Table 5.2. Again the majority of respondents felt that the new toilets were an improvement in every way over their old fixture. Here it can be seen that 60 percent of the participants liked their new toilets more than the old ones and 9 percent liked them less. Forty-nine percent felt the new toilets clogged less frequently, 36 percent said the clogged the same amount, and 9 percent said the clogged more often.

Table 5.2 Comparison ratings of new and old toilets

Question: Compared to your old toilet…	**Response Percentages**			
	More	**Same**	**Less**	**Not Sure**
…do you like your new toilet(s)?	60.6%	30.3%	9.1%	0.0%
…do your new toilet(s) clog?	9.1%	36.4%	48.5%	6.1%
…do your new toilet(s) require double flushing?	30.3%	33.3%	33.3%	3.0%
…do your new toilet(s) require bowl cleaning?	36.4%	36.4%	27.3%	0.0%

Most people (66.6 percent) indicated that the new toilets required the same or less frequent double flushing while 30 percent felt the new toilets were double flushed more. Respondents were split on the subject of bowl cleaning with 36 percent indicating that more bowl cleaning was required, 27 percent indicating that less was required, and 36 percent reporting it was the same.

Niagara vs. Caroma

Since primarily two brands of ULF toilet were installed for this study it is possible to compare customer satisfaction ratings with both brands. These results are presented in Table 5.3.

Both toilets received a favorable overall rating with the Niagara "tipping bucket" flapperless toilet beating out the Caroma Caravelle dual flush 4.65 to 4.13. The Niagara averaged a score of higher than 4 in all categories and nearly got a perfect 5.0 for leakage. The Caroma only received at rating of 3.13 for bowl cleaning. This toilet has a rather small water spot that may contribute to bowl cleaning difficulties.

Table 5.3 Customer ratings of Caroma and Niagara Toilets

Rating Category	Caroma Toilets (n=34)	Niagara Toilets (n=33)
Bowl cleaning	3.13	4.36
Flushing performance	3.88	4.43
Appearance	4.44	4.79
Noise	4.25	4.57
Leakage	4.44	4.93
Maintenance	4.64	4.86
Overall Average	4.13	4.65

Rating scale from 1 – 5 where 1 = unsatisfied and 5 = completely satisfied

The Caromas were praised for their appearance, low leakage rates, and maintenance. The Niagaras received high marks for flushing performance, appearance, lack of noise, low leakage rates, and maintenance. Twelve out of 14 households equipped with Niagara toilets indicated that they would recommend the toilet to a friend, one said the wouldn't, and another was unsure. Ten of 16 Caroma-equipped homes said they would recommend the toilet, three respondents said they would not recommend the Caroma, and two respondents were unsure about making a recommendation. Overall, the Niagara was the most popular toilet in the test homes and saved the most water on a per capita basis. The Caroma, which has a more experimental design scored fairly well in most categories and was popular with the majority of users.

Clothes Washers

Nine of the 33 survey respondents (27.3 percent) indicated that they experienced a problem with their new clothes washer during the first six months. The problems included difficulty is properly leveling the Fisher-Paykel machine, improper cycle functions, complete

failure (and subsequent replacement) of a machine, and rinsing problems. Seventy percent of the households did not report any problems.

Most of the respondents (70 percent) liked their new clothes washer better than their old one and only 9.1 percent like it less. Eighty-five percent said they would recommend the machine to a friend, six percent would not recommend their new machine, and 9 percent were unsure. Less than half of the respondents (48 percent) agreed that if they were in the market for a washer they would be willing to pay a premium of $150 to get an equivalent quality conserving washer. Thirty-three percent said they would not be willing to pay the extra money and another 19 percent were unsure.

Study participants rated the performance of their existing clothes washers during the initial audit interview. As part of the New Product Information and Satisfaction Survey they were asked to rate their new washer on exactly the same points. The responses to both surveys are shown in Table 5.4. Participants rated the new clothes washers higher in every single category. Of note were the substantially higher ratings of the new machines for noise and moisture content of the clothes. The new machines scored above 4.5 overall and were particularly praised for cleaning of clothes, moisture content of clothes, and detergent use. The old machines did not score above 4.5 in any category. Respondents also expressed satisfaction with the wash cycle time, cycle selection and reliability of the machines. The new machines scored a 4.33 rating for noise and capacity. A number of respondents made comments and suggestions regarding the machines. These are presented in full in Appendix C.

Table 5.4 Comparison ratings of non-conserving and conserving clothes washers

Rating Category	**Non-Conserving Clothes Washer** (n=33)	**Conserving Clothes Washer** (n=33)
Cleaning of clothes	4.23	4.70
Reliability	4.43	4.48
Noise	3.17	4.33
Moisture content of clothes	3.57	4.73
Cycle selection	4.11	4.45
Capacity	4.11	4.33
Wash cycle time	NA	4.45
Detergent use	NA	4.61
Overall Average	3.94	4.51

Rating scale from 1 – 5 where 1 = unsatisfied and 5 = completely satisfied

Clothes washer ratings by brand

The same rating system shown in Table 5.4 can be used to compare the performance of the three models of clothes washer tested in this study: Frigidaire Gallery (FWT449), Fisher-Paykel Ecosmart (GWL10), and Whirlpool Super Capacity Plus (LSW9245BQ). These results are shown in Table 5.5.

Table 5.5 Comparison ratings of clothes washer by brand

Rating Category	**Fisher-Paykel Ecosmart** (n=13)	**Frigidaire Gallery** (n=9)	**Whirlpool Super Capacity Plus** (n=11)
Cleaning of clothes	4.85	4.33	4.82
Reliability	4.69	3.78	4.82
Noise	4.15	4.33	4.55
Moisture content of clothes	4.77	4.67	4.73
Cycle selection	4.54	4.11	4.64
Capacity	4.62	3.44	4.73
Wash cycle time	4.77	3.78	4.64
Detergent use	4.85	4.33	4.55
Overall Average	4.65	4.10	4.68

Rating scale from 1 – 5 where 1 = unsatisfied and 5 = completely satisfied

All of the clothes washers received good ratings from the study participants. The Whirlpool and Fisher-Paykel machines (both top loaders) were tied for the highest rating followed by the front loading Frigidaire. The Frigidaire Gallery received high ratings for cleaning of clothes, noise, moisture content of clothes and detergent use. It's lowest scores were for reliability, capacity, and wash cycle time. The Fisher-Paykel machine received particularly high ratings for cleaning of clothes, reliability, moisture content of clothes, capacity, wash cycle time, and detergent use. The Fisher-Paykel received a 4.15 score for noise. The Whirlpool was rated above 4.5 in all categories. It score its highest rates for cleaning of clothes, reliability, moisture content of clothes, and capacity.

Showerheads

New low-flow showerheads were installed in 30 of the 33 participating study homes. Participants were generally satisfied with these showerheads and gave them an overall

satisfaction rating of 4.50 as shown in Table 5.6. The showerheads received a favorable rating in each category and no specific problems emerged although several respondents indicated that they removed or replaced the original showerhead provided with a different low flow brand.

Sixty-four percent of the respondents said they would recommend the showerhead to a friend and 9 percent said they would not recommend the fixture. More than 80 percent of the respondents said they liked the new showerhead the same or better than their old fixture. Thirteen percent liked it less.

Table 5.6 Showerhead satisfaction ratings

Showerhead Rating Category	**Rating** (n=30)
Water flow	4.43
Flow pattern	4.43
Appearance	4.67
Clogging	4.90
Adjustability	4.07
Overall average	4.50

Rating scale from 1 – 5 where 1 = unsatisfied and 5 = completely satisfied

Faucet Aerators

The faucet aerators installed on most kitchen sinks and all bathroom faucets received satisfactory ratings from the study. Sixty-seven percent of the respondents would recommend the aerators to a friend, 10 percent said they would not recommend the devices, and 23 percent were not sure. Forty percent like the new aerators more than their old faucet fixtures and another 40 percent felt they were the same. Only 10 percent liked the aerators less than their old ones.

Participants were asked to rate the performance of the aerators in a number of areas. Those results are presented in Table 5.7. All of the ratings were in the "somewhat satisfied" through "completely satisfied" range. People were most satisfied with the appearance of the aerators and least satisfied with the water flow and flow pattern. These results suggest that these faucet aerators have a good level of acceptability.

Table 5.7 Faucet aerator satisfaction rating

Faucet Aerator Rating Category	Rating (n=30)
Water flow	4.06
Flow pattern	4.10
Appearance	4.71
Clogging	4.68
Overall average	4.39

Rating scale from 1 – 5 where 1 = unsatisfied and 5 = completely satisfied

Study Participation

The final section of the New Product Information and Satisfaction Survey dealt with the experience of participating in the study and perceptions about behavioral changes that may have been brought about by participation. These responses can be used to improve implementation of conservation programs and similar future research efforts.

The majority of respondents (63 percent) did not feel that participating in the study had affected their water use behavior, but 22 percent did feel that their behavior had changed. Fifteen percent were not sure. Some of the comments about these changes included:

"I have always been a water saver. The study helped me spread the word to family and friends."

"Greater awareness of water use."

"Probably use less water as we have become more aware of conservation."

"I'm very conscious of water use and try to cut back, I.e. full washer loads, no unnecessary flushing."

"I do my laundry twice instead of once on many occasions."

"Always flush toilets via half flush."

Study participants were asked if they plan to remove or change any of the new products after the conclusion of the study. Seventy-two percent said no, but 16 percent indicated that they did plan to make changes, and 12 percent were unsure. Some of the planned changes were described as follows:

"Toilets - they suck!"

"Toilet - have to hold handle for full flush."

"The clothes washer. So I could add softener without having to wait for the extra rinse cycle."

"Maybe one of the aerators - it sprays on the counter top."

"May change showerhead to more adjustable unit."

"Master bath showerhead."

"Have already removed aerator in kitchen and showerhead."

"Faucet aerator is gone and the washer may go also."

Based on these comments, most changes involve aerators or showerheads, but a few may remove their clothes washer and two plan to replace their toilets.

More than half of the participants (52 percent) reported a noticeable reduction in their water and sewer bill as a result of the fixture retrofit. Fifteen percent felt there had not been a reduction and the remainder were unsure.

Participants were also asked to rate their experience in participating in the home water conservation study. These results are presented in Table 5.8. Most people felt completely satisfied in all aspects of participation in the study. The overall experience of participation was rated at 4.55 out of 5. Fixture installation was the biggest area of complaint – primarily because of problems with the plumber. In spite of these problems most participants were positive about their experience in the study.

Table 5.8 Study participation satisfaction rating

Study Participation Rating Category	**Rating** (n=33)
Ease of participation	4.63
Response to problems	4.47
Scheduling convenience	4.30
Courtesy of study staff	4.85
Fixture installation	3.97
Overall experience	4.55

Rating scale from 1 – 5 where 1 = unsatisfied and 5 = completely satisfied

For complete satisfaction survey results please see Appendix C.

CHAPTER 6 ANALYSIS OF COSTS AND BENEFITS

This study was not specifically designed with cost-benefit analysis in mind, but it was possible to utilize the results to calculate cost of each conservation measure fixture and the value of the water saved. For this analysis three conservation measures were considered: toilets, clothes washers, and showerheads. A cost benefit analysis of faucet aerators was not performed because those devices did not effect a statistically significant difference in per capita use because of increased duration of faucet use during the post-retrofit period.

TOILETS

The costs and benefits of the primary toilet models tested in this study, the Niagara Flapperless and the Caroma Caravelle, were evaluated separately. In addition to considering the water saved by the toilet itself, the water saved through the reduction in leakage was also included because the elimination of leaks was judged to be a direct result of the toilet retrofit. The water saved and the value of that water are shown in Table 6.1.

As discussed earlier, although both models of ULF toilets tested in this study saved water, the Niagara Flapperless toilets saved a little more water than the Caroma Caravelle. Water saved through the elimination of leaks in these houses was also added to the savings. The value of saved water was set at $2.20 per hundred cubic feet (ccf) or $2.94 per kgal, which is the sum of the East Bay Municipal Utility District's water and wastewater charges. The savings attributed to the Caroma Caravelle was valued at $73.94 per year while the savings from the Niagara Flapperless was valued at $76.42 per year.

Table 6.1 Water reduction and cost savings from ULF toilets

Toilet Brand	Toilet Model	Annual Per Capita Water Savings* (gal)	Annual per Household Savings (gal)	Annual per Household Savings (ccf)	Water & Sewer Cost per ccf**	Water and Sewer Savings per Year
Niagara	Flapperless	10,111	25,984	34.7	$2.20	$76.42
Caroma	Caravelle	9,782	25,140	33.6	$2.20	$73.94

*Includes water saved from toilet retrofits and reduction in leakage
*$2.20 = $1.77 per ccf for water and $0.43 per ccf for wastewater

The toilets tested in this study were priced in the middle range of toilet products that can run from $80 -$800 per toilet. The Niagara Flapperless retails for approximately $165 and the Caroma Caravelle for about $350. Installation costs vary, but for the cost-benefit analysis it was assumed that a professional plumber performed the work at a cost of $120 per toilet. Results of the cost-benefit analysis for toilets are shown in Table 6.2. The incremental cost for toilets was assumed to be 50 percent on the total installed cost. This is based on the assumption that each new toilet replaces a fixture that has one-half of its economic life remaining.

Table 6.2 Costs and payback period of ULF toilets

Toilet Brand	Toilet Model	Cost per Toilet	Cost of Installation per Toilet	Toilets Installed per House (median)	Incremental Cost*	Annual Water & Sewer Savings	Payback period (years)
Niagara	Flapperless	$ 165	$ 120	2	$ 285	$76.42	3.7
Caroma	Caravelle	$ 350	$ 120	2	$ 470	$73.94	6.4

*Set at 50 percent of the total installed cost

Given the fairly low annual water and sewer savings shown in Table 6.1, the payback period for installing 2 Niagara Flapperless toilets (the average installed in this study) is under 4 years and for the 2 Caroma Caravelle toilets installed for this study is under 7 years. The payback period for these toilets is still shorter than the expected product life of 20 years, but is higher than what was found in Seattle. In Seattle, because of the substantially higher costs for water and wastewater ($6.42 per ccf) the payback period for the Caroma Caravelle was just 2 years, and the payback for the Toto Drake was less than four years.

The toilet replacements also represent a capital improvement to the property. Although it is a small improvement, the replacements do affect the resale value of the house.

Utility Cost Savings

To measure utility water conservation savings benefits, EBMUD calculates its avoided cost of water supply at $280 per acre-foot or about $0.64 per ccf. For the utility rate-payer cost-effectiveness perspective, EBMUD calculates the water savings of the conservation measure and compares it to its avoided cost of water supply.

Table 6.3 shows the annual utility cost savings associated with the installation of ULF toilets. EBMUD saves between $21 and $23 per year per household converted to ULF toilets in

various avoided water and treatment costs. These savings can provide some limited justification for incentive programs such as toilet rebates that encourage installation of high efficiency products.

Table 6.3 Utility cost savings from ULF toilets

Toilet Brand	Toilet Model	Annual Water Savings per household (ccf)	Utility Cost Savings per ccf	Annual Savings	Life of Product Savings*
Niagara	Flapperless	34.7	$0.64	$22.21	$444.16
Caroma	Caravelle	33.6	$0.64	$21.50	$430.08

*Assuming a 20 year product life

CLOTHES WASHERS

High efficiency clothes washers like those evaluated in this study typically cost more than traditional washers because they utilize the latest technology, offer more settings and options, and have spin speeds that are often twice as fast as older models. The three washer models tested in this study included two front loading horizontal axis washers – the Frigidaire Gallery and the Fisher & Paykel Ecosmart; and the Whirlpool Super Capacity Plus (aka Resource Saver). Because costs differed widely and each machine offered different options, the costs and benefits of each machine was evaluated individually.

Table 6.4 shows the annual water savings for each clothes washer based on an average of 2.57 residents per household. The Whirlpool and Frigidaire machines each reduced demand by about 7.5 ccf per year while the Maytag saved 5.7 ccf per year. The dollar savings for water and sewer charges are also shown in this table as well as an estimate of the annual energy savings from reduced hot water demand and reduced clothes drying time.

Energy savings were estimated using the EPA Energy Star clothes washer savings calculator and an assumed energy cost of $0.116 per kilowatt-hour (kWh). This calculator utilizes data about each machine provided by the manufacturer along with user inputs to calculate savings. The machines used in this study have faster spin speeds than conventional washers, resulting in less remaining moisture in the clothes, and shorter drying times. In

EBMUD, most homes use dryers. As a result, the retrofit washers save energy both by using less hot water and by reducing drying time.

Table 6.4 Water reduction and cost savings from conserving clothes washers

Washer Brand	Washer Model	Annual per Capita Water Savings (gal)	Annual per Household Savings* (ccf)	Water & Sewer cost per ccf	Water & Sewer Savings per Year	Energy Savings per Year**
Frigidaire	Gallery	2,362	8.1	$2.20	$17.82	$57.26
Fisher & Paykel	Ecosmart	1,639	5.6	$2.20	$12.32	$56.89
Whirlpool	Super Capacity Plus	1,825	6.3	$2.20	$13.86	$41.78

*Assumes 2.57 people per household.
**Calculated from the EPA Energy Star clothes washer savings calculator. Based on $0.116 per kWh (PG&E standard rate)

Washer costs were based upon typical retail cost in the EBMUD service area. These data are shown in Table 6.5. Incremental costs were calculated as the price difference between the high efficiency washer and product of comparable quality from the same or similar manufacturer. Clearly less expensive washing machines are available, but they do not offer nearly as many features or the same level of quality as the machines tested in this study. The Fisher & Paykel Ecosmart was the most expensive machine with a typical price of $699 and a comparable top loading machine could be purchased for $500. The Frigidaire Gallery cost $682 and Frigidaire sells a comparable top loader for $500. The Whirlpool Super Capacity Plus cost $550 and similar non-conserving Whirlpool top loading machine can be purchased for $489.

