WATER AND ENERGY SAVINGS FROM HIGH EFFICIENCY FIXTURES AND APPLIANCES IN SINGLE FAMILY HOMES

Volume 1

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CHAPTER 1 EXECUTIVE SUMMARY

As the population increases, the demand on municipal water providers to provide treated water for a variety of household end uses continues to grow. Residential water conservation retrofits and retrofit rebate programs are frequently subsidized by municipal providers and represent an essential element of water conservation planning and programs. This report serves to answer questions that have been raised about the actual impact of residential retrofits on per-capita and per household water use – particularly on individual end uses over time. It contains the combined results of data collected in three separate studies on residential water use patterns and the impact of best available technology practices on water conservation in single family homes. The impact of these savings on wastewater and energy costs are also evaluated. These measurements are essential for long-range projections of the impacts of conservation projects on urban water and energy demands.

Aquacraft, Inc. conducted studies in Seattle, Washington, East Bay Municipal Water District (EBMUD) service area, and Tampa, Florida during the period from 2000 to 2003. A systematic random sampling procedure was used to select homes that were representative of the entire single family customer database. A subset of these homes was used to provide information about the number of residents, household characteristics and per capita usage of individual fixtures and appliances.

Two weeks of baseline water use was determined from the sample of homes and then each home was retrofit with high efficiency toilets, clothes washers, showerheads and faucets. Two weeks of flow trace data were collected one month following the retrofit and then a second set of post-retrofit data was collected about six months later to identify any behavioral effect that may have occurred as a result of introducing conservation products into the home that changed the impacts of the devices on water use.

An important goal of the study was to test products that are readily available. Homes were therefore retrofit with fixtures and appliances that are typical products and currently available on the market. It was also important that customers were satisfied with these products in order to insure their continued use after the termination of the study. About four months after the installation of the new products customers were asked to complete a product satisfaction survey that rated the product in numerous categories including but not limited to repair rate, appearance, functionality, and, performance. Most of these questions were intentionally made identical to questions asked on the initial survey, prior to the retrofits so that responses could be compared.

Finally, the payback period for the conserving products was determined by calculating the savings from both water and energy and comparing this to both the full and incremental costs of the new devices. A range of product prices and utility rates were used that would allow payback periods from different service areas across the country to be determined. This information will be useful to utilities in determining the rebates that can be offered to their customers for these products.

PRODUCTS TESTED

For these analyses four types of conservation products were considered: toilets, clothes washers, faucet aerators and showerheads.

- Toilets
  - Standard gravity 1.6 gallons per flush (gpf)
  - Dual flush (0.8/1.6 gpf) – flush volume selected by the user
  - Pressure assist 1.1 gpf
  - Flapperless 1.6 gpf
- Showerheads
  - 2.5 gallons per minute (gpm)
  - 2.35 hand-held w/shutoff
  - 1.7 gpm w/shutoff
- Clothes washers
  - 25 gallons per load (gpl) front and top loaders
  - 14 gpl front loaders
- Kitchen faucet aerators
  - 2.2 gpm
  - 1.5 gpm w/shutoff
  - Hands free controller
- Bathroom faucet aerators
  - 1.5 gpm
  - 1.0 gpm
  - 1.0 gpm e-faucet

HOUSEHOLD CHARACTERISTICS

The impact of a variety of water using fixtures and appliances was studied on 33 EBMUD homes, 37 Seattle homes and 26 Tampa homes. The characteristics of the homes used in this study are shown in Table ES-1.1. All of the homes were owner occupied, single family residences. Most of the homes were older with an average age of 46 years. Older homes are less likely than newer homes to be equipped with water conserving products and are therefore more likely to benefit from the installation of water conserving products. The average household consisted of 2.7 residents and was less than 2,000 sq ft in floor area. All homes were equipped with clothes washers and the average home had 1.5 baths. There was a wide range of rates for water and wastewater in the three cities from a low of $3.66 in EBMUD to a high of $11.27 in Seattle.

Table ES-1.1 Summary of household characteristics

	East Bay (n=33)	Seattle (n=37)	Tampa (n=26)	Combined (n=96)
Avg. age of house (yrs)	44	55	35	46
Avg. house size (sf)	2054	1879	1627	1868
Avg. no. of residents	2.74	2.51	2.92	2.70
Avg. no. bathrooms	1 ¾	1 ¾	1	1.5
Avg. no. bedrooms	4	3	3	3.3
% homes w/clothes washer	100	100	100	100
% homes w/dishwasher	NA	NA	58	NA
% homes w/swimming pool	11.4	0	7.7	6.0
% homes w/hot tub	22.8	14	11.5	16.3
% homes w/water treatment	0	0	11.5	3
Cost of water/wastewater* (per kgal)	$3.66	$11.27	$5.67	$7.14

*Cost is given per kgal in 2004 rates

RESULTS

The water use databases from the 96 study homes were combined and water use patterns pre and post retrofit were examined. The basic analyses were done on the daily water use by category for the homes in the study groups. Each home was given equal weight in the analysis.

Reductions in total household water use

The mean daily household indoor use for the three groups during the baseline was 175 gpd, which dropped 39 percent to 107 gpd after the installation of the new high-efficiency fixtures and appliances. Savings ranged from 59 gpd in Seattle to 89 gpd in Tampa. The greatest savings were achieved in Tampa where the initial use was the highest of the three cities at 192 gpd and the most conserving products were installed. The graphical results are shown in Figure ES-1.1 and clearly demonstrate the effect of installing water-conserving products.

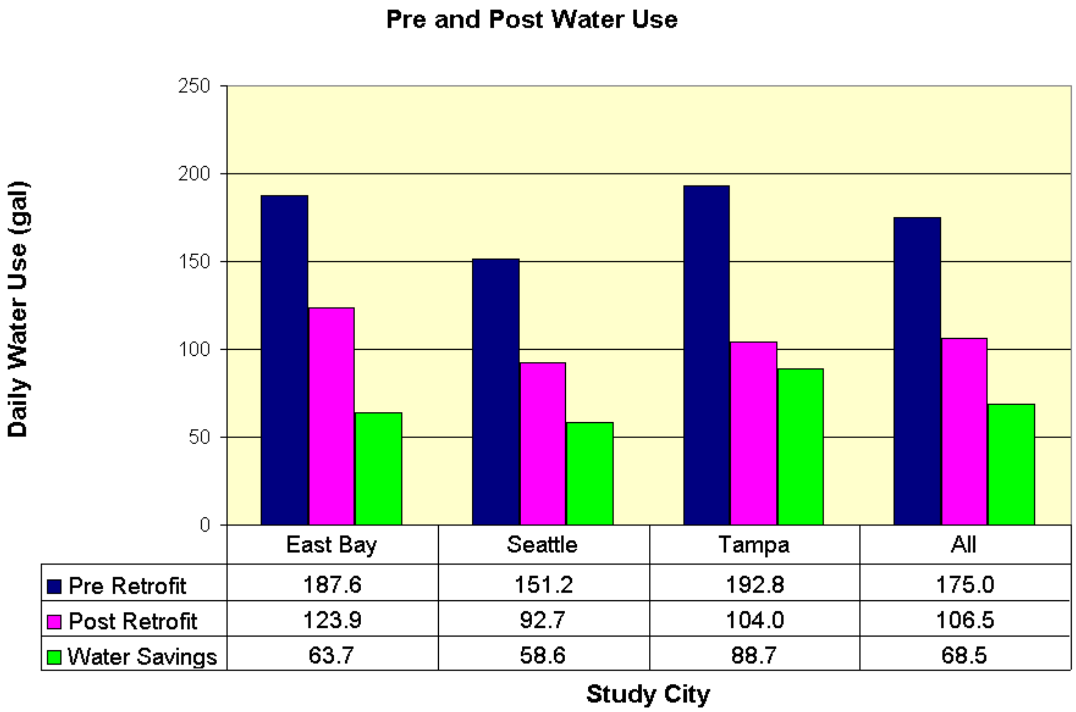


Figure ES-1.1 Total household water use before and after retrofits

While the installation of water conserving products clearly had an effect on household water use it was important to consider other factors that may have had an impact on household use such as number of residents, size of home, number of bathrooms, and cost of water and wastewater. Models were created where the total daily household use was the dependent variable and each of the other factors were the independent variables. Based on the analysis using six variables only two were found to be significant. A final analysis was conducted using just the number of residents and the size of the home since these two variables showed the strongest explanatory value for both pre and post retrofit conditions. The numerical models developed from these two factors are shown in Table ES-1.2.

Table ES-1.2 Models for daily water use vs residents and house size

State	Model	Adjusted R^2
Pre Retrofit	$9.5 \times Res^{.687} \times SF^{.295}$	0.460
Post Retrofit	$5.0 \times Res^{.767} \times SF^{.307}$	0.561
Savings	$37.45 \times Res^{.555}$	

A set of curves developed for an average 1850 sf home, shown in Figure ES-1.2, demonstrates the impact that the number of residents has on household water savings with and without conserving fixtures and appliances.

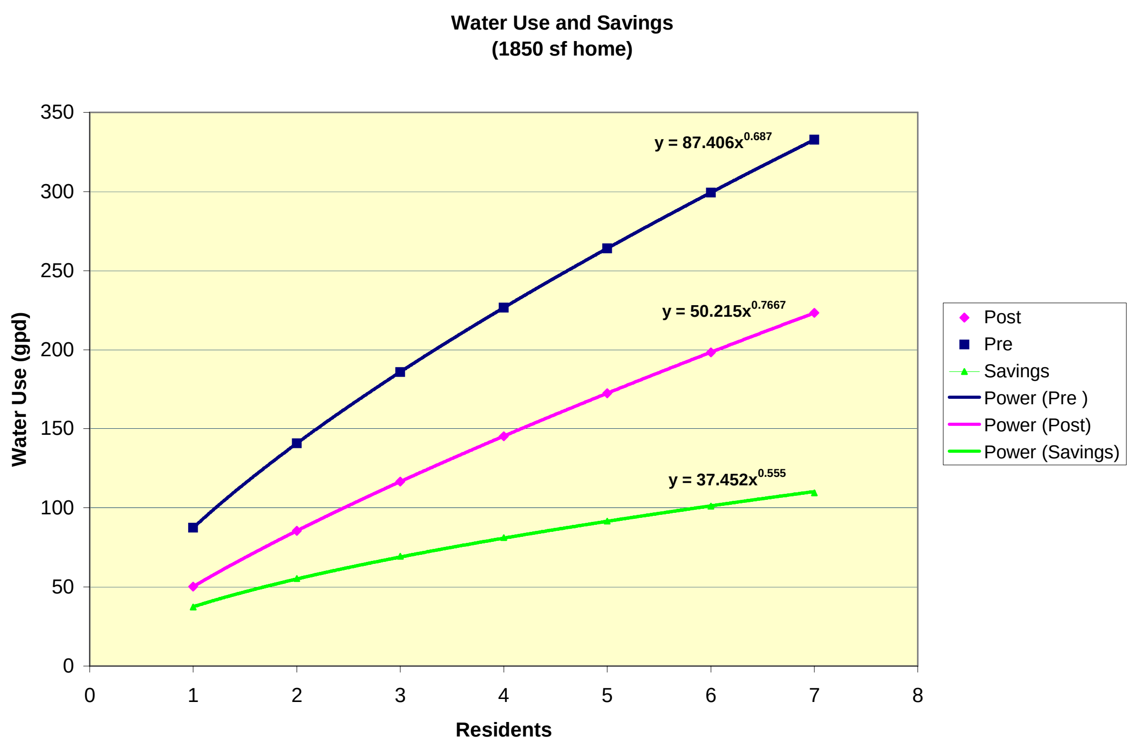


Figure ES-1.2 Total daily use vs. number of residents for an average size home pre and post retrofit

Hot Water Use

Twenty of the homes (10 homes each in Seattle and EBMUD) were equipped with separate water meters on the feed lines to the hot water tanks. This allowed reductions in hot water to be evaluated on these homes. A decrease in hot water use was expected since, with the exception of the toilets, all of the retrofit products use hot water. Prior to the retrofits the homes used an average of approximately 55 gpd (20 kgal/yr) of hot water. The average reduction in household hot water use in the 20 homes was 10.8 gpd (3.9 kgal/yr), which represented a reduction of approximately 20% in hot water use. The only variable that was found to be significant in explaining the amount of hot water used was the number of residents in the home. Figure ES-1.3 shows the set of curves developed for household hot water use, pre and post-retrofit, versus the number of residents in the home.

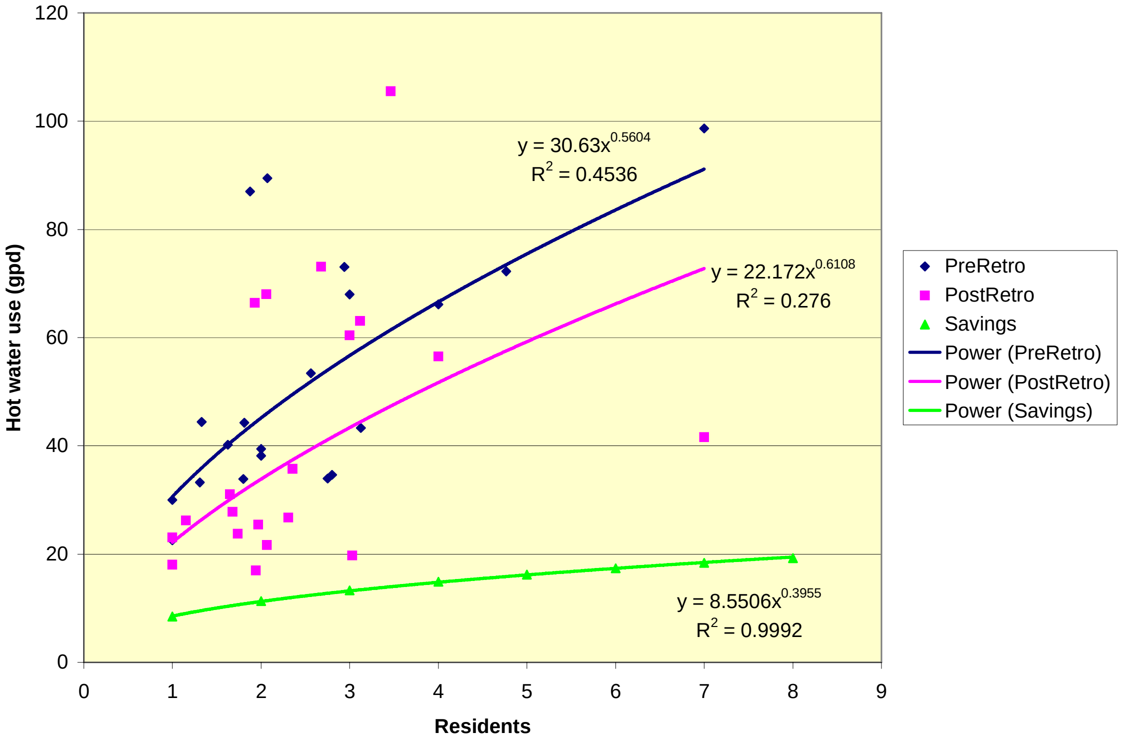


Figure ES-1.3 Total daily hot water use vs. number of residents

Annual savings from retrofit products

Toilet retrofits resulted in the greatest savings in household water use. Although they are much smaller than clothes washers volumetrically, the frequency with which they are used results in their high water usage. The savings from showerheads and faucets was less noticeable than that of the toilets or clothes washers for two reasons: faucets are sometimes used for purposes that require a set volume of water, for example filling a pot, and many homes already had low flow faucet aerators and shower heads in place prior to the retrofit. Table ES-1.3 shows the average annual savings that can be expected from retrofitting a household with water conserving products. The percent reduction achieved by these retrofits is shown in Figure ES-1.4.

Table ES-1.3 Anticipated annual water savings from typical retrofits

Fixture	Total Water Savings (kgal)	Hot Water Savings (kgal)
Toilets/Leaks/other	21.13	1.1
Clothes Washers	5.6	1.4
Shower heads	1.6	0
Faucet Aerators	1.4	1.4
Total	29.73	3.9

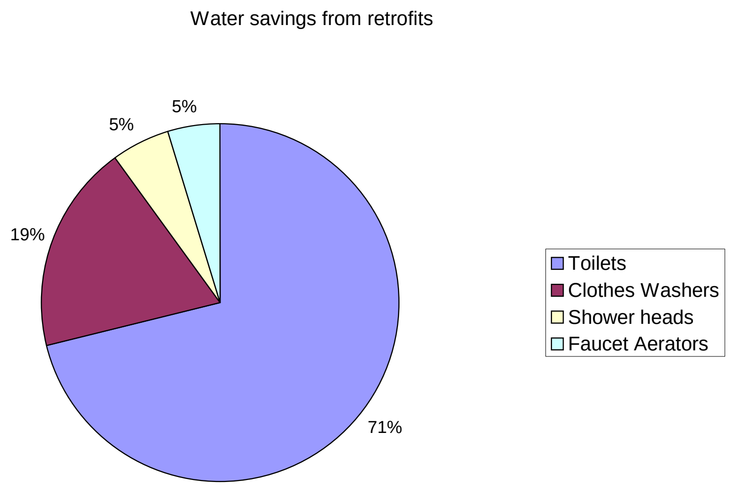


Figure ES-1.4 Percent savings from interior retrofits

BENEFITS AND COSTS OF RETROFITS

The costs and benefits of these retrofits were considered from three perspectives: the consumer, the utility and the community. This is important because the saved water from the program has value to both the consumer and the utility. Both need to be included in order to have a complete picture of the value. The value to the community is the sum of the values to the consumers and the utility, and represents the most comprehensive and complete way to consider the economics of these types of programs.

Customer Perspective

From a consumer's perspective the key factors in deciding whether to replace the fixtures and appliances are costs and benefits of the upgrades. These can be measured in dollars. However the issue is complicated by the residual value in the existing devices. If they are all new and can't be sold then the full replacement costs must be used. However, if they are at the end of their life, or some salvage value can be captured then only the incremental costs (the difference in the cost of standard versus conserving devices) needs to be included. It is safe to say, however, that the cost to the consumer lies somewhere between the full replacement cost to purchase new equipment and just the incremental cost between new standard and new water conserving equipment.

If we just examine the cost to retrofit homes with new fixtures and appliances as part of a retrofit program, and ignore any residual values, rebates or the economic life of the existing equipment in the homes we will have the top end of the cost spectrum, based on gross costs. These gross costs, savings and payback period for each of the replacement products are shown in Table ES-1.4. One can see that under these circumstances the payback to the consumer is 5.8 years. So, a consumer who junks the existing toilets, clothes washers, faucet aerators and showerhead, and purchases new conserving models of these will recoup the total investment[1] in just under 6 years.

1 Payback periods for the individual fixtures and appliances are provided in the main body of the report.

In many cases this, along with the enjoyment of the better equipment, may be sufficient incentive to do the retrofits. If the utility makes it easy by providing financing that could also improve the rate of retrofits in these customers.

The case of replacement of new equipment is really the exception. In most cases we are dealing with devices that are well into their economic lives. The life expectancy of most toilets is 20-40 years and clothes washers have a life expectancy of 12-15 years. In order to deal with the problem of economic life consistently the costs were calculated from the perspective of the customer deciding whether to replace a non-conserving appliance that is still working and has approximately half its life left with one that is conserving. If this assumption is made, then the incremental cost to perform the retrofits drops to approximately $700 and the payback to 2.6 years. This is a far more appealing set of numbers for the consumer.

Table ES-1.4 Gross costs and savings of fixtures with no utility subsidies

	Gross Costs			**$ Savings**			**Payback**
Fixture	No.	Unit Cost	Total Cost	Water ($)	Energy ($)	Total ($)	Years
Toilets	2	$363	$726	$130		$130	5.6
Clothes Washers	1	$818	$818	$81	$42	$123	6.5
Showerheads	2	$12.50	$25	$10		$10	2.5
Faucet Aerators	3	$5	$15	$10		$10	1.5
Totals	**8**		**$1584**	**$231**		**$273**	**5.8**

The Utility Perspective

The water that is saved as a result of residential retrofits has a value to the water utility in the form of the capital cost of developing new firm-yield supply. This represents a major value and is frequently overlooked in conservation planning. The value needs to be based on firm yield (available in dry years) rather than a the cost of water on the spot market when available. Water developed in this way can be used for supplying new growth, as a drought reserve, or for environmental enhancement.

In parts of the country with limited supplies, the capital cost to develop a new firm yield can easily exceed $10,000/acre foot. A savings of 30 kgal per existing customers amounts to 0.092 af/customer, which, at $10,000/af, would have a capital value of $920/af. If the utility provided this money to the customers this would reduce the total gross cost of the retrofits frp, $1584 to $664 and the pay-back period down to 2.4 years. So homes in which the existing fixtures and appliances had a full economic life in front of them could be replaced with a payback period to the customer down at the incremental cost range. The capital value of the saved water would accrue to the utility as a one time amount in the year that the retrofit project was performed. So, a utility with an active retrofit program with savings and costs as described above would realize a capital value of $920,000 per year in water supply[2] for each 1000 homes retrofit.

Community Perspective

The real power of programs like residential retrofits can be seen at the community level. This is a community based approach to problem solving where the value to the community equals the sum of the value to the customers and the utility plus the intangible values from environmental preservation etc. One might also look at the value of the jobs created by the retrofit programs and sales of devices.

Figure ES-1.5 shows the costs and savings for a hypothetical community retrofit program where 1000 homes per year are upgraded in the first year and this number increases by 10% per year. At the end of 10 years this community would have spent a total of $19.9 million to implement this retrofit program, and the total savings to the community would have equaled $30.5 million, for a total net savings of $10.6 million. Notice that the net savings line crosses into positive territory in year 3 when the total annual community savings exceeds the annual cost of the program. The net savings to the community reaches $3 million per year by the 10th year, making this one of the best examples of a win-win resource management project one can imagine.

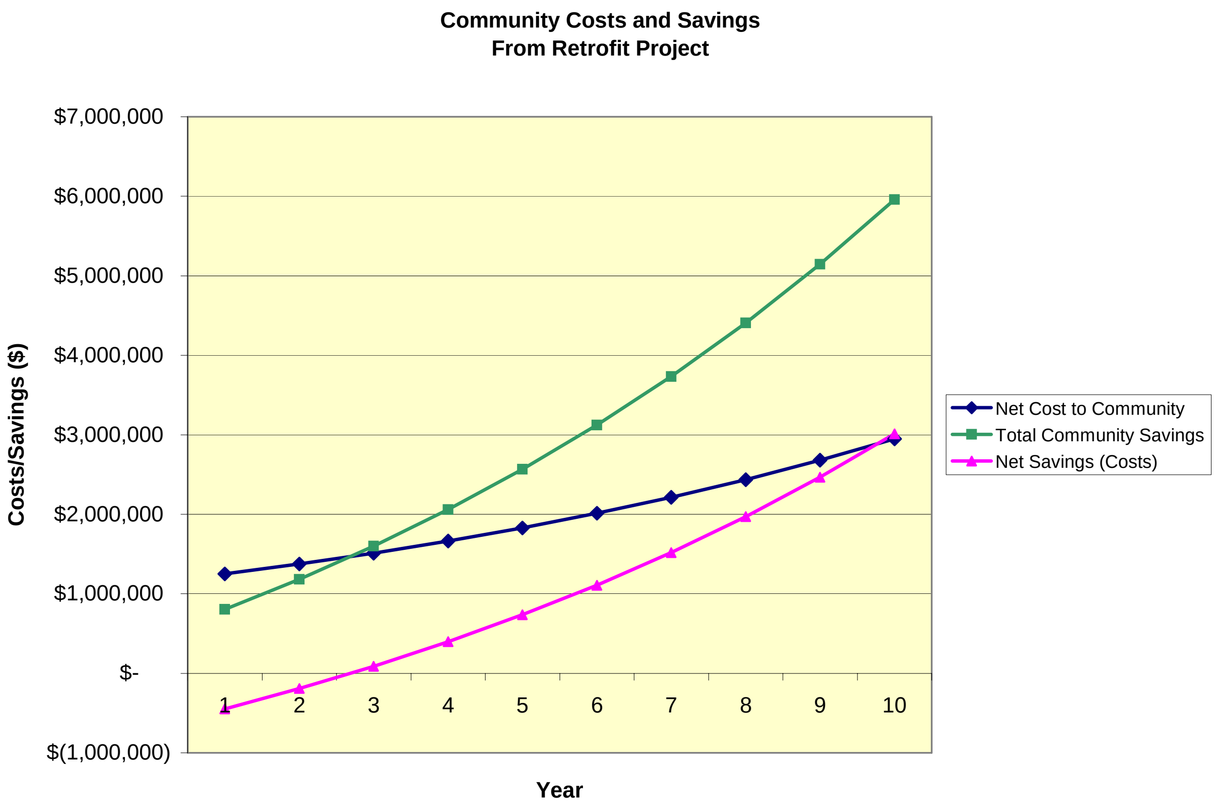


Figure ES-1.5: Value of retrofit program to community

2 0.092 af/home x $10,000/af x 1000 homes/yr = $920,000/yr

CUSTOMER RESPONSES AND ACCEPTANCE OF NEW TECHNOLOGY

Poor performance of the early prototypes of water conserving products has led to skepticism by the general public of their ability to perform adequately. Customers were therefore given surveys that rated their satisfaction levels with their fixtures and appliances before and after the retrofits. Responses were given on a scale from 1 to 5 where 1 equaled unsatisfied and 5 equaled completely satisfied. In nearly ever category the new products rated better than the old products and a high percentage of respondents thought that they would be willing to recommend the new product to a friend. The overall numerical rating for each of the four conserving products is shown in Table ES-1.5.