The customer payback period for the clothes washers ranged from just over one year for the Whirlpool to just under three years for the Fisher & Paykel. With an expected useful product life of 13 years[21], all of these washers effect a net cost savings. The Whirlpool machine offers the quickest payback, but also offers the least savings in the long run. Arguments can be made for the quality and features of the Fisher & Paykel, which received high satisfaction ratings from EBMUD customers. As discussed in Chapter 4, all three machines received high satisfaction ratings from the participants in this study.

[21] Current national average (Department of Energy)

Table 6.5 Costs and payback period for conserving clothes washers

Brand	Cost	Comparable Washer Cost (same brand)	Incremental Cost	Annual Cost Savings*	Payback period (years)
Frigidaire	$ 682	$ 500	$ 182	$75.08	2.4
Fisher & Paykel	$ 699	$ 500	$ 199	$69.21	2.9
Whirlpool	$ 550	$ 489	$ 61	$55.64	1.1

*Water and wastewater + energy savings

Utility Cost Savings

From the utility perspective, assuming a 13-year product life, the life of product savings for these clothes washers is between $45 and $70. This represents the maximum rebate value that makes economic sense for EBMUD to offer to encourage installation of these devices. These results are shown in Table 6.6. If the energy savings are considered then the life of product savings will increase.

Table 6.6 Utility cost savings from conserving clothes washers

Washer Brand	Washer Model	Annual Water Savings per household (ccf)	Utility Cost Savings per ccf	Annual Savings	Life of Product Savings*
Frigidaire	Gallery	8.1	$0.64	$5.18	$67.34
Fisher & Paykel	Ecosmart	5.6	$0.64	$3.58	$46.54
Whirlpool	Super Capacity Plus	6.3	$0.64	$4.03	$52.42

*Assuming a 13 year product life

SHOWERHEADS

Showerheads are one of the least expensive conservation measures available. These devices can be purchased in bulk for a few dollars each or individually for about $10. It should be understood that the water savings from the showerheads tested in this study were not overwhelming (1.3 gcd), and these savings were not found to be statistically significant at the 95 percent confidence level but were significant at the 90 percent level. The calculated annual water savings and cost benefits for these devices are shown in Table 6.7. On average the showerheads saved 1.6 ccf per household: a financial benefit of $3.59 per year.

Table 6.7 Water reduction and cost savings from showerheads

Brand	Annual Per Capita Water Savings (gal)	Annual per household savings (gal)	Annual per household savings (ccf)	Water & Sewer cost per ccf	Water and Sewer Savings per Year
New Resources	475	1,219	1.63	$2.20	$3.59

Installation of showerheads is quite simple and can be done by a typical homeowner without difficulty. For this analysis it was assumed that the homeowner would replace all showerheads in a household – an average of 1.7 showerheads were installed per study home. Total cost for the showerhead retrofit was generously estimated at $25, $20 for the hardware and $5 for installation time. The incremental cost for showerheads was assumed to be 50 percent on the total installed cost. This is based on the assumption that each new showerhead replaces a fixture that has one-half of its economic life remaining. This results in a payback period of 3.5 years for the showerheads, as shown in Table 6.8.

Table 6.8 Cost and payback period for showerheads

Aerator Brand	Hardware Cost	Installation	Incremental Cost*	Annual Water & Sewer Savings	Payback period (years)
New Resources	$ 10 x 2	$ 5	$12.50	$3.59	3.5

*Set at 50 percent of the total installed cost

Utility Cost Savings

From the utility perspective, assuming a 10-year product life, the life of product savings for these showerheads is about $10. These results are shown in Table 6.9.

Table 6.9 Utility cost savings from conserving showerheads

Aerator Brand	Annual Water Savings per household (ccf)	Utility Cost Savings per ccf	Annual Savings	Life of Product Savings*
New Resources	1.63	$0.64	$1.04	$10.43

* Assuming a 10 year product life

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

RESEARCH FINDINGS

The EBMUD Indoor Residential Water Conservation Study found that significant, verifiable indoor water savings can be achieved through the installation of high efficiency plumbing fixtures and appliances. Not only did these high efficiency fixtures save water, but for the most part participants reported that they worked better than their old non-conserving fixtures. An analysis of benefits and costs showed that these products pay for themselves in water and sewer cost savings within the expect life of the product.

In this study, 33 single-family homes were retrofit with new toilets, clothes washers, showerheads, and faucet aerators. Precise data on the quantity of water used for each end use was measured before and after the retrofit so that the savings effected by each device could be evaluated. The retrofit program implemented in this study resulted in an average reduction of 36 percent in per household water use from 191.0 gpd to 123.3 gpd. On an annual basis this equates to a savings of 24.7 kgal per household.

Per Capita Use

After the retrofit, leakage (17.1 percent), which had previously been the largest component of indoor use dropped below toilets into fourth place. Toilets (18.6 percent), which have previously been the second largest component of indoor use moved into third place behind faucets. Showers became the largest indoor water use followed by faucets and toilets. The combination of showers and baths form the largest block of indoor use in the post-retrofit era at 25.5 percent. Overall, indoor water per capita use decreased to 52.2 gcd – a 39.4 percent drop. Baseline per capita use was measured at 86.1 gcd and after the retrofit per capita use was 52.2 gcd.

More than 30 gallons of the 33.9 gcd average saved through the retrofit was the result of three end uses: toilets, clothes washers, and leaks. Installation of ULF toilets, including some dual flush models saved an average of 10.1 gcd. The new conserving clothes washers saved an average of 5.1 gcd. A reduction in leakage resulted in big savings of 16.8 gcd. The leakage savings were almost certainly the result of the toilet retrofit. Toilet leaks, primarily flapper leaks,

are the single largest contributor to household leakage. In this study, replacing old toilets through the retrofit eliminated almost all of these toilet leaks and resulted in substantial savings. None of the other measures implemented through this study (clothes washers, showerheads, or faucet aerators) should have had any impact on the leakage rate.

Statistically significant reductions in water use occurred in some of the end use categories impacted by the retrofits: toilets, leaks and clothes washers. Shower use declined by nearly 11 percent, but the change was only statistically significant at the 90 percent confidence level. Faucets did not show any significant water use reduction, even though new aerators were installed. The remaining categories not targeted by the retrofit (baths and dishwashers) also showed no change.

Customer Satisfaction with New Products

About six months after installation of the new fixtures and appliances the study participants were asked to rate their performance. Each participating household was asked to complete a "New Product Information and Satisfaction Survey" that sought information about customer satisfaction with each of the products installed and with participation in the study. Many of the questions were intentionally made identical to questions asked on the initial Audit Survey so that responses could be compared.

The results of the survey showed a favorable response to the new high efficiency fixtures and appliances particularly toilets and clothes washers. This is perhaps surprising given the often repeated assertions (often based on unscientific anecdotal evidence) that these devices are less satisfactory. The new ULF toilets were rated higher in performance than the old non-conserving models. Seventy percent of the respondents said they would recommend the fixtures to a friend, sixty percent liked their new toilets more than their old ones, and 30 percent liked the new toilets the same as the old ones. Only 10 percent like the new toilet less than their old model.

Most of the respondents (70 percent) liked their new clothes washer better than their old one and only 9.1 percent like it less. Eighty-five percent said they would recommend the machine to a friend, six percent would not recommend their new machine, and 9 percent were unsure. Less than half of the respondents (48 percent) agreed that if they were in the market for a washer they would be willing to pay a premium of $150 to get an equivalent quality conserving

washer. Thirty-three percent said they would not be willing to pay the extra money and another 19 percent were unsure. Participants rated the new clothes washers higher in every single category. Of note were the substantially higher ratings of the new machines for noise, moisture content of the clothes, and cleaning of clothes.

Cost-Benefit Analysis

This study was not specifically designed with cost-benefit analysis in mind, but it was possible to utilize the results to calculate cost of each conservation measure fixture and the value of the water saved. For this analysis three conservation measures were considered: toilets, clothes washers, and showerheads. A cost benefit analysis of faucet aerators was not performed because those devices did not effect a statistically significant difference in per capita use because of increased duration of faucet use during the post-retrofit period. For all three measures considered, the payback period calculated was less than the expected life of the product. For clothes washers where energy and water savings are considered, the payback period was less than three years.

Toilets

The costs and benefits of the primary toilet models tested in this study were evaluated separately. In addition to considering the water saved by the toilet itself, the water saved through the reduction in leakage was also included because the elimination of leaks was judged to be a direct result of the toilet retrofit. As discussed earlier, although both models of ULF toilets tested in this study saved water, the Niagara Flapperless toilets saved a little more water than the Caroma Caravelle dual flush. Water saved through the elimination of leaks in these houses was also added to the savings. The value of saved was set at $2.20 per hundred cubic feet (ccf), which is the combination of the EBMUD charges for water and wastewater. The savings attributed to the Caroma Caravelles were valued at $73.94 per year while the savings from the Niagara Flapperless were valued at $76.42 per year.

The toilets tested in this study were priced between $160 (Niagara) and $350 (Caroma) which is in the mid-range for toilets that typically cost between $60 and $800. Installation costs vary, but for the cost-benefit analysis it was assumed that a professional plumber performed the

work at a cost of $120 per toilet. The incremental cost for toilets was assumed to be 50 percent on the total installed cost.

Given the annual water and sewer savings, the payback period for installing two Niagara Flapperless toilets (the median installed in this study) is 3.7 years and for the 2 Caroma Caravelle toilets installed for this study is 6.4 years. The payback period for these toilets is less than the expected product life of 20 years, but because of the low EBMUD water and sewer rates much longer than was found in the Seattle retrofit study. From the customer's perspective installing either of these toilet models only makes sense if the customer plans to stay in the house for the foreseeable future.

Clothes washers

High efficiency clothes washers like those evaluated in this study typically cost more than traditional washers because they utilize the latest technology, offer more settings and options, and have spin speeds that are often twice as fast as older models. The three washer models tested in this study included one front loading horizontal axis washer – the Frigidaire Gallery; and two top loading machines - the Fisher & Paykel Ecosmart and the Whirlpool Super Capacity Plus. Because costs differed widely and each machine offered different options, the costs and benefits of each machine was evaluated individually.

The Frigidaire machine reduced demand by about 8.1 ccf per year, the Whirlpool cut use by 6.3 ccf per year, and the Fisher & Paykel saved 5.6 ccf per year. The dollar savings for water and sewer charges are also shown in this table as well as an estimate of the annual energy savings from reduced hot water demand and reduced clothes drying time.

Energy savings were estimated using the EPA Energy Star clothes washer savings calculator and an assumed energy cost of $0.116 per kilowatt-hour (kWh). This calculator utilizes data about each machine provided by the manufacturer along with user inputs to calculate savings. The Frigidaire and Fisher & Paykel offer the most energy savings because they have high spin speeds, which leave clothes drier, thus substantially reducing drying time. The Frigidaire spin speed is 700 rpm, Fisher & Paykel spins at 1000 rpm, and the Whirlpool spins at 600-650 rpm. A traditional top loading washer's spin speed is typically 400 rpm.

Washer costs were based upon the actual retail price of these products in the EBMUD service area. Incremental costs were calculated as the price difference between the high efficiency washer and product of comparable quality from the same or similar manufacturer.

Clearly less expensive washing machines are available, but they do not offer nearly as many features or the same level of quality as the machines tested in this study. The Fisher & Paykel Ecosmart was the most expensive machine with a typical price of $699 and a comparable top loading machine could be purchased for $500. The Frigidaire Gallery cost $682 and Frigidaire sells a comparable top loader for $500. The Whirlpool Super Capacity Plus cost $550 and similar non-conserving Whirlpool top loading machine can be purchased for $489.

The customer payback period for the clothes washers ranged from just over one year for the Whirlpool to just under three years for the Fisher & Paykel. With an expected useful product life of 13 years[22], all of these washers effect a net cost savings. The Whirlpool machine offers the quickest payback, but also offers the least savings in the long run. Arguments can be made for the quality and features of the Fisher & Paykel, which received high satisfaction ratings from EBMUD customers.

Showerheads

Showerheads are one of the least expensive conservation measure available. These devices can be purchased in bulk for a few dollars each or individually for about $10. It should be understood that the water savings from the showerheads tested in this study were not overwhelming (1.3 gcd), and these savings were not found to be statistically significant at the 95 percent confidence level but were significant at the 90 percent level. On average the faucet aerators saved 1.6 ccf per household – a financial benefit of $3.59 per year.

Installation of showerheads is quite simple and can be done by a typical homeowner without difficulty. For this analysis it was assumed that the homeowner would replace all showerheads in a household – an average of 1.7 showerheads were installed per study home. Total cost for the showerhead retrofit was generously estimated at $25, $20 for the hardware and $5 for installation time. The incremental cost for showerheads was assumed to be 50 percent on the total installed cost. This is based on the assumption that each new showerhead replaces a fixture that has one-half of its economic life remaining. This results in a payback period of 3.5 years for the showerheads.

[22] Current national average (Department of Energy)

RECOMMENDATIONS

The results from this study make it clear that residential retrofits from the customer perspective can be a cost-effective tool for saving water and that customers are quite satisfied with the performance of the new high efficiency toilets and clothes washers currently available. These results provide powerful evidence of the effectiveness of interior water conservation measures and justification for continued support of cost-effective programs across the country.

The effects of conservation retrofits is an important area for future research. Clearly, the more sites that can be included in similar projects, the better and more reliable the results will be for generalizing to wider populations. Examination of the variability in the reductions in water use across several cities is an essential part of determining the ability to make generalizations from the results. A similar study is underway in Tampa, Florida and when that is concluded the results from all three studies will be combined into a single report document published by the US EPA.

Ongoing Research

Tracking the consumption of the EBMUD study group via billing data, and collecting more end use data after 2 years or more time has elapsed is an important to confirm the stability of the savings. The persistence of water savings over time is a critical component in water supply planning that includes water efficiency and more research in this area is needed. There is also interest in conducting more research into the capabilities and accuracy of the flow trace analysis technology used in this study.

Future studies should also include additional water saving technology such as one gpf toilets, instant hot water systems, and hands free faucet controllers. While these may not be economically justified strictly on the basis of water savings, many customers or builders may wish to include them for their convenience, and their water savings should be evaluated.

APPENDIX A

INVITATION LETTER

Dear Valued EBMUD Water Customer:

You are one of several hundred randomly selected homeowners invited to participate in a special **Home Water Use Study** sponsored by the East Bay Municipal Utility District (EBMUD) and the U.S. Environmental Protection Agency. This invitation is only being extended to several hundred homes, selected at random from homes throughout the EBMUD service area. Only one out of six of the invited homes will be selected as finalists to participate in the study - your home is not guaranteed to be among those finally selected. If you would like to be considered for participation and your home is selected, you will receive new, high-quality water conserving fixtures and appliances, ***free of charge***, listed below, installed by a licensed plumber.

- **Water and Energy Saving Clothes Washer**
- **Ultra Low Flush Toilets**
- **Water and Energy Saving Showerheads and Faucet Aerators**

If you are determined to be eligible and selected the appliances and fixtures provided in the Home Water Use Study will be *yours to keep* in return for your highly valued time and cooperation during the study. It is estimated that the study will take about 12 months and require about 4-6 hours of your time in total. You will need to be present for an initial review of your appliances and fixtures by EBMUD staff and/or a professional consultant and to answer a short survey. You will also need to be present a second time for the installation of the water saving products. Please refer to the fact sheet on the back of this letter for more information.

EBMUD will use the results of the Home Water Use Study to plan future conservation activities. Your participation is key to the success of this important research study. If you have any questions, please call 287-0590. Otherwise**, please fill out the self-addressed post card and mail it back as soon as possible**. If we do not hear from you soon, a District representative may contact you to determine your interest in participating in the study. Thank you for your time and cooperation.

Sincerely,

DICK BENNETT,
Home Water Use Study Project Manager

INVITATION FACT SHEET

WHAT IS THE STUDY?
The project will involve studying the water use at approximately 35 homes within the East Bay Municipal Utility District (EBMUD) service area. Water use for existing home fixtures and appliances will be collected and analyzed for several weeks. Next, the existing water using fixtures will be replaced with water and energy efficient (conserving) models and data collected and analyzed for another several weeks. Approximately nine months later, household use will again be monitored for another two weeks.

WHY CONDUCT THE STUDY?
The purpose of the study is to: 1) determine the amount of water used by different household appliances and fixtures, 2) determine the amount of water saved with various water saving products, and 3) evaluate homeowner satisfaction with the new water efficient products. This information will help the District better understand the performance of various water saving products and help prioritize its conservation program.

WHO WILL ADMINISTER THE STUDY?
EBMUD staff will administer the study along with a consultant team that will collect and analyze home water use information.

HOW WILL THE STUDY BE CONDUCTED?
Data loggers will be installed on the customer water meter located outside by the street that will record daily water use for analysis by a team of EBMUD staff and professional consultants. No monitoring equipment will be placed inside the home.

WHEN WILL THE STUDY TAKE PLACE?
The study is anticipated to start in December 2000 and end in December 2001.

HOW MUCH OF MY TME WILL BE NEEDED?
The entire study will require only about 4-6 hours of your time. The homeowner will need to be present for about one hour for an initial survey and to answer any questions the consultant may have. Someone will also need to be present about one month after the initial visit for the installation of the appliances and fixtures. This second visit could take several hours. Finally, you will be asked to fill out a brief survey regarding your satisfaction with the products.

WHAT COOPERATION IS REQUIRED BY ME?
If eligible and selected as a finalist for the study, you will need to sign an agreement with the District whereby you agree to cooperate in the study and plan to remain at your present address for one year. If, for example, you decide to move before December 2001, the District reserves the right to reclaim the installed products. So, to participate, you should be planning on staying in your home for one year and should be interested in cooperating in the study.

INITIAL PARTICIPATION QUESTIONNAIRE

You have been randomly selected as a potential candidate and may have an opportunity to participate in a residential water use study and may be eligible to receive free water using products. **Please complete this brief questionnaire and when you are done, simply fold this sheet in half and staple it or tape it at the top and place it in the mail. Address information and postage have been provided. Thank you very much.**

(Address Label) _____
_____
_____

Please correct any of the above information in the space provided.

Phone: (_____) _____ (____) _____
(Home) *(Work)*

☐ **No,** I prefer not to participate in the home water use study.

☐ **Yes,** I am interested in further pursuing possible participation in the water use study. If I become eligible and am chosen to participate in the study, I hereby agree to cooperate with the research effort in exchange for the free products I may receive.

If you answered yes, please fill in the information below.

Estimated age of home: _____ years.
Number of occupants: _____.
Please tell us about any water using fixtures that have been replaced in your home.

Fixture	**Number Replaced**	**Year Replaced**	**Make, Model**
TOILETS			
SHOWERHEADS			
FAUCETS			
OTHER			

4) Please tell us about your clothes washer.

Clothes Washer Brand	**Model**	**Year of Manufacturer** (approximate)	**Is Machine Top Loading** (Y/N)

Thanks for taking the time to fill out and return this questionnaire. The final group of participants will be randomly selected from EBMUD customers that expressed interest. You will be notified within 4-6 weeks whether you have been selected for the study.

East Bay Municipal Utility District
Attention: Mr. Richard Bennett MS 901
PO Box 20455
Oakland, CA 94623-1055

(fold line)

(fold line)

EAST BAY MUNICIPAL WATER UTILITY DISTRICT
HOME WATER CONSERVATION STUDY AUDIT FORM

CUSTOMER DATA

Customer Name _____ Keycode _____

Service Address _____

_____

Date of Audit _____ Time of Audit _____

1. Total number of full-time residents _____
   - Children (0-12 yrs) _____
   - Teens (13-19 yrs) _____
   - Adults (20+) _____

2. Here during baseline logging period? _____
   - Number absent _____
   - Dates not present _____
   - _____

3. When did you move to this house? _____

4. Year was the house built? _____

5. Floor area of the house _____

6. Number of stories _____

7. Garage size *(1 car, 2 car, etc.)* _____

8. Number of bedrooms _____

9. Full baths _____ 3/4 baths _____ 1/2 baths _____

10. Irrigation system? _____ Month irrigation begins/ends _____

SURVEY QUESTIONS

1. How many showers per week are taken outside the home? *(at school, work, swimming pool, health club, etc)* _____
2. During a typical week day, (9am – 5pm) how many people are at home? _____

3. Is there a home office in this home? _____

   If so, do people come into the house to work? _____

4. Are there any other business activities in the home? _____

5. During the next two weeks how often do you expect to irrigate your yard?

   0_____ 1-2 times_____ 3-5 times _____ more than 5 times _____

6. Do you ever have laundry other than dry cleaning done at a Laundromat or laundry service?

   (outside the home) _____

7. What times of day do most showers occur in your home? _____

8. How often do people in the home take baths? *(instead of or in addition to showers)*

   Daily_____ Weekly _____ Monthly _____ Yearly _____

   What time of day do baths occur _____

9. When was the last time you had a problem with your existing toilet? _____

10. Please describe the nature of this problem? _____

    _____

11. How frequently do you have to use a plunger on your existing toilets?

    Daily_____ Weekly _____ Monthly _____ Yearly _____

12. How frequently do you have to "double flush" your current toilets?

    Daily_____ Weekly _____ Monthly _____ Yearly _____

13. How satisfied are you with your current toilets in the following areas? *(unsatisfied 1-5 completely satisfied)*

	NON-ULF1	NON-ULF2	ULF (if any)
a) Bowl cleaning	_____	_____	_____
b) Flushing performance	_____	_____	_____
c) Appearance	_____	_____	_____
d) Noise	_____	_____	_____
e) Leakage	_____	_____	_____
f) Maintenance	_____	_____	_____

14. Do you use your toilet to dispose of waste (such as tissues, cigarettes, paper etc.)?

Yes _____, No _____, Don't Know _____

15. If yes, how often do you dispose of waste in your toilet?

Per Day_____ Per Week _____ Per Month _____ Per Year _____

16. How satisfied are you with your current clothes washer in the following areas? *(unsatisfied = 1 – 5=completely satisfied)*

a) Cleaning of clothes _____

b) Maintenance/reliability _____

c) Noise _____

d) Moisture content of clothes _____

e) Cycle selection _____

f) Capacity _____

17. What interested you in participating in this study? *(check all that apply)*

Free products _____ Water conservation _____ Help the environment _____

Civic duty _____ None of these _____ *Please describe* _____

_____

26. Expected # of home car washes this month _____

27. Expected # of sidewalk/driveway washes per month _____

KITCHEN INFO

28. Dishwasher make _____ Model _____

Preferred wash setting _____

29. Kitchen faucet make _____ Time _____ Leak_____

Aerator Compatible? *(Y/N)* _____ Hand sprayer? *(Y/N)* _____

30. Home water treatment? *(Y/N)* _____ Make/model _____

Point of Entry _____ Point of Use _____ Regen? _____

31. Recirculating hot water? *(Y/N)*_____ Make/model _____
Serving which fixtures? _____

32. Ice maker on fridge? _____

33. Garbage disposal? _____

UTILITY/OTHER

34. Clothes washer make _____ Model _____Year *(if known)*_____

35. Utility sink? _____ Time _____Leak_____

36. Swimming pool? _____ Length_____ Width_____ Avg. Depth _____

Fill method _____ Fill timing _____

37. Hot tub *(not in bathroom)*? _____Length_____ Width_____ Avg. Depth _____

Fill method _____ Fill timing _____

38. Other water using fixtures or items of note:

_____

_____

_____

_____

_____

_____

_____

_____

HOT Water Pressure (psi) _____

Hot water meter installed? YES _____ NO _____

BATHROOM INFORMATON:

		1	2	3	4	5
39	Description (master, guest, kids)					
40	Size (full, ¾, 1/2)					
41	LEAKS					
42	TOILET Make					
43	Toilet model					
44	Year of manufacture					
45	Counter height (in) Rough-in (in)					
46	Time of flushes					
47	ULF or dual flush?					
48	BATH?					
49	Size of tub (length, width, depth)					
50	Time of bath					
51	SHOWER?					
52	Type of showerhead					
53	Time of shower					
54	Does Bath leak during Shower?					
55	SINK?					
56	Aerator?					
57	Time of sink					
58	Other?					
59	Other?					

OUTDOORS

---

60. Number of hose bibs _____Times 1 _____2_____Leaks_____

61 Front yard landscape description and estimated irrigated area: _____ sf

Grass_____ % Trees/Shrubs _____% Hardscape_____ % Flowers_____ % Xeriscape_____ % Other_____ % _____

62. Quality score *(poor = 1, excellent = 5)* _____

63. Back yard landscape description and estimated irrigated area: _____ sf

Grass_____ % Trees/Shrubs _____% Hardscape _____ % Flowers_____ % Xeriscape_____ % Other _____ % _____

64 Quality score *(poor = 1, excellent = 5*) _____

65 Outdoor water pressure psi (static)_____ w/indoor use_____

66 Irrigation Clock Runtime/Landscape:

	Runtime	Landscape Irrigated
Zone 1	_____	_____
Zone 2	_____	_____
Zone 3	_____	_____
Zone 4	_____	_____
Zone 5	_____	_____
Zone 6	_____	_____
Zone 7	_____	_____
Zone 8	_____	_____
Zone 9	_____	_____
Zone 10	_____	_____
Zone 11	_____	_____
Zone 12	_____	_____

Landscape Description

1. *Poor quality. Bare ground or no maintenance at all, weeds, dead grass and bushes. Is not mowed.*
2. *Below average. Grass is patchy with many dead spots, shrubs unattended.*
3. *Average. Grass mostly green, shrubs trimmed in last two years.*
4. *Above average. Grass green and mowed, shrubs and plants trimmed, no dead spots.*
5. *Excellent. Entire landscape is exceptionally maintained.*

HOME WATER USE STUDY
Participation Agreement

This Agreement is made and entered into this _____ day of February, 2001, between The East Bay Municipal Utility District, a public entity, hereinafter called "EBMUD" and _____, the homeowner(s) hereinafter called "Participant", at _____
(address)
In consideration of the mutual promises contained herein, Participant and EBMUD agree as follows:

AGREEMENT

1. Purpose and Nature of Study

A. The Home Use Study (Study) is being conducted by EBMUD with financial support from the Environmental Protection Agency. The purpose of the Study is to determine the end uses of water by single family customers and the water savings achieved by various water savings appliances and fixtures. The Study will involve the monitoring of use at 35 single-family homes throughout EBMUD's service area through the use of a data logger installed at the water meter. About 10 homes will also have a meter installed on the hot water tank feed line. The Study will involve several visits to the home by EBMUD personnel and by EBMUD representative's to conduct a fixture survey and to install fixtures and appliances. The Study is expected to begin in January and take about 12 months to complete.

B. The Study will measure impacts on water use resulting from the replacement of certain existing water using fixtures and appliances ("Existing Appliances") with new fixtures and appliances that are designed to save water ("Study Appliances"). Study Appliances will include some or all of the following: washing machine, toilets, showerheads, faucet aerators, and faucet flow control devices. EBMUD or its assigned contractors will replace Existing Appliances with Study Appliances, connect the Study Appliances to Participant's plumbing system, and install equipment that monitors water use.

C. EBMUD will be responsible for all Study costs, including the replacement of Existing Appliances; the purchase, installation and connection of Study Appliances; and the purchase, installation and removal of water use monitoring equipment. At the conclusion of the Study, all Study Appliances will become the property of Participant, at no cost to Participant.

D. The Study will include up to five visits to Participant's home by EBMUD staff or that of its assigned contractors. The purpose of these visits includes initial inspection of home for suitability (as described below), installation and removal of water use monitoring equipment; replacement of Existing Appliances and installation of Study Appliances, and collection of data from the water monitoring equipment.

Entry into the home will be needed at least twice, once to conduct a survey of the fixtures and appliances and to obtain flow traces and once to replace fixtures and appliances. Several other site visits will be necessary to either install or retrieve the data logger at the meter, but no entry into the home will be required. The first site visit is expected to take about one hour and the homeowner is expected to be available on site to answer questions. The second site visit will be by a licensed plumber and could take from one to three hours to replace the existing fixtures and appliances with the Study Appliances. The homeowner is also expected to be at home during the second visit. The first site visit is expected to occur in January and the second site visit is expected to occur in February or March. A final entry into the home may be needed to remove Study Appliances, if necessary.

E. Participant and EBMUD agree that only homes with existing plumbing conditions which, in the opinion of EBMUD, are able to support the safe replacement of Existing Appliances with Study Appliances without significant repairs or modifications of the Home or its plumbing system will be included in the Study. The parties further agree that EBMUD staff or that of its assigned contractors shall make an initial inspection to determine suitability of the home for the Study. Such inspection shall be limited to those portions of Participant's plumbing system directly involved in the replacement of the Study Appliances ("Study Plumbing"), and not other portions of Participant's plumbing system ("Other Plumbing").

F. The Study activities will commence when this Agreement is signed by Participant and EBMUD, and will conclude December 1, 2001.

2. Installation of Fixtures and Appliances

A. EBMUD staff or that of its assigned contractors, at EBMUD's cost and expense, will replace Participant's Existing Appliances with Study Appliances selected by EBMUD from those described below. Selection of brands or models by Participant is not implied.

B. EBMUD makes no representation or warranty (1) that Participant will be satisfied with the performance of the Study Appliances or (2) that Study Appliances actually will use less water than Existing Appliances

C. EBMUD reserves the right to reclaim the Study Appliances if (1) Participant chooses to terminate this Agreement prior to the Study's conclusion, (2) Participant's home is sold or rented prior to December 1, 2001, or (3) Participant does not meet its obligations under this Agreement. If EBMUD chooses to reclaim the new fixtures upon early termination of this Agreement, it will restore Participant's Existing Appliances to pre-Study conditions.

3. Connections to Plumbing System.

EBMUD staff or its assigned contractors will make necessary connections to Participant's Study Plumbing. Such connections may include reasonable, inexpensive plumbing repairs required to ensure the proper functioning of the Study Appliances. EBMUD reserves the right to terminate this Agreement if, after the initial inspection, conditions are revealed which require repairs deemed by EBMUD to be unreasonable. In this case, EBMUD will restore Participant's Existing

Appliances and Study Plumbing to pre-Study conditions. All work done on Participant's Study Plumbing will be done under the oversight of a licensed plumber under the general direction of EBMUD.

4. Limits of EBMUD's Responsibility

A. EBMUD will not be responsible for any cost or work that is not directly related to the replacement of Existing Appliances, the installation of Study Appliances, their proper functioning, and the connection of the Study Appliances to Study Plumbing. Any modifications beyond those described in the previous sentence, including any remodeling or cosmetic changes that might be desired by Participant, must be pre-arranged and approved by EBMUD prior to being undertaken and must not interfere with the Study design or schedule. Participant shall conduct or contract for such modifications and be solely responsible for their cost.

B. EBMUD will assume no liability for any loss or damage related to the Other Plumbing.

C. At the end of the Study, EBMUD will replace Study Appliances with Existing Appliances, if requested to do so by the homeowner.

5. Requirements for Participation

A. Participant agrees that if, upon initial inspection, EBMUD determines that the existing plumbing conditions are unsuitable for inclusion in the Study, EBMUD may terminate this Agreement, with no further obligation on the part of EBMUD or Participant. Participant agrees that EBMUD also may terminate this Agreement pursuant to Section 3 and other provisions of this Agreement

B. Participant shall cooperate with scheduling, be available for visits as described in Section 1, provide information of the type described in this Agreement as requested by EBMUD, and permit reasonable access to the home for Study purposes.

C. Participant shall not disturb, tamper with, or remove any of the water monitoring equipment installed for this Study. Participant will not replace, disconnect, modify or intentionally damage any of the Study Appliances prior to the conclusion of the Study.

D. Participant shall provide EBMUD with data on household characteristics, including number and ages of household members, water using fixtures and appliances, water use practices, and other information pertaining to the Study, as requested.

E. Participant agrees to systematically operate each of the new fixtures and appliances and record the time that each event occurs on a log and return it to the District or consultant.

F. Participant agrees to answer survey questions regarding satisfaction with Study Appliances.

G. Participant voluntarily agrees to join in the Study.

H. Selection of Fixtures and Appliances. The Study objectives require that a certain number of designated appliances and fixtures be installed. To meet Study objectives, any one of the appliances and fixtures listed below, including water saving showerheads and faucet aerators, may be installed in the study participant's home. It is conceivable that some appliances or fixtures may not be suitable for use at a given site due to space or plumbing limitations.

Clothes washers	**Toilets**	**Faucet Control Device**
Fisher-Paykel	Caroma (dual-flush)	Aerators
Frigidaire	Niagara	
Whirlpool	Sloan	

6. Study Data.

All information obtained from this Study will be the sole property of EBMUD. The information will be used for statistical purposes only. Unless otherwise required by law, EBMUD will make no public disclosure of any information about Participant's person, family, home, address, or water consumption.

7. Release.

Participant releases and agrees to hold harmless the EBMUD, its officers, employees and contractors, from any and all claims, losses, harms, costs, liabilities, damages and expenses (collectively, "Losses") directly or indirectly resulting from or related to Participant's participation in the Study, except as such Losses directly result from the removal of Existing Appliances, the installation of Study Appliances, the connection of the Study Appliances to the Study Plumbing, or the installation, use or removal of the equipment to monitor water use.

8. Representations.

Participant represents that he/she/they has the authority to execute this Agreement and to authorize installation of the Study Appliances and water use monitoring equipment. Participant also represents that there are no other agreements between EBMUD and Participant, oral or written, concerning the Study.

9. Entire Agreement and Governing Law.

This Agreement shall be governed by the laws of the State of California and constitutes the entire Agreement of the parties, superseding all prior agreements written or oral and superseding the reverse side of the purchase order, between them on the subject.

10. No Waiver.

The EBMUD's waiver of the performance of any covenant, condition, obligation, representation, warranty or promise in this Agreement shall not invalidate this Agreement or be deemed a waiver of any other covenant, condition, obligation, representation, warranty or promise. The

EBMUD's waiver of the time for performing any act or condition hereunder does not constitute a waiver of the act or condition itself.

In witness whereof, the parties have executed this Agreement on the dates indicated below.

EBMUD Approved As To Form

By: _____ **By:_____**

Dick Bennett, Home Water Use Study Manager for the Office of the General Counsel

Date: _____

Participant (Home Owner (s))

By:_____

Print Name:_____

By:_____

Print Name:_____

Date:_____

EBMUD HOME WATER CONSERVATION STUDY
NEW PRODUCT INFORMATION AND SATISFACTION SURVEY

Please take a few minutes to complete this survey about your new conserving fixtures. Your answers will help us select the best products for water conservation programs in your area. When you have completed the survey, simply fold it in half and place it in the addressed and stamped envelope provided. Thank you very much for your assistance.

CUSTOMER DATA

Customer Name: Keycode:

Address:

Please review the following information about the new products installed in your home and correct any errors.

Number of new toilets? Correct information: _____

Toilet brand? Correct information: _____

Clothes washer brand? Correct information: _____

Please indicate the number of faucet aerators and showerheads installed in your home.