Table ES-1.5 Combined product satisfaction rating of the three study groups

Fixture	Overall Rating
ULF Toilets	4.50
High Efficiency Clothes Washer	4.65
Low-flow Showerheads	4.51
Low-flow Faucet Aerators	4.36

CHAPTER 2 BACKGROUND

NEED FOR STUDY

Nationally, residential customers account for a large percentage of all municipal water deliveries. They also generate a significant amount of wastewater that needs treatment. The energy used to heat domestic water is a significant factor in this equation as well. By use of best available technology for water using fixtures and appliances both the demands at the tap and the amount of wastewater that needs to be treated can be reduced significantly. This study aimed to quantify the amount of hot and cold water that can be saved in domestic (indoor) uses by single family customers. It also tracked the responses and acceptance of the customers to this technology and the costs and benefits of upgrading to high efficiency devices in the home. The results of this study are directly applicable to single family homes, but can be extended to the entire residential class of customers with reasonable adjustments.

RESIDENTIAL END USES OF WATER STUDY

The REUWS[1] formed an important baseline for this study. It was conducted from 1996 to 1999 and involved collection of detailed information on random sets of single family homes. It represents a time and place snapshot of how water was used in single-family homes in twelve North American locations. Similarities and differences among end uses of water were tabulated for each location, analyzed and summarized. Great care was taken to create a statistically significant representative sample of customers of each of the twelve locations. The diversity of the water use data found over the twelve locations illustrated the importance of utility specific information on how individual behavior influences home water use. However, a striking conclusion of this report was the *similarity* among the twelve locations in the amount of water used by fixtures and appliances. The range of the amount of water used by hardware such as toilets, clothes washers, showerheads, dishwashers, faucets, and fixture leaks was documented and was surprisingly similar – suggesting that this portion of the data has significant transfer value across North America.

RETROFIT PROJECTS

One of the conclusions of the REUWS was that there was a relatively low penetration of high efficiency water using fixtures and appliances and in fact the average household use from the REUWS group was approximately 195 gallons per day for all indoor uses. Many devices on the market claimed to be able to reduce these domestic uses substantially, and many water providers had set up aggressive programs of replacing showerheads and faucet aerators. However, there was not a lot of hard data on how much water these new and existing programs might save.

Using the water use disaggregation and survey techniques from the REUWS it was possible to install a range of fixtures and appliances in study homes, track their performance separately, and obtain actual measurements of water use and savings associated with the best available technologies. By installing separate water meters in the inflow lines to the hot water tanks it was also possible to track and disaggregate hot water use in the same manner. This was the central theme and purpose of the three retrofit projects jointly sponsored by the U.S. Environmental Protection Agency and the three sponsoring water agencies. Ninety-six homes were included in the studies: Seattle (37 homes)[2], East Bay Municipal Utility District[3] (33 homes) and Tampa[4] (26 homes).

ACKNOWLEDGEMENTS
This research would not have been possible without the assistance of John Flowers, Manager of the U.S. EPA Water Efficiency Program. John immediately saw the benefits of this research and moved to support the project.

We would also like to thank former and present members of the Tampa Water Department staff, Seattle Public Utilities and East Bay Municipal Utility District. From Tampa these include: Sandra E. Anderson, APR, Consumer Affairs Manager: Janet Hamilton, Assistant Consumer Affairs Manager; Mary Margaret Hull, Conservation Specialist; Lisa Krenz; Robert Lauria, Meter Superintendent, Neil Mingledorf, Program Manager, Arnold Nieman, Systems Analyst; and David L, Tippen, P.E., Director of Tampa Water Department.

From East Bay MUD these include: Richard Harris, Manager of Water Conservation; Richard Bennett, Project Manager; and Dan Muir who provided valuable field support.

From Seattle these include: Al Dietemann, Conservation Manager; Tim Skeel, Senior Economist; Terry Love, Al Lane and Jim Stockholm, Seattle area plumbers; Laurie Van Leuven, Highline Water District and Patricia Burgess, City of Bellevue.

This project benefited greatly from the support of the manufacturers who provided both products and technical assistance for this project. They are Niagara, Caroma, Toto, Whirlpool, Fisher & Paykel, Maytag, Frigidaire, Delta, Aqua Lean and New Resources.

And finally the staff people from Aquacraft who collected and analyzed the data: John Wright, David Lewis, Tiffany Fulcher, Erin Towler and Leslie Martien.

CHAPTER 3 GOALS AND METHODOLOGIES

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.

PROJECT GOALS

The main goal of this project was to determine as precisely as possible the impact of a range of interior retrofit fixtures and appliances on the average daily household water use in typical single family customers. Water savings were to be determined for each category of single family domestic water use in a way that kept their savings separate from one another as much as possible.

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. Data on the costs and savings were also to be determined as part of the retrofit studies so that their economic effectiveness could be analyzed.

METHODOLOGY

These studies were all pre-post analyses using a groups of homes that were representative of the bulk of the single family customers and measuring their water use in detail before and after they were retrofit with high efficiency water fixtures and appliances. Water use was disaggregated into end-uses by means of flow trace analyses. Demographic information and customer opinions were obtained by means of surveys. A combination of water use data and survey information were then used to identify relationships between the new fixtures/appliances and changes in the observed water use patterns in the homes.

In these studies, randomly selected single-family homes were equipped with new water conserving fixtures including toilets, clothes washers, showerheads, electronic faucets 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, while changes in ancillary uses (such as leakage) could also be isolated. In order to provide input on user satisfaction the participants were asked to rate both their old fixtures and the new products using a consistent set of survey criteria for both sets.

The Retrofit Studies generally 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 these projects and the planning and installation of the high efficiency plumbing fixtures.

Selection of Study Participants

The goal of the study group selection was to obtain a sample of single-family homes spread across the Tampa, Seattle and East Bay Municipal Utility District service areas. The staff from the three water departments utilized a systematic random sampling procedure to select a representative sample of 1,000 single-family accounts from their entire population of single family accounts. To obtain this random sample each single-family account from the three databases was listed in order of their annual water consumption from largest to smallest. The data sets were divided into 1000 groups customers, and a customer was chosen from the same random slot number in each group. For example, if there were 350,000 single family accounts in a given service area then the accounts were first listed in order of their annual water consumption. The entire group was then divided into 1000 subgroups of 350 members each and a random number, *n,* between 1 and 350 was chosen. The *n*th customer in each of the 1000 groups was chosen to be part of the 1000 home sample, which was also referred to as the Q_{1000}. A distribution analysis was done on the annual water use of the Q_{1000} to insure that its characteristics were the same as the entire population of single family customers.

Invitation Letter

An invitation to participate in the retrofit study was sent to a subset of the Q_{1000} that we hoped would be large enough to obtain approximately 40 positive responses. This number was approximately 350 homes per site, which proved adequate. The bottom 10% to 20% of the customers were excluded because these homes were more likely to be only partially occupied or already have high efficiency devices. The invitation packet included a cover letter, a description of the study, stressing the fact that there would be no costs to the customers, and a brief questionnaire. The questionnaire included questions about the number of people in the household and the number of fixtures that had previously been retrofit. The purpose of the questionnaire was to help select valid candidates for the study, and not to obtain data for the modeling studies, which was collected in other surveys obtained at the time of the data logging.

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 gallons per capita per day (gcd). A utility representative contacted each household to schedule a site visit audit and finalize participation. In Seattle and East Bay M.U.D. the final groups were selected so that all geographic regions in the utility service area were equally represented.

Types of products Used for Study

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 the following four categories: toilets, clothes washers, showers, and faucets. Dishwashers were not included because even the standard dishwashers found in the baseline houses use relatively little water (3-5 gal/hh/day), so the potential savings from dishwasher replacement were not great. Even though there are new dishwashers that use less water than the present models, the cost to install them in the study homes was too great to justify their use.[3]

There are a wide variety of low water use toilets on the market. All toilets currently sold in the U.S. (with a few exceptions for high traffic applications) must conform to the 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. In addition, there are several toilets now available that use less than 1.6 gpf; some of these were included in these studies. The toilets used in the studies included gravity flush, dual flush and flapperless models.

In the 1990s a number of manufacturers began offering high efficiency clothes washers that use less water and energy than traditional models. Unlike faucets and showerheads, no specific criteria has been determined for clothes washers, however, machines using 25 gallons or less per cycle were considered high efficiency for the purposes of this study. Originally, most of the high efficiency washers operated on a horizontal axis (h-axis) and opened on the front of the machine instead of the top. In the past few years several companies have entered the high efficiency washer market with top loading models. Both horizontal and vertical axis machines were used in these studies.

Showerheads and faucets, like toilets, are regulated under the Federal Energy Policy Act. Showerheads must restrict flow to 2.5 gpm and faucets must restrict flow to 1.5 gpm. Most of the faucets and showerheads were units that just met these criteria, but some of the units were designed to deliver less than the maximum allowed flow. These included showerheads that used only 1.7 gpm and faucets that used as little as 0.5 gpm for bathrooms. In theory, there should be water savings from use of quick on/off devices on the showerheads and faucets that allow the user to use the water in short bursts rather than continuous flows. These were used at some sites. Finally, some homes were equipped with electronic faucets that use a sensor to turn them on and off, and two homes were equipped with hands free activation devices for their kitchen faucets that allowed the water to be controlled by leaning against a bar mounted to the counter. Without listing any manufacturers or models by name a list of appliances and fixtures used for the study is shown in Table 3.1.

Table 3.1 Types of fixtures and appliances used in retrofits

Device	Type	Comment
Toilets	Gravity 1.6 gpf	1 model used
	Dual flush	1 model used 4l/6l flush selected by user
	Pressure assisted	1.1 gpf units were ordered, but not

[3] This is not to say the high efficiency dish washers, those that use less than 8 gallons per load, should not be used in new construction, since then only the incremental cost needs to be considered in the calculations.

		available for study
	Flapperless	1 model used
Clothes Washers	Front loading, Horizontal axis	3 models used
	Top loading	3 models used
Shower heads	2.5 gpm standard	2 models used
	1.75 gpm w/shut off	1 model used
	2.35 gpm handheld w/shutoff	1 model used
Kitchen faucets	2.2 gpm standard	1 model used
	1.5 gpm w/shut off	1 model used
	Hands free controller	1 model used
Bathroom faucets	1.5 gpm standard	1 model used
	1.0 gpm	1 model used
	1.0 gpm e-faucet	1 model used

Initial Site Visits and Audits

The initial site visit and audit 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 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 and a staff member from the utility. During the first few days, the visits were frequently attended by an additional representative from Aquacraft and when needed a plumber hired to install water meters on the hot water tank.

Flow recorders (data loggers) were placed on the water meter at each participants' home and were set to begin recording water use immediately. A representative(s) from Aquacraft installed the flow recorders on the same day, prior to the audit. The goal was to collect two weeks of pre-retrofit baseline water use data from each participating household. These recorders were scheduled to be in place for a total of 15 days each. When necessary water meters were replaced with a new standard magnetic drive meter in order to insure the maximum accuracy of the consumption data. 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.

The audit questionnaire form was developed by Aquacraft and contained numerous 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 and edited by a staff member from each utility.

During the audit, the Aquacraft staff member administered the audit questionnaire, which involved sitting down with the customer to obtain the necessary information. Each questionnaire took approximately 20 minutes to complete.

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 long enough 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.

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, however, provided useful information that simplified the analysis.

Another task accomplished during the visit was for the utility 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. It was critical that customers understand and feel comfortable with the participation agreement to ensure their full participation in the study. The entire audit process typically took between 45 and 90 minutes per household.

Pre Retrofit Logging

During the pre-retrofit logging period data loggers were installed on the main water meters outside the homes, and additional loggers were installed on some of the homes where new hot water meters had been installed above the hot water tanks. There were traces down-loaded from data loggers that could not be used from several of the homes due to complete logger failure caused by water damage or electrical interference. These homes were re-logged until good data were obtained from each home.

The goal of the data logging was to obtain a two-week flow trace from each of the study homes prior to the retrofit. The flow trace allowed the study team to disaggregate the domestic use into its components, including uses for toilet flushing, showering, bathing, dishwashing, clothes washing and faucet use.

The water savings available from individual fixtures which these studies are investigating may only be a few gallons per household per day. For example, replacing faucet aerators and showerheads results in savings in this range. Trying to quantify effects on water use this small is virtually impossible using only billing data. Having the data disaggregated into end uses, however, makes the statistical analyses much easier and more accurate and allows even small effects to be quantified.

The most fundamental type of analysis for example, is comparing average values from a group or groups and determining whether any variations between the values is statistically significant or due simply to the type of random variations one would expect from repeated measurement of a parameter from a group. Generally, the more variability in the data measurements the more difficult it becomes to establish that a specific change in average values is significant. By grouping water uses into groups of similar events, such as toilet flushes, faucet draws, showers, dishwashers, etc., the amount of variability in the data is greatly reduced, because only a single type of water use is being measured, and there isn't as much opportunity for random uses or leaks to muddle the situation. Data logger measurement makes it far easier to accurately identify smaller variations, making it well worth the effort.

Retrofit installations

The retrofit program required the most effort from the local utility staff since they had to manage the effort and see to it that all of the required replacements were made. A final retrofit plan for each of the participating households was developed based upon the physical requirements of the house, requests from the homeowners (some people expressed a product preference), and the availability of various fixtures. Under the agreement between the utility and the selected plumbing contractor, the plumber was in charge of ordering the products for the retrofit and finalizing the list of products to be installed.

A plumber was contracted to remove old fixtures and install new ones for this study. They were responsible for installing toilets, faucets, and showerheads in study homes as well as the new clothes washers although in some cases the clothes washers were installed by a representative from the dealer. To ensure that the proper fixtures were actually installed in the study homes, the plumber completed a product installation form for each house. This survey specified the exact make and model of the fixtures installed at each home. Initial audit data included a detailed list of existing fixtures in each study home.

In two cities we also installed water meters on the inflow lines to the hot water tanks. The plumber located the hot water tank and installed a $5/8^{th}$-inch water meter on the cold water feed line. This turned out to be a fairly simple process, and in all cases the meter was installed in the 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.

Post retrofit logging and surveys

After the old fixtures and appliances in the homes had been replaced, a few weeks were allowed for the customers to get used to the new devices. This minimizes the effect of behavioral changes that can impact water use when customers are making a conscious effort to conserve water. A survey was then sent out to each customer asking the same questions about the opinions on the performance and level of satisfaction with the new devices. They were also asked to report on any installation problems as well as verify the products installed in their home as part of the study.

Statistical analyses

A range of statistical analyses was applied to the data, in order to quantify the changes in household water use attributable to the retrofits. These included simple descriptive statistics and various modeling techniques to quantify the impacts on household water use. Models of household water use were created against the explanatory parameters such as size and age of the house, number of occupants and the cost of the water. Water utilities normally deal with their customers as household accounts rather than as individual members, and they sell water taps to supply households, so this seems like the most applicable and useful way to model the results.

The event level data, created as an Access database from the flow trace analysis, contained one record for each water use event. These data were summarized into tables of average daily water use for each study home both before and after the retrofits. Daily use was broken down into end-use categories such as toilets, clothes washers, showers, toilets, etc. Information from the surveys was also recorded for each home. These tables were set up in Excel, which was used to perform the statistical analyses. The water use and survey data for each house comprised one record for the pre retrofit data and a second record for the post retrofit data. The houses were identified only by a code number to insure the anonymity of the customers. Survey data collected consisted of:

- The number of residents in the household
- The square footage of the home
- The number of bathrooms
- The number of bedrooms
- The brand of clotheswasher and dishwasher
- The cost of water
- The number and types of appliances and fixtures that might effect overall water use such as icemakers, utility sinks, irrigation systems, and water treatment

Each record also contained average day household water use disaggregated by end use including:

- clotheswasher
- toilets
- showers
- faucets
- dishwasher
- leaks
- other
- total indoor use

Separate data loggers were installed on the hot water heaters of a random sample of homes in Seattle and the East Bay region. The same type of database was implemented to evaluate the effect of the retrofit on hot water use.

Statistical analyses were applied to the log transformed raw data and included descriptive analyses, t-tests and scatter plots looking for differences in the means pre and post-retrofit. When differences were found regression analyses were performed on the data for each end use to determine which parameters influenced water use in the homes. This analysis tool performs linear regression analysis by using the "least squares" method to fit a line through a set of observations. Individual tables were created with the data for each end use and the variables thought to be useful for explaining water use. Next, stepwise regressions were done to determine which variables were significant, and from there final models were developed.

It was then possible to analyze how a single dependent variable (water use) was affected by the value of one or more independent variables (number of residents, size of the house, number of bathrooms, etc.). One of the statistics returned from the regression analysis was the P-value, which indicates the likelihood that an observed change in water use is due to chance. The smaller the p-value the less likely the affect was random, and the greater the likelihood that the relationship between water used and the variable significant and not due to chance. For example, if the p-value for the square footage of the houses was 0.01 then there was only a 1% probability that the amount of water used was due to chance and a 99% probability that water use was a result of the square footage of the home. Conversely, a p-value of one indicates that there is no correlation between the particular variable and the amount of water used. Regression analysis was performed on each of the end uses for both hot and cold water use and the significant variables were identified for each.

Perhaps not surprisingly, the variable most likely to affect water use was the number of residents in the home. A few types of water use were also sensitive to the size of the home. Regression analysis was repeated including only the variables found to be significant initially. This analysis includes ANOVA or Analysis of Variance, a calculation procedure to allocate the amount of variation in a process in order to determine if it is significant or is caused by random noise. In addition, the Excel descriptive statistics analysis tool was applied to the data. This tool generates a report of univariate statistics for data in the input range, providing information about the central tendency and variability of the data.

Graphs were made of the pre and post-retrofit data as well as the savings achieved and trendlines were fit to the data. These trendlines were used to develop models that can be used by the utilities when determining the savings that are available from retrofits of various fixtures and appliances.

CHAPTER 4 STUDY GROUP DESCRIPTIONS

DEMOGRAPHICS AND HOUSEHOLD CHARACTERISTICS

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 utility service area and across the United States.

NUMBER OF RESIDENTS PER HOUSEHOLD

Survey results showed that the average number of residents per household was 3 persons or less in each of the three study sites. Seattle reported the fewest number of residents with an average of 2.51 full time residents and Tampa had the most with 2.92. East Bay reported 2.74 full time residents. With the exception of one home in Seattle that reported seven full time residents none of the homes had more than four full time adult residents. The number of each type of resident as well as the total number of residents for each study group is given in Table 4.1.

Table 4.1 Household residents in the three study sites

	Adults	Teens (13-19 yrs)	Children (0-12 yrs)	Total
Seattle	2.16	0.03	0.32	2.51
East Bay	2.20	0.17	0.37	2.74
Tampa	2.08	0.35	0.50	2.92
Average	2.15	0.16	0.39	2.70

HOUSEHOLD INFORMATION

All of the houses in the study were owner occupied single family residences. Most of the houses in the study were older homes with an average age for the entire group of 46 years. Owners of older homes may be more likely to volunteer for a retrofit study since newer homes are more likely to be equipped with water conserving fixtures.

Hot tubs were found in some of the homes in each of the three groups and several homes in Tampa and East Bay had swimming pools. The only group where water treatment was found was Tampa. Several of the homes in each of the study groups had installed ULF toilets in at least one of the bathrooms. All of the homes had clothes washers as a requirement of study participation. The household data are summarized for each of the three groups in Table 4.2.

East Bay

The median age of the houses in East Bay was 44 years old (built in 1957). The oldest house was built in 1911 and the newest house was built in 1990. On average, residents moved into their house in 1984. The earliest reported move-in date was 1950 and the most recent was 1997. The typical house in East Bay was 2 stories tall with a 2-car garage, 4 bedrooms, one full bath, one ¾ bath and averaged 2,054 sf. The smallest house was 900 sf and the largest was 6,000 sf.

There was a hot tub in eight of the houses and four houses had swimming pools. There was at least one ULF toilet installed in four of the houses prior to the retrofit. Water and sewer costs were one-third of the cost of water and sewer in Seattle at $3.66 per kgal

Seattle

The oldest group of houses was in Seattle with a median age of 55 years (built in 1945) with the oldest house built in 1885 and the newest house built in 1979. The average move-in date was 1981. The earliest reported move-in was 1941 and the most recent was 1999. The typical house was two stories tall with a 1-car garage, 3 bedrooms, one full bath, one ¾ bath and averaged 1,879 square feet (sf). The smallest house was 850 sf and the largest was 3,400 sf.

Five of the houses had hot tubs installed but none of the houses in this group had swimming pools. There was at least one ULF toilet installed in five of the houses prior to the retrofit. Water and sewer costs were the highest of the three groups at $11.27 per thousand gallons (kgal).

Tampa

The newest group of houses was in Tampa where the median age of the houses was 35 years (built in 1968). The oldest house in this group was built in 1924 and the newest house was built in 1996. The average move-in date was 1990 with the earliest move-in reported as 1958 and the most recent was 2001. The typical house in Tampa was one story tall with a 1-car garage, 3 bedrooms, one full bath and averaged 1,627 sf. The smallest house was 850 sf and the largest was 2,800 sf.

Three houses had hot tubs and two had swimming pools. There were three homes that had water treatment. At least one ULF toilet was installed in twelve of the houses prior to the retrofit. Water and sewer costs were $5.67 per kgal.

Table 4.2 Summary of household information

	East Bay (n=33)	Seattle (n=37)	Tampa (n=26)	Combined (n=96)
Avg. age of house (yrs)	44	55	35	46
Avg. house size (sf)	2054	1879	1627	1868
Avg. no. of residents	2.74	2.51	2.92	2.70
Avg. no. bathrooms	1 ¾	1 ¾	1	1.5
Avg. no. bedrooms	4	3	3	3.3
% homes w/clothes washer	100	100	100	100
% homes w/dishwasher	NA	NA	58	NA
% homes w/swimming pool	11.4	0	7.7	6.0
% homes w/hot tub	22.8	14	11.5	16.3
% homes w/water treatment	0	0	11.5	3
Cost of water/wastewater* (per kgal)	$3.66	$11.27	$5.67	$7.14

*Cost is given per kgal in 2004 rates

CHAPTER 5 PRODUCTS USED IN THE STUDY

Showerheads, faucet aerators, and toilets are regulated under the Federal 1992 Energy Policy Act (EPAct) which regulates the maximum flow rate for showerheads and faucets and the flush volume for toilets. At the time of the three studies, although EPAct standards were not set for clothes washers, an effort was made to replace clothes washers with appliances that reduced water use to 25 gallons per load or less. They needed to be readily available, reasonably priced and similar in capacity to the typical clothes washer currently on the market, as well.

TOILETS

There are several water conserving toilets on the market. The most common type uses 1.6 gallons per use and flushes with gravity. At the start of the study there was a single make of toilet that used gravity assist, dual flush technology and allowed a choice of either 0.8 gallons (3L) or 1.6 gallons (6L) per flush. Since then more have come onto the market. An example of a dual flush toilet and the flushing mechanism are shown in Figure 5.1. Pressure assisted toilets were used that take advantage of the pressure in the water line to force a stream of water into the bowl in order to provide a better flush. For this study we used a 1.1 gpf pressure assisted toilet. The final type of toilet included was a 1.6 gpf (6L) flapperless toilet that replaced the leak prone flapper valve with a water trough. An example of the flapperless technology is shown in Figure 5.1[2].

Figure 5.1 Example of dual flush toilet with the dual flushing mechanism shown in the inset

Figure 5.2 Example of a flapperless toilet with tipping bucket mechanism

CLOTHES WASHERS

There were several models of water conserving clothes washers available for this study. Three of the models were front-loading horizontal axis machines (shown in Figure 5.3) and three of the models were the more traditional top loaders (shown in Figure 4.4), but all of the clothes washers averaged less than 30 gallons per load. On average the front-loading models used less water per load than the top loading machines. The results of the study indicated that water conservation on a gallons per load basis did not occur as a result of decreased capacity since the average number of loads per capita per day actually decreased during the study. Rather, the water savings occurred as a result of improved designs and technology such as the ability to "sense" the size of the load and adjust the volume accordingly. Several of the machines had smaller, shorter rinse cycles and/or adjustable water levels.

Figure 5.3 Typical example of a horizontal axis clothes washer

Figure 5.4 Energy and water efficient top-loading clothes washer

SHOWERHEADS

Showerheads installed for these three studies were designed to flow at less than 2.5 gpm. One of the study groups installed showerheads designed to flow at 1.7 gpm. The actual measured flow rates ranged from 1.7 to 1.9 gpm, slightly less than the average maximum flow rate of 2.2 gpm prior to the retrofit. Most of the showerhead models were wall-mounted but some of the models were hand held and included an on/off slide switch. The most efficient models had design flows of 1.7 gpm with on/off switches.

FAUCET AERATORS

Both kitchen and bathroom faucet aerators were replaced with low flow models. Kitchen aerators were designed to flow between 1.5 and 2.2 gallons per minute (gpm) and bathroom aerators had flow rates between 1.0 and 1.5 gpm. The aerators were designed with a pressure compensating feature that allowed them to operate under a variety of water pressures. Some of the kitchen aerators were equipped with an on/off flip lever that was designed to maintain a consistent water temperature and shorten run times. An example of this type of faucet aerator is shown in Figure 5.5.

Figure 5.5 Faucet aerator with on/off flip lever

OTHERS

Two types of hands free faucets were installed in a small number of homes. The e-faucet has an infrared sensor that turns on the flow when it detects motion. This prevents water waste that occurs when a faucet is turned on and left on while the user performs non-faucet related tasks. The other hands free faucet controller has a bar installed in the front of the sink and flow is activated when the user leans against the bar. Moving away from the sink immediately stops the flow. This device is shown in Figure 5.6.

Figure 5.6 Hands free faucet controller (black bar under counter sill)

CHAPTER 6 IMPACTS OF HIGH EFFICIENCY PRODUCTS

This chapter provides information on the household water use at the 96 study homes before and after the retrofits. This information was derived from the three water use databases collected for the individual retrofit studies. There is a slight variation in the data analysis for this combined study however. In the individual studies the data were analyzed on a daily level for all homes, so there were a total of 1,200 or more days in each data set. In the combined study, however, we took the average daily use for each home before and after the retrofits. This produced a data set of approximately 200 points where each point represented the average daily use for each home either before or after the retrofit. The impact of this is that each home is given equal weight in the analysis, where in the individual studies homes that had more days of data collected were weighted a bit more heavily than homes with fewer days of successful data. The results are similar, but not identical, and we think that the equal weighting approach used for the combined report is more representative of actual conditions, and was the preferred method of analysis.