New faucet aerators ❑ 0 ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ Don't Know

New showerheads ❑ 0 ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ Don't Know

Kitchen aerator installed? ❑ Yes ❑ No ❑ Don't Know

1. Have any of the above products installed for this study been removed or changed?

   ❑ Yes ❑ No ❑ Not sure

2. If yes, please list those removed or changed and explain why. _____

_____

_____

TOILETS

3. Have you experienced any flushing or performance problems with your new toilet(s)?

   ❑ Yes ❑ No ❑ Not sure

4. If yes, please describe the nature of these problems. _____

_____

5. If you had problems, did you request a repair?

   ❑ Yes ❑ No ❑ Not sure

6. If you requested a repair, was the repair completed to your satisfaction?

   ❑ Yes ❑ No ❑ Not sure

7. How frequently do you have to use a plunger on your new toilet(s)?

   ❑ Daily ❑ Weekly ❑ Monthly ❑ Less than monthly ❑ Never

8. How frequently do you have to "double flush" your new toilet(s)?

   ❑ Daily ❑ Weekly ❑ Monthly ❑ Less than monthly ❑ Never

9. On a scale of 1 – 5, how satisfied are you with your new toilets in the following areas?

1=dissatisfied, 2=somewhat dissatisfied, 3=neutral, 4=somewhat satisfied, 5=completely satisfied

g) Bowl cleaning	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
h) Flushing performance	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
i) Appearance	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
j) Noise	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
k) Leakage	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
l) Maintenance	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5

10. Compared to your old toilets, do you like your new toilet(s)?

❑ More ❑ Same ❑ Less ❑ Not sure

11. Compared to your old toilets, do your new toilet(s)?

a) Clog…	❑ More	❑ Same	❑ Less	❑ Not sure
b) Require double flushing…	❑ More	❑ Same	❑ Less	❑ Not sure
c) Require bowl cleaning…	❑ More	❑ Same	❑ Less	❑ Not sure

12. Would you recommend your new toilet to others?

❑ Yes ❑ No ❑ Not Sure

13. If your new toilet(s) have a dual flush feature (two flush buttons), how often do you use the "half flush" button?

❑ Don't have dual flush ❑ Never ❑ Less than half the time

❑ About half the time ❑ More than half the time ❑ Always

14. If there were one thing you would want the manufacturer of your toilets to change, what would it be?_____

_____

_____

15. Other comments about your new toilet(s):_____

_____

_____

CLOTHES WASHER

16. Have you experienced any problems with your new clothes washer?

❑ Yes ❑ No ❑ Not sure

17. If yes, please describe any problems with your new clothes washer. _____

_____

_____

18. On a scale of 1 – 5, how satisfied are you with your new clothes washer in the following areas?

1=dissatisfied, 2=somewhat dissatisfied, 3=neutral, 4=somewhat satisfied, 5=completely satisfied

a) Cleaning of clothes	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
b) Maintenance/reliability	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
c) Noise	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
d) Moisture content of clothes	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
e) Cycle selection	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
f) Capacity	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
g) Wash cycle time	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
h) Detergent use	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5

19. Does your new clothes washer have an extra rinse option?

❑ Yes ❑ No ❑ Not sure

20. If your clothes washer has an extra rinse option, how often do you use it?

❑ Always ❑ Sometimes ❑ Never ❑ Not sure

21. Compared to your old clothes washer, do you like the new clothes washer?

❑ More ❑ Same ❑ Less ❑ Not sure

22. Would you recommend your new clothes washer to others?

❑ Yes ❑ No ❑ Not sure

23. You received your new washer free as part of this study. But, if you were *buying* a washer, would you pay $150 more for your new washer than for an equivalent quality, conventional (i.e., top-loading, non-water saving) model?

❑ Yes ❑ No ❑ Not sure

24. If there were one thing you would want the manufacturer of your new clothes washer to change, what would it be? _____

_____

_____

25. Other comments about your new clothes washer:_____

_____

_____

SHOWERHEADS

Only answer the following questions if you received new showerhead(s).

26. On a scale of 1 – 5, how satisfied are you with the performance of your new showerhead in the following areas?

1=dissatisfied, 2=somewhat dissatisfied, 3=neutral, 4=somewhat satisfied, 5=completely satisfied

a) Water flow	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
b) Flow pattern	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
c) Appearance	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
d) Clogging	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
e) Adjustability	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5

27. Would you recommend your new showerhead(s) to others?

❑ Yes ❑ No ❑ Not Sure

28. Compared to your old showerhead(s), do you like your new showerhead(s)?

❑ More ❑ Same ❑ Less ❑ Not sure

29. Compared with your old showerhead(s), is your showering time with your new showerhead(s)?

❑ Shorter ❑ About the same ❑ Longer ❑ Not sure

30. Other comments about your new showerhead(s):_____

_____

_____

FAUCET AERATORS

Only answer the following questions if you received new faucet aerators.

31. On a scale of 1 – 5, how satisfied are you with the performance of the new aerator(s) installed on your faucets in the following areas?

1=dissatisfied, 2=somewhat dissatisfied, 3=neutral, 4=somewhat satisfied, 5=completely satisfied

a) Water flow	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
b) Flow pattern	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
c) Appearance	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
d) Clogging	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5

32. Would you recommend your new faucet aerators to others?

❑ Yes ❑ No ❑ Not Sure

33. Compared to your old aerators, do you like the new aerators?

❑ More ❑ Same ❑ Less ❑ Not sure

34. Other comments about your new aerators: _____

_____

_____

STUDY PARTICIPATION

35. Have you changed any of your water use behaviors as a result of participating in this study?

    ❑ Yes ❑ No ❑ Not sure

36. If yes, please describe the changes in your water use behaviors. _____

    _____

    _____

37. Do you plan on removing or changing any of the new products after the conclusion of this study *(fall 2002)*?

    ❑ Yes ❑ No ❑ Not sure

38. If yes, please list those you plan to remove or change and explain why. _____

    _____

    _____

39. Have you noticed any reduction in your water and sewer bill as a result of participating in this study?

    ❑ Yes ❑ No ❑ Not sure

40. If yes, by about how much do you think your bill has gone down?

    ❑ Less than 5% ❑ 5-10% ❑ 11-20% ❑ 21-30% ❑ More than 30%

41. On a scale of 1 – 5, rank your experience participating in the home water conservation study in the following areas?

1=dissatisfied, 2=somewhat dissatisfied, 3=neutral, 4=somewhat satisfied, 5=completely satisfied

a) Ease of participation	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
b) Response to problems	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
c) Scheduling convenience	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
d) Courtesy of study staff	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
e) Fixture installation	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
f) Overall experience	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5

42. Please respond to the following statement: "I feel my home has been improved by the installation of the water conserving products in this study".

❑ Strongly agree ❑ Agree ❑ Neutral ❑ Disagree ❑ Strongly Disagree

43. If there were one thing you would change about the study, what would it be? _____

_____

_____

44. Other comments: _____

_____

_____

Thank you for completing this survey. Please place the survey form in the pre-addressed and stamped envelope provided, and place it in the mail.

APPENDIX B

FLOW TRACE ANALYSIS DESCRIPTION[23]

The development of compact, battery powered, waterproof data loggers with extended memory capabilities along with advancements in personal computing made this research effort possible. The data loggers provided precise flow data at 10 second intervals and the computers allowed researchers to collect and analyze an extensive amount of data over the course of the entire study.

With data logging technology now available, precise data on where water is used inside a residence can be collected in a simple non-intrusive manner, directly from the water meter (DeOreo, Heaney, and Mayer 1996; Mayer and DeOreo 1995; Mayer 1995; Dziegielewski, 1993b). Each logger is fitted with a magnetic sensor that is strapped to the water meter of each study residence. As water is used inside the home, it flows through the water meter spinning the internal magnets. The sensor picks up each magnetic pulse as water moves through the meter and the logger counts the number of pulses detected and stores the total every 10 seconds. The logger has sufficient internal memory and battery life to record for more than 14 days at the 10 second interval.

Using the physical characteristics of each specific brand and model of water meter, the magnetic pulse data is transformed into instantaneous flow data for each 10 second interval. This flow trace is precise enough to detect the individual flow signatures of each type of appliance and plumbing fixture in the residence, and that of the outside hoses and sprinklers. Using a custom signal processing software package called Trace Wizard, each flow trace was disaggregated into its component end uses: toilets, showers, clothes washers, dishwashers, baths, faucets, irrigation, leaks, evaporative coolers, etc.

Data Logging Equipment

The logger used in this study was the Meter-Master 100EL manufactured by the F.S. Brainard Company of Burlington, NJ. The Meter-Master 100EL logger, shown in Figure B.1, offered the essential combination of data storage capacity, battery life, and ease of use.

[23] From the Residential End Uses of Water, Mayer, et. al. 1999, American Water Works Association

The data loggers used in this study are compact and sit comfortably out of sight in the meter box or pit during the logging period. Installation took between 3 and 7 minutes per logger (not including travel between houses) depending on the location and condition of the meter box. These loggers can be installed on most magnetic-driven water meters on the market although the positioning of the sensor varies by brand, model and, size. Adapters are also available so that the loggers can be used with mechanical meters, but magnetic-driven meters were a requirement for participation in this study and participating utilities replaced any meters that were not compatible with the logging system. EBMUD chose to replace all of the water meters in their study group in an effort to improve accuracy and ease of installation.

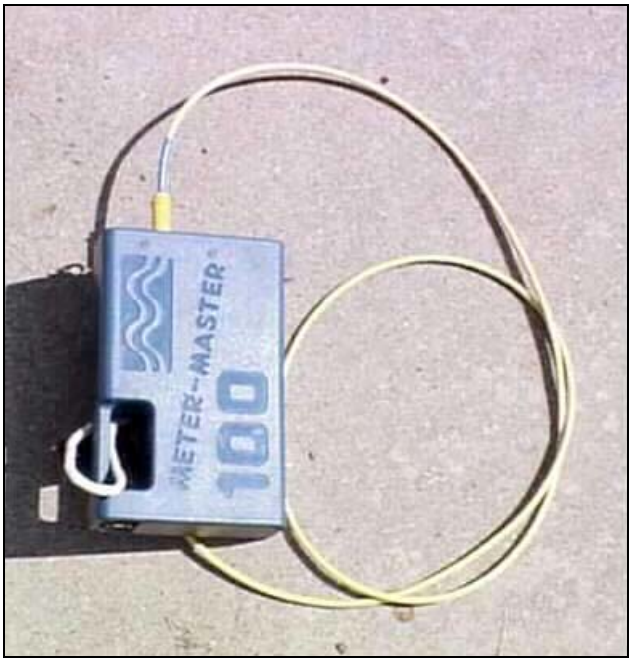


Figure B.1 One of the 110 data loggers used in the study

The basic assumption behind the data logging system in that the water meter is accurately recording flow volume. The logger is not truly measuring flows, but rather only records the spinning movement of the magnetic piston inside the water meter as water flows through the meter. The loggers records the number of magnetic pulses counted in a 10-second interval and once the data is downloaded, a the data logger control program automatically converts the pulse count into flow using the exact specifications of each water meter. The water meters used in this study provided resolution of between 80 and 120 magnetic pulses per gallon. When the logger is

downloaded, the logged volume is compared to meter readings taken at the time of installation and removal to ensure the accuracy of the flow trace.

End Use Data Analysis

The concept of flow trace analysis was first noted by Dr. Benedykt Dziegielewski who suggested that a single data logger attached to a residential water meter might yield data which could be disaggregated into its individual end uses (Dziegielewski, et.al., 1993b). The idea is based on the fact that there is consistency in the flow trace patterns of most residential water uses. A specific toilet will generally flush with the same volume and flow rate day in and day out. A specific dishwasher exhibits the same series of flow patterns every time it is run. The same is true for clothes washers, showers, irrigation systems, etc. By recording flow data at 10 second intervals, a rate determined by Aquacraft to optimize accuracy and logger memory, the resulting flow trace is accurate enough to quantify and categorize almost all individual water uses in each study home.

The application of flow trace analysis to quantify residential water use was successfully implemented for the first time in the 1994-95 Heatherwood Study in Boulder, Colorado (DeOreo and Mayer, 1994; Mayer, 1995; Mayer and DeOreo, 1995). During subsequent studies in Boulder and Westminster, Colorado, Aquacraft refined the flow trace analysis process and tested new hardware and software which would make it possible to collect and analyze such precise data from a large sample (DeOreo, Heaney, and Mayer, 1996).

The purpose of flow trace analysis is to obtain precise information about water use patterns: Where, when, and how much water is used by a variety of devices including toilets, showers, baths, faucets, clothes washers, dishwashers, hand-held and automatic irrigation systems, evaporative coolers, home water treatment systems, leaks, and more. In this study this was accomplished by recording flow rates from a magnetic driven water meter every 10 seconds using specially designed data loggers. This data is precise enough that individual water use events such as a toilet flush or a clothes washer cycle or filling up a glass of water from the kitchen tap can be isolated, quantified and then identified. The recorded flow trace data is precise enough to distinguish between even relatively similar events such as toilet leaks and faucet use. This technique makes it possible to disaggregate most of the water use in a single-

family residence and to quantify the effect of many conservation measures, from toilet and faucet retrofit programs to behavior modification efforts.

Trace Wizard

Trace Wizard is a 32-bit expert systems software package developed by Aquacraft, specifically for the purpose of analyzing flow trace data. Trace Wizard provides the analyst with powerful signal processing tools and a library of flow trace patterns for recognizing a variety of residential fixtures. Any consistent flow pattern can be isolated, quantified, and categorized using Trace Wizard including leaks, evaporative coolers, humidifiers, and swimming pools. Trace Wizard is integrated with the Meter-Master for Windows software that comes with the F.S. Brainard data logging system.

Analysis with Trace Wizard is currently a multi-step, iterative process. First Trace Wizard takes the raw gallons per minute flow data from the Meter-Master for Windows program and disaggregates the data into individual water use events from the smallest leak to the largest automatic sprinkler session. During the event calculation process, Trace Wizard calculates a specific set of statistics about each water use event. These statistics are: start time, stop time, duration, volume (gal), peak flow rate (gpm), mode flow rate (gpm) and mode frequency. All of these statistics are included in the final data base of water use events.

Once all the water use events have been isolated and quantified and statistics generated, Trace Wizard implements a user defined set of parameters developed for each individual study residence to categorize the water use events and assign a specific fixture designation to each event. These parameters can include the volume, duration, peak flow rate, and mode flow rate of each specific fixture. For example, a toilet may be defined as using between 3.25 and 3.75 gallons per flush, the peak re-fill flow rate is between 4.2 and 4.6 gpm, the duration of flush event is between 30 and 50 seconds, and the mode flow rate is between 4 and 4.5 gpm. Similar parameters are established for each of the fixtures found in the household. This simple signal processing routine runs quickly and assigns a fixture category (toilet, shower, clothes washer, etc.) to each water use event. The routine is re-run by the analyst frequently during the analysis process as the parameters are “fine tuned” to fit the fixtures in each specific house. The analyst uses the survey response data detailing the specific water-using appliances and fixtures in the

house to build the parameter file which assigns fixtures to water use events. The graphical interface of Trace Wizard allows the analyst to visually inspect water use events and build the parameter file so that it correctly identifies as many of the water use events as possible. When working for the first time with data from a residence it takes a trained analyst approximately one hour per week of data to complete flow trace analysis using Trace Wizard. Once an accurate parameter file has been created for that specific residence, the analysis time can be reduced significantly.

Trace Wizard is also capable of recognizing simultaneous events that frequently occur in residential households. For example, if someone is taking a shower in one bathroom and someone else in the house flushes the toilet and uses a faucet, Trace Wizard is able to separate these three distinct events through a set of user defined parameters.

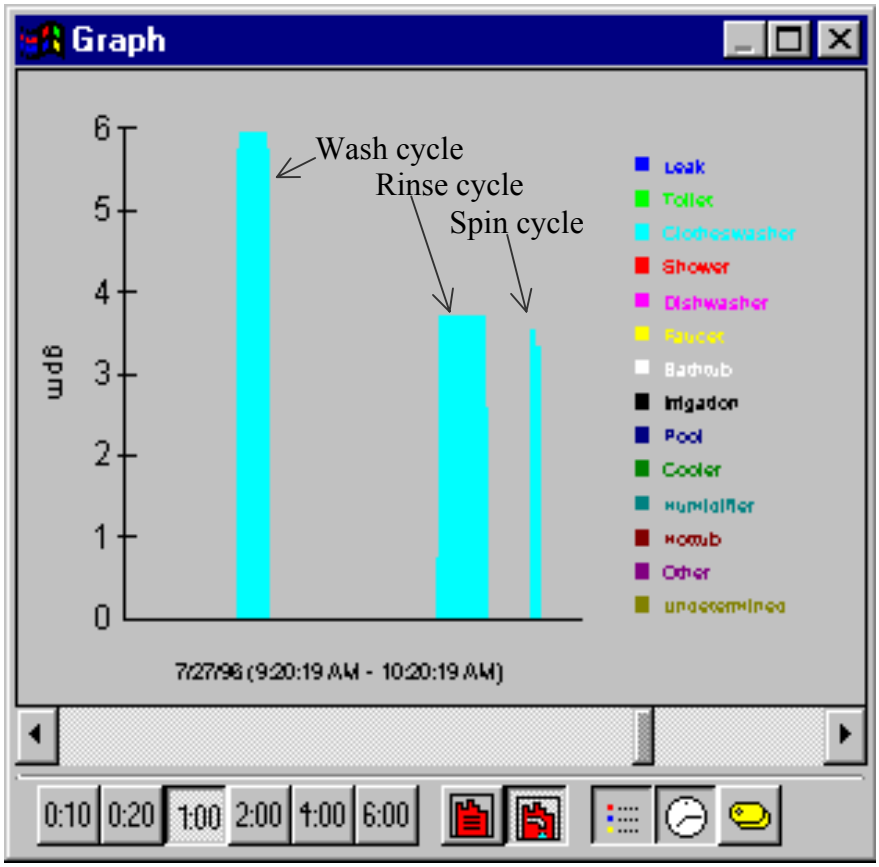


Figure B.2 Sample flow trace from Trace Wizard showing a one hour view. Water events depicted include a three cycle clothes washer.

Figure B.2 shows a one hour portion of a typical flow trace in Trace Wizard. The three light blue spikes are clothes washer cycles. The first is the wash cycle, the second is a rinse cycle, and the third is a spin cycle. Note that the times shown on the graph's x-axis are the time interval depicted in the graph. The Trace Wizard graph has six time interval settings: 10 minutes, 20 minutes, 1 hour, 2 hours, 4 hours, and 6 hours. The analyst may use any of these "views" during the flow trace analysis process.

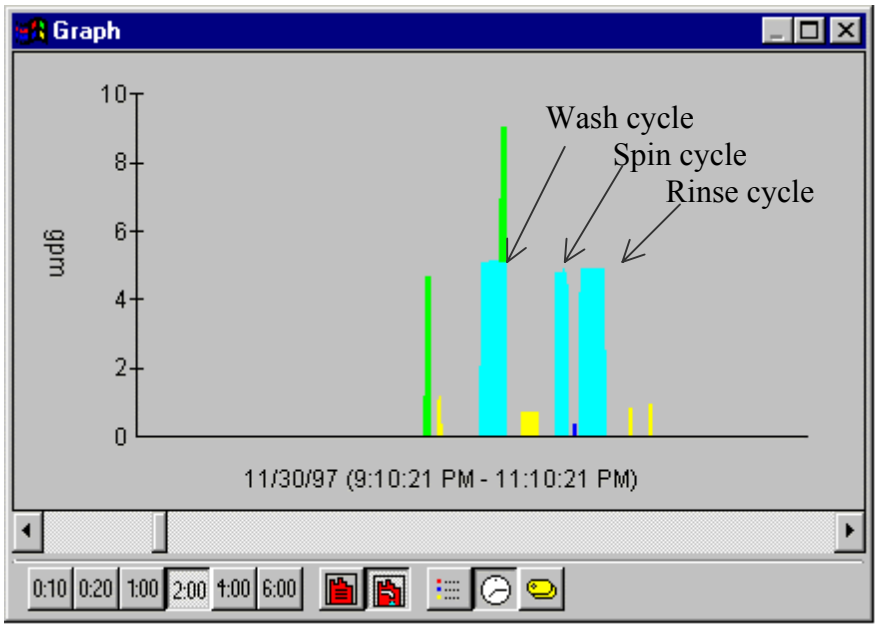


Figure B.3 Sample flow trace from Trace Wizard showing a two hour view. Water events depicted include two toilet flushes, a three cycle clothes washer, and several faucets.

Figure B.3 shows two toilet flushes, miscellaneous faucets, and another three cycle clothes washer. The first green spike in a toilet flush with a refill rate of approximately 5 gpm. The small yellow spikes are miscellaneous faucet uses and the small dark blue spike is a leak. The three light blue spikes are clothes washer cycles. A second toilet flush occurs during the first clothes washer cycle and is easily distinguished by Trace Wizard as a simultaneous event.

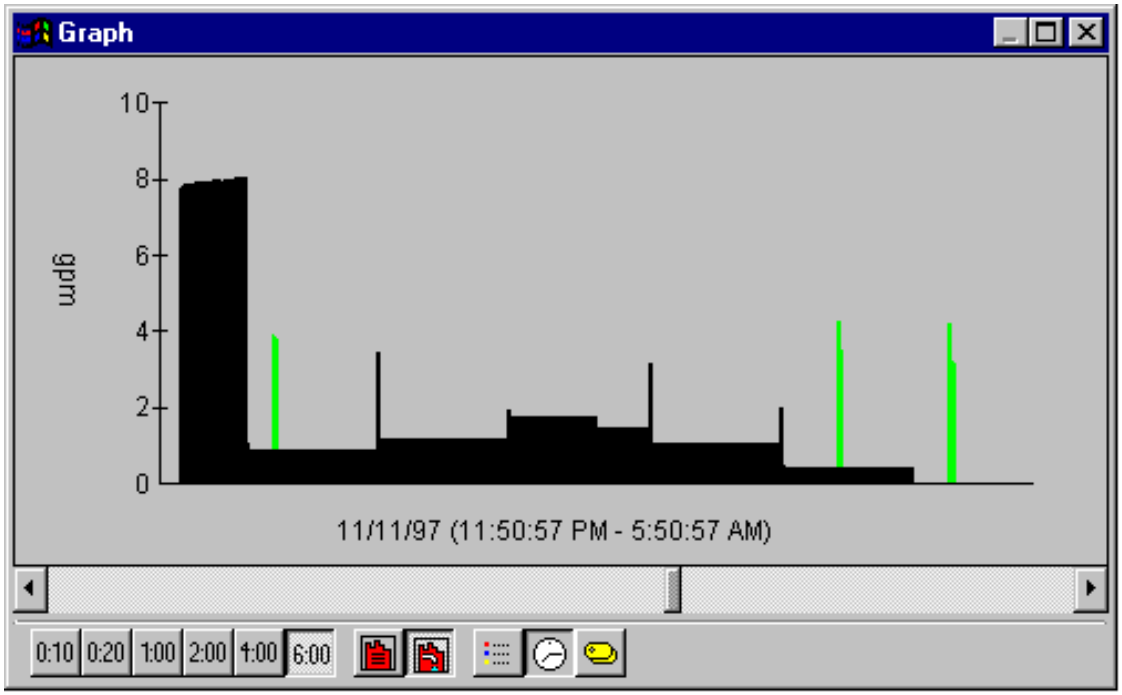


Figure B.4 Sample flow trace from Trace Wizard showing a six hour view. Water events depicted include a multi-zone automatic irrigation system and three toilet flushes.

Additional simultaneous water use events can be seen in Figure B.4 taken from a home in Phoenix, AZ. Here, in a six hour view, two toilet flushes can be observed occurring simultaneously with a seven-zone drip/combination irrigation system. The irrigation system zones are clearly delineated by small and consistent differences in flow rate over the 4.5 hour irrigation session. The first zone with an 8 gpm flow rate is a turf area and the remaining six zones cover different drip irrigation areas.

At the conclusion of analysis, the final product is a database of water use events that have been given fixture identification. This database is created in Microsoft Access and can be further analyzed using either version of Access or any compatible database product. The seven-zone irrigation event from Figure B.4 would appear in the database as a single water use event as will each of the three individual toilet flushes.

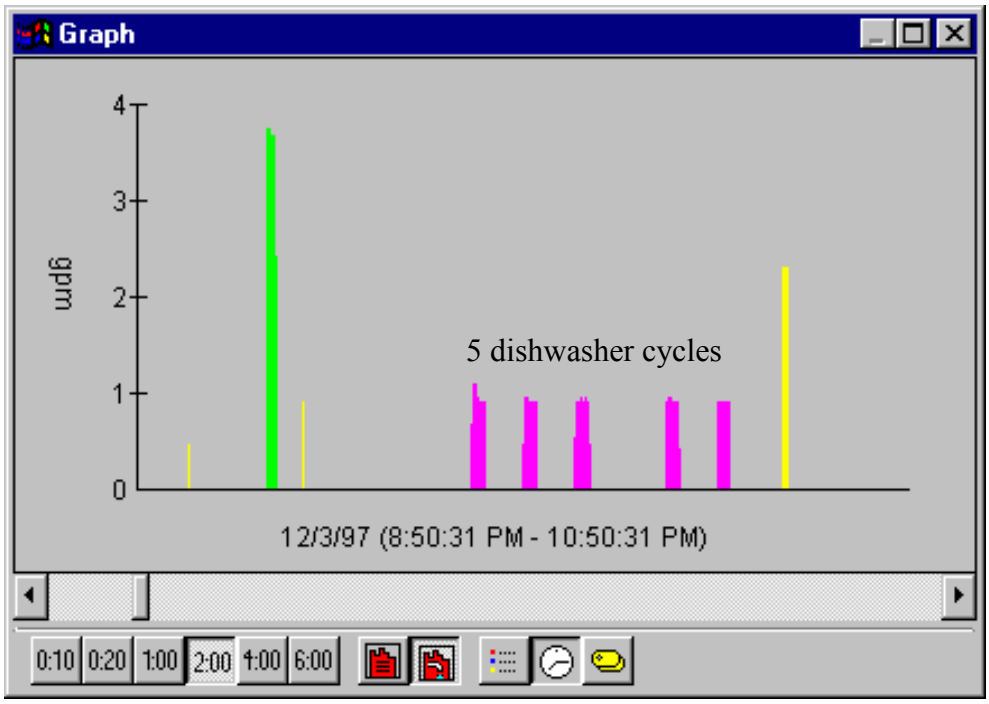


Figure B.5 Sample flow trace from Trace Wizard showing a two hour view. Water events depicted include a toilet flush, a five cycle dishwasher, and various faucet uses.

Figure B.5 shows a typical five cycle dishwasher that was run between approximately 9:30 and 10:30 p.m. Dishwashers typically have between three and eight cycles and use a total of between 8 and 20 gallons for a full load. They are easy to distinguish because of their box-like shape and consistent volume, flow rate, and duration.

Figure B.6 shows the capability of Trace Wizard's simultaneous event calculating routine. The red shower event is typical of bath/shower combination traces. The water is started in the bath for about 30 seconds while the temperature is adjusted then the shower diverter valve is pulled and the water starts to flow through the showerhead – in this case a low-flow head which restricts the flow to 2.5 gpm. The shower continues for about 10 minutes at this consistent flow rate until the water is shut off. What makes this example unusual are the blue clothes washer extraction and rinse cycles which are plainly visible on top of the shower. The second set of extraction cycles occur shortly after the shower had ended.

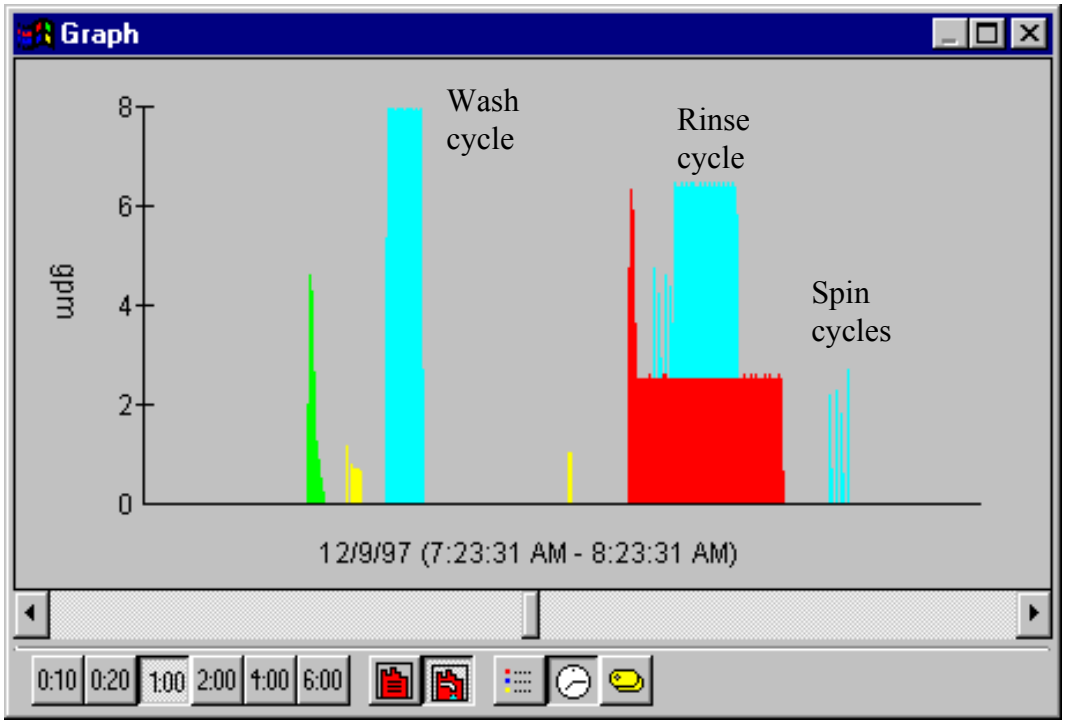


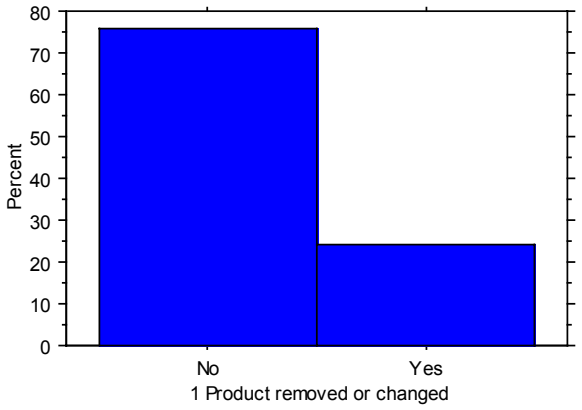
Figure B.6 Sample flow trace showing a one hour view. Water events depicted include a toilet flush, multi-cycle clothes washer, and shower.

APPENDIX C

COMPLETE SURVEY RESPONSES
NEW PRODUCT INFORMATION AND SATISFACTION SURVEY

1. Have any of the above products installed for this study been removed or changed?

   24% Yes 76% No 0% Not sure



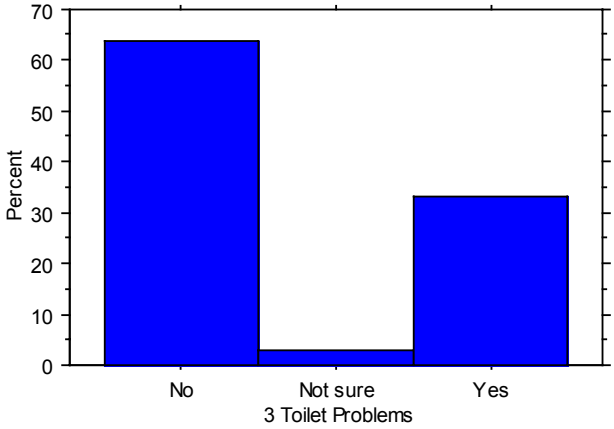
2. If yes, please list those removed or changed and explain why:

   1. Two showerheads removed (unsatisfied)
   2. Showerhead keeps breaking - cracks at ball joint. Kitchen aerator also.
   3. Showerhead broke. Kitchen aerator became clogged because of a dip tube problem.
   4. Shower stall showerhead removed because it leaked. It was not replaced by other model. We were told our existing plumbing was not compatible with available models.
   5. K. faucet aerator was removed. It was too stiff to operate. Both toilets were REPEATEDLY visited by the "plumbers" to stop leaks at the tank.
   6. I asked EBMUD to change the showerheads because the water was stinging and my daughter refused to take showers.
   7. Faucet aerators - too much restriction on the water flow.
   8. Changed two showerheads to another brand that was much better. Best of all products. Houseguests raved as well.

TOILETS

3. Have you experienced any flushing or performance problems with your new toilet(s)?

   33% Yes 64% No 3% Not sure

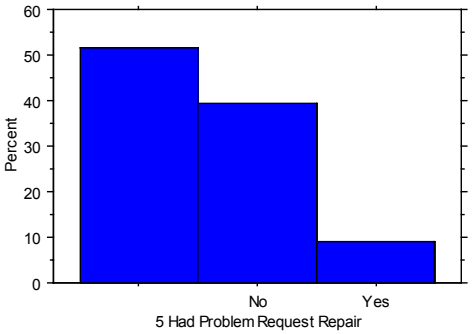


4. If yes, please describe the nature of these problems.

    1. Used plunger a few times
    2. The catch comes loose.
    3. Tank valve is failing. Float sticks (fixed it myself). The installing plumber was incompetent and I do not want him back in my house.
    4. Sometimes poop sticks to the toilet above the water line. A second flushing does not solve the problem.
    5. Some times have to flush twice.
    6. Solid waste doesn't always go down.
    7. Slight water release 2 - 3 time a day.
    8. One toilet seems to clog frequently - have to use plunger
    9. Not as clean. Once in a while I hear it running.
    10. Caroma - maybe 10% of the time had to flush 2 times. Also about 1-2 times a day, there is a partial flush event on its own volition.
    11. Both toilets leaked from the tank.
    12. 3 sewer stoppages under house, not outside.

5. If you had problems, did you request a repair?

    52% No answer 39% No 9% Yes

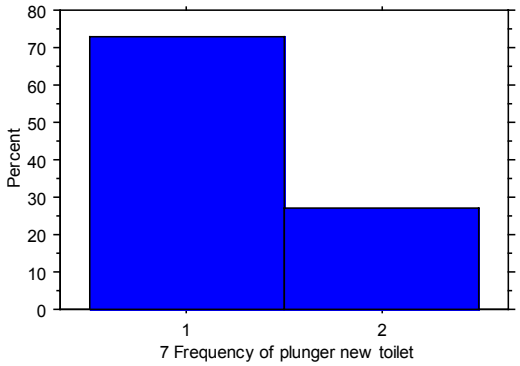


6. If you requested a repair, was the repair completed to your satisfaction?

9% Yes 0% No 3 % Not sure 88% No answer

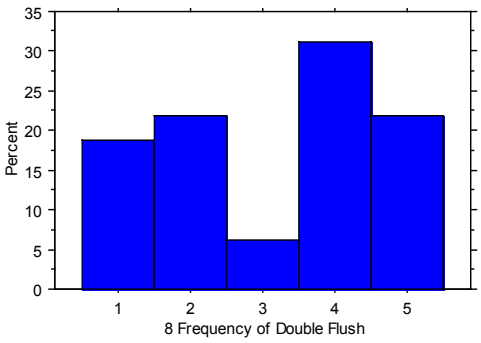
7. How frequently do you have to use a plunger on your new toilet(s)?

73% Never (1), 27% Less than monthly (2), 0% Monthly (3), 0% Daily, 0% Weekly



8. How frequently do you have to "double flush" your new toilet(s)?

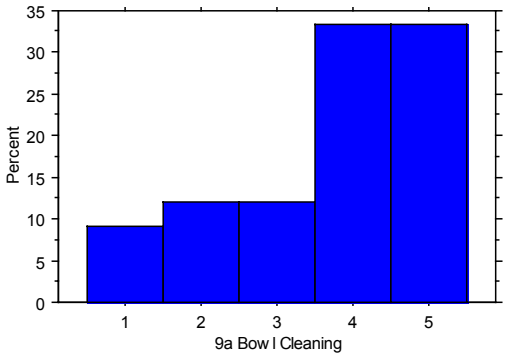
19% Never (1), 22% < monthly (2), 6% Monthly (3), 31% Weekly (4), 23% Daily (5)



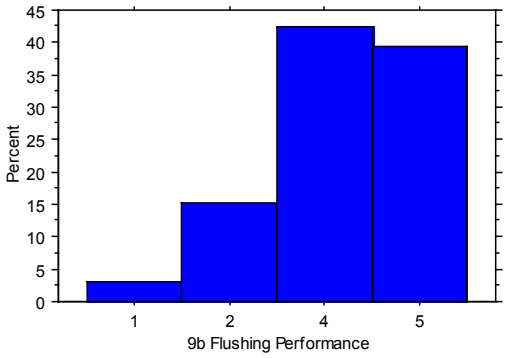
9. On a scale of 1 – 5, how satisfied are you with your new toilets in the following areas?