IMPACTS ON OVERALL HOUSEHOLD WATER USE

Changes in Total Water Use

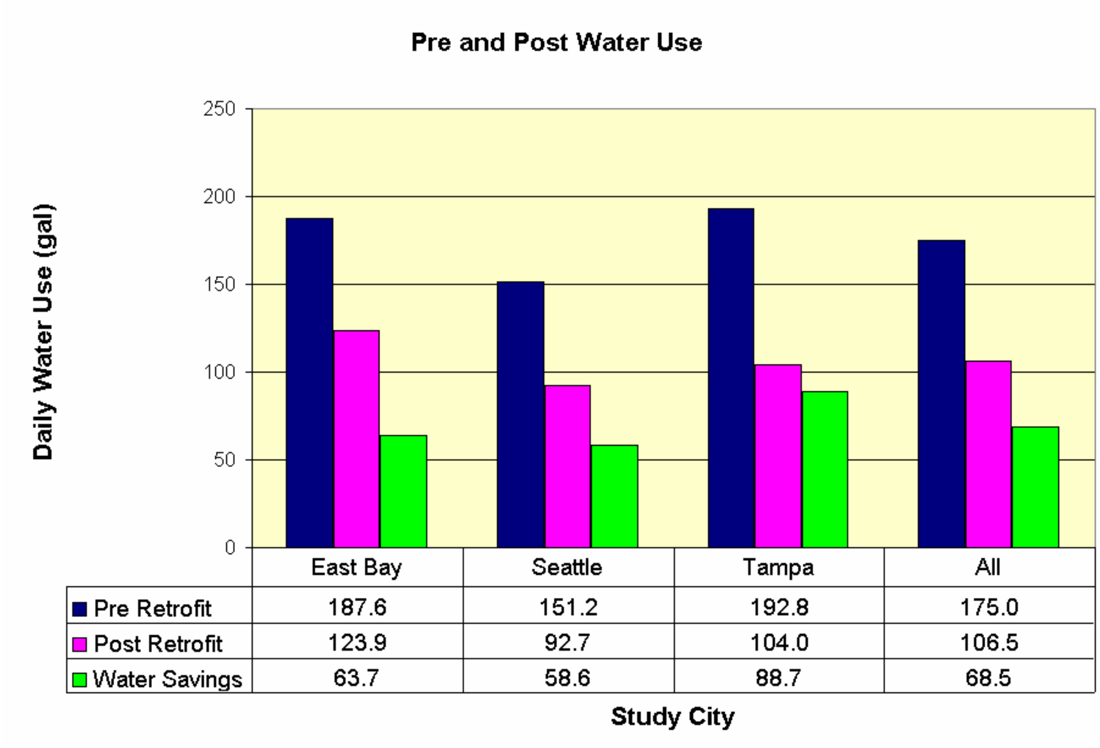
The data show clearly that the retrofits had a profound impact on the daily household water use at all three sites. Table 6.1 shows the individual and combined results for daily household water use prior to and after the retrofits. This table also shows the results from paired t-tests on the significance of the changes in the average daily water use for each paired sample. In this case the pairings are the sets of the homes before and after they were upgraded with the more efficient fixtures and appliances. The t-statistic shows the ratio of the change in the means to the standard errors of the data, and for this statistic a larger value implies a higher significance in the difference between the means. The second statistic is the p-statistic, which tells the probability that the change in the means is due merely to coincidence. A p-statistic of 0.01, for instance, means that there is a 1% chance that the change in means is due to chance and a 99% probability that the change is due to some effect other than chance. In our case, the effect we are testing is whether or not the homes were retrofit or not. The water use and savings data are shown graphically in Figure 6.1.

The results from these 96 homes show that the indoor water use started out at an average of 175 gpd (63 kgal/yr) and dropped to 107 gpd (39 kgal/yr) after the retrofits. This represents a 39% reduction in indoor water use for the three sites. The city with the highest initial water use, Tampa, also showed the greatest savings, of 89 gpd. Conversely, Seattle, the city with the lowest initial water use had the smallest savings, at 59 gpd, but they also ended the study with the lowest indoor water use, at 93 gpd. In annual terms the savings achieved in this study range from 21.4 kgal in Seattle, to 32.4 kgal in Tampa, with an average of 25 kgal. All of these changes in water use are statistically significant at a 95% level of confidence.

Figure 6.2 shows the distribution of daily household water use for the homes before and after the retrofits. What is striking about this graph is the number of homes that fall into the lowest three bins after the retrofits. Before the retrofits there was only a single home that used 50 gpd or less for their indoor uses, but after the retrofit a total of 7 homes fell into this category. Likewise the number of homes using between 50 and 100 gpd doubled as a result of the retrofits. Prior to the retrofits only 45% of the homes were using less than 150 gpd for indoor purposes and afterward 88% of the homes used less than 150 gpd.

Table 6.1 Summary statistics for total water use

SUMMARY STATISTICS: Indoor Water Use per Home (gpd)					
		East Bay	Seattle	Tampa	All
Pre-Retrofit	Average (gpd)	187.6	151.2	192.8	175.0
	Count	33	37	26	96
	Std Dev	88.5	70.5	96.9	85.7
Post-Retrofit	Average (gpd)	123.9	92.7	104.0	106.5
	Count	33	37	26	96
	Std Dev	63.1	35.4	47.2	50.9
Water savings (gpd)		63.7	58.6	88.7	68.5
Percent reduction		34%	39%	46%	39%
t-stat		5.800	6.187	4.823	9.424
p-stat		0.000	0.000	0.000	0.000



	East Bay	Seattle	Tampa	All
Pre Retrofit	187.6	151.2	192.8	175.0
Post Retrofit	123.9	92.7	104.0	106.5
Water Savings	63.7	58.6	88.7	68.5

Figure 6.1 Total household water use before and after retrofits

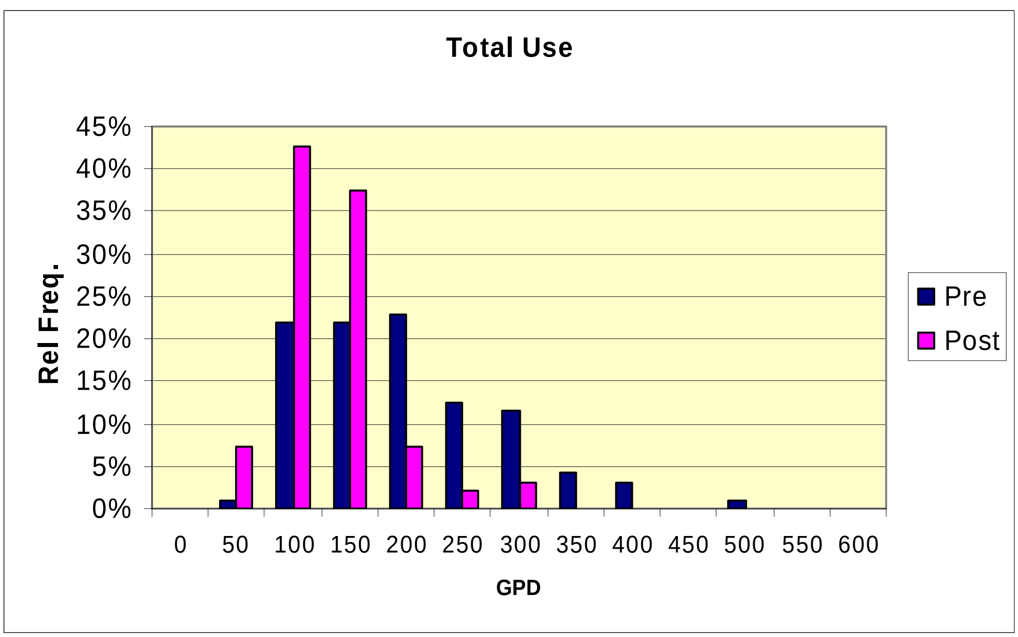


Figure 6.2 Histogram of daily household water use before and after retrofits

Models of Total Indoor Water Use

The data presented above show clearly that total water use is affected by the presence or absence of high efficiency fixtures and appliances, but other factors affect water use as well. In order to get a feel for the data a simple model of the household use versus the number of residents in the home was plotted in Figure 6.3 and trend lines were fitted to the pre and post retrofit data. This graph shows that there is clearly a relationship between the number of people living in the home and the total daily water use. It also shows the amount of scatter in the data. No formulas were developed for the lines because these were just exploratory plots.

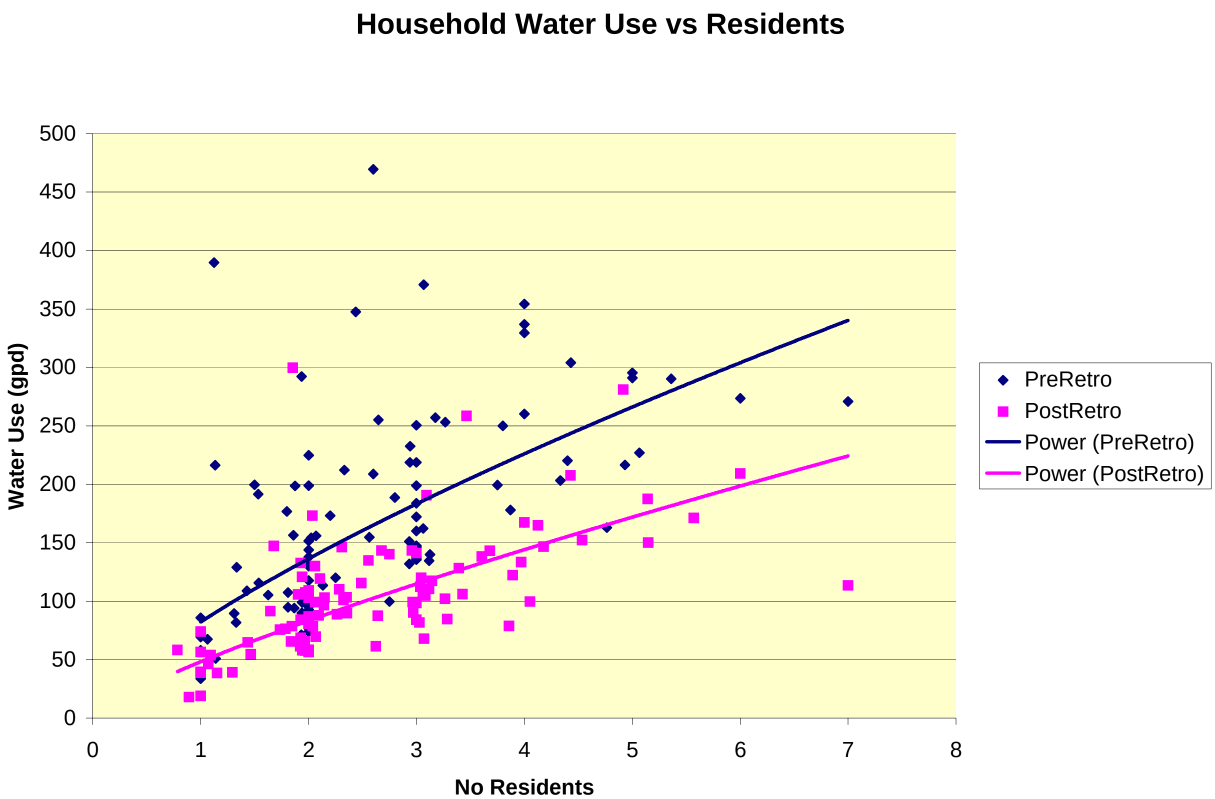


Figure 6.3 Total household water use vs. number of residents

In all likelihood there are other variables besides the number of residents that affect household water use. Using the water use data, in addition to household information obtained from customer surveys, additional relationships were developed. In these models the total daily household water use was the dependant, or Y, variable, and the following were used as independent, or X, variables: the number of residents, the area of the house, the number of bedrooms, the number of bathrooms, the age of the house, and the cost for water. Because we doubted that any of these relationships would be purely linear in nature the data were first transformed into logarithms (base 10) and a multiple regression analysis was conducted.

The results of this model are shown in Table 6.2. We can see from this table that prior to the retrofit the total indoor use was related to the number of residents, the area of the home and the cost of the water. After the retrofits the only two significant explanatory variables were the number of residents and the size of the home. The cost of the water became insignificant as the amount of excess use decreased in the homes, and only less discretionary uses remained. In both cases, however, the number of residents in the home was the most important explanatory variable followed by the area of the home.

Table 6.2 Total indoor water use vs. 6 variables

	Pre Retrofit				*Post Retrofit*			
Variable	*Coef*	*t Stat*	*P-value*	*Sig?*	*Coef*	*t Stat*	*P-value*	*Sig?*
Log Res	0.646	7.613	0.000	Yes	0.747	9.657	0.000	Yes
Log SF	0.346	2.368	0.020	Yes	0.316	2.283	0.025	Yes
Log Bed	0.172	0.963	0.338	No	0.005	0.030	0.976	No
Log Bath	-0.155	-1.143	0.256	No	0.001	0.011	0.991	No
Log Age	0.044	0.599	0.551	No	-0.080	-1.206	0.231	No
Log Cost	0.256	2.876	0.005	Yes	0.031	0.387	0.700	No

Based on the analysis using six variables a final analysis was conducted using just the two variables showing the strongest explanatory value for both pre and post retrofit conditions: the number of residents and the size of the home. The models for the pre and post retrofit data are shown in Table 6.3. These show that in order to predict either baseline or post retrofit indoor water use both the number of residents and the size of the house must be considered. These also show that the increase in water use with either residents or house size is not linear, but follows a power curve relationship with exponents less than 1. This results in a set of curves for a home of 1850 sf, as shown in Figure 6.4. This demonstrates that as the number of residents increases the water use also increases, but at a gradually lower rate. The difference between the pre and post retrofit conditions show the amount of water saved in an 1850 sf home through these retrofits as $37.45 \times Res^{.555}$. This relationship is important because it shows the danger of trying to use a single per capita amount to describe an affect that is neither linear nor a function of a single variable. It is interesting that after the retrofits the models became slightly more linear, with exponents closer to 1. This implies that water use after the retrofit had less randomness and usage that is independent of the number of persons living in the homes, such as leakage.

Table 6.3 Models for daily water use vs residents and house size

State	Model	Adjusted R^2
Pre Retrofit	$9.5 \times Res^{.687} \times SF^{.295}$	0.460
Post Retrofit	$5.0 \times Res^{.767} \times SF^{.307}$	0.561

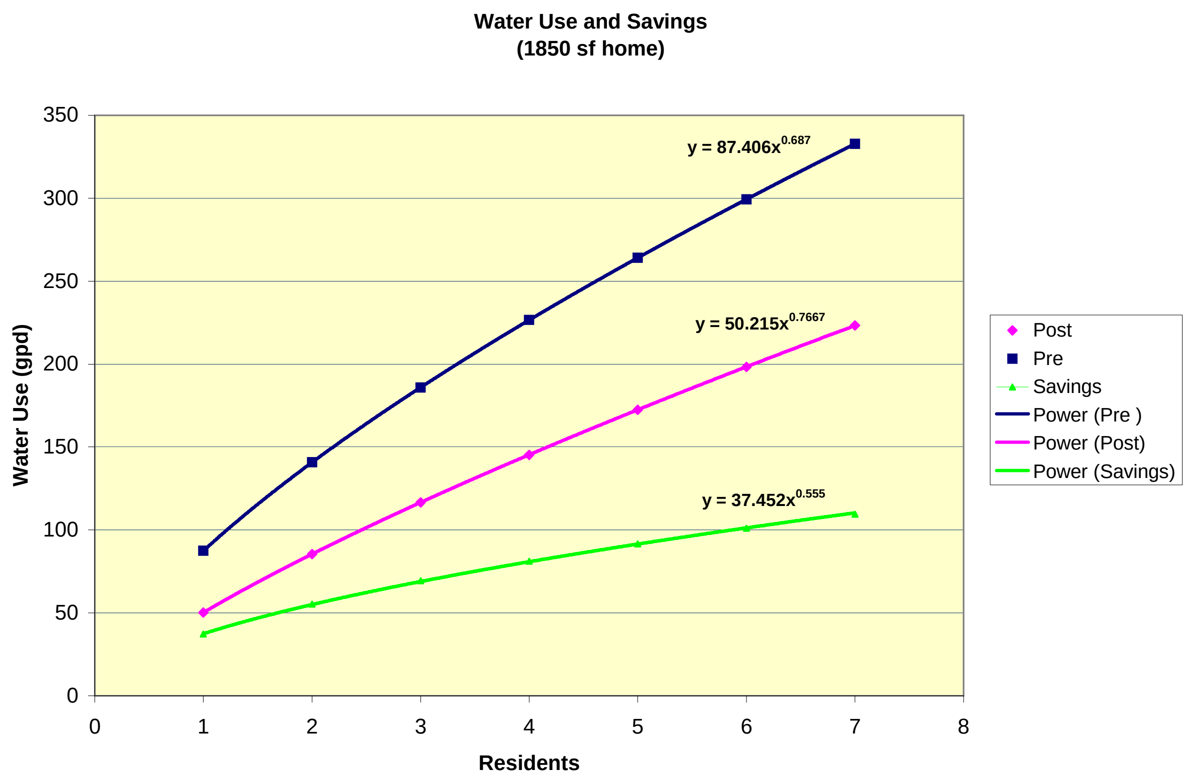


Figure 6.4 Total daily use vs. number of residents for an average size home

Changes in Hot Water Use

The reduction of hot water use following the retrofits is clearly shown in Table 6.4. This result is not surprising since all retrofit fixtures except the toilets use hot water. The data show both the combined and individual results for Seattle and East Bay prior to and after the retrofits.

The results from the 20 retrofit homes show an average decrease in daily hot water use of 10.8 gpd from 52.3 gpd to 41.6 gpd. This represents a 20.6% decrease in overall hot water use. The largest change was found in East Bay with a decrease of 12.3 gpd. Seattle had the highest total hot water use of 55.4 gpd and showed the smallest post retrofit decrease of 9.2 gpd. All of these changes in water use are statistically significant at a 95% level of confidence.

The histogram in Figure 6.5 shows a definite reduction in hot water use. Prior to the retrofit only 5% of households used less than 40 gpd of hot water but following the retrofit the number of households using less than 40 gpd increased to 50%. A rather surprising finding was that the percentage of high end users did not decrease substantially. Prior to the retrofit 35% of households used 70 gpd or more and after the retrofit the percentage only decreased to 30% with 5% of homes using 110 gpd of hot water.

The only factor shown to be statistically significant in reducing total hot water use for the post retrofit is the number of residents in the homes. The models for the pre and post retrofit are shown in Table 6.5.

As with total water use, the curves in Figure 6.6 show a non-linear relationship between the amount of hot water used and the number of residents in the home. The hot water use increases as the number of residents increases but at a gradually decreasing rate. The effect of the number of residents on hot water use is nearly the same before and after the retrofit as demonstrated by the nearly linear cost curve with an exponent of 0.994.

Table 6.4 Summary statistics of total hot water use

SUMMARY STATISTICS: Total Household Hot Water Use (gpd)				
		East Bay	Seattle	Combined
Pre Retrofit	Average	49.2	55.4	52.3
	Count	10	10	20
	Std Dev	20.1	25.0	22.3
Post Retrofit	Average	36.9	46.2	41.6
	Count	10	10	20
	Std Dev	26.5	22.22	24.3
Water Savings		12.3	9.2	10.8
Percent Reduction		25.0%	16.6%	20.6%
t-stat		2.02	1.23	2.29
p-stat		0.037	0.125	0.017

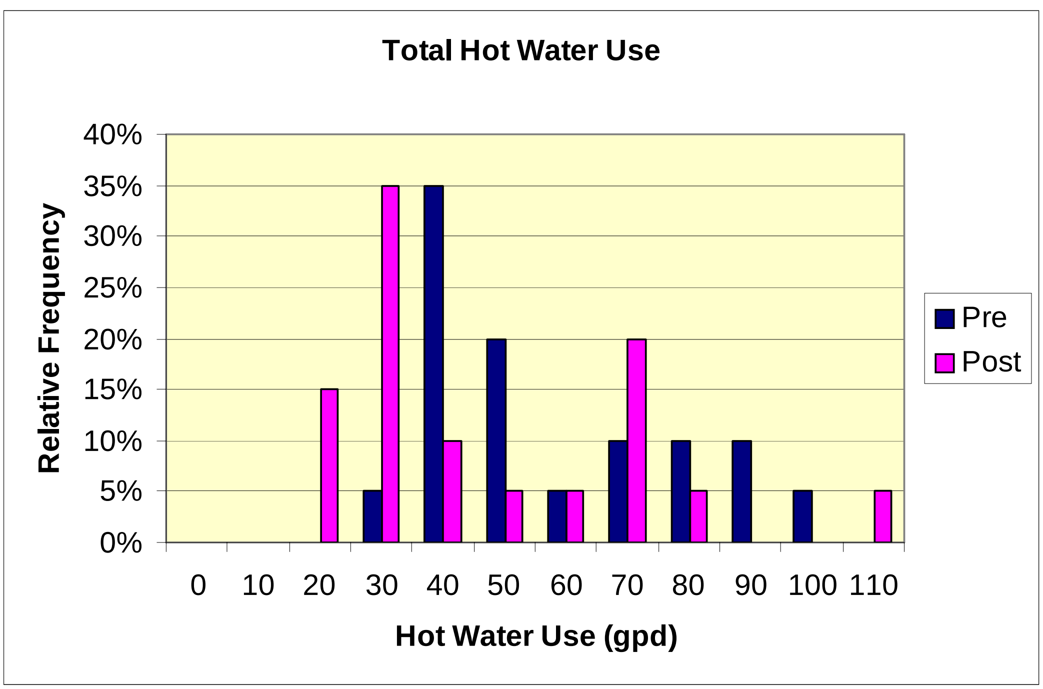


Figure 6.5 Distribution of total hot water use pre and post retrofit

Table 6.5 Models for daily hot water use vs number of residents

State	Model	Adjusted R^2
Pre-Retrofit	$30.63 \times Res^{.5604}$	0.454
Post-Retrofit	$22.172 \times Res^{.6108}$	0.276
Savings	$8.5506 \times Res^{0.3955}$	0.9992

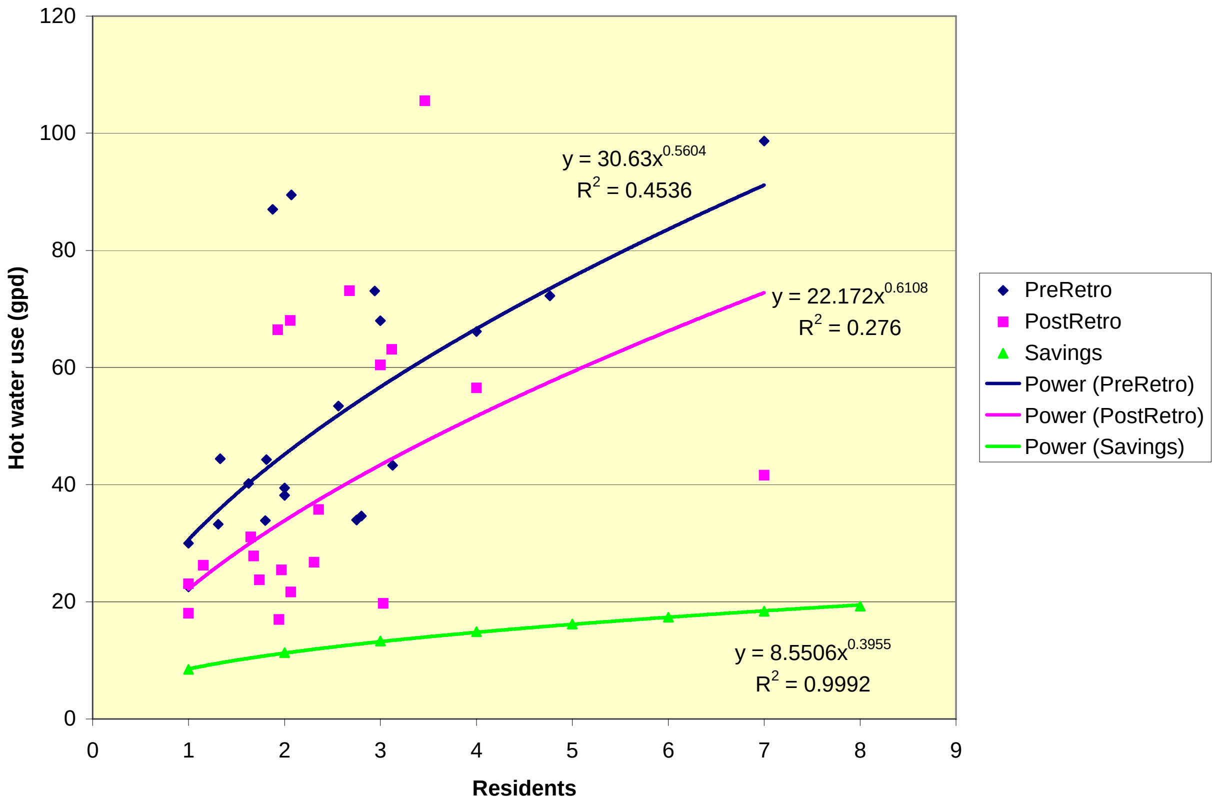


Figure 6.6 Total daily hot water use vs. number of residents

IMPACTS ON END USES

The previous section described the changes in total indoor water use that were attributable to the interior retrofit programs from the three study sites, but it does not tell us how much savings were caused by each type of retrofit. Because the data logging technique used in this study allowed the uses to be disaggregated according to their end uses it was possible to develop statistics and mathematical models for the individual end uses as well. This level of detail would not be possible using just meter data. The following sections provide information on the observed relationships between the retrofits and the changes in individual domestic end uses of water in the study group.

Toilet Use

Evaluation of potential reductions in toilet flushing use was one of the main objectives of this study. Toilet flushing is the single largest end use of water in single-family homes where it comprises as much as 30 percent of the water used daily.

The majority of the new toilets installed in the homes were 1.6 gpf devices of varying designs and manufacturers. The exceptions to this were the homes in Seattle and East Bay that had dual flush toilets installed. (As described above).