1=dissatisfied, 2=somewhat dissatisfied, 3=neutral, 4=somewhat satisfied, 5=completely satisfied

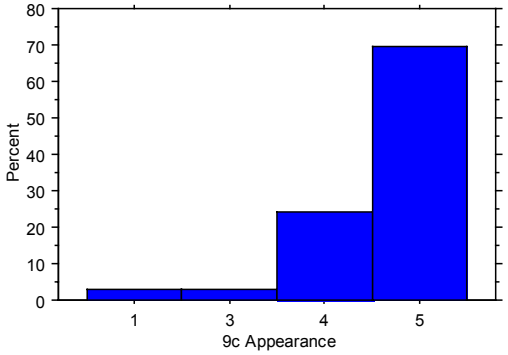
a) Bowl cleaning: 9% Dissatisfied (1), 12% Somewhat dissatisfied (2), 12%Neutral (3), 33% Somewhat satisfied (4), 33% completely satisfied (5)



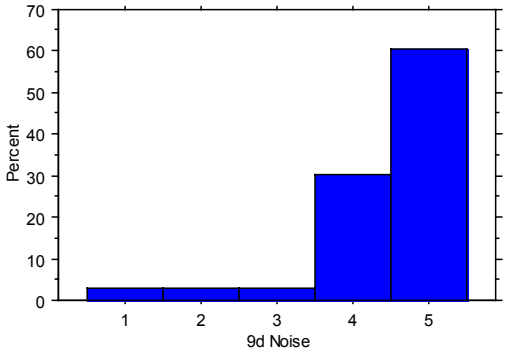
b) Flushing performance: 3% Dissatisfied (1), 15% Somewhat dissatisfied (2), 0%Neutral (3), 42% Somewhat satisfied (4), 49% completely satisfied (5)



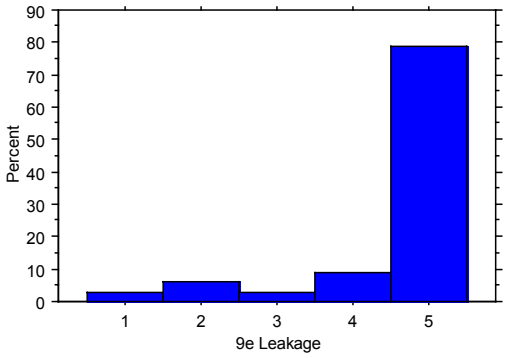
c) Appearance: 3% Dissatisfied (1), 3% Somewhat dissatisfied (2), 0%Neutral (3), 24% Somewhat satisfied (4), 70% completely satisfied (5)



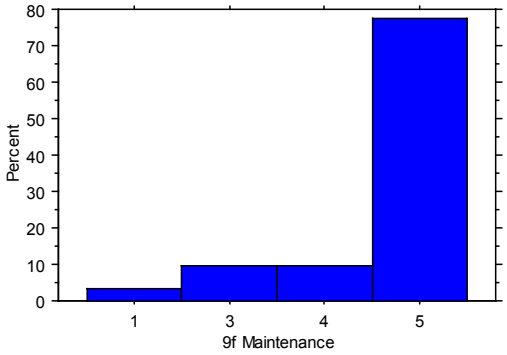
d) Noise: 3% Dissatisfied (1), 3% Somewhat dissatisfied (2), 3%Neutral (3), 30% Somewhat satisfied (4), 61% completely satisfied (5)



e) Leakage: 3% Dissatisfied (1), 6% Somewhat dissatisfied (2), 3% Neutral (3), 9% Somewhat satisfied (4), 79% completely satisfied (5)

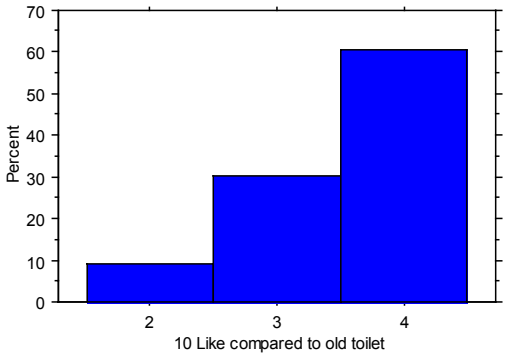


f) Maintenance: 3% Dissatisfied (1), 10% Neutral (3), 10% Somewhat satisfied (4), 77% completely satisfied (5)



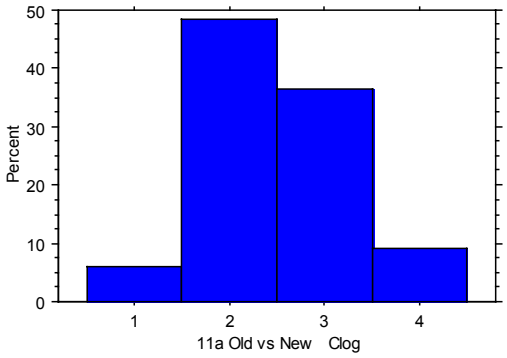
10. Compared to your old toilets, do you like your new toilet(s)?

9% Less (2), 30% Same (3), 61% More (4)

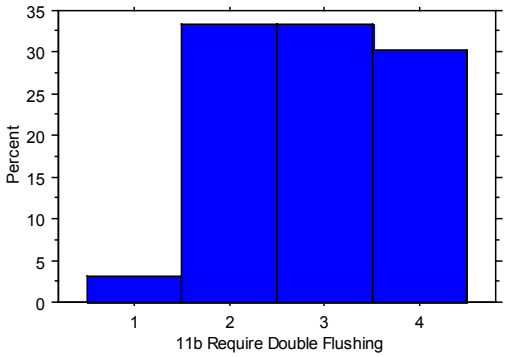


11. Compared to your old toilets, do your new toilet(s)?

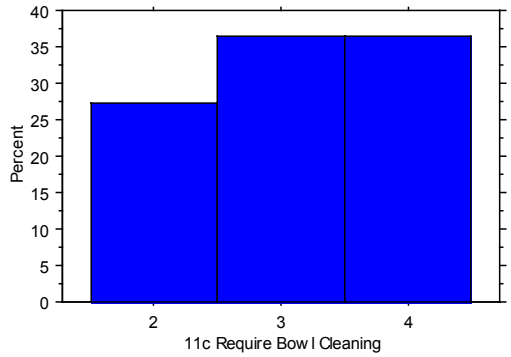
a) Clog: 6% Not sure (1), 48% Less (2), 36% Same (3), 9% More (4)



b) Require double flushing: 3% Not sure (1), 33% Less (2), 33% Same (3), 30% More (4)

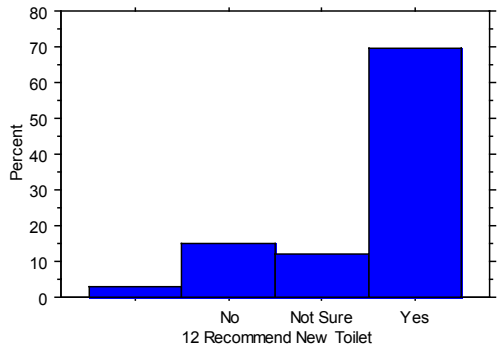


c) Require bowl cleaning: 27% Less (2), 36% Same (3), 36% More (4)



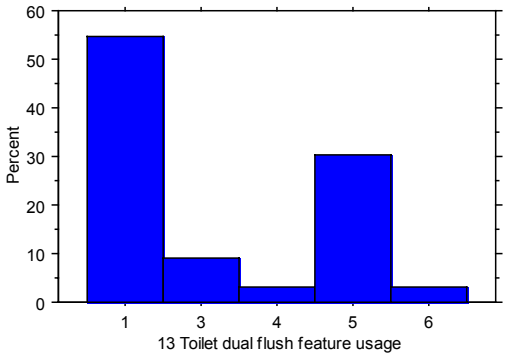
12. Would you recommend your new toilet to others?

15% No, 12% Not sure, 70% Yes, 3% No Response



13. If your new toilet(s) have a dual flush feature (two flush buttons), how often do you use the "half flush" button?

55% Don't have (1), 0% Never (2), 9% Less than half (3), 3% about half the time (4), 30% More than half the time (5), 3% Always (6)



14. If there were one thing you would want the manufacturer of your toilets to change, what would it be?

    1. With the same amount of water is it possible to have a STRONGER flush?
    2. Toilet height - prefer higher toilets.
    3. The shape makes it hard to clean. I have purchased a smaller brush and this works well.
    4. The catch!!
    5. Softer flushing noise.
    6. Sleeker, contemporary looking, and less quiet.
    7. Raise the water in toilets a little when not flushing (water spot?)
    8. Only one of the three toilets clogs.
    9. OK as is.
    10. Nothing, we love them.
    11. Nothing.
    12. None.
    13. Noise when flushing.
    14. No place for blue toilet cleaner tablet - a small lining.
    15. I want a dual flush feature (just in case).
    16. Holding down handle for full flush is inconvenient.
    17. Higher water level in bowl.
    18. Correct automatic water release.
    19. Change the need for bowl cleaning.
    20. Better quality of parts - the Caroma's guts are plastic and probably not really good quality
    21. Better quality control for internal parts. Flush water should wash more of bowl surface.
    22. Better flushing on flush. Increase size of bold and gasket and washer that attaches tank to the bowl.
    23. A little more water retained in bowl.
    24. "Make the built more sturdier".

15. Other comments about your new toilet(s):

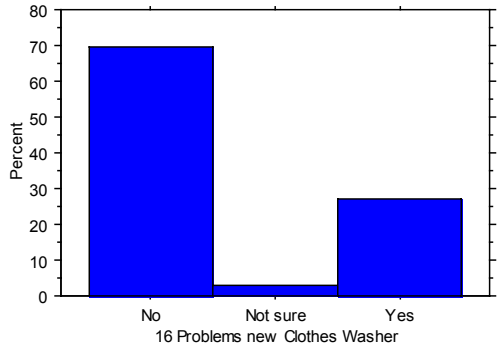
    1. Wonderful
    2. We would probably keep the two Caromas - but…
    3. They're fine
    4. The small tank is a great space saver. Also, the toilets were quite popular with guests. They generated much discussion.
    5. Seem just fine. Could use more water in bowl when not flushing. Waste falls on bowl which requires double flushing.
    6. Satisfied.
    7. Require a lot of cleaning.
    8. Quite a conservation article! (dual flush).
    9. Outside surface cleans easily. Dual flush works well.
    10. OK this year. Will I find parts in 5 or 10 years?
    11. None.
    12. None.
    13. I think the dual flush design is great.

14. I had 10 - 12 visits by the "plumbers" to fix the leaks on the toilets or on some occasions they never showed up.
15. Design is nice.

CLOTHES WASHER

16. Have you experienced any problems with your new clothes washer?

70% No, 3% Not sure, 27% Yes



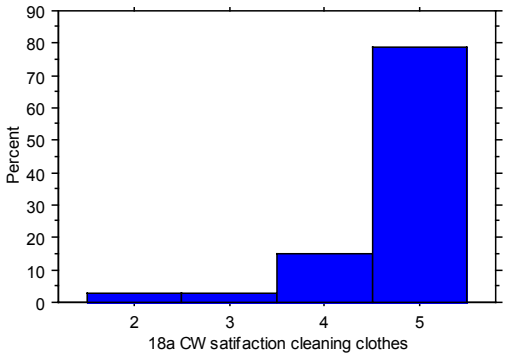
17. If yes, please describe any problems with your new clothes washer.

1. The machine does not work in all functions (cycles).
2. The first machine didn't work even after 4+ visits from the repair man. The second one works fine. They changed the timer 3 times.
3. Sometimes lint clings to the wet clothes. (Had same problem with previous washer.)
4. Sometimes it did not spin - would have to run cycle again.
5. Plumber tried two times to level, didn't succeed. Terrible bumping noises! My daughter leveled it - works OK.
6. Not rinsing completely on occasion.
7. Loads are smaller and on a single rinse still small like detergent no matter how little I use. Also side opening door is less convenient than up/down opening.
8. I would like the water level to give more water.
9. Hard to level for installers at first. Then later, it needed to be done again so it would operate without stopping.

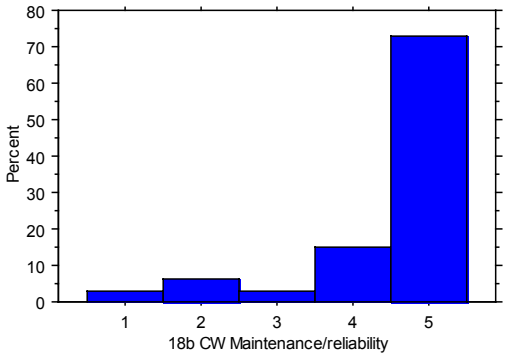
18. On a scale of 1 – 5, how satisfied are you with your new clothes washer in the following areas?

1=dissatisfied, 2=somewhat dissatisfied, 3=neutral, 4=somewhat satisfied, 5=completely satisfied

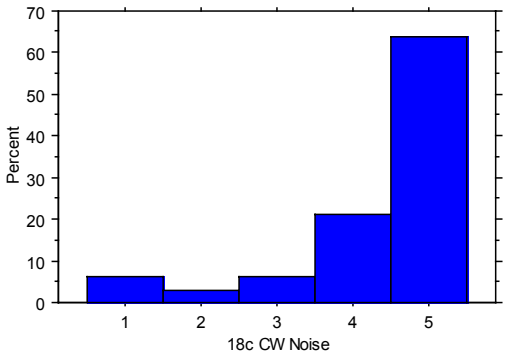
a) Cleaning of clothes: 3% Somewhat dissatisfied (2), 3% Neutral (3), 15%Somewhat satisfied (4), 79% Completely satisfied (5)



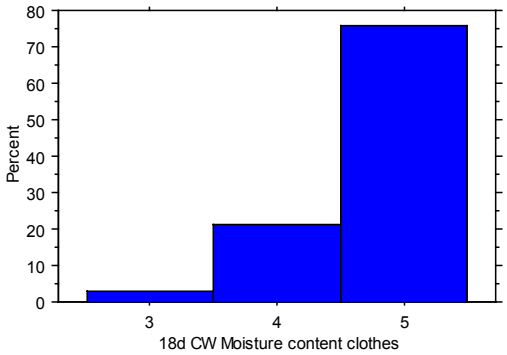
b) Maintenance/reliability: 3% Dissatisfied (1), 6% Somewhat dissatisfied (2), 3% Neutral (3), 15% Somewhat satisfied(4), 73% Completely satisfied (5)



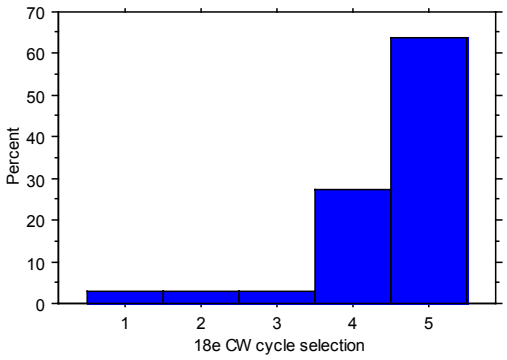
c) Noise: 6% Dissatisfied (1), 3% Somewhat dissatisfied (2), 6% Neutral (3), 21% Somewhat satisfies (4), 64% Completely satisfied (5)



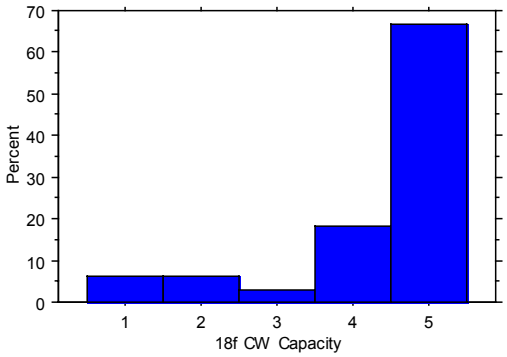
d) Moisture content of clothes: 0% Dissatisfied (1), 3% Somewhat dissatisfied (2), 6% Neutral (3), 17%Somewhat satisfied(4), 74% Completely satisfied (5)



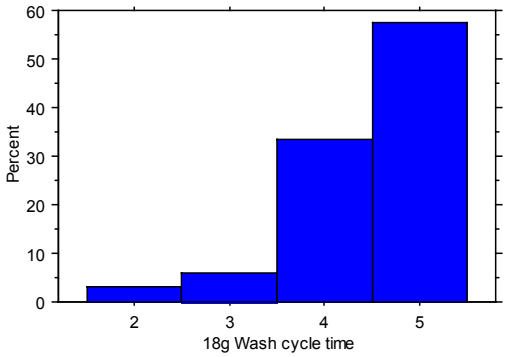
e) Cycle selection: 3% Dissatisfied (1), 3% Somewhat dissatisfied (2), 3% Neutral (3), 27%Somewhat satisfies (4), 64% Completely satisfied (5)



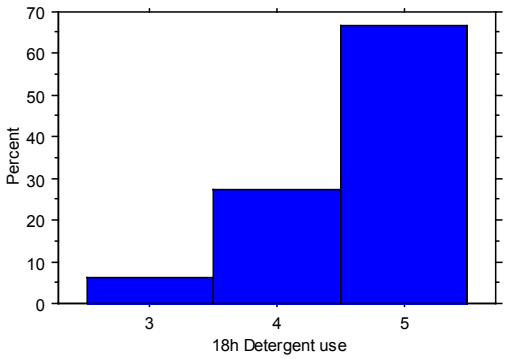
f) Capacity: 6% Dissatisfied (1), 6% Somewhat dissatisfied (2), 3% Neutral (3), 13%Somewhat satisfied(4), 67% Completely satisfied (5)



g) Wash cycle time: 0% Dissatisfied (1), 3% Somewhat dissatisfied (2), 14% Neutral (3), 6%Somewhat satisfies (4), 77% Completely satisfied (5)

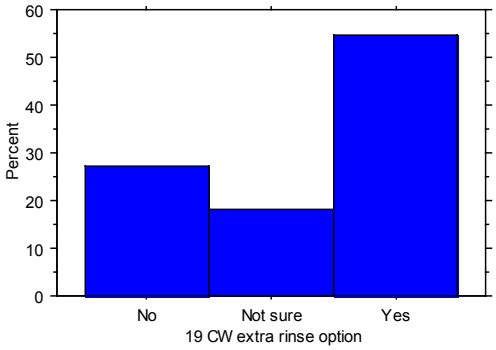


h) Detergent use: 0% Dissatisfied (1), 0% Somewhat dissatisfied (2), 6% Neutral (3), 27%Somewhat satisfies (4), 67% Completely satisfied (5)



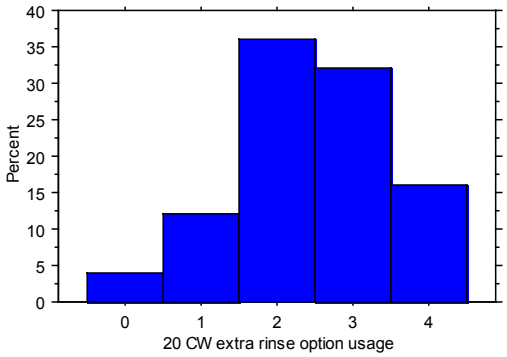
19. Does your new clothes washer have an extra rinse option?

27% No, 18% Not sure, 55% Yes



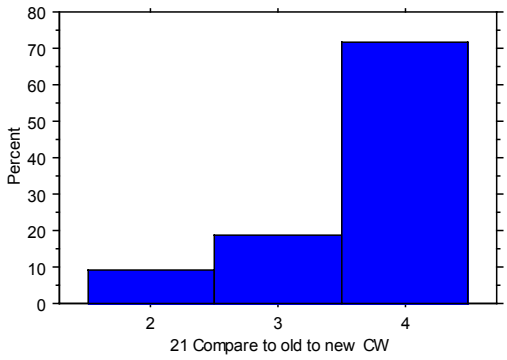
20. If your clothes washer has an extra rinse option, how often do you use it?

4% No answer (0), 12% Not sure (1), 36% Never (3), 32% Sometimes (4), 16% Always (4)



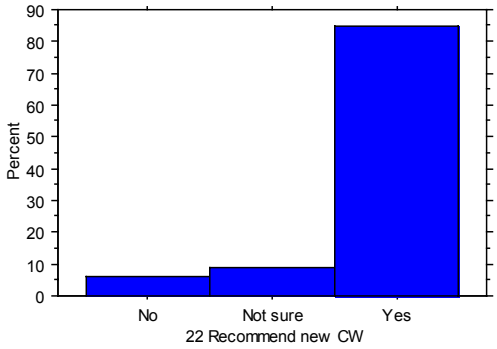
21. Compared to your old clothes washer, do you like the new clothes washer?

0% Not sure (1), 9% Less (2), 19% Same (3), 72% More (4)



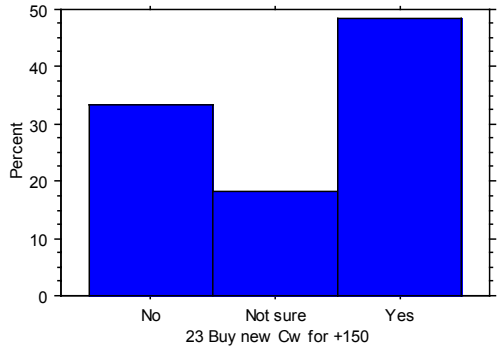
22. Would you recommend your new clothes washer to others?

9% Not sure, 6% No, 85% Yes



23. You received your new washer free as part of this study. But, if you were *buying* a washer, would you pay $150 more for your new washer than for an equivalent quality, conventional (i.e., top loading, non-water saving) model?

33% No, 18% Not sure, 48% Yes



24. If there were one thing you would want the manufacturer of your new clothes washer to change, what would it be?

    1. Wish it had a more durable top, not just plastic.
    2. Top loading.
    3. Too many problems at first. Needs to be more reliable.
    4. To have selection of hot water only.
    5. To be able to add softener (liquid) to first rinse cycle. Is there water savings when using the extra rinse cycle?
    6. The lid would open right to left instead of front to back. When I start the water running the lid hits the knob and shuts off the water!
    7. Small load cycles. Shorter cycle time.
    8. Self adjusting to level machine.
    9. Reposition start/stop button. When open door it hits the knob and turns it off.
    10. Perfect!
    11. Nothing.
    12. Nothing, maybe larger capacity.
    13. Nothing.
    14. Nothing.
    15. Make it quieter.
    16. Make a matching drier with a "port hole" door.
    17. Just fine as is.
    18. If I have any trouble with the clothes washer, who do I call? Is there a warranty?
    19. Get rid of lint clinging to wet clothes.
    20. Cleaner rinse. Bigger capacity.
    21. Capacity
    22. Better rinse of clothing. Better washing of very dirty clothes. Options of how the door swing can be configured.
    23. A little faster - door lock is a little unclear.

25. Other comments about your new clothes washer:

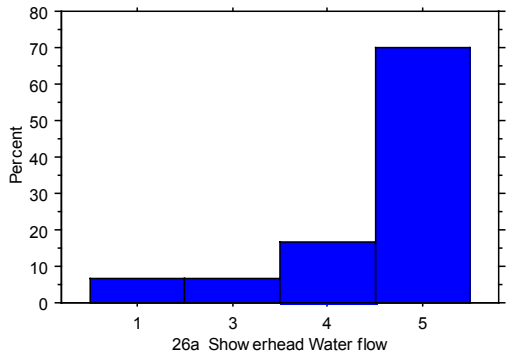
    1. Wonderful.

2. Without actually having used this washer it would be hard to compare, but now after having it for 9 months I would definitely buy another.
3. We love it!!
4. Very satisfied with performance overall!
5. Very dirty work clothes require two washings.
6. This is my 3rd Whirlpool washer in 51 years. I am happy this new one is as good as the others. The quality is still excellent.
7. The water consumption is very very little compared to the top loader we had. It also uses much less soap.
8. The clothes tended to become very twisted/tangled. I liked the water temperature choices.
9. Surely does spin the clothes dry.
10. Seems to be fine. Clothes come out dryer and are clean.
11. Satisfied.
12. None.
13. Love it.
14. Just that some times it hasn't spinned - maybe it was over loaded.
15. It's cute and amusing. I use less time in dryer because it spins so efficiently.
16. I might pay the $150, but as I recall the difference was more like $300.
17. Good concept to be water saving.
18. Good color.

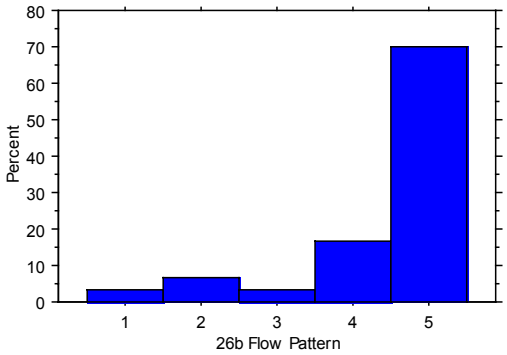
SHOWERHEADS

26. On a scale of 1 – 5, how satisfied are you with the performance of your new showerhead in the following areas?
1=dissatisfied, 2=somewhat dissatisfied, 3=neutral, 4=somewhat satisfied, 5=completely satisfied

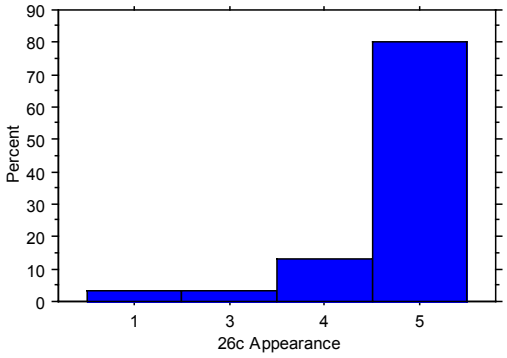
a) Water flow: 7% Dissatisfied (1), 0% Somewhat dissatisfied (2), 7% Neutral (3), 17% Somewhat satisfied (4), 70% Completely satisfied (5)



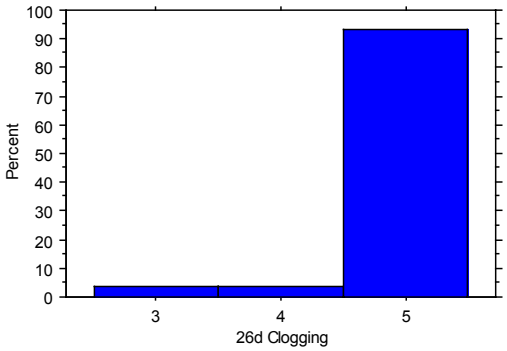
b) Flow pattern: 3% Dissatisfied (1), 7% Somewhat dissatisfied (2), 3% Neutral (3), 17% Somewhat satisfied (4), 70% Completely satisfied (5)



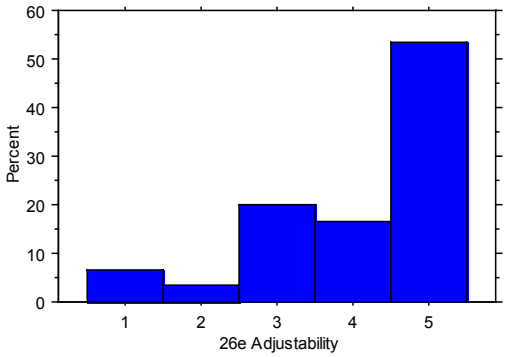
c) Appearance: 3% Dissatisfied (1), 0%Somewhat dissatisfied (2), 3% Neutral (3), 13% Somewhat satisfied (4), 80% Completely satisfied (5)



d) Clogging: 0% Dissatisfied (1), 0% Somewhat dissatisfied (2), 3% Neutral (3), 3% Somewhat satisfied (4), 93% Completely satisfied (5)

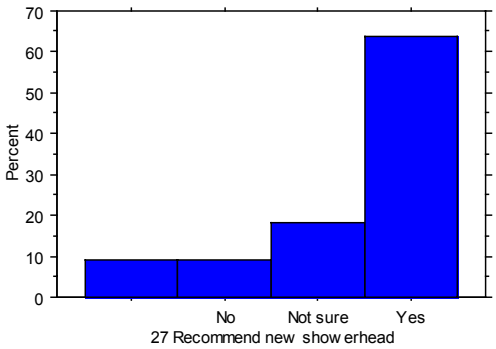


e) Adjustability: 6% Dissatisfied (1), 3% Somewhat dissatisfied (2), 20% Neutral (3), 17% Somewhat satisfied (4), 53% Completely satisfied (5)



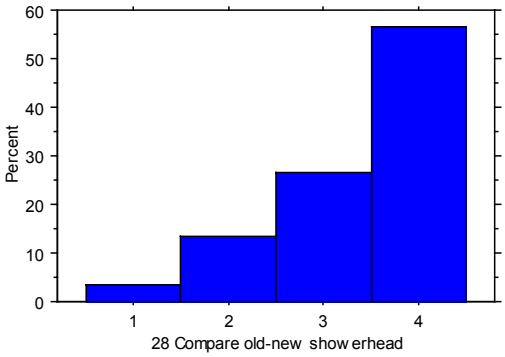
27. Would you recommend your new showerhead(s) to others?

    9% No answer, 18% Not sure, 9% No, 64% Yes



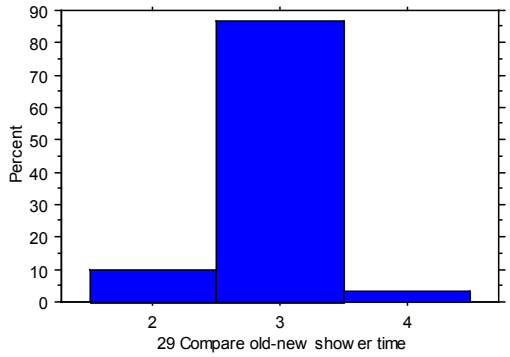
28. Compared to your old showerhead(s), do you like your new showerhead(s)?

    3% Not sure (1), 13% Less, (2), 27% Same (3), 57% More (4)



29. Compared with your old showerhead(s), is your showering time with your new showerhead(s)?

    0% Not sure(1), 10% Longer (2), 87% About the same (3), 3% Shorter (4)



30. Other comments about your new showerhead(s):

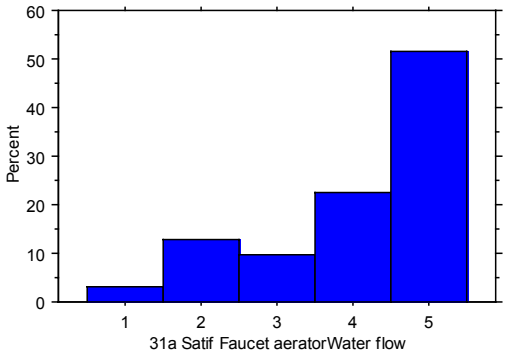
1. Very good
2. The showerheads replaced are the very same as we had before the change.
3. The second set of replacement showerheads we received from EBMUD are wonderful!
4. Survey results apply to second set of showerheads replaced by the customer (brand unknown). "They were great!"
5. Shower time is about the same because it was installed in the kids bathroom. Teenagers don't know how to take a short shower.
6. Like water flow.
7. Inferior material - keeps cracking when we adjust it. We're not using it.
8. I used to run out of hot water with the old shower head. I NEVER run out with the new head.
9. I had a low flow shower head before so the new one is not much of a change. It works better, however.
10. Force of water can be painful.
11. Difficult to change to pulse.
12. Couldn't adjust the showerhead first installed. Replacement works easily.

FAUCET AERATORS

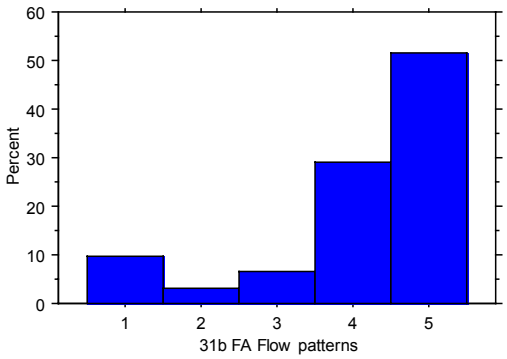
31. On a scale of 1 – 5, how satisfied are you with the performance of the new aerator(s) installed on your faucets in the following areas?

    1=dissatisfied, 2=somewhat dissatisfied, 3=neutral, 4=somewhat satisfied, 5=completely satisfied

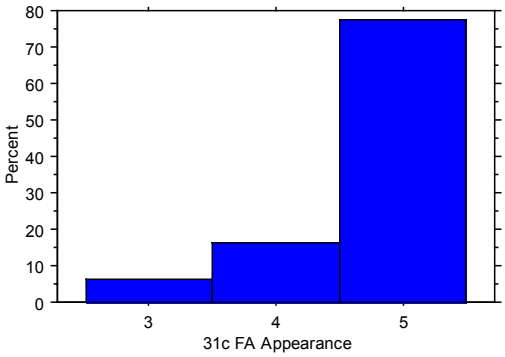
    a) Water flow: 3% Dissatisfied (1), 13% Somewhat dissatisfied (2), 10% Neutral (3), 22%Somewhat satisfied (4), 52% Completely satisfied (5)



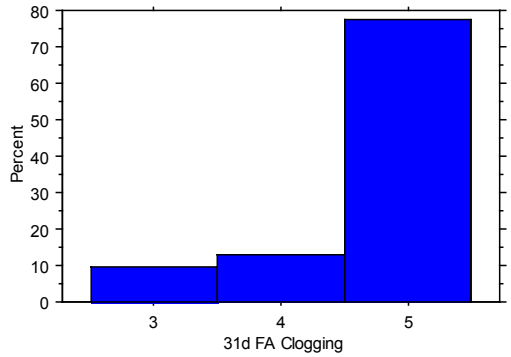
b) Flow pattern: 10% Dissatisfied (1), 3% Somewhat dissatisfied (2), 6% Neutral (3), 29%Somewhat satisfied(4), 52% Completely satisfied (5)



c) Appearance: 0% Dissatisfied (1), 0% Somewhat dissatisfied (2), 6% Neutral (3), 16%Somewhat satisfied (4), 77% Completely satisfied (5)

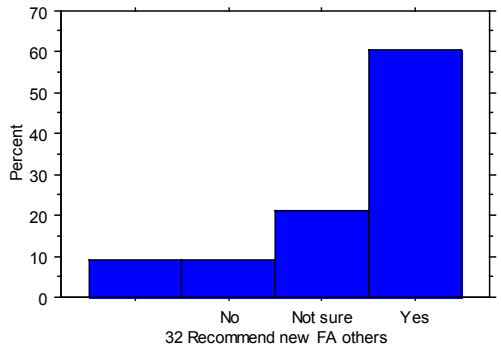


d) Clogging: 0% Dissatisfied (1), 0% Somewhat dissatisfied (2), 10% Neutral (3), 13% Somewhat satisfied (4), 77% Completely satisfied (5)



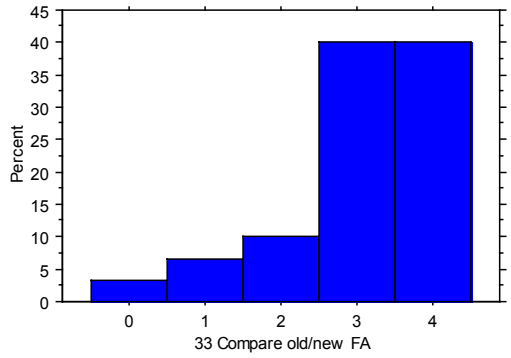
32. Would you recommend your new faucet aerators to others?