Household Toilet Use

Water use for toilet flushing was reduced significantly by the retrofit program. Very few of the homes in the study had any ULF toilets prior to the retrofits, so these numbers show the impacts of moving from a relatively sparse number of ULF toilets to an almost complete retrofit. The results in Table 6.6 show that the household use for toilet flushing was reduced between 52% and 59% by the retrofits, with the average reduction of 55%. In terms of gallons per household, the reductions ranged from 22 to 27 gpd, with the average of 25 gpd, or approximately 9000 gallons per year per household. Another way of stating this is that these homes went from using over 16,000 gallons of water for toilet flushing to 7,000 gallons per year as a result of the replacement program.

Table 6.6 Summary statistics for toilet water use

SUMMARY STATISTICS: Toilets					
		East Bay	Seattle	Tampa	All
Pre-Retrofit	Average (gpd)	46.0	45.4	42.2	44.7
	Count	33	37	26	96
	Std Dev	23.6	27.6	21.0	24.4
Post-Retrofit	Average (gpd)	22.0	18.7	20.2	20.2
	Count	33	37	26	96
	Std Dev	9.1	9.3	9.5	9.3
Water savings (gpd)		24.0	26.7	22.0	24.5
Percent reduction		52%	59%	52%	55%
t-stat		7.011	7.340	5.497	11.59
p-stat		0.0000	0.0000	0.0000	0.0000

The impact of replacing of old toilets with high efficiency fixtures is shown in visual form in Figure 6.7. Prior to the replacements there were homes using up to 120 gallons per day for toilet flushing. Afterwards, none of the homes used more than 50 gpd, and the majority of homes used less than 30 gpd. This dramatic reduction in the average water use is clearly linked with achieving savings throughout, but with even larger savings obtained in those homes with very high toilet use, perhaps due to their having the oldest and largest water using devices to begin with.

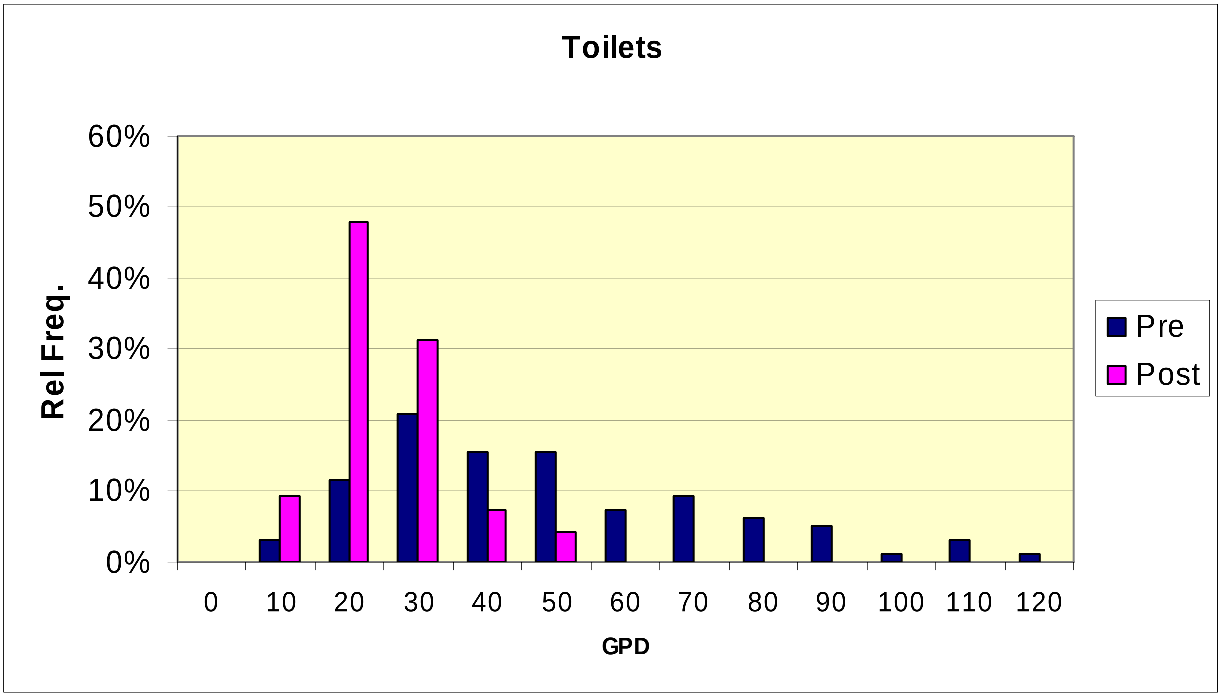


Figure 6.7 Histogram of daily household water use for toilet flushing pre and post retrofits

Models for Toilet Water Use

An analysis of the data showed that as with total indoor use the most significant variables for household use were the number of residents and the size of the home. Using the same logarithm transformation process used for the total use model revealed the following relationships.

Table 6.7 Models for household toilet water use

State	Model	Adjusted R^2
Pre Retrofit	$0.377 \times Res^{.586} \times SF^{.552}$	0.392
Post Retrofit	$0.685 \times Res^{.616} \times SF^{.367}$	0.383

If the results for an 1850 sf home are calculated, which is the average size for this group, then the relationships for water use before and after the retrofits, and the water savings shown in Figure 6.8 result. Similar sets of curves can be developed for homes of different sizes depending on the circumstances of the customers.

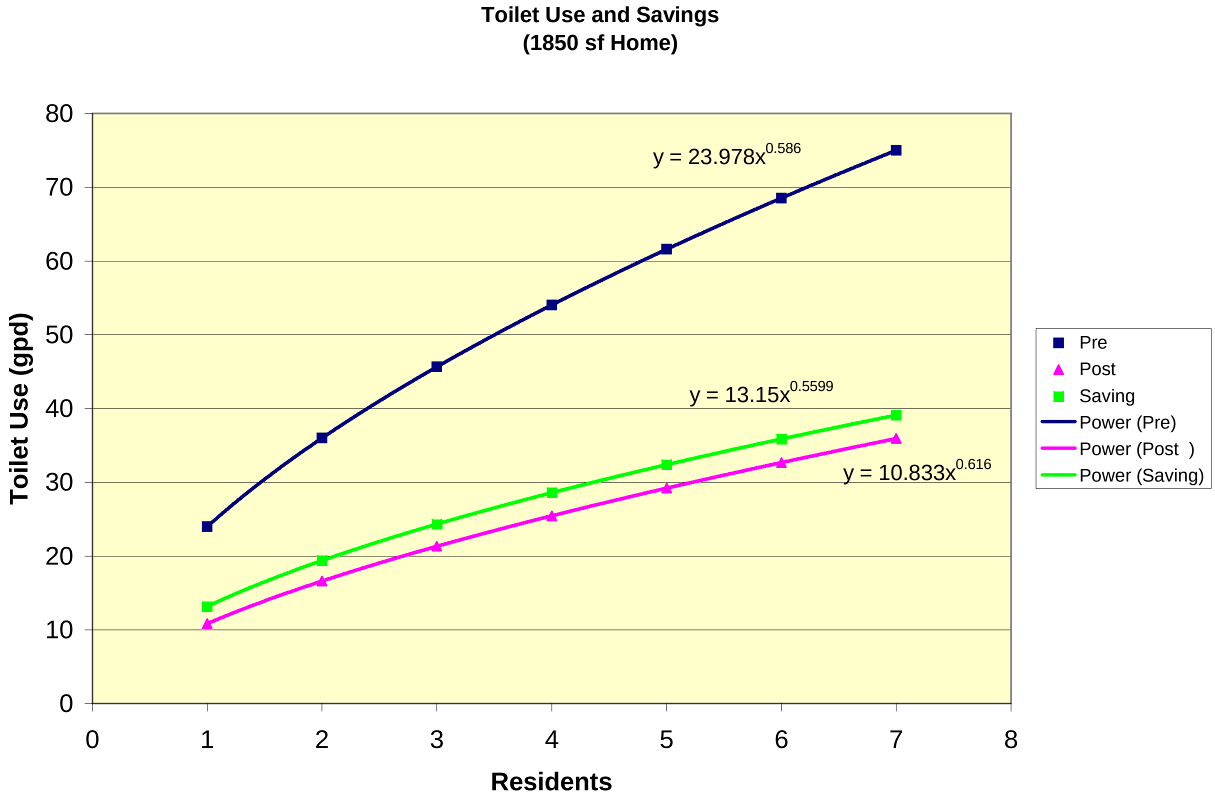


Figure 6.8 Water use and savings models for household toilets

Flushes per Capita per Day

Despite data to the contrary, ULF toilets are thought by some to be ineffective at saving water because they may require double flushing. However, the data show clearly that while the flushing frequency went up slightly in two of the three participating study groups it decreased slightly in one of the groups. Furthermore, when a *t-test* (two-tailed) assuming unequal variances was conducted at the 99 percent confidence level to determine the difference between the baseline and post-retrofit mean flushes per capita per day (fpcd) the increased flushing was found to be significant only in East Bay. The small increase in flushing did not outweigh the water savings accomplished through the installation of low flow toilets (see Figure 6.8). The results of flushing frequency are shown in Table 6.8.

Table 6.8 Per capita flushing frequency pre and post-retrofit for the three study groups

	Seattle	Tampa	East Bay
Pre-Retrofit (fpcd)	5.17	5.01	5.14
Post-Retrofit (fpcd)	5.46	4.89	5.74
Difference	0.29	-0.12	0.60
Statistically Significant?	No	No	Yes

Flush Volume

During the post-retrofit data collection period a total of 33,460 toilet flushes were recorded from 96 study homes over 2,573 days. Although several of the households kept one of their non-conserving toilets these were toilets that were rarely used. Therefore, as shown in Table 6.9, the overall reduction in average flush volume is substantial.

Table 6.9 Average flush volume pre and post-retrofit for the three study groups

	Seattle	Tampa	East Bay	Combined
Pre-Retrofit (g/f)	3.61	3.51	3.88	3.68
Post-Retrofit (g/f)*	1.38	1.59	1.64	1.52
Percent Reduction	62%	55%	58%	59%

*Not all of the toilets in the study homes were replaced which resulted in a slightly higher value of flush volume in the post-retrofit data

Clothes washers

Water use for clothes washing ranks just behind toilet flushing in terms of average daily use. Fortunately, the number of options for consumers wishing to purchase low water use clothes washers is constantly growing. At the start of the study only a few domestic models of high efficiency washers were available, but during the course of the study several new models were introduced by major U.S. manufacturers. These include both horizontal axis machines that use less than 15 gallons per load and vertical axis machines that use less than 25 gallons per load.

Household Clothes Washer Use

As was the case with toilet use, water use for clothes washing was reduced dramatically by the use of high efficiency machines. This was true in all study sites where the percent reductions ranged from 34% to 43% and averaged 38% for all three sites. The water savings from the clothes washer retrofits ranged from 11.5 gpd (4,197 gal/yr) to 15.1 gpd (5,511 gal/yr). The site with the highest savings was Tampa where the machines with the lowest per load water use were installed. These included the horizontal axis washers manufactured by a major U.S. company that use as little as 14 gallons for a standard-sized load.

The distribution of daily use for clothes washing, shown in Figure 6.9 shows the familiar pattern of reductions in the large use bins and increases in the lower use bins. Where prior to the retrofits a significant proportion of the customers used more than 50 gallons per day for washing clothes, afterward only a single customer used more than 50 gpd, and most used less than 30 gpd.

Table 6.10 Summary statistics for clothes washer use before and after retrofits

SUMMARY STATISTICS: Clothes Washers (gpd)					
		East Bay	Seattle	Tampa	All
Pre-Retrofit	Average (gpd)	33.5	34.2	35.4	34.3
	Count	33	37	26	96
	Std Dev	18.7	19.5	21.9	19.7
Post-Retrofit	Average (gpd)	22.0	21.6	20.3	21.4
	Count	33	37	26	96
	Std Dev	12.9	11.6	10.2	11.6
Water savings (gpd)		11.5	12.6	15.1	12.9
Percent reduction		34%	37%	43%	38%
t-stat		5.133	5.37	4.45	8.64
p-stat		0.000	0.000	0.000	0.000

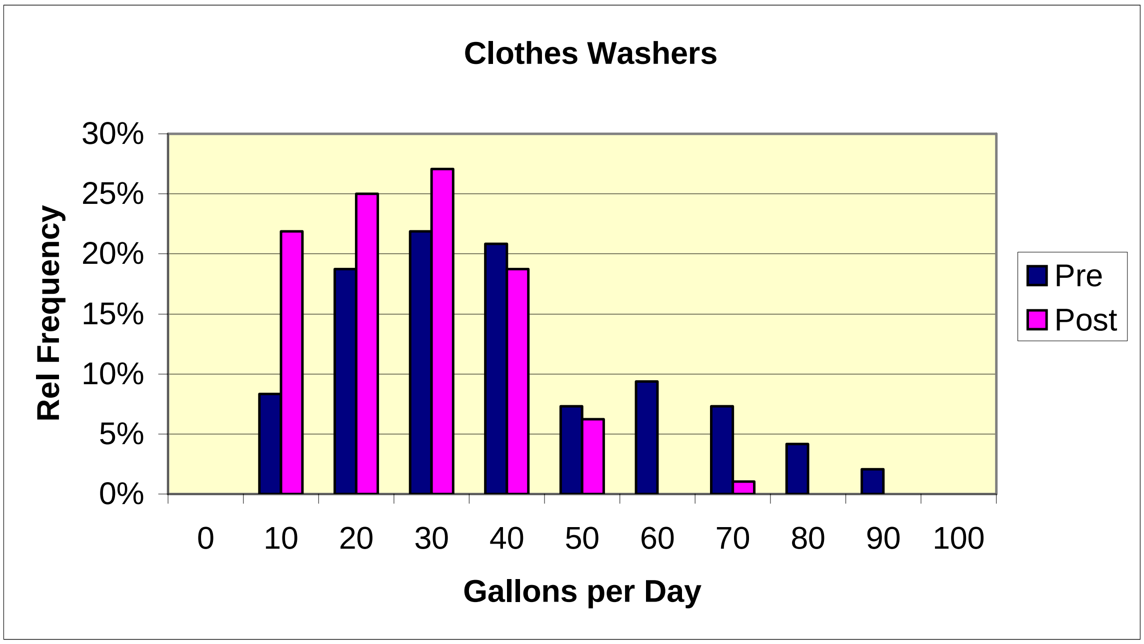


Figure 6.9 Distribution of clothes washer use before and after retrofits

Models for Clothes Washer Use

Unlike the total use or toilet use, data for clothes washer water use showed a relationship to only the number of persons living in the home, and was not related to either the cost of the water or the size of the home. This meant that a simple model of daily use versus the number of residents present was adequate to describe the water use. The resulting model is shown in Table 6.11. It is noteworthy that the clothes washer water use comes closest to a purely linear function, with exponents of 0.820 of .973 before and after the retrofits.

Table 6.11 Model of clothes washer water use before and after retrofits

State	Model	Adjusted R^2
Pre Retrofit	$14.068 \times Res^{.820}$	0.356
Post Retrofit	$7.701 \times Res^{.973}$	0.433

The daily use data before and after the retrofits and the calculated savings from clothes washer replacements are plotted in Figure 6.10. Because this model is a function of a single variable the individual data points are shown on the graph along with the trend lines. The water use lines both appear relatively linear, but the savings line rises at a decreasing rate with residents and appears to approach 20 gpd as a practical maximum.

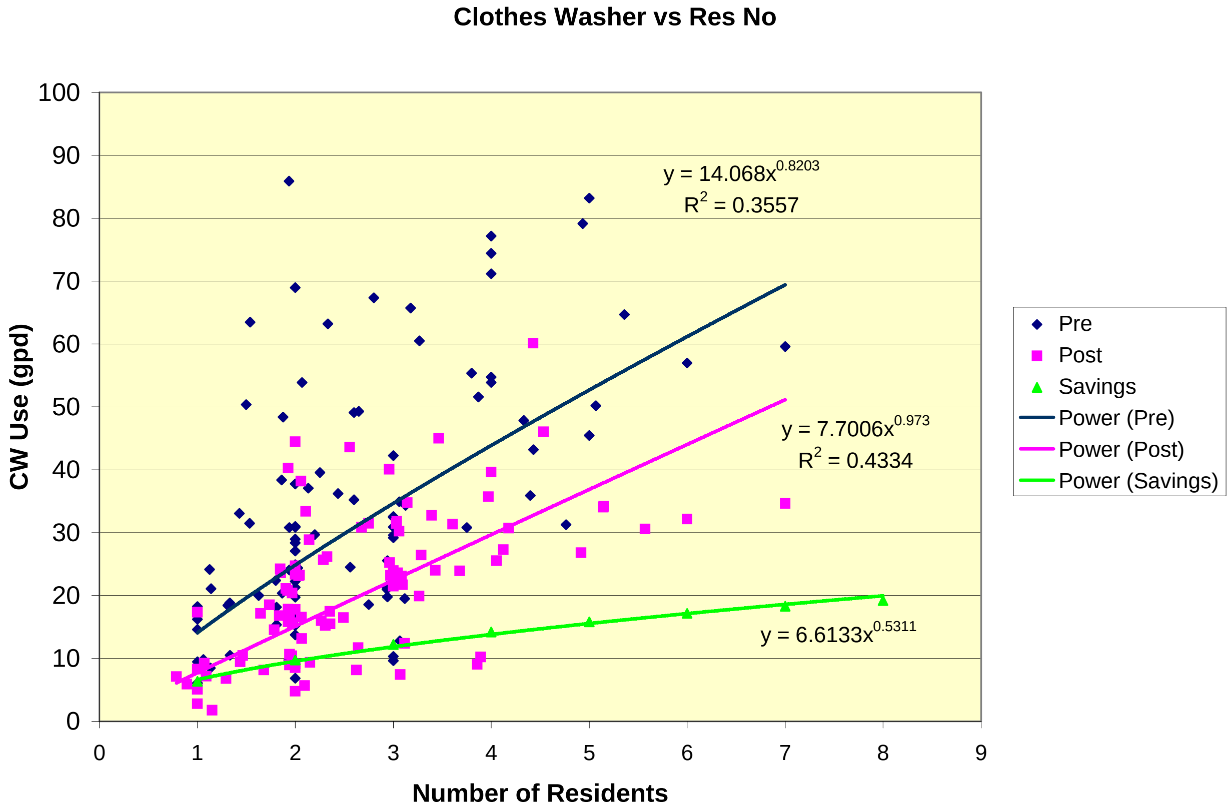


Figure 6.10 Household clothes washer water use before and after retrofit vs. number of residents

Gallons per Load

The volume of water used per load decreased substantially after the retrofit. Interestingly, although Tampa used the least amount of water per load prior to the retrofit they showed the greatest reduction in water use after the retrofit where the volume decreased 43 percent from 35.9 gpl to 20.5 gpl. The gallons per load used for clothes washing pre and post retrofit and the percent reduction is shown in Table 6.12.

Table 6.12 Gallons per load used for clothes washing pre and post-retrofit

	Seattle	Tampa	East Bay	Combined
Pre-Retrofit (gpl)	40.9	35.9	40.7	39.5
Post-Retrofit (gpl)	24.3	20.5	27.2	24.3
Percent Reduction	41%	43%	33%	38.8%

Loads per Capita per Day

The concern exists that savings from water conserving clothes washers may be partly negated by an increase in the number of loads as a result of decreased capacity. As shown in Table 6.13 only a slight increase in frequency was noted in Seattle, both Tampa and East Bay experienced a decrease. This suggests that the capacity of water conserving clothes washers is adequate and did not result in increased use.

Table 6.13 Number of clothes washer loads per capita per day pre and post retrofit

	Seattle	Tampa	East Bay	Combined
Pre-Retrofit (lpcd)	0.36	0.42	0.36	0.38
Post-Retrofit (lpcd)	0.38	0.38	0.32	0.36
Percent Savings	-5.5%	9.5%	11%	4.2%

Hot Water Use for Clothes Washers

Of all fixtures, clothes washers show the greatest percentage of water reduction post retrofit. Although Seattle had a greater reduction of 59% or 5.2 gpd, the average daily use, prior to the retrofit, was double that of East Bay as shown in Table 6.14. Combined, both cities showed an average reduction in their hot water use for clothes washers of 3.7 gpd or 56 percent.

Models for Clothes Washer Hot Water Use

The only factor shown to be statistically significant in reducing hot water use in clothes washing for the post retrofit is the number of residents in the homes. The models for the pre and post retrofit are shown in Table 6.16.

Table 6.14 Summary statistics for clothes washer hot water use

SUMMARY STATISTICS: Clothes Washers				
		East Bay	Seattle	Combined
Pre-Retrofit (gpd)	Average	4.5	9.0	6.7
	Count	10	10	20
	Std Dev	1.9	6.5	5.2
Post-Retrofit (gpd)	Average	2.2	3.7	3.0
	Count	10	10	20
	Std Dev	1.7	2.9	2.4
Water Savings (gpd)		2.2	5.2	3.7

Percent Reduction	50%	59%	56%
t-stat	3.06	3.65	3.93
p-stat	0.007	0.003	0.000

Table 6.15 Models for clothes washer hot water use vs number of residents

State	Model	Adjusted R^2
Pre-Retrofit	$3.075 \times Res^{0.681}$	0.2484
Post-Retrofit	$0.648 \times Res^{1.378}$	0.3337
Savings	$-0.0141x^2 + 1.0485x + 1.608$	0.9799

Prior to the retrofit 5% of homes used 16 gpd and 10% used 20gpd of hot water for clothes washing. After the retrofit none of the homes used more than 10 gpd and 50% of them used no more than 2 gpd as shown in Figure 6.11.

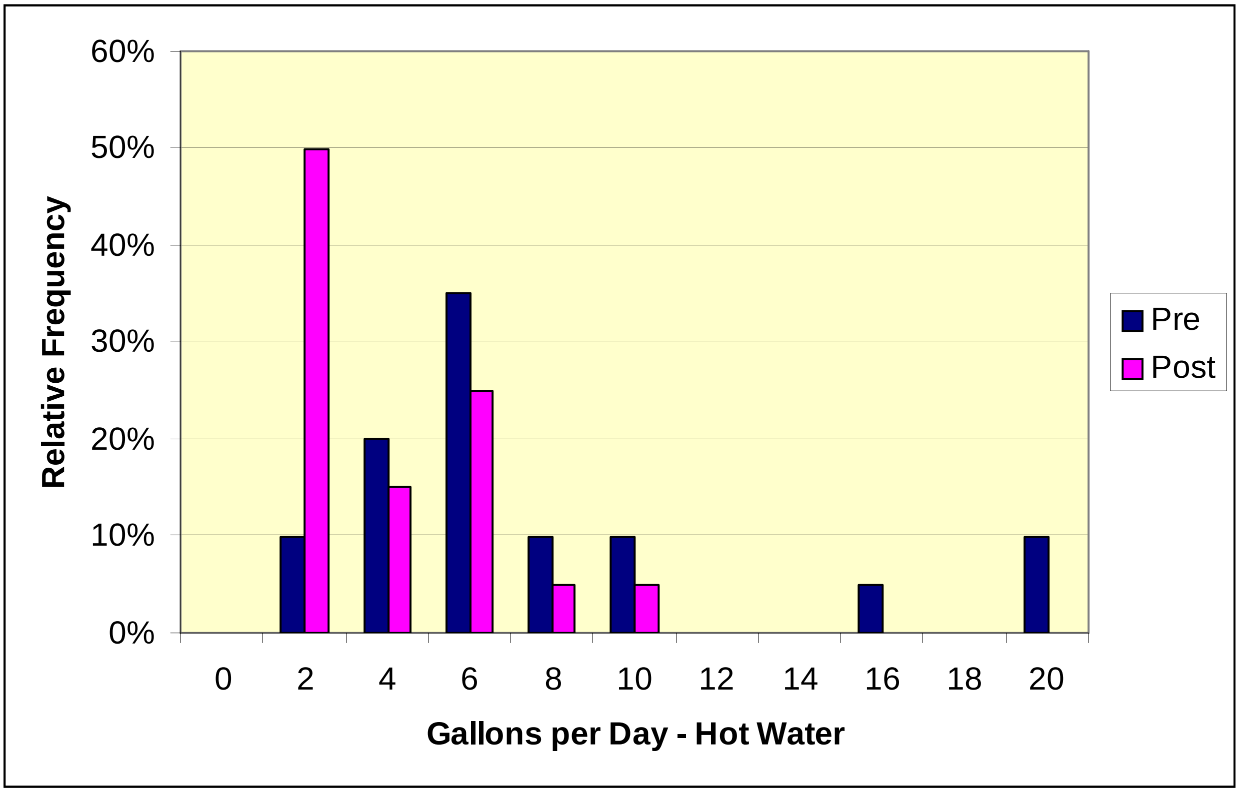


Figure 6.11 Distribution of daily hot water use for clothes washing pre and post retrofit

Table 6.16 Models for clothes washer hot water use vs number of residents

State	Model	Adjusted R^2
Pre-Retrofit	$3.075 \times Res^{0.681}$	0.2484
Post-Retrofit	$0.648 \times Res^{1.378}$	0.3337
Savings	$-0.0141x^2 + 1.0485x + 1.608$	0.9799

Prior to the retrofit, clothes washer hot water use decreased slightly as the number of residents in the home increased as evidenced by the curve shown in Figure 6.12. Following the retrofit the hot water used for clothes washing increased slightly as the number of residents in the home increased. This is despite the overall decrease in hot water use as a function of the number of residents as shown in Figure 6.6. The best fit curve is a polynomial function as shown in Table 6.16 which shows that hot water savings begins to decline as the number of residents in the household exceeds four.