9% No answer, 9% No, 21% Not sure, 61% Yes



33. Compared to your old aerators, do you like the new aerators?

3% No answer (0), 7% Not sure (1), 10% Less (2), 40% Same (3), 40% More (4)



34. Other comments about your new aerators:

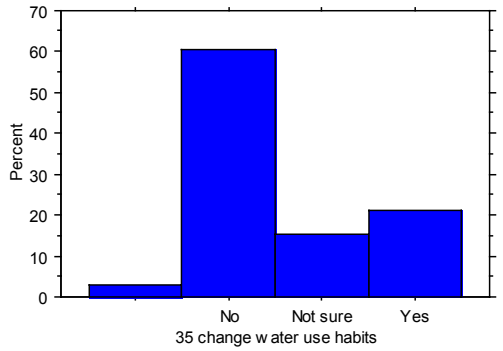
1. Water flow is too restricted. Even guests have complained about the very slow flow of water.
2. Too hard to change flow - up & down. Pulls on faucet - not using it anymore.

3. To change aerator from a straight flow to a spray was very hard and put pressure on the faucet nozzle so I put the aerator in the recycle pile and put on the old one.
4. Takes too long to fill a glass of water.
5. Takes too long for warm water to appear and they splash!
6. Swivel head would be helpful in kitchen sink..
7. Same as the old ones. Kitchen aerator has a spray. I don't believe that we got the aerators that you think we did.
8. It takes longer for the hot water to come out - probably because less water is flowing through.
9. I find in kitchen sink it takes longer to fill sink or make juice, etc. So I have to use same amount of water - it just takes longer.
10. Flow is a little slow, but I am sure it is saving water!
11. Especially like the kitchen aerator.

STUDY PARTICIPATION

35. Have you changed any of your water use behaviors as a result of participating in this study?

3% No Answer, 15% Not sure, 61% No, 21% Yes



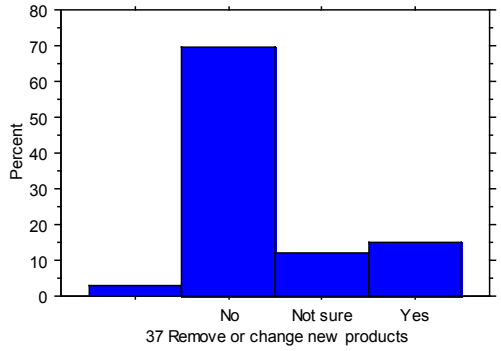
36. If yes, please describe the changes in your water use behaviors.

1. We have always tried to practice water conservation.
2. We have always been water use conscious.
3. Probably use less water as we have become more aware of conservation.
4. In washing dishes.
5. I'm very conscious of water use and try to cut back, I.e. full washer loads, no unnecessary flushing.
6. I have always been a water saver. The study helped me spread the word to family and friends.
7. I do my laundry twice instead of once on many occasions.
8. Greater awareness of water use.

9. Always flush toilets via half flush,

37. Do you plan on removing or changing any of the new products after the conclusion of this study?

3% No Answer, 12% Not sure , 70% No, 15% Yes

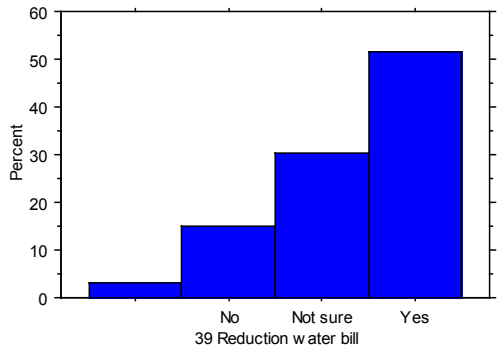


38. If yes, please list those you plan to remove or change and explain why.

1. Toilets - the suck!
2. Toilet - have to hold handle for full flush.
3. The clothes washer. So I could add softener without having to wait for the extra rinse cycle.
4. Maybe one of the aerators - it sprays on the counter top.
5. May change showerhead to more adjustable unit.
6. Master bath showerhead.
7. Have already removed aerator in kitchen and showerhead.
8. Faucet aerator is gone and the washer may go also.

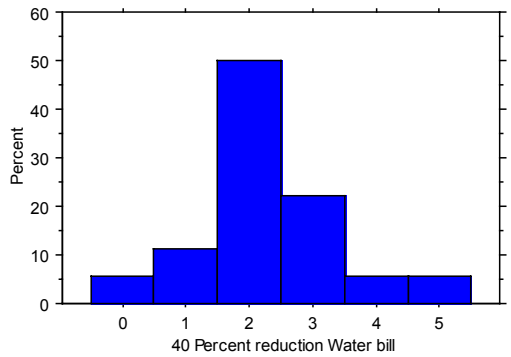
39. Have you noticed any reduction in your water and sewer bill as a result of participating in this study?

3% No response, 15% No, 30% Not sure, 52% Yes



40. If yes, by about how much do you think your bill has gone down?

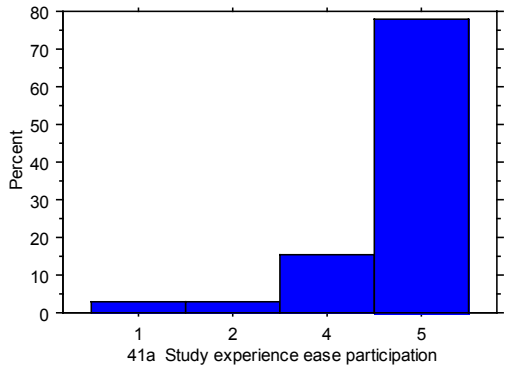
6% No answer (0), 6% More than 30% (5), 6% 21-30 (4), 22% 11-20 (3), 50% 5-10 (2), 11% less than 5 (1)



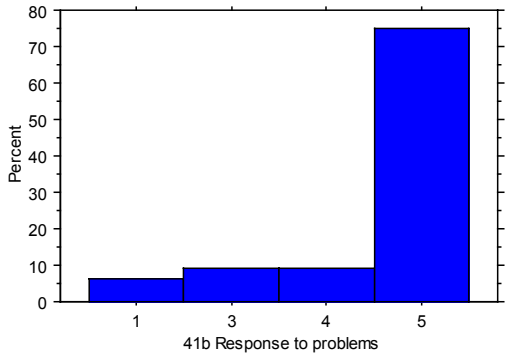
41. On a scale of 1 – 5, rank your experience participating in the home water conservation study in the following areas?

1=dissatisfied, 2=somewhat dissatisfied, 3=neutral, 4=somewhat satisfied, 5=completely satisfied

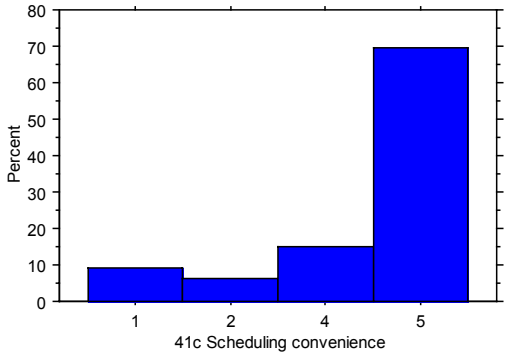
a) Ease of participation: 3% Dissatisfied (1), 3% Somewhat dissatisfied (2), 0% Neutral (3), 16%Somewhat satisfied (4), 78% Completely satisfied (5)



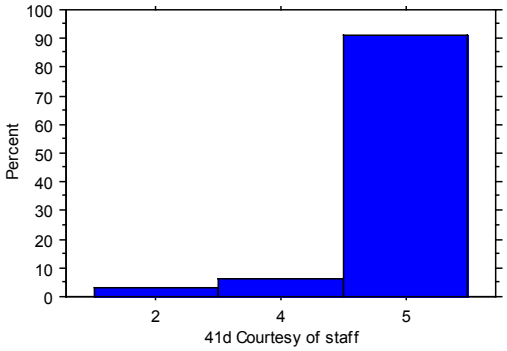
b) Response to problems: 6% Dissatisfied (1), 9% Somewhat dissatisfied (2), 0% Neutral (3), 9%Somewhat satisfied (4), 75% Completely satisfied (5)



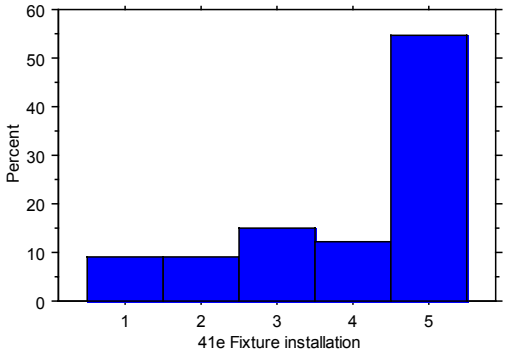
c) Scheduling convenience: 9% Dissatisfied (1), 6% Somewhat dissatisfied (2), 0% Neutral (3), 15%Somewhat satisfied (4), 70% Completely satisfied (5)



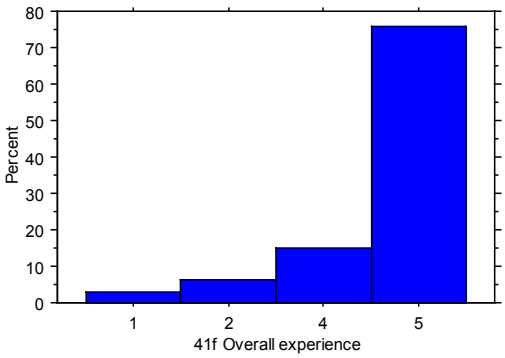
d) Courtesy of study staff: 0% Dissatisfied (1), 3% Somewhat dissatisfied (2), 0% Neutral (3), 6 %Somewhat satisfied (4), 91% Completely satisfied (5)



e) Fixture installation: 9% Dissatisfied (1), 9% Somewhat dissatisfied (2), 15% Neutral (3), 12% Somewhat satisfied (4), 54% Completely satisfied (5)

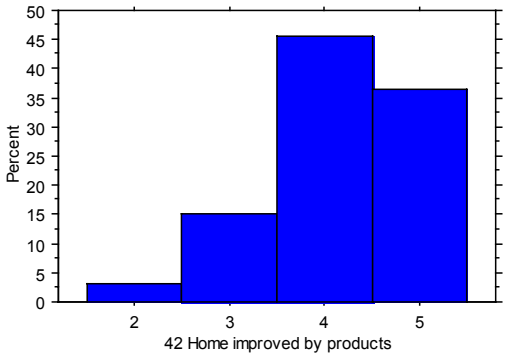


f) Overall experience: 3% Dissatisfied (1), 6% Somewhat dissatisfied (2), 0% Neutral (3), 15% Somewhat satisfied (4), 76% Completely satisfied (5)



42. Please respond to the following statement: "I feel my home has been improved by the installation of the water conserving products in this study".

0% Strongly disagree (1), 3% Disagree (2), 15% Neutral (3), 45% Agree (4), 36 % Strongly agree (5)



43. If there were one thing you would change about the study, what would it be?

1. We had to dispose of our old toilets & washing machine ourselves. I would have preferred that the plumber take them away when he installed the new fixtures.
2. Toilets.
3. The study was not really complete at our house. Sub contractors were unreliable.
4. The response sheets need to be reorganized. I had to try to squeeze entries in too small spaces.
5. The plumbers who installed fixtures were hard to reach, hard to schedule, they had to come out 4 or 5 times before everything was installed. They were disorganized.
6. Take away the old fixtures.
7. Show different for outdoor and home use. Only your time study shown the actual use of water for each fixture before and after.
8. Shorter duration, but understand. Explain more thoroughly in the beginning what water involved.
9. Plumbers.
10. Nothing.
11. Nothing, but I am very interested to know if our water use was lower. My water bills didn't seem lower, but the prices seemed higher, really I didn't pay close enough attention.
12. Installers that call, tell time, and speak English.
13. Installer should show up on time.
14. Install new toilet seats with new toilets provided.
15. Include devices for the garden.
16. I was disappointed with the removal and replacement of the new toilets, especially with the old toilet. The new toilet stuck out from the wall and exposed an un-painted area and several holes. Also, I had to go and buy a toilet seat myself.
17. I think if fixtures are going to be replaced, that "other" accessories and necessary parts to the fixture should be replaced correctly and available upon request.
18. I am REALLY interested in a copy of the results of the study. Thank you for allowing us to participate.
19. Hire real plumbers. Ones hired were unqualified and broke many appts. I rqd. EBMUD employee to be here to witness the lack of ability and breaking of apts and lack of response phone calls. EBMUD employees were sympathetic, but by hiring low bid/non union/…

20. Hire a new plumber. Scheduling convenience score because of "that goddamn plumber".
21. Can't think of anything.
22. Being more on time. The start of the study was seriously delayed, as was all subsequent communications.
23. After installation, have someone from the study check installers workmanship.

44. Other comments:

1. We were happy to be part of the survey. Thank you for the wonderful appliances.
2. We are very happy with the new fixtures and especially since our water bill has been reduced by almost 50%!
3. We are happy to participate because we believe in conservation of our limited water supplies which will be worse as the population increases.
4. Two toilets were never replaced. They were coming back to do that (they are wall hung) but never did. Most of our water is used to take care of the garden.
5. The installer did not provide a toilet seat!! THIS STUDY HAD GONE ON TOO LONG.
6. Thanks for the experience and new fixtures.
7. Thank you.
8. Thank you!
9. Study field staff and the office staff were great to work with. I feel fortunate to have been chosen as a study participant. Thanks.
10. Non qualified companies to do installation they were put in a position where all they could offer was sympathy. I was at one point 1 broken apt. away from hiring my own plumber and suing. I would NOT do the survey again.
11. Make sure wife is consulted prior to disposal of old equip. My husband told the installers to take it away. He was not clear as to where the old washer would end up. When I found out I didn't like the new washer and our old washer was gone I felt stuck.
12. Keep up the good work!
13. Integrity of installer is suspect.
14. Installer missed first appointment and didn't even call.
15. Installer crossed hot & cold water on washing machine. Crooked seat cover and toilet not aligned straight. I called installers and came back and fixed it to satisfaction.
16. Initially I was to get two toilets - I got only 1 due to plumbing location. Another could have been substituted, but wasn't. The toilet installed is in the guest bath and rarely used.
17. I appreciate the new washer and toilets and found the study interesting.

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ABBREVIATIONS

ANOVA	analysis of variance
ATTN.	Attention:
Ave.	avenue
AWC	average winter consumption
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
Blvd.	boulevard
CCF	hundred cubic feet
CDM	conditional demand model
CF	cubic feet
CIS	customer information system
CUSTID	customer identification number
e.g.	for example
EBMUD	East Bay Municipal Utility District
EGLS	estimated generalized least-squares
ET	evapotranspiration
gal.	gallon
gcd	gallons per capita per day
gpcd	gallons per capita per day
gpd	gallons per day
gpf	gallons per flush
gpm	gallons per minute
gpsf	gallons per square foot
HCF	hundred cubic feet
HUD	U.S. Department of Housing and Urban Development
i.e.	for example
Inc.	incorporated
KEYCODE	unique identifying number for survey respondents

kgal	thousand gallons
kL	thousand liters
L	liter
Lcd	liters per capita per day
LF	Low-flow
Lpd	liters per day
Lpf	liters per flush
Lpm	liters per minute
Lpsf	liters per square foot
min.	minute
MWD	Municipal Water District
PC	personal computer
pop.	population
Q1000	systematic random sample of 1000 single family accounts
Q125	sample of 125 accounts for data logging
Q150	sample of 150 accounts for data logging
QA	quality assurance
QAQC	quality assurance and quality control
R^2	coefficient of determination
Rd.	road
RE	random effects
REUWS	Residential End Uses of Water Study
RMSE	root mean square error
SHWCS	Seattle Home Water Conservation Study
sf	square foot
SPU	Seattle Public Utilities
St.	street
St. Dev.	Standard deviation
Std. Dev.	Standard deviation

TW	Trace Wizard
ULF	Ultra-low-flush
ULFT	Ultra-low-flush toilet
UPS	United Parcel Service
WD	Water District

DEFINITION OF MATHEMATICAL TERMS

Term	**Definition**
Average	The sum of the observations divided by the number of observations.
Degrees of freedom	A term from the analysis of variance (ANOVA). It is the number of parameters that a model is estimating to test for the significance of an effect. Typically calculated as: n - 1
Mean	(see Average)
Median	The middle value in a set of observations that is ordered from lowest to highest value.
Mode	The value that occurs most often in a set of observations.
P-value	A probability that expresses the likelihood that the sample mean and the hypothesized value are the same. A ***p-value*** close to 1 means it is very likely that the sample means are the same. A small ***p-value*** (for example 0.01) means it is unlikely (only a 1 in 100 chance) that such a difference would occur by chance if the two means were the same.
Standard Deviation	The most common measure of "spread" for a set of observations. Calculated with the following equation: $$Std.Dev. = \sqrt{\frac{\sum\left(y_i - \bar{y}\right)^2}{n-1}}$$ where: y_i = each individual observation $\tilde{y}$ = the mean of the observation and n = the number of observations
Statistical Significance Test	A significance test is performed to determine if an observed value of a statistic differs enough from a second value of a parameter to draw the inference that the second value of the parameter is not the true value. For example, a statistical significance test at the 95% confidence level was performed to determine if the average number of toilet flushes per person per day during the baseline study period was different from the average number of toilet flushes during the post-retrofit study period.

Term	Definition
t-value	Typically obtained from a table, the ***t-value*** expresses the difference between the mean and the hypothesized value in terms of the standard error.
Variance	Another common measure of "spread" for a set of observations. Calculated as the square of the Standard Deviation as follows: $$Variance = (Std.Dev.)^2 = \frac{\sum (y_i - \bar{y})^2}{n-1}$$ where: y_i = each individual observation $\tilde{y}$ = the mean of the observation and n = the number of observations