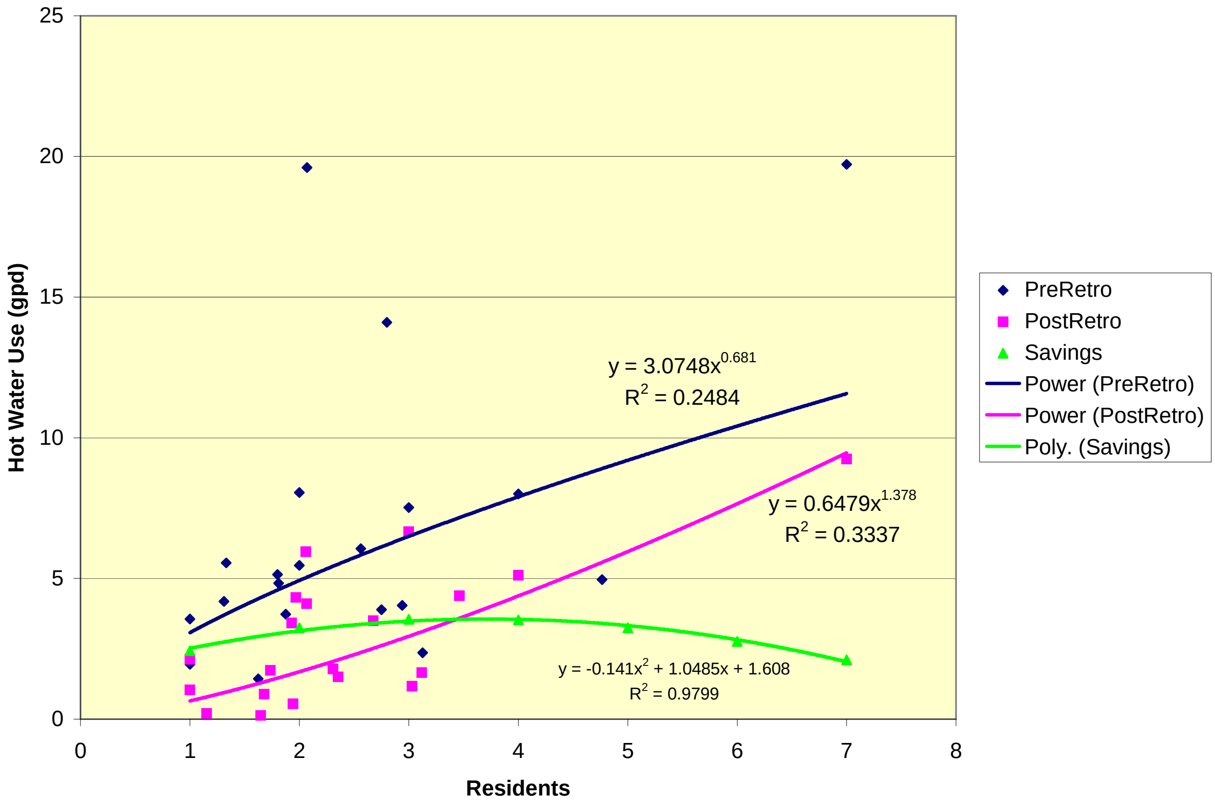


Figure 6.12 Daily clothes washer hot water use vs. number of residents

Showers

The data for water savings associated with showers is a lot less clear-cut than for the previous categories, but there does appear to be some savings achievable from showerhead replacements. The key is in understanding the different types of showerheads used in each city. In Table 6.17 we see that only Tampa had significant water savings from showerhead replacements. In both

Seattle and East Bay 2.5 gpm showerheads were used as replacements, but in Tampa the replacement showerheads were either 1.75 gpm models or they were handheld 2.5 gpm devices with shut-off buttons. Use of the latter two types of devices appears to have led to a 28% reduction in water use for showering which was statistically significant, compared to 9% reductions in both Seattle and East Bay that were not statistically significant.

Table 6.17 Household shower water use before and after retrofits

SUMMARY STATISTICS: Showers					
		East Bay	Seattle	Tampa	All
Pre-Retrofit	Average (gpd)	29.1	22.0	35.4	28.1
	Count	33	37	26	96
	Std Dev	23.1	16.4	26.8	22.3
Post-Retrofit	Average (gpd)	26.4	20.1	25.7	23.8
	Count	33	37	26	96
	Std Dev	22.3	12.4	17.2	17.7
		2.6	1.9	9.8	4.3
Water savings (gpd)					
Percent reduction		9%	9%	28%	15%
t-stat		1.096	1.018	2.55539	2.801
p-stat		0.1407	0.1576	0.0085	0.0031

The results for shower heads are strongly suggestive that use of most 2.5 gpm shower heads will not lead to significant savings in typical single family homes, but that savings are achievable with 1.75 gpm or handheld models with shut-off valves used in Tampa. If just the data for Tampa are modeled, the relationships shown in Figure 6.13 result. This figure shows that for small households the savings from use of 1.75 gpm shower heads is non-existent, but as the number of persons living in the home increases the savings go up. The best fit for the savings data line is a polynomial function as shown in the table. In a house with 3 residents savings from use of a 1.75 gpm shower head are predicted by this model to be 7.7 gpd or 2800 gal/yr, which coincidentally is close to the annual savings observed in Tampa.

Table 6.18 Shower water use and savings in Tampa, with 1.75 gpm showerheads

State	**Model**	**Adjusted R^2**
Pre-Retrofit	$6.014 \times Res^{1.47}$	0.446
Post-Retrofit	$6.53 \times Res^{1.139}$	0.286
Savings	$0.921\ Res^2 + 0.338\ Res - 1.56$	--

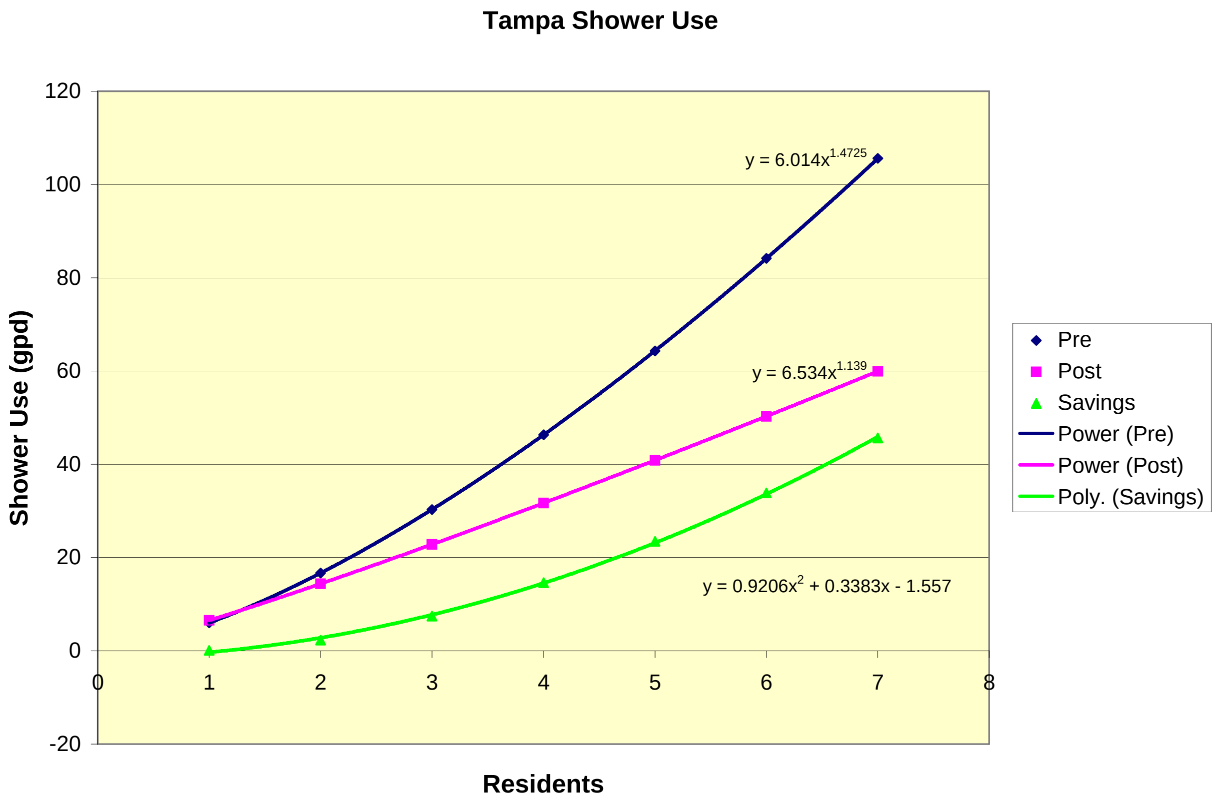


Figure 6.13 Shower use before and after retrofits in Tampa

Shower Usage

The goal of low flow showerheads is to reduce the flow thereby reducing the shower volume. The new showerheads were designed to flow at 2.5 gallons per minute or less. Interestingly, prior to the retrofit the baseline flow rate was below 2.5 gallons per minute (gpm) in all three groups which would suggest that there was little room for savings. Following the retrofit however, all three groups lowered their average flow rate with Tampa being the lowest at 1.74 gpm. The reduction in flow for all three groups was statistically significant at the 95 percent confidence interval. The reduction in flow rate succeeded in reducing the shower volume in all three groups.

It has been hypothesized that the introduction of low flow showerheads and the subsequent reduction in shower flow rate could cause people to increase the length of time spent in the shower. The data from this study do not support that hypothesis and in fact the showering duration actually decreased in all three groups. The decrease was only found to be statistically significant in East Bay at the 95 percent confidence level where the average showering time was reduced by 41 seconds. The average pre and post retrofit shower duration for the three study groups is shown in Table 6.19.

The savings that may have resulted from the decrease in shower volume was offset by the increase in the number of showers per capita per day in Seattle and East Bay. The increase was considered significant at the 95 percent confidence level for both of these groups.

Table 6.19 Average shower usage comparison pre and post retrofit

	Seattle		Tampa		East Bay	
	Pre-Retro	Post-Retro	Pre-Retro	Post-Retro	Pre-Retro	Post-Retro
Shower Volume (gal)	18.06	14.93	16.54	13.38	18.40	15.34
Shower Duration (min)	7.91	7.84	7.98	7.75	8.88	8.20
Shower Flow Rate (gpm)	2.24	1.88	2.08	1.74	2.00	1.81
Showers per Capita per Day	0.51	0.59	0.92	0.82	0.65	0.74

Hot Water Use for Showers

Table 6.20 shows that the change in hot water usage for showering is not statistically significant. for either of the sites. This result makes sense because neither of these sites showed a significant reduction in total water use for showering and hot water use is large component of the total water use for showering.

Table 6.20 Summary statistics for shower hot water use

SUMMARY STATISTICS: Showers, hot water				
		East Bay	Seattle	Combined
Pre-Retrofit	Average (gpd)	16.7	15.9	16.3
	Count	10	10	20
	Std Dev	13.9	12.8	13.0
Post-Retrofit	Average (gpd)	16.7	17.5	16.5
	Count	10	10	20
	Std Dev	13.9	11.3	14.6
Water savings (gpd)		0.00	-1.55	-0.16
Percent reduction		0.0%	-9.8%	-1.0%
t-stat		0.57	-0.63	-0.10
p-stat		0.290	0.273	0.462

Following the retrofit the number of households that used 20 gpd or less for showering decreased from 70% of households to 65% of households. Prior to the retrofit none of the households used more than 50 gpd of hot water for showering, however, following the retrofit 5% of households used 65 gpd.

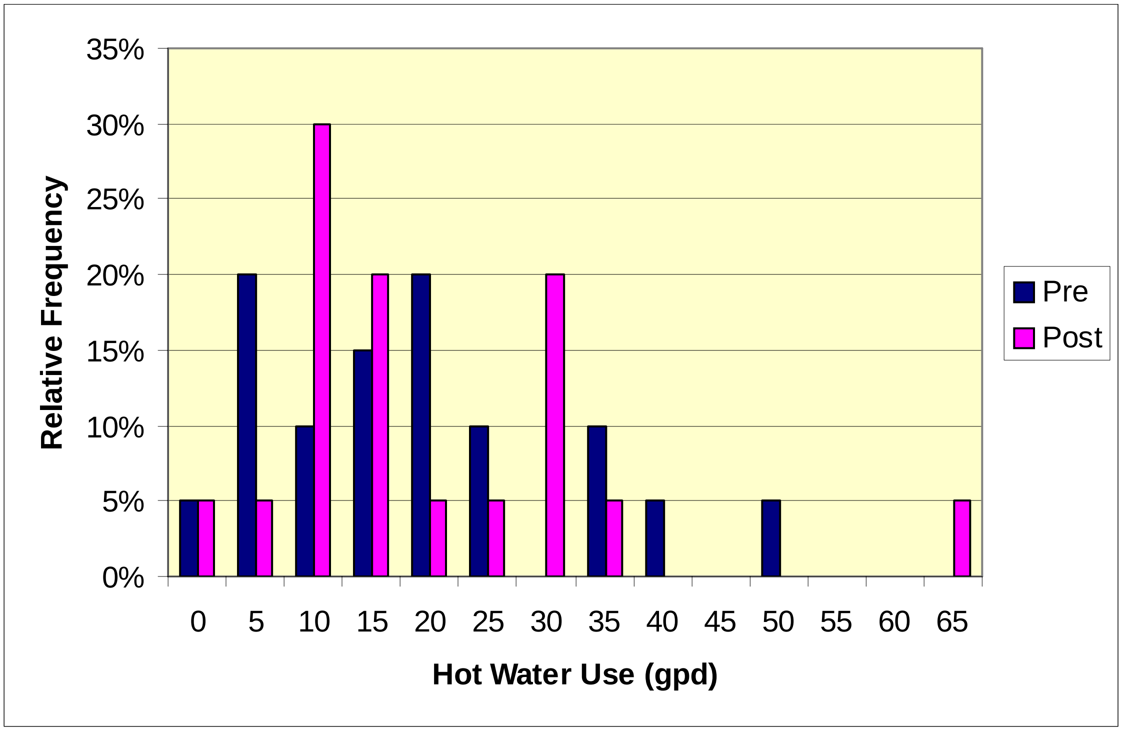


Figure 6.14 Distribution of hot water use for showers pre and post retrofit

Models for hot water shower use

Only the number of residents is statistically significant in the amount of hot water used for showering prior to the retrofit. Following the retrofit the number of residents was not found to be significant in hot water use and in fact the hot water use rose more rapidly as the number of residents increased. The curves for pre and post retrofit hot water use for showering are nearly identical in Figure 6.15 when the number of household residents is fewer than three and begin to diverge as the number of residents increase. The models for hot water use in showers are shown in Table 6.21.

Table 6.21 Models for shower hot water use before and after retrofit

State	Model	Adjusted R^2
Pre-Retrofit	$6.012 \times Res^{0.8842}$	0.2509
Post-Retrofit	$5.39 \times Res^{0.979}$	0.202
Savings	$-0.601 \times Res + 1.668$	0.968

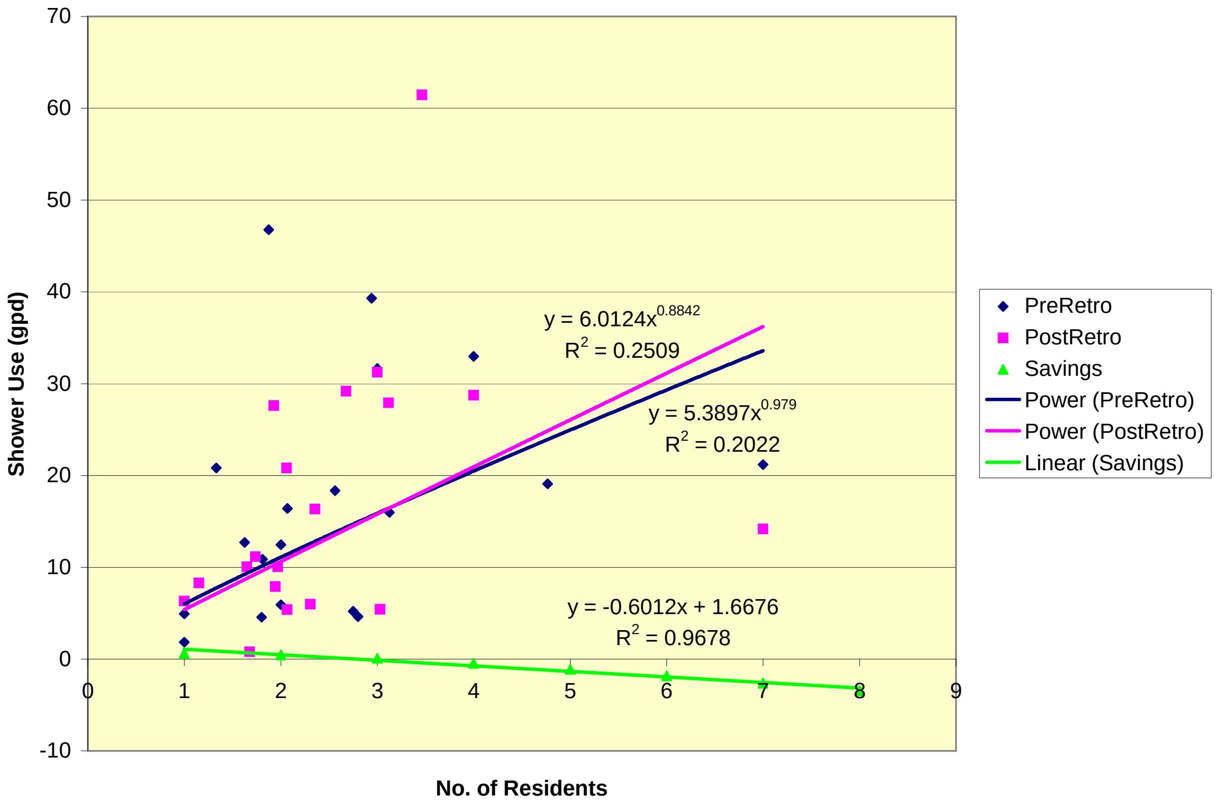


Figure 6.15 Hot water shower use before and after retrofits

Faucets

Average daily faucet use is similar to that of showers and accounts for approximately 12 percent of household use.

Household Faucet Use

Water savings from faucet aerators were similar to, if more modest than, the water savings from showerheads. In East Bay almost no water savings were achieved with the equipment used there. In Seattle a 3.3 gpd savings (1200 gal/yr) was observed, which was statistically significant. In Tampa, where the most aggressive faucet retrofits were done, a savings of 7.0 gpd (2550 gal/yr), which was 28% of the pre retrofit use, was observed. These savings were also statistically significant. The overall savings for the three groups was 3.4 gpd, but like the shower head data, these reflect such a wide range of treatments in the three cities that it is better to look at the three sites separately as shown in Table 6.22.

Table 6.22 Household faucet use before and after retrofits

SUMMARY STATISTICS: Faucets					
		East Bay	Seattle	Tampa	All
Pre-Retrofit	Average (gpd)	24.7	21.2	24.7	23.3
	Count	33	37	26	96
	Std Dev	12.7	14.0	17.4	14.5
Post-Retrofit	Average (gpd)	24.0	18.0	17.7	20.0
	Count	33	37	26	96
	Std Dev	11.5	9.3	11.7	11.1
Water savings (gpd)		0.7	3.3	7.0	3.4
Percent reduction		3%	15%	28%	15%
t-stat		0.358	1.82	2.6	2.79
p-stat		0.361	0.038	0.008	0.003

Examination of the distribution of daily household faucet water use before and after the retrofits, shown in Figure 6.16, shows a shift in the number of customers in the lower daily use bins, which tends to reinforce the statistical results in the previous table. The number of homes using under 30 gpd for faucet use increased, while the number using more than 30 gpd decreased.

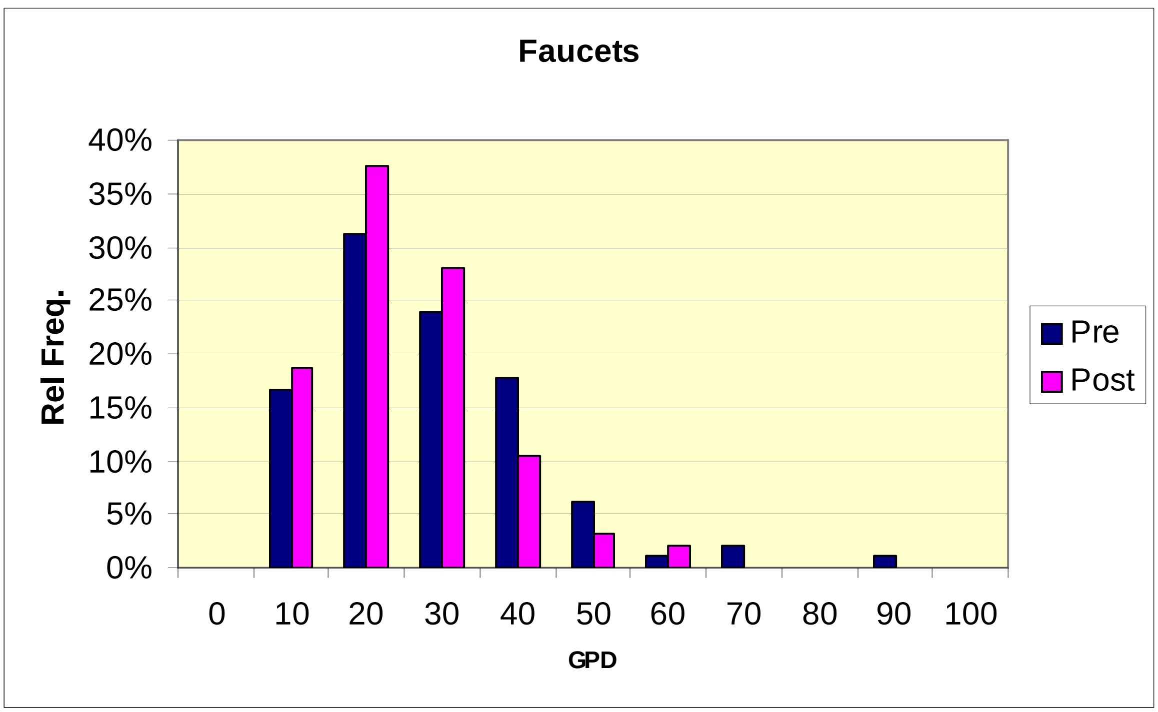


Figure 6.16 Household faucet use before and after retrofits

Model of Faucet Use

Faucet use was found to be related only to the number of residents in the home. The equations for the pre and post use and the savings as a function of the residents is shown in Table 6.23. The data points and trend lines are shown in Figure 6.17. As was the case for shower use, the savings increased exponentially with the number of residents in the home. In typical homes the anticipated savings would fall between 3 and 7 gpd (1100 and 2500 gal/yr) depending on the extent and nature of the retrofit devices used.

Table 6.23 Model for household faucet use before and after retrofits

State	Model	Adjusted R^2
Pre-Retrofit	$9.6 \times Res^{0.804}$	0.327
Post-Retrofit	$9.11 \times Res^{0.73}$	0.323
Savings	$0.55 \times Res^{1.43}$	--

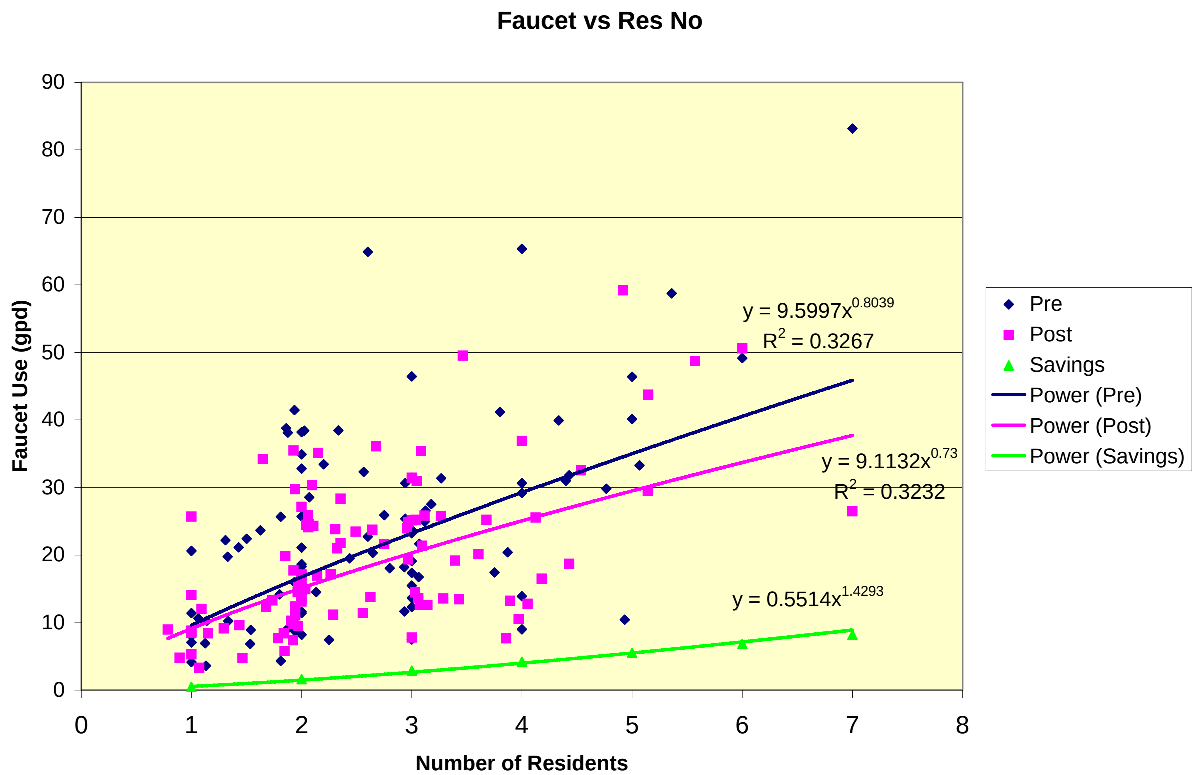


Figure 6.17 Household faucet use before and after retrofits

Hot Water Use for Faucets

Faucet use accounts for the greatest amount of daily hot water use both pre and post retrofit. The retrofit resulted in savings of 20% for the two sites, however, the savings in East Bay were the most substantial as shown in Table 6.24. There, hot water use was reduced by a third or 6.3 gpd. Annually this results in a reduction of 2,400 gallons per household.

Table 6.24 Summary statistics for faucet hot water use

SUMMARY STATISTICS: Faucets hot water (gpd)				
		East Bay	Seattle	Combined
Pre-Retrofit	Average (gpd)	19.2	18.8	19.0
	Count	10	10	20
	Std Dev	5.5	10.1	7.9
Post-Retrofit	Average (gpd)	12.9	17.3	15.1
	Count	10	10	20
	Std Dev	7.3	9.6	8.6
Water savings (gpd)		6.3	1.5	3.9
Percent reduction		33%	8%	20%
t-stat		2.53	0.43	1.81
p-stat		0.016	0.338	0.043

The histogram in Figure 6.18 shows an overall shift to the left of the post retrofit data indicating a reduction in daily faucet hot water use. There is a substantial increase in the number of homes using less than 15 gpd and no homes use over 35 gpd. The number of homes using more than 20 gpd has decreased by 30 percent.

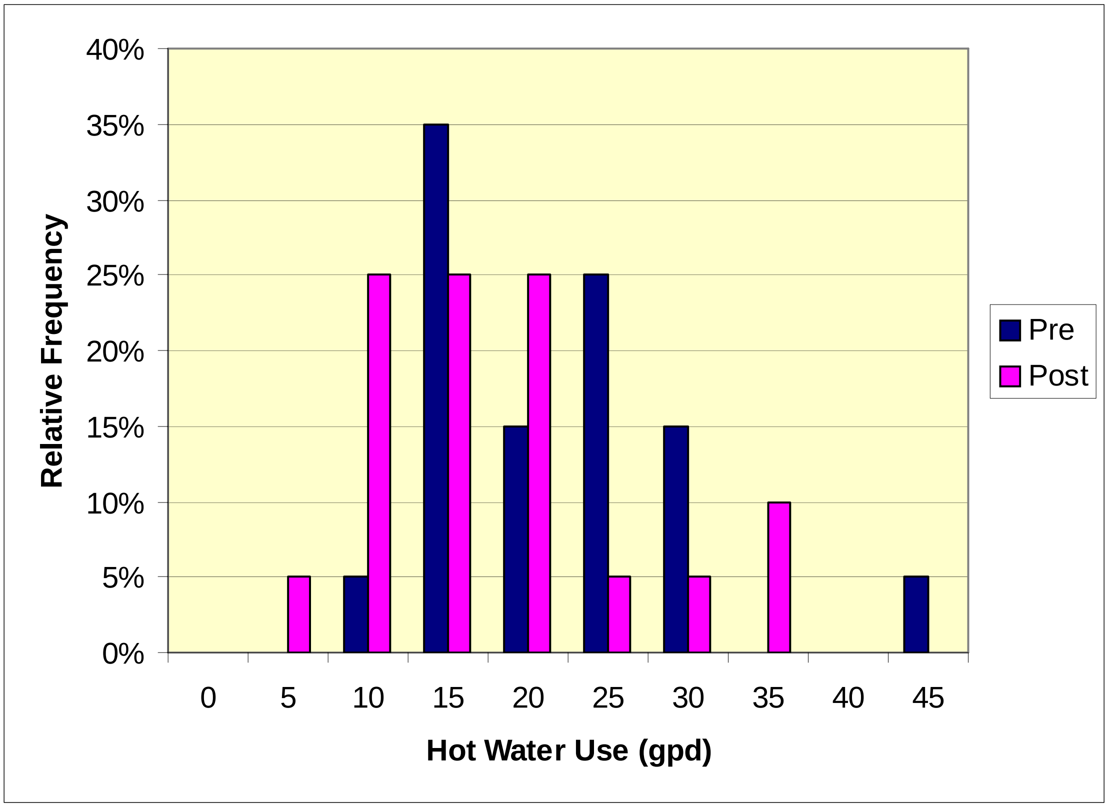


Figure 6.18 Distribution of hot water faucet use pre and post retrofit

Model of Faucet Hot Water Use

Hot water faucet use is dependent only on the number of residents in the household. The equations for the pre and post retrofit as well as the savings are found in Table 6.25. Following the retrofit, the hot water use increased as the number of residents increased but at a gradually decreasing rate. The savings curve can be seen in Table 6.20 and shows that savings also increases as the number of residents increases but at a fairly slow rate.

Table 6.25 Model for household hot water faucet use before and after retrofit

State	Model	Adjusted R^2
Pre-Retrofit	$11.573 \times Res^{0.5152}$	0.3953
Post-Retrofit	$8.504 \times Res^{0.5208}$	0.5208
Savings	$3.07 \times Res^{0.4993}$	1

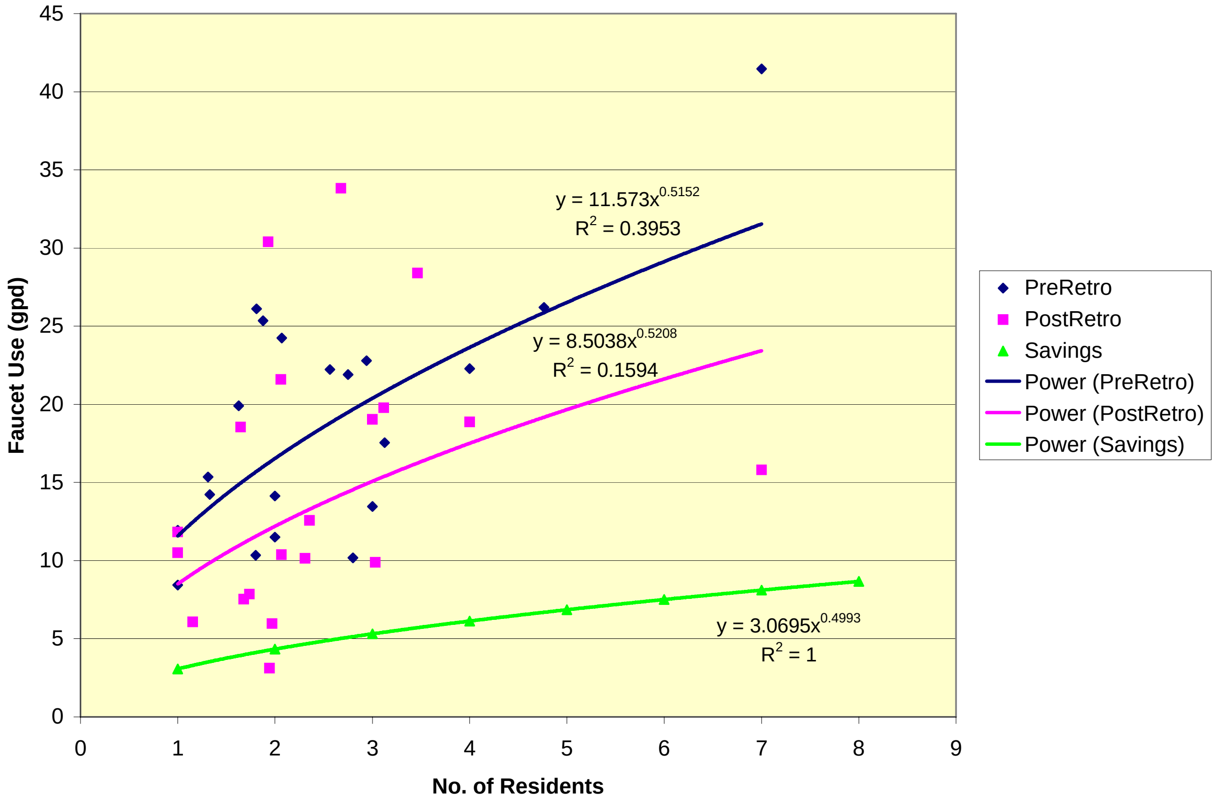


Figure 6.19 Household hot water faucet use pre and post retrofit

Leaks

Household leakage patterns

Even though these studies only addressed leakage as an incidental effect of replacement of the fixtures and appliances, the net result, as summarized in Table 6.26, was a dramatic decrease in the average daily leakage rates. This was true for all three study sites, and in all cases the reductions in leakage were statistically significant. Daily water savings ranged from 11.8 gpd in Seattle to 36.1 gpd in Tampa. This is equivalent to annual savings from 4,300 to 13,200 gal/yr. The average reductions at all three sites was 22.4 gpd (8200 gal/yr). This made water savings from leakage reduction among the biggest categories of savings in the study.

Table 6.26 Summary statistics on household leakage before and after retrofits

SUMMARY STATISTICS: Leaks					
		East Bay	Seattle	Tampa	All
Pre Retrofit	Average (gpd)	43.2	17.3	44.6	33.6

	Count	33	36	26	95
	Std Dev	69.7	34.1	65.0	57.8
Post Retrofit	Average (gpd)	19.6	5.5	8.4	11.2
	Count	33	37	26	96
	Std Dev	35.5	6.1	12.6	22.8
Water Savings (gpd)		23.6	11.8	36.1	22.4
Percent Red		55%	68%	81%	67%
t-stat		2.48	2.18	2.84	4.290
p-stat		0.009	0.018	0.004	0.000

The combined data confirmed the results from the individual studies that the leakage rates are highly asymmetrical, and that a small number of homes are responsible for most of the leakage on any given day. This can be seen by examining the distribution of daily household leakage shown in Figure 6.20. Both before and after the retrofits the majority of homes were leaking at less than 50 gpd. The median leakage rate prior to the retrofits was only 9.5 gpd compared to the mean rate of 33.6 gpd. The median value represents the mid-point of the data, so half the homes were leaking at less than 9.5 gpd and half were leaking at more than 9.5. The average was elevated to 33.6 gpd by a few homes leaking at very high rates. There were 2 homes leaking in each of the bins from 150 up to 300 gpd.

After the retrofits the average leakage rate decreased from 33.6 to 11.2 gpd, a reduction of 67%, but the median dropped as well, to 4.6 gpd, which shows that the leakage rates are still heavily skewed to the right.

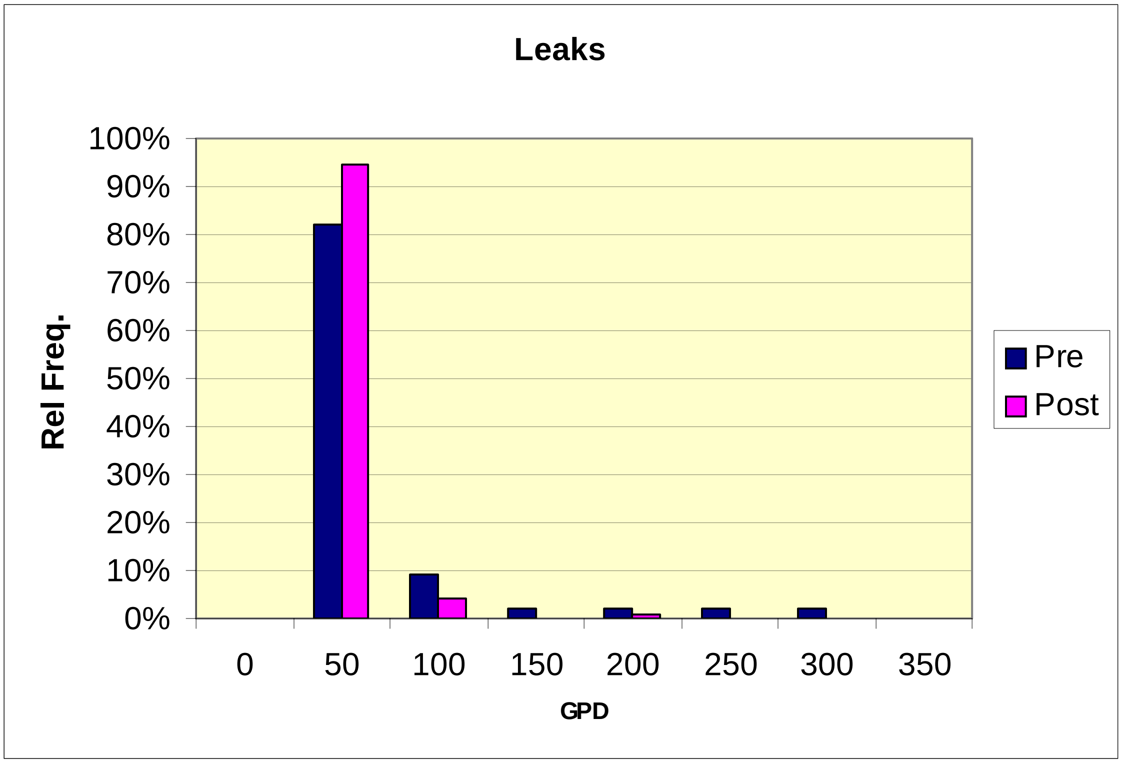


Figure 6.20 Distribution of household leakage before and after retrofits

Models of Leakage

The leakage data are unique in this set in that they are statistically related to the number of residents, the size of the home and the cost of water both before and after the retrofits. Also, the number of residents is the least important of the three variables in explaining leakage, which is just the opposite of all other types of water use discussed to this point. The models for leakage are shown in Table 6.27. The slopes of the three variables all have the expected slopes. Leakage is directly related to the number of residents and house size, but inversely related to the cost of the water and sewer. Even though the R^2 values for these models are low the relationships are still useful for estimating average leakage rates in groups of customers, but it would not be advisable to attempt to use these models for individual customers or small groups. This same caveat applies to all of the models developed in this report—the larger the group to which they are applied the more likely they are to be accurate.

Table 6.27 Models for household leakage before and after retrofits

State	Model	Adjusted R^2
Pre-Retrofit	$0.056 \cdot Res^{.571} \cdot SF^{.802} \cdot CST^{-.683}$	0.102
Post-Retrofit	$0.014 \cdot Res^{.481} \cdot SF^{.891} \cdot CST^{-.685}$	0.185

In order to show how leakage rates are affected by these variables, and the large spread in the data the leakage rates have been plotted against resident number, home size and cost in the following three figures.

Figure 6.21 Leakage vs Residents

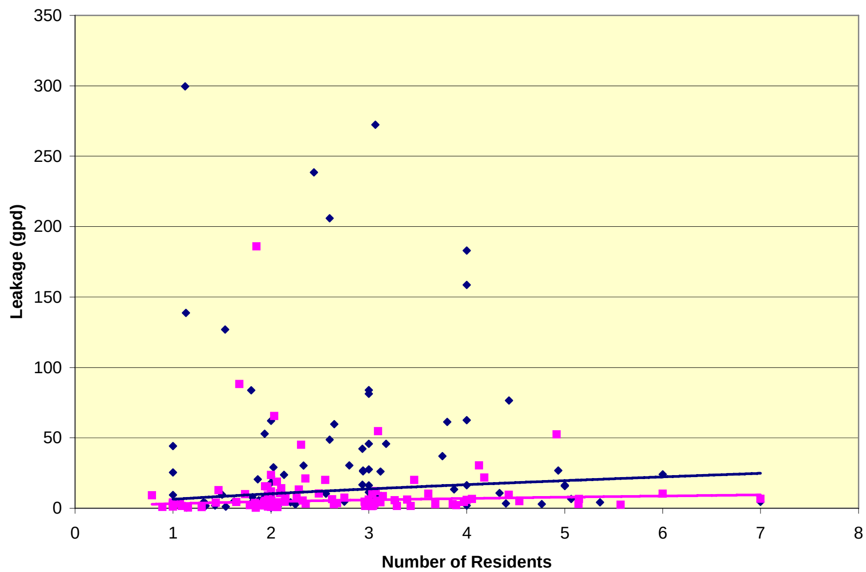


Figure 6.22 Leakage vs House Size

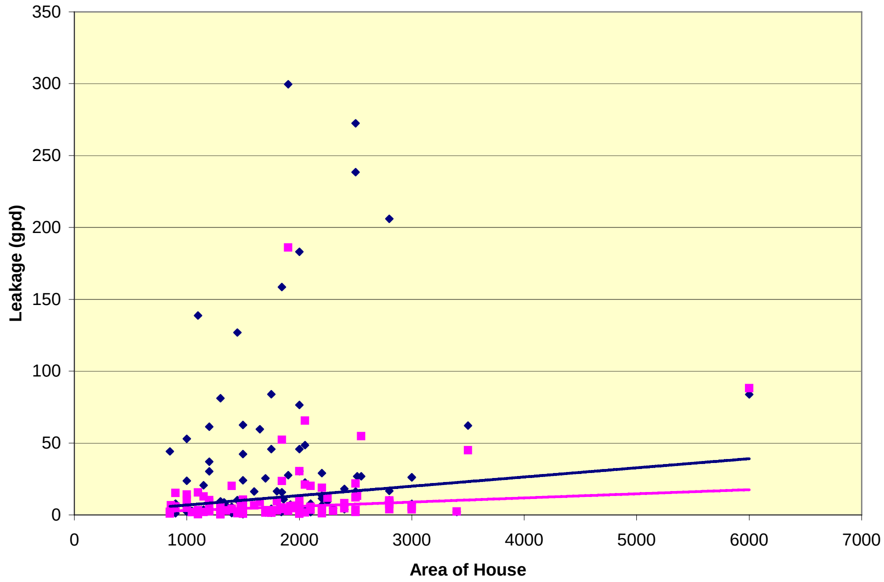
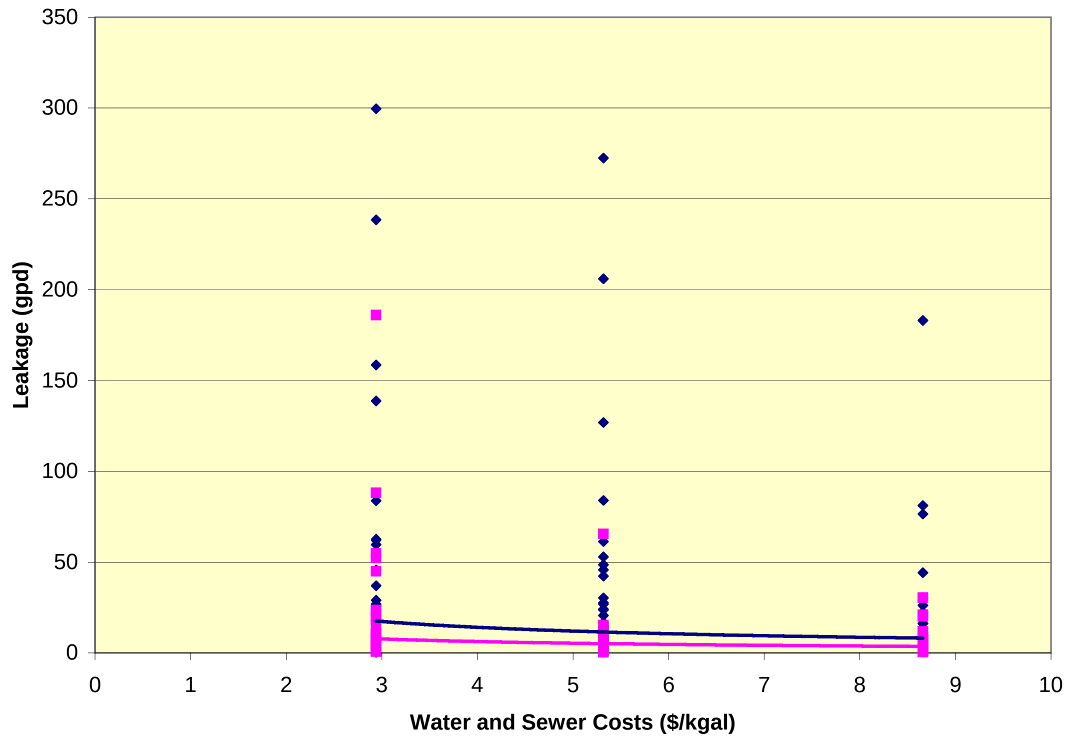


Figure 6.23 Leakage vs Water and Sewer Costs



When leakage rates before and after retrofits are plotted against the number of residents in average size homes (1850 sf) and paying the average water and wastewater fees of $5.79/kgal the curves for leakage and savings shown in Figure 6.24 result. It is interesting that for these homes the total savings never equal the averages shown in Table 6.26. The reason for this is that the savings estimate is very sensitive to the cost of the water, and at $5.79/kgal both leakage and savings are lower. This also shows that most of the savings came from the utility with the lower cost water, which can also be seen in Figure 6.23.

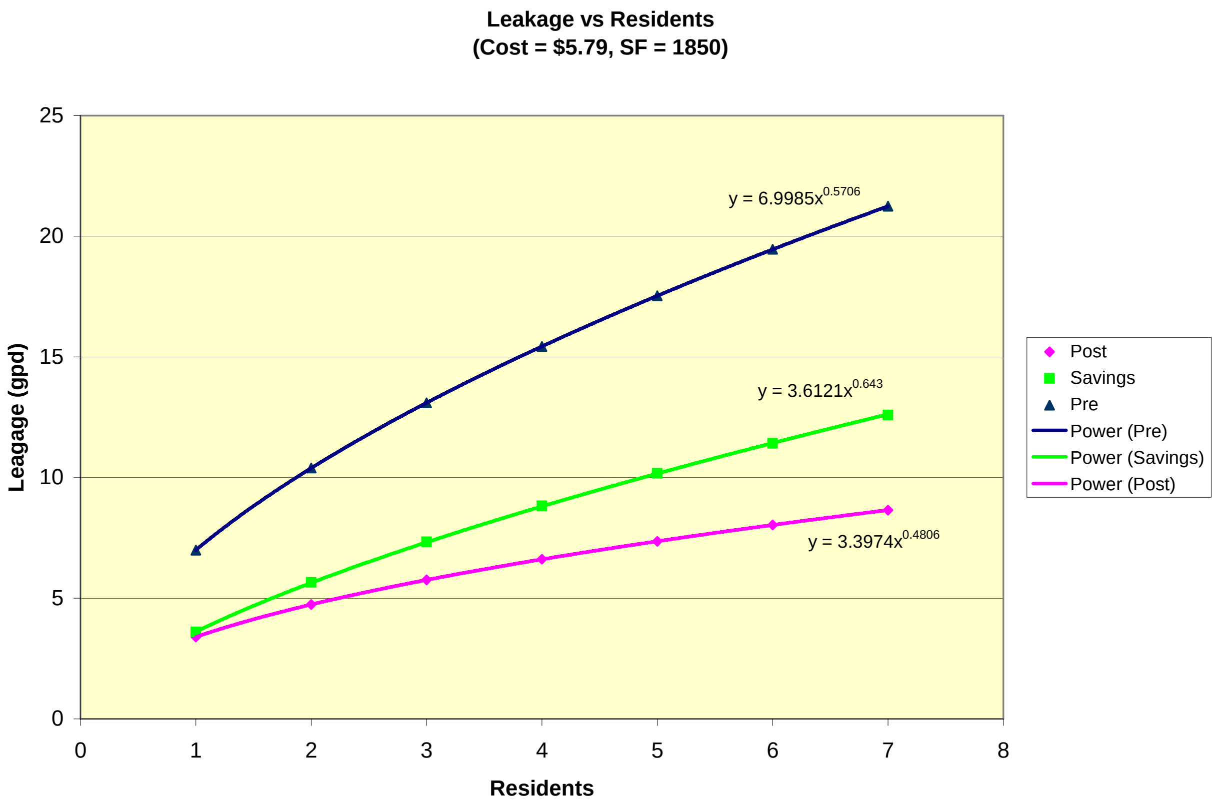


Figure 6.24 Leakage vs residents for average size and average cost

Hot Water Use for Leakage

The decrease in hot water use due to leakage was fairly small at both sites because the amount of hot water attributed to leaks is a very small percentage of the total daily water leakage. This is not surprising due to the fact that most leakage is the result of leaking toilet flappers and would therefore not have an impact on hot water use.

Hot water leakage is only statistically significant in Seattle as shown in Table 6.28. Seattle homes had a 43% reduction in leakage from 3 gpd to 1.7 gpd. There was only a 2% reduction in East Bay with both sites combined showing a 29% or 0.66 gpd leak reduction.

Table 6.28 Summary statistics of household hot water leakage before and after retrofits

SUMMARY STATISTICS: Leaks, hot water				
		East Bay	Seattle	Combined
Pre Retrofit	Average	1.5	3.0	2.2
	Count	10	10	20
	Std Dev	1.1	2.2	1.8
Post Retrofit	Average	1.5	1.7	1.6
	Count	10	10	20
	Std Dev	0.8	1.0	0.9
Water Savings		0.04	1.27	0.66
Percent Red		2%	43%	29%
t-stat		0.12	1.93	1.71
p-stat		0.455	0.043	0.052

Following the retrofit none of the homes had more than 3.5 gpd of hot water use due to leakage as shown in Figure 6.25. Eighty percent of the homes had less than 2 gpd hot water use that was attributable to leakage.

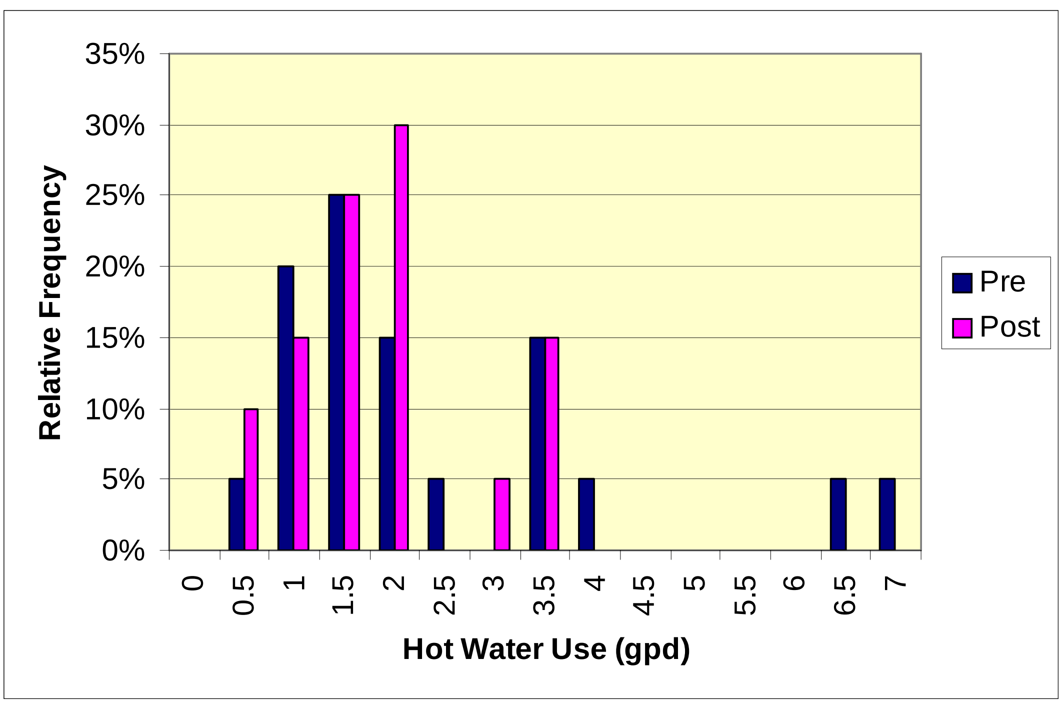


Figure 6.25 Distribution of hot water use due to leakage pre and post retrofit

Models of Hot Water Leakage

Prior to the retrofit the amount of hot water use from leakage was only related to the cost of water. Following the retrofit none of the factors were statistically significant in effecting the amount of hot water used for leakage. This is likely due to the fact that the amount of daily hot water used for leakage is a very small percentage of the overall hot water used for all fixtures and tends to be random.

Table 6.29 Models of hot water leakage before and after retrofits

State	Model	Adjusted R^2
Pre-Retrofit	$0.6795 \times CST^{0.5685}$	0.1774
Post-Retrofit	$1.1994 \times CST^{0.071}$	0.0041

The curves in Figure 6.26 confirm that there is no response to the cost of water in water use following the retrofit. Prior to the retrofit hot water use actually increases as price increases although is likely a spurious result due to the fact that hot water use is a very small percentage of the total water use due to leakage.

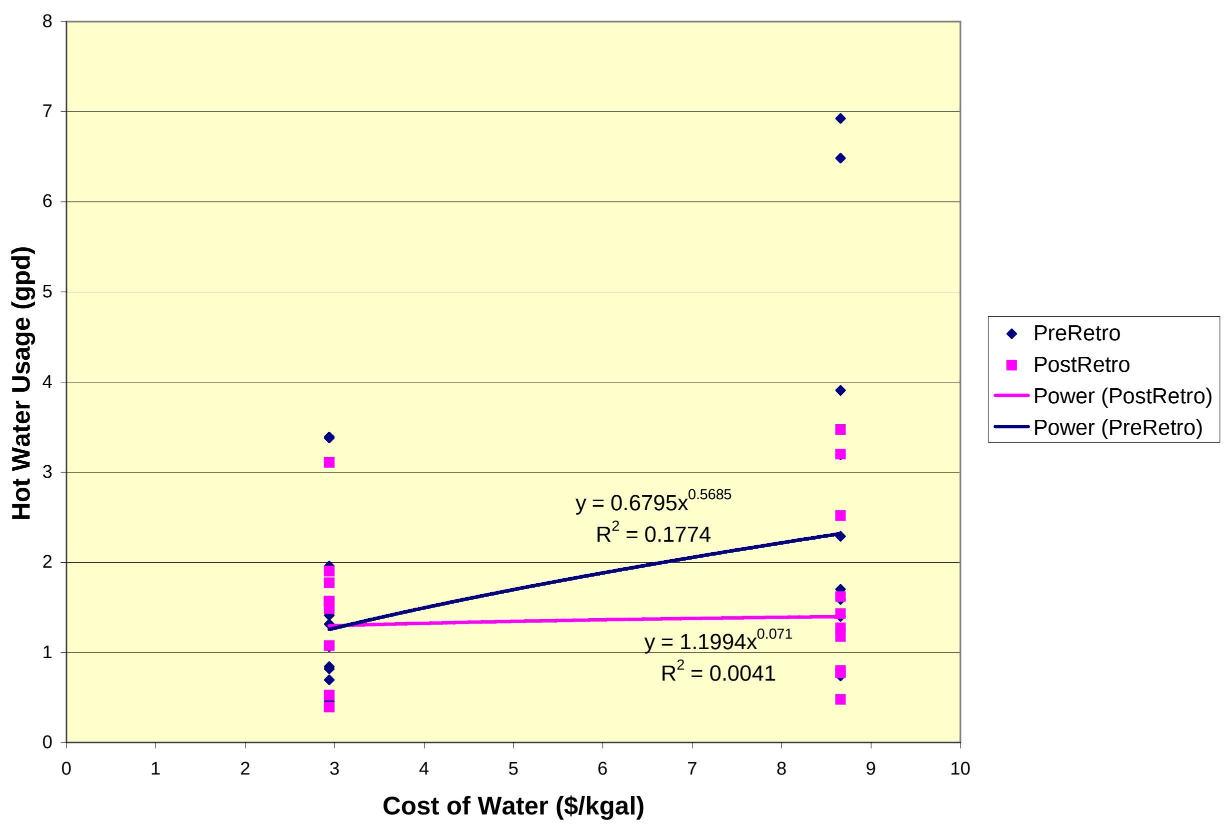


Figure 6.26 Hot water leakage vs cost of water

Dishwashers

Dishwashers were not retrofitted for this study. Water use for dishwashers normally makes up a small percentage of total daily water use so even though there are dishwashers available that use less water than standard models, the anticipated savings from switching to these units is not great enough to justify the cost of retrofitting them. Consequently, one would not expect to see a significant change in water use for dishwashing before and after the retrofit. If the distribution data are examined in Figure 6.27, they show that the pattern of daily use appears very similar before and after the retrofits. This leads to the conclusion that the dishwasher use was not affected in any but the subtlest manner by the retrofits. Because dishwashers are typically plumbed to the hot water line most of the water used for dishwashing is hot water.

Table 6.30 Summary statistics for household dishwasher use

SUMMARY STATISTICS: Dishwashers				
	East Bay	Seattle	Tampa	All
Average (gpd)	2.2	3.2	1.4	2.4
Count	66	74	52	192
Std Dev	2.1	3.3	1.9	2.7
t-stat	2.23	0.867	0.861	1.94
p-stat	0.016	0.196	0.199	0.028

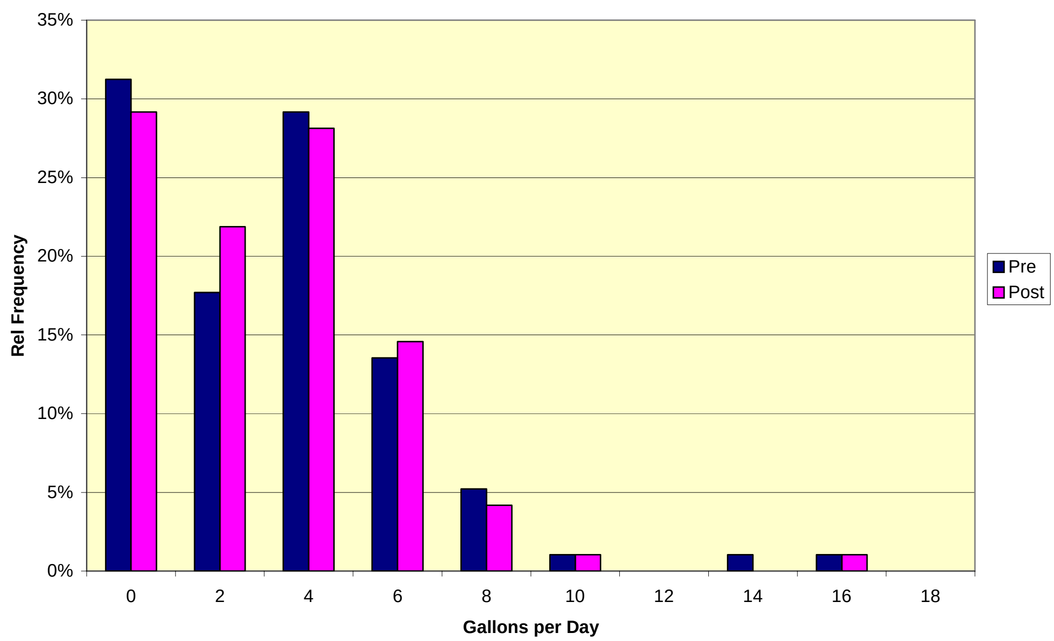


Figure 6.27 Distribution of dishwasher use

Model for Dishwasher Use

Not all houses either had or used their dishwashers during the course of the study and so had zero dishwasher use. Only 67 out of 96 homes showed dishwasher use at least once during the logging period. The most likely explanation for this is that these homes (30%) did not have a working dishwasher, or if they had one the occupants chose not to use it. When these 29 houses were dropped from the data set and only those houses that used dishwashers were included the relationship shown in Figure 6.28 and Table 6.31 results, where daily dishwasher use is a function of the number of residents in the home. This is a fairly poor model with a high degree of scatter in the data, but it could be used for large scale models to estimate water use for this category of residential use.

Table 6.31 Dishwasher use model

State	Model	Adjusted R^2
Pre/Post Retrofit	$1.72\ Res^{.472}$	0.05

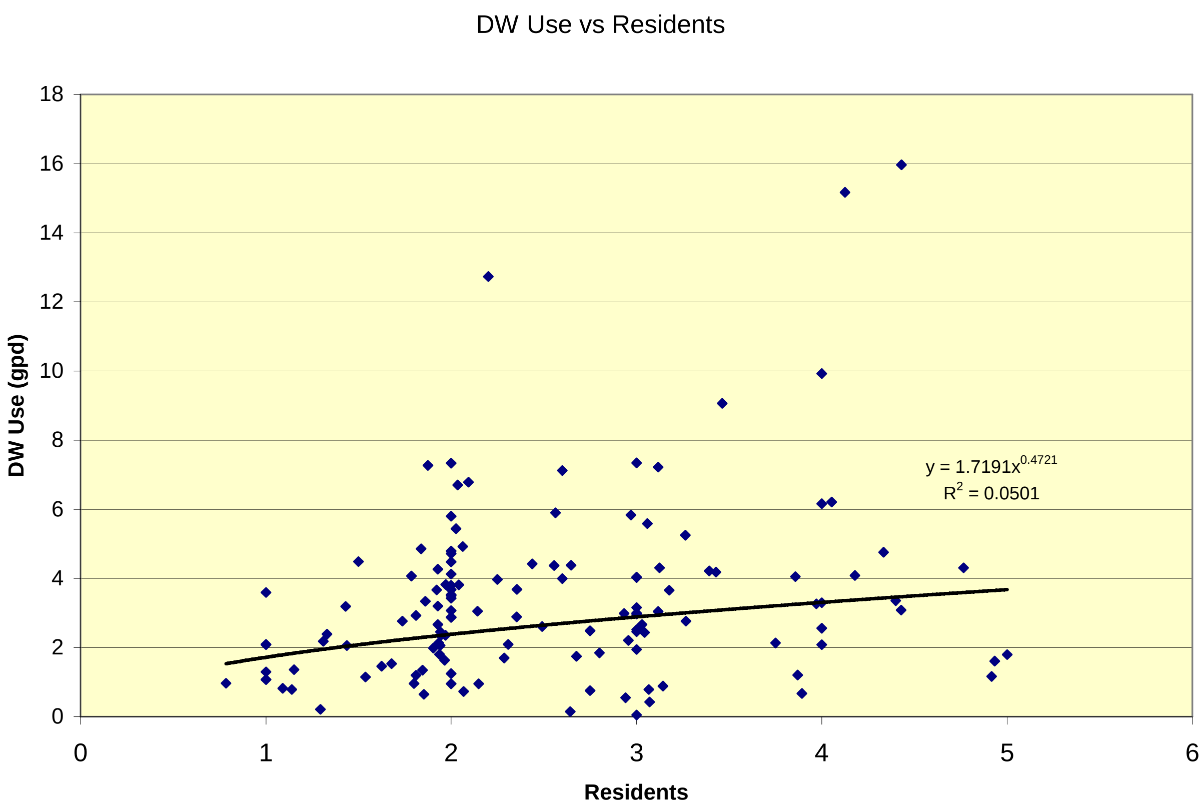


Figure 6.28 Dishwasher use vs. residents for houses using dishwashers

Table 6.32 summarizes the average daily water use for fixtures and appliances that typically use both cold and hot water. The table shows the total amount of water used, the amount of hot water used and the percentage of water used that is hot water for each. Water use decreased after the retrofits in all areas, even those that were not specifically targeted for retrofits such as leaks and dishwashers. There is an increase in the hot water used as a percentage of the total use for showers and leaks. Because most of the leak reduction occurred as a result of the toilet retrofits it is not surprising that hot water is a larger component of the remaining leakage which is likely to come from showers and faucets.

Table 6.32 Summary of hot water use in Seattle and East Bay

End Use	Pre-Retro Water Use (gpd)	Hot Water Use (gpd)	Hot Water %	Post-Retro Water Use (gpd)	Hot Water Use (gpd)	Hot Water %
Clothes washers	33.9	6.7	20%	21.8	3.0	14%
Showers	25.3	16.3	64%	23.1	16.5	72%
Faucets	23.0	19.0	83%	21.0	15.1	72%
Dishwashers	2.9	2.5	86%	2.5	2.2	88%
Leaks	30.3	2.2	8%	12.6	1.6	13%
Total	168.4	52.3	31%	107.4	41.6	39%

Other Uses

Any water use that did not fall into the previously discussed categories of end-uses was classified as "other domestic use". These include things like use of utility sinks to fill buckets, or hoses for cleaning, filling fish tanks or other small uses that would not appear to be irrigation, but wouldn't fit into the defined indoor uses. No change in these uses was anticipated, and the data from the study confirmed this hypothesis. As can be seen in Table 6.33 the only city in which there was a significant reduction in other water use was Seattle, but is not clear whether there is any reason to attribute this to anything that was done as part of the retrofits. Taken as a group, the other use was 8.5 gpd prior to the retrofits and 7.8 gpd afterwards, but this was not a statistically significant change.

Table 6.33 Summary statistics of "other" water uses

SUMMARY STATISTICS: Other Domestic Use					
		East Bay	Seattle	Tampa	All
	Average	8.3	7.7	9.7	8.2
	Count	33	37	26	96
	Std Dev	13.2	9.5	9.5	11.0
t-stat		0.795	1.749	-0.990	1.008
p-stat		0.216	0.044	0.166	0.158

Model of Other Water Use

The data for other water use showed a relationship only between the number of residents in the home and the daily other water use. The best fit for these data was the logarithmic trend line shown in Figure 6.29. The equation is shown in Table 6.34, and this is a general model that is irrespective of whether a retrofit has occurred. Again, the R^2 value of this trend line is low, so care should be taken in applying it to a customer database.

Table 6.34 Model of other water use vs. residents

State	Model	Adjusted R^2
Pre/Post Retrofit	1.677·ln(Res) + 1.77	0.105

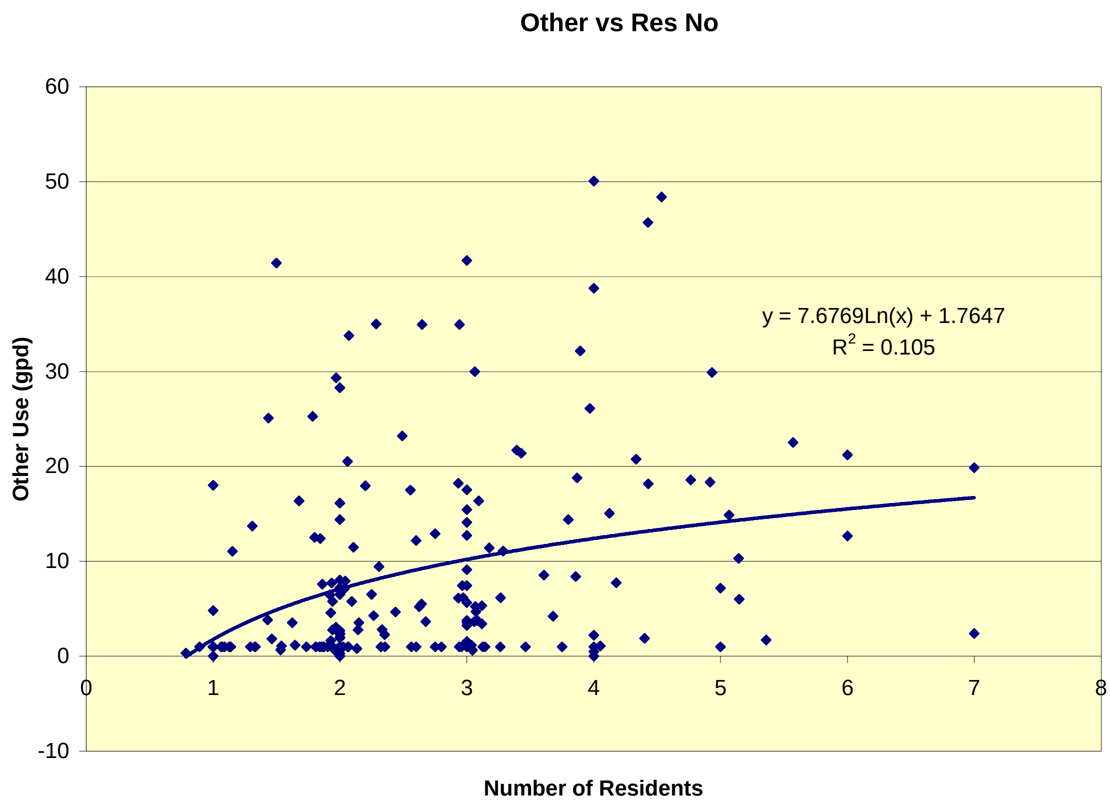


Figure 6.29 Model of other water use vs. number of residents in home

Customers were also asked about the presence or absence of several other fixtures or appliances that might affect either water categorized as "other" or total water use. These items were pools or hot tubs, utility sinks, icemakers, garbage disposal and water treatment and none of these uses was disaggregated individually. When regression analysis was performed on the data none of these uses was statistically significant on their effect of "other uses" and only the presence of pools or hot tubs was a significant factor in total water use. The presence of a pool or hot tub increased total indoor use by 37 gallons per day or 13.5 kgal per year. This may be offset by a reduction in irrigation which was not considered as part of this study.

WATER SAVINGS FOR THE TYPICAL SINGLE FAMILY RESIDENCE

We have discussed the water savings from a multiplicity of devices and situations. From the perspective of the utility or the community, however, it is useful to consider the overall average savings that can be anticipated in a population of typical homes were they to be retrofit from standard fixtures and appliances to high efficiency devices. The water savings information has been summarized in Table 6.35 and this shows that on average, just under 30 kgal per year of water savings can be anticipated from the homes. The bulk of this comes from replacement of the toilets and repairing leaks. This is followed by the replacement of the clothes washers, showerheads and faucet aerators. As can be seen in Figure 6.30 toilets and leaks account for 71% of the savings, followed by clothes washers at 19% and showerhead and faucets at 5% each of the total savings.

Table 6.35 Anticipated water savings from typical retrofits

Fixture	Total Water Savings (kgal)	Hot Water Savings (kgal)
Toilets/Leaks/Other	21.1	1.1
Clothes Washers	5.6	1.4
Shower heads	1.6	0
Faucet Aerators	1.4	1.4
Total	29.7	3.9

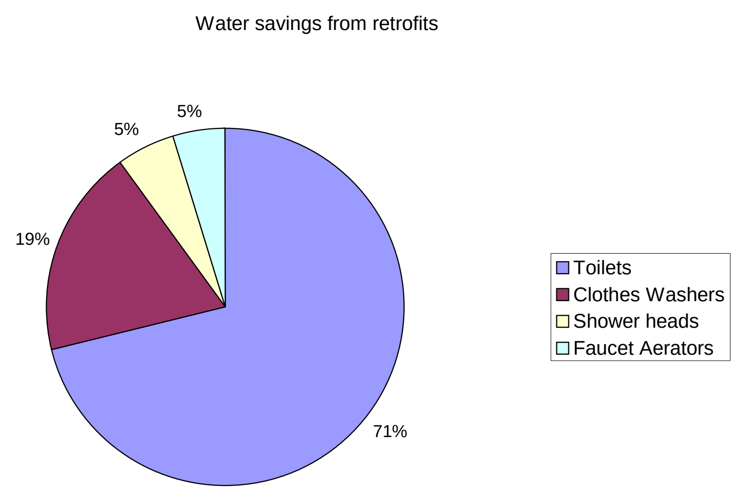


Figure 6.30 Percent savings from interior retrofits

CHAPTER 7 COSTS AND BENEFITS

INTRODUCTION

Determination of the benefits of replacing plumbing fixtures and appliances is a straightforward exercise in calculating savings from reduced water and energy use over the life of the product. On the other hand, determination of costs is complicated by the fact that in any retrofit program one will be replacing fixtures and appliances at various stages of their economic life. Products at the end of their economic life will have zero residual value, while those at the beginning will have a value close to their replacement cost. It is not reasonable to assume that over a large population a utility would need to pay the gross replacement cost in order to affect retrofits.

From the utility perspective, a retrofit program needs to consider how to provide economic incentives for customers to upgrade to high efficiency devices. This is really a function of how much value the customer places in the existing devices compared to the benefits from their replacement. The most effective way to encourage retrofits might be to simply pay the full replacement costs for the new devices. Presumably, even customers with newer standard devices would take advantage of this offer, since it would be at no cost to them. This would also be the most expensive way to proceed, and it would miss the fact that many customers have old and outmoded equipment that needs replacement anyway. In the extreme case of customers with broken devices they will either replace them or not have them. Assuming that the customers will want to maintain the presence of toilets and clothes washers in their homes the question then becomes how much more will a high efficiency device cost compared to a standard device. This is the incremental cost, and if the utilities offer a rebate equal to just this amount they will presumably entice those customers that are going to replace their equipment anyway to do so with high efficiency devices. So, this brackets the amount between the full replacement and incremental costs. If one wishes to accelerate the retrofit progress without going to the extreme of paying the full replacement cost then the rebate can be set at the net replacement cost which is the sum of the incremental cost for the high efficiency device plus the remaining economic value of the existing device. Both the full replacement costs and net replacement costs were used in this analysis.

This analysis holds from the customers' perspective as well. An individual with a 15 year old clothes washer does not place the same value on that machine as would be placed on a new machine. So the customer does the same type of price evaluation in determining whether or not to replace the devices. Presumably, if a rebate or incentive is offered that matches the customer's perceived cost for making the rebate then the customer will do the replacement.

Costs of retrofitting the homes were examined from two perspectives: first, as the net replacement cost, which was set equal to the incremental cost between a high efficiency and a standard device and the remaining economic value of the existing product, and second, as the gross replacement costs, which is just the full replacement cost of the product. For the group as a whole it was assumed that the net replacement cost is one half the cost of the newly installed device.

BENEFITS AND COSTS FROM THE CUSTOMER PERSPECTIVE

Net benefits to customers were calculated as the present worth of the savings in water, wastewater and energy minus the cost of replacing a fixture or appliance[4]. Costs were considered in two ways. First the net replacement , as described above and second, the gross replacement cost, which is the full cost of installing the new device.

As expected, products with high efficiency will provide the greatest savings and customers that pay the highest rates for water and wastewater will have the shortest payback periods. Customers will see the greatest economic benefit when they have products that are due to be replaced or where utilities pay a portion or all of the replacement cost of the product. Matrices showing payback periods and savings for a range of water and wastewater costs and product costs have been included in the analysis. These tables are based on full replacement costs.

Toilets

The costs and benefits of the toilet models tested in the three studies were evaluated as a group where both the fixture costs and the water and sewer costs for the individual cities were considered. In addition to considering the water saved by the toilets themselves, 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 retrofits. Cost savings occurred as a result of reducing both water and sewer costs. Wherever possible, all of the toilets were replaced, although on occasion the configuration of the bathroom or difficulty with the plumbing prevented an old toilet from being replaced. The annual per household water savings, shown in Table 7.1, was based on the replacement of an average of two toilets per household.

Toilet A was used in Tampa and Seattle. It has a unique flapperless design that eliminates the leaks that result from deteriorating flappers, particularly in older toilets. Toilet B, used in East Bay and Seattle, was a dual flush model that provided the option of a 1.6 gpf or 0.8 gpf with an average flush volume of 1.1 gpf. Toilet C was a standard gravity feed ULF that was used in Seattle. This toilet was more typical of the toilet design to which homeowners are accustomed.

Tampa had the greatest annual household water savings for toilet flushing of the three groups. Installation of the flapperless toilets resulted in average annual savings of 27.0 kgal and 25.9 kgal in Tampa and East Bay respectively. While installation of the dual flush toilets achieved savings of 25.1 kgal per year in East Bay, the savings in Seattle were much lower at 15.7 kgal annually. Nevertheless, this was greater than the savings of 11.8 kgal provided by the gravity feed toilets used in Seattle.

Table 7.1 shows the current cost (2004 rates) of water and sewer per thousand gallons (kgal) for each of the three cities and the impact that those costs have on annual water and sewer savings. There is a wide range in cost from a low in East Bay of $3.66 per kgal to a high in Seattle of $11.27 per kgal. The current cost of water and sewer was then used to calculate the savings available to the average household in the three cities.

4 2004 rates

Table 7.1 Water reduction and cost savings from ULF toilets

Toilet Brand	Toilet Model	City	Annual per Household Savings (kgal) ††	Water & Sewer Cost per kgal†,*,‡	Water and Sewer Savings per Year
Toilet A	Flapperless	East Bay	25.98	$3.66	$95.09
Toilet B	Dual Flush	East Bay	25.14	$3.66	$92.01
Toilet C	Gravity Feed	Seattle	11.82	$11.27	$133.21
Toilet B	Dual Flush	Seattle	15.73	$11.27	$177.28
Toilet A	Flapperless	Tampa	27.02	$5.67	$153.20
Average			21.13	$6.87	$130.15

†† Includes water saved from toilet retrofits and leak reduction

† $3.66 includes $1.96 per kgal for water and $1.70 per kgal for wastewater

* $11.27 includes $3.38 per kgal for water and $7.89 per kgal for wastewater

‡ $5.67 includes $1.39 per ccf for water and $4.28 per ccf for wastewater

Once the annual water and sewer savings have been calculated it becomes a simple matter to calculate the payback period for the various toilets. Because an average of two toilets was replaced in each home during the study, the water savings, installation costs, and payback period were calculated for two toilets. The incremental cost for toilets was assumed to be 50 percent of 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. To determine the cost and payback period of full replacement it is a simple matter of doubling the incremental cost as shown in Table 7.2

Toilet A was priced in the midrange of toilets at approximately $165. Due to a manufacturer's discount, Toilet B was available in Seattle for $150 however the cost for the same toilet in East Bay was $350 which, when combined with the lower cost of water and sewer in East Bay, resulted in a longer payback period. Gradually, the cost of many ULF toilets is coming down and currently the suggested retail price for Toilet B is $250. Toilet C was available for $280.

The longest payback period was for Toilet B in East Bay where the cost of water was the least expensive. Inexpensive water combined with an expensive toilet resulted in a payback period of 5.1 years. Despite the low cost of water and sewer in East Bay the payback period for Toilet A was only 3 years. This is less than one-fifth of the 20-year life expectancy of the product.

Although the reduction in water use in Seattle was less than that of East Bay or Tampa the water and sewer savings were higher due to the higher cost of water and sewer. This resulted in a payback period for the two ULF toilets used in Seattle of three years or less.

Tampa had the shortest payback period of the three cities due to the moderate price of water and sewer, the low cost of the ULF toilets installed and the high annual water and sewer savings. The payback period for the toilets in Tampa was less than two years. The payback period for each of the toilets in each of the cities can be found in Table 7.2. As can be seen from the table, if one uses the full replacement cost for the toilets this doubles the pay-back period.

Table 7.2 Cost and payback period for ULF toilets in the three study groups

Toilet Brand	City	Annual Water & Sewer Savings	Full Replacement Cost for 2 Toilets	Full Payback Period (years)	Net Replacement Cost for 2 Toilets*	Net Payback Period (years)
Toilet A	East Bay	$95.09	$570	6.0	$285	3.0
Toilet B	East Bay	$92.01	$940	10.2	$470	5.1
Toilet C	Seattle	$133.21	$800	6.0	$400	3.0
Toilet B	Seattle	$177.28	$540	4.2	$270	2.1
Toilet A	Tampa	$153.20	$570	3.8	$285	1.9
Average		$130	$684	5.9	$342	3.0

†Cost includes installation
*Based on half the life of the product remaining.

Water Savings and Payback Periods

Table 7.3 is a matrix showing the payback period for the purchase of one ULF toilet in several price ranges with water and sewer prices that range from $4.00 a kgal to $12.00 a kgal and average annual water savings of 10.5 kgal per toilet.

The table clearly shows that even when water and sewer costs are low it is possible to purchase a ULF toilet with a payback period of less than 5 years which is 25 percent of the average life of a 20-year toilet. The average payback period of the nine scenarios shown in Table 7.3 is 2.5 years and only three of the scenarios have payback periods longer than 3 years.

Table 7.3 Savings and payback periods for a range of toilets prices and water rates*

	Toilet Retrofit Cost†					
	$200		$250		$300	
Water and Wastewater Cost	Annual Water & Sewer Savings	**Payback Period (years)**	Annual Water & Sewer Savings	**Payback Period (years)**	Annual Water & Sewer Savings	**Payback Period (years)**
$4 per kgal	$44	**4.5**	$44	**5.7**	$44	**6.8**
$8 per kgal	$84	**2.4**	$84	**3.0**	$84	**3.6**

$12 per kgal	$126	**1.6**	$126	**2.0**	$126	**2.4**

*Based on an average annual water savings from the three groups of 10.5 kgal per toilet
†These are replacement costs with an installation allowance

Cost and Payback for Toilet Upgrades

As technology continues to improve flush volumes have gotten smaller. Currently there are a number of high efficiency toilets on the market that utilize 1.1 gpf or less resulting in a reduction in flush volume of approximately 0.5 gpf compared to the current standard. Assuming an average of 15 flushes per household per day, an average household would save an additional 2.7 kgal per year. However, as is often the case with new technology the cost of the 1.1 gpf toilets are typically higher than those for 1.6 gpf toilets, and in fact the dual flush toilet used in two of the groups was the most expensive of the three toilets. However, new models coming onto the market will inevitably cost less. Despite the additional cost for some 1.1 gpf toilets Table 7.4 shows that the additional savings in water and sewer costs tend to compensate for the additional cost of the products.

Table 7.4 Water and sewer savings and payback periods for high efficiency toilets

	Toilet Retrofit Cost†					
	$250		$300		$350	
Water & Sewer Cost	Total Annual Water & Sewer Savings	**Payback Period (yrs)**	Total Annual Water & Sewer Savings	**Payback Period (yrs)**	Total Annual Water & Sewer Savings	**Payback Period (yrs)**
$4 per kgal	**$53**	**4.7**	**$53**	**5.7**	**$53**	**6.6**
$8 per kgal	**$106**	**2.4**	**$106**	**2.8**	**$106**	**3.3**
$12 per kgal	**$158**	**1.6**	**$158**	**1.9**	**$158**	**2.2**

†These are full replacement costs plus $50 for installation.
*Based on an average annual water savings, per toilet of 13.2 kgal which is the savings achieved from flush volumes of 1.1gpf

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. Because costs differed widely and each machine offered different options, the costs and benefits of each machine were evaluated individually. 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. As a result, the retrofit washers save energy both by using less hot water and reducing drying times.

Table 7.5 shows the annual water savings for the six clothes washers installed in the three cities. Washer A used in Seattle and East Bay is a front loading model that reduced annual water demand by 5.54 kgal and 6.01 kgal respectively. The water and energy savings found in East Bay were based on an average of 2.74 residents per household[5] and the water and energy savings in Seattle were based on an average of 2.51 residents per household[6]. Washers B and C were both top loaders, and Washer B, used in East Bay reduced annual demand by 4.19 kgal annually. Washer C, used in East Bay and Seattle reduced annual water demand by 4.71 and 5.61 respectively. A front-loading clothes washer was installed in some of the homes in Tampa and a top-loader was installed in the other homes. Washer E, a front-loading model, reduced demand by about 8.00 kgal per year in Tampa while Washer F, a top loader, saved 6.21 kgal per year. These savings were based on an average of 2.92 residents per household[7].

In addition to the dollar savings for water and sewer charges Table 7.5 shows 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 the current cost of energy in the three cities. This calculator utilizes data about each machine provided by the manufacturer along with user inputs to calculate savings. It is interesting to note that while East Bay had the lowest savings from water and sewer annually the energy savings was higher here than in the Seattle or Tampa. Conversely, although Seattle had the highest water and sewer savings annually it had the lowest annual energy savings.

Table 7.5 Water reduction and energy cost savings from conserving clothes washers

Washer Brand	Washer Model	City	Annual per Household Water Savings (kgal)	Water & Sewer Cost per kgal	Water & Sewer Savings per Year	Energy Savings per Year
Washer A	Front load	East Bay	6.01	$3.66	$22.00	$62.20†
Washer B	Top load	East Bay	4.19	$3.66	$15.34	$61.79†
Washer C	Top load	East Bay	4.71	$3.66	$17.24	$45.38†
Washer A	Front load	Seattle	5.54	$11.27	$62.44	$20.40*
Washer D	Front load	Seattle	4.26	$11.27	$48.01	$30.60*
Washer C	Top load	Seattle	5.61	$11.27	$63.22	$16.20*
Washer E	Front load	Tampa	8.00	$5.67	$45.36	$54.00‡

[5] This was the average number of residents calculated from the initial household audit
[6] This was the average number of residents calculated from the initial household audit
[7] This was the average number of residents calculated from the initial household audit

Washer F	Top load	Tampa	6.21	$5.67	$35.21	$49.00‡
Average			5.56	6.86	$38.60	$42.15

†Calculated from the EPA Energy Star clothes washer savings calculator. Based on $0.126 per kWh (PG&E standard 2004 residential rate)
*Calculated from the EPA Energy Star clothes washer savings calculator. Based on $0.042 per kWh (Seattle City Light standard 2004 residential rate)
‡ Calculated from the EPA Energy Star clothes washer savings calculator. Based on $0.09 per kWh (Tampa Electric standard 2004 residential rate)

Water Savings and Payback Periods

As with toilets, the costs for the clothes washers were determined both with and without consideration of the economic value of the existing appliance. The net replacement cost for clothes washers was assumed to be 50 percent of the total installed cost and includes a $50 installation fee. This is based on the assumption that each new clothes washer replaces an appliance that has one-half of its economic life remaining. The full replacement costs are also considered, as shown in Table 7.6.

Table 7.6 shows the annual water savings for the six clothes washers installed for the three groups. The dollar savings for water and sewer charges are combined with energy savings shown in Table 7.5. The energy savings are a result of reduced hot water demand and reduced clothes drying time for a total annual savings from the clothes washer retrofits. Energy savings were estimated using the EPA Energy Star clothes washer savings calculator. This calculator utilizes data about each machine provided by the manufacturer along with user inputs to calculate savings. As with the toilets, the full replacement cost payback periods are twice the net periods.

Washer C was the least expensive clothes washer and was used in East Bay and Seattle. The incremental cost of this machine was only $300. The low cost of the machine combined with annual water, sewer and energy savings in Seattle, resulted in a payback period of 3.8 years.

In East Bay, although the initial cost for Washers A and B was nearly 40 percent higher than Washer C the payback period for Washer C was actually longer than the payback period for Washer A and nearly identical to that of Washer B. This was due to the fact that Washers A and B had greater annual water, sewer and energy savings than Washer C.

Washer D was the most expensive machine and was used in Seattle. It had a payback period of 7 years due to the high initial cost of the machine and the fact that the water and energy savings were nearly the same as Washers A and C which were considerably less expensive.

Table 7.6 Costs and payback period of conserving clothes washers

Washer Brand	Annual Water, Sewer & Energy Savings	Full Replacement Cost per Washer†	Full Payback Period (years)	Net Replacement Cost*	Net Payback Period (years)

Washer A	$84.20	$732	8.6	$366	4.3
Washer B	$77.13	$749	9.8	$375	4.9
Washer C	$62.62	$600	9.6	$300	4.8
Washer A	$82.84	$752	9.0	$376	4.5
Washer D	$78.61	$1116	14.2	$558	7.1
Washer C	$79.42	$606	7.6	$303	3.8
Washer E	$99.36	$1049	10.6	$525	5.3
Washer F	$84.21	$949	11.2	$475	5.6
Average	$81.05	$819	10.0	$409	5.0

†Cost includes an installation allowance
*Set at 50 percent of total installed cost

The payback period for conserving clothes washers is substantially longer than the payback period for ULF toilets due to the lower annual savings (they save 5.6 kgal annually as opposed to 10.5 kgal annually for one toilet) and higher capital cost. In addition, the life expectancy for the average clothes washer is 13 years whereas toilets have a life expectancy of 20 years. Table 7.7 shows a clothes washer with high capital cost and low water and energy savings can result in a payback period that is nearly as long as the life expectancy of the clothes washer. The left column of the table is close to the incremental cost of a high efficiency machine. The middle column represents the full cost of a new mid-range high efficiency machine, and the third column represents the full cost for a deluxe high efficiency machine. For clothes washers, it is doubtful the water savings alone would be sufficient incentive for replacements of existing machines that are in good condition, but once customers are ready to replace their existing machines then the incremental cost to upgrade to a high efficiency machine is the important number, which are between 3 and 7 years depending on the cost for water and energy.

Table 7.7 Savings and payback periods for a range of clothes washer prices and water and energy savings

Clothes Washer Retrofit Cost†					
$350		$750		$1100	
Annual Water, Sewer & Energy Savings*	**Payback Period (years)**	Annual Water, Sewer & Energy Savings*	**Payback Period (years)**	Annual Water, Sewer & Energy Savings*	**Payback Period (years)**
$50	**7.0**	$50	**15**	$50	**22**
$75	**4.7**	$75	**10**	$75	**15**
$100	**3.5**	$100	**7.5**	$100	**11**

†Replacement costs plus installation allowance
*Based on an average annual water and energy savings from the three groups of 5.6 kgal and 511 kWh

Savings and Payback Period for Clothes Washer Upgrades

When consumers need to replace their clothes washers because the old machines are worn out then they have an opportunity to purchase a high efficiency machine if they are willing to pay the incremental costs between the high efficiency machine and a standard but comparable machine. The incremental cost will be smaller than the replacement costs discussed above, and can be balanced against the likely savings in water, wastewater and energy delivered by the machines.

Incremental costs were calculated as the price difference between the high efficiency washer and product of comparable quality from the same manufacturer. Incremental costs for the clothes washers are shown in Table 7.8. The average incremental cost is $312, but there are two machines at $200 and one at less than $100. Experience has shown these to be perfectly serviceable machines, which the customers reported to be highly satisfactory. Using these prices and brings the payback period down to between 1.5 and 3 years.

Table 7.8 Incremental cost of conserving clothes washers

Model	Cost of Conserving Clothes Washer	Comparable Washer Cost (same brand)	Incremental Cost
Washer A	$690	$495	$195
Washer B	$700	$500	$200
Washer C	$555	$489	$66
Washer D	$1066	$550	$516
Washer E	$999	$500	$499
Washer F	$899	$500	$399
Average	$818	$506	$312

Table 7.9 shows the payback periods for a range of prices and savings. From an economic standpoint purchasing a clothes washer with the greatest conservation potential and the lowest incremental cost makes the most sense.

Table 7.9 Incremental cost and payback period of clothes washer upgrade

Annual Water, Sewer & Energy Savings*	Incremental Cost of Upgrade				
	$100	$200	$300	$400	$500
	Payback Period (yrs)	Payback Period (yrs)	Payback Period (yrs)	Payback Period (yrs)	Payback Period (yrs)
$50	2.0	4.0	6.0	8.0	10.0
$75	1.5	3.0	4.5	6.0	7.5

$100	1.0	2.0	3.0	4.0	5.0

*Based on an average annual water and energy savings from the three groups of 5.6 kgal and 511 kWh

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. Installation of showerheads is quite simple and can be done by a typical homeowner without difficulty. The total cost for replacing all of the showerheads in the home (2 units) was generously estimated at $25; $20 for the hardware and $5 for installation time. In this case, since costs and life cycles of showerheads are relatively low the full replacement costs were used in determining the payback period.

Because many homes already used low flow showerheads (2.5gpm or less) the only city where water and wastewater savings was fairly significant was Tampa where 1.7 gpm showerheads were installed. Here, average daily household shower use decreased by 28 percent from 34 gpd to 26 gpd. Table 7.10 shows the difference in the pre and post-retrofit average daily household shower volume.

Table 7.10 Comparison of pre and post-retrofit shower use

City	Avg Daily Household Shower Volume Pre-Retrofit (gallons)	Avg Daily Household Shower Volume Post-Retrofit (gallons)	Percent Reduction
East Bay	29	26	10%
Seattle	22	20	9%
Tampa	34	26	28%

Despite the fairly low water savings achieved by retrofitting showerheads the low replacement and installation costs result in a fairly short payback period for all three groups. Overall, East Bay customers had an average annual household savings of 1.1 kgal with a payback period of 6.2 years. Despite the fact that Seattle had the lowest annual savings of the three groups the high cost of water and sewer resulted in a short payback period of 3.0 years. All costs and savings are shown in Table 7.11. Tampa, which had the highest savings had a payback period of just 1.5 years.

Table 7.11 Cost and payback period for showerheads

City	Annual per Household Savings (kgal)	Water & Sewer Cost per kgal	Water & Sewer Savings per Year	Full Replacement Cost	Payback Period (years)
East Bay	1.1	$3.66	$4.03	$25.00	6.2
Seattle	0.73	$11.27	$8.23	$25.00	3.0
Tampa	2.92	$5.67	$16.57	$25.00	1.5

Average	1.6	$6.86	$9.64	$25.00	3.6

Faucets

Faucet aerators are perhaps the least expensive conservation measure available. These devices can be purchased in bulk for just a few cents each or individually for a dollar or two. Installation of faucet aerators is quite simple and can be done by the typical homeowner without difficulty. In this case, since costs and life cycles of faucets are relatively low we will include the full replacement costs in determining the payback period. The total cost for replacing all of the faucet aerators in the home was generously estimated at $15 (3 units): $10 for the hardware and $5 for the installation time.

Because many homes already used low flow faucets (2.2 gpm or less) the water and wastewater savings in the three groups was relatively low although overall the savings for faucets was higher than for showerheads. The greatest savings was seen in Tampa where the lowest flow rate aerators were used in addition to electronic faucets and hands free activators. The results from the three cities are shown in Table 7.12.

Table 7.12 Comparison of pre and post-retrofit faucet reduction

City	Avg Daily Household Faucet Volume Pre-Retrofit (gallons)	Avg Daily Household Faucet Volume Post-Retrofit (gallons)	Percent Reduction
East Bay	24.7	24	3%
Seattle	21.2	18	15%
Tampa	24.7	17.7	28%

Table 7.13 shows that although the cost of water and sewer in Tampa is moderate, the water savings achieved with the faucet aerator retrofits resulted in a very short payback period of one year. Seattle's high cost of water and sewer also resulted in a payback period of slightly more than a year. On the other hand the payback period in East Bay was 16 years far exceeds the 3 year life expectancy of the aerator.

Table 7.13 Cost and payback period for faucets

City	Annual Household Savings (kgal)	Water & Sewer Cost per kgal	Water & Sewer Savings per Year	Full Replacement Cost	Payback Period (years)
East Bay	0.26	$3.66	$0.94	$15	16.0
Seattle	1.2	$11.27	$13.52	$15	1.1
Tampa	2.6	$5.67	$14.74	$15	1.0

Average	1.35	$6.86	$9.73	$15	6

Specialty devices

Several homes in Tampa were fit with faucets that allow hands-free operation. One type of faucet used an electronic on/off system and the other used a diaphragm valve on/off system. Unlike faucet aerators that require the replacement of a single part, these units are fairly expensive because they require the hardware for a complete faucet system and may require the services of a plumber. The faucet aerators and electronic faucets in Tampa both saved similar amounts of water, 3.7 kgal and 3.0 kgal per year, respectively. The calculated annual water savings and cost benefits for the electronic devices are shown in Table 7.14. A valid cost savings analysis could not be conducted for the mechanical system because the estimated per capita water savings had too small a sample size to be statistically valid.

Table 7.14 Water reduction and cost savings from electronic faucets

Faucet	Annual Household Savings (kgal)	Water & Sewer Cost per kgal	Water & Sewer Savings per Year
Electronic Faucet	3.0	$5.67	$17.01

Electronic faucets cost more than traditional faucet fixtures because they utilize the latest technology. The electronic faucet costs were based upon typical retail costs gathered from the Faucets Plus web site. These data are shown in Table 7.15.

Table 7.15 Cost and payback period for the electronic faucet

Model	**Cost**	**Comparable Faucet Cost (same brand)**	**Incremental Cost**	**Annual Cost Savings***	**Payback Period (years)**
Electronic faucet	$317	$119	$198	$17.01	11.64

Summary of Benefits from Customer Perspective

In general, a standard home will require around eight devices in order to bring it up to grade as a water conserving home. By installing these, the homeowner can expect to save approximately 30 kgal of water per year, which will yield an average cash savings of $230 per year: $188 per year in water/wastewater and $42 per year in energy. If we assume that the customer must bear the total out of pocket expense for this retrofit and ignore any discounting, rebates, or remaining economic life of the existing products, then the average cost to accomplish the retrofit will be approximately $1580. This represents around a 7 year payback to the homeowner, assuming no increases in either water or energy prices, which would shorten the payback. This information is summarized in Table 7.16. If rebates are available or the existing products need to be replaced anyway, then the costs drop closer to just the incremental costs, which as shown above, amount to around $500, and results in a payback period in the two year range.

This then brackets the economic payback from the perspective of the water customer at two to seven years for a complete home makeover, including a clothes washer. Typical costs to accomplish this range from $500 if only the incremental costs are included to $1580 for full replacement costs.

Customers derive benefits from the new products that encompass more than just their water and energy savings. All of these ancillary benefits can be summarized in the fact that they get the pleasure of having new fixtures and appliances in their homes. One needs only to review the responses of the participants about their satisfaction with the new products to see that this represents a major benefit. The fact that the customers enjoy the new products makes the entire proposition of how to encourage their use much more tractable. It is not as though governments were trying to get people to use devices they hate. Then it would truly be an up-hill battle. The utilities need to find the most effective way to encourage retrofits to occur with the minimum necessary incentives.

Table 7.16 Summary of household retrofits

		Gross Costs		$ Savings			Water
Fixture	No.	Unit Cost	Total Cost	Water ($)	Energy ($)	Total ($)	Savings (kgal)
Toilets	2	$ 363.00	$ 726.00	$ 130.00		$ 130.00	21.13
Clothes Washers	1	$ 818.00	$ 818.00	$ 39.00	$ 42.00	$ 81.00	5.6
Showerheads	2	$ 12.50	$ 25.00	$ 9.64		$ 9.64	1.6
Faucet Aerators	3	$ 5.00	$ 15.00	$ 9.73		$ 9.73	1.4
Totals	8		$1,584.00	$ 188.37	$ 42.00	$ 230.37	29.73

BENEFITS AND COSTS FROM THE UTILITY PERSPECTIVE

The water saved as part of a conservation project has value to the customer based on savings in water, wastewater and energy bills. In addition, however, the water also has value to the water utility based on its capital value as a marginal supply. This can be greater than the value to the customer, and is frequently not given adequate consideration.

At a unit savings of 30 kgal per home the utilities will save approximately 0.092 acre-feet (af) of water for every home retrofit. Using gross costs of $1584/home and savings of 0.092 af/home the per acre foot cost comes to $17,200. If the utilities can get retrofits done for the incremental cost of $500 per home then their cost for water would be $5500/af of new yield. These costs need to be compared to the marginal cost of new firm supply in order to decide if it makes economic sense to sponsor a particular retrofit program.

For example, in parts of the country with limited supplies, the capital cost to develop a new firm yield can easily exceed $10,000/acre foot. At this cost water saved per home would have a capital value of $920/home. This is 4 times the $230/home saved by the customer. If the utility provided this $920 to the customers this would reduce the total gross cost of the retrofits to $664 and the customer payback period down to 2.4 years. The capital value of the saved water would accrue to the utility as a one time amount in the year that the retrofit project was performed. A utility with savings and costs as described above would realize a capital value of $920,000 per year in water supply[8] for each 1000 homes retrofit. These calculations can be repeated for whatever the capital value of firm yield may be for the particular utility, but the basic premise remains that same, which is that the water utility stands to gain more from the mining of savings from their existing customer base than do the customers. This is the main justification for utilities

Utilities, of course, have more options for accomplishing retrofits than just providing lump payments in the form of rebates to their customers. They can provide incentives in the form of low interest loans, or require retrofits on sales of property. They can encourage retrofits by advertising, using bill inserts, or via education programs in schools and community functions. In any case, however, the value derived by the utility needs to be factored into the equation when deciding on the efficacy of residential retrofits.

VALUE TO THE COMMUNITY

The real power of programs like residential retrofits can be seen at the community level. This is a community based approach to problem solving where the value to the community equals the sum of the value to the customers and the utility plus the intangible values from environmental preservation etc. One might also look at the value of the jobs created by the retrofit programs and sales of devices.

Let's consider a medium size hypothetical community that is experiencing moderate growth and needs new supplies of raw water to provide for its new taps. In this community water saved by its existing customers can and will be purchased by new customers who will pay tap fees and purchase the saved water at the prevailing water rates. Consequently, savings to the participating customers will not result in net losses in revenue to the utility. The utility, however, will be able to sell the saved water to new customers without having to purchase new supplies, which will result in a savings to the utility of the marginal cost of whatever their new water supplies might be. The customers will be able to enjoy the savings in water and energy averaging $272 per house per year.

If we assume our hypothetical community sets up a substantial retrofit program where they start with 1000 homes in the first year and increase this by 10% per year for ten years, then by the end of the 10^{th} year a total of 15,937 homes would have been retrofit.

Next we will assume that the total cost for the retrofits is $1500 per home, of which the utility subsidizes $500, the customer pays $1000 and there is $250 of salvage value based on the

8 0.092 af/home x $10,000/af x 1000 homes/yr = $920,000/yr

remaining life of the clothes washers replaced. These washers are sold to other members of the community who need machines, but are not ready to switch to high efficiency models at the time. So the sold machines are merely replacing other standard machines in the service area rather than increasing the number of standard machines present. Over the course of the 10 year program the total net cost to the community would equal $19.92 million for the retrofit program.

The savings to the utility can be calculated by multiplying the amount of new water saved each year by the capital value of the water, which we are assuming is $5000/af. This will amount to $7.3 million over the ten year program life. The savings to the customers are calculated at $272 per year for the cumulative number of houses in the program each year. They are not one time savings, but annual savings so they add up quickly. In year 1, there are 1000 homes in the program so the total savings that year amounts to $272,000. In year 2, however, there are 2100 homes in the program so the savings that year are $571,000, and so on until in year 10 there are a total of 15,937 homes in the program and the savings to the customers amount to $4.33 million. Over the course of the 10 years the total savings to the customers equals $20.4 million. This is money saved by customers which can be spent in the community for other purposes, and will not impact the overall revenues for the water utility since the new customers in the system are purchasing that water.

The final category of savings we are attributing to the hypothetical community is for intangible savings, and we are assuming that these amount to 10% of the calculated savings. These represent things like avoidance of damage to the environment from water projects or transfers. They might also include employment created in the community for performing the retrofits. These intangible benefits total $2.7 million over the course of the 10 years.

At the end of 10 years our community would have spent a total of $19.9 million to implement this retrofit program, and the total savings to the community would have equaled $30.5 million, for a total net savings of $10.6 million. The annual costs, savings and net savings are shown in Figure 7.1. Notice that the net savings line crosses into positive territory in year 3 when the total annual community savings exceeds the annual cost of the program. The net savings to the community reaches $3 million per year by the 10^{th} year, making this one of the best examples of a win-win resource management project one can imagine.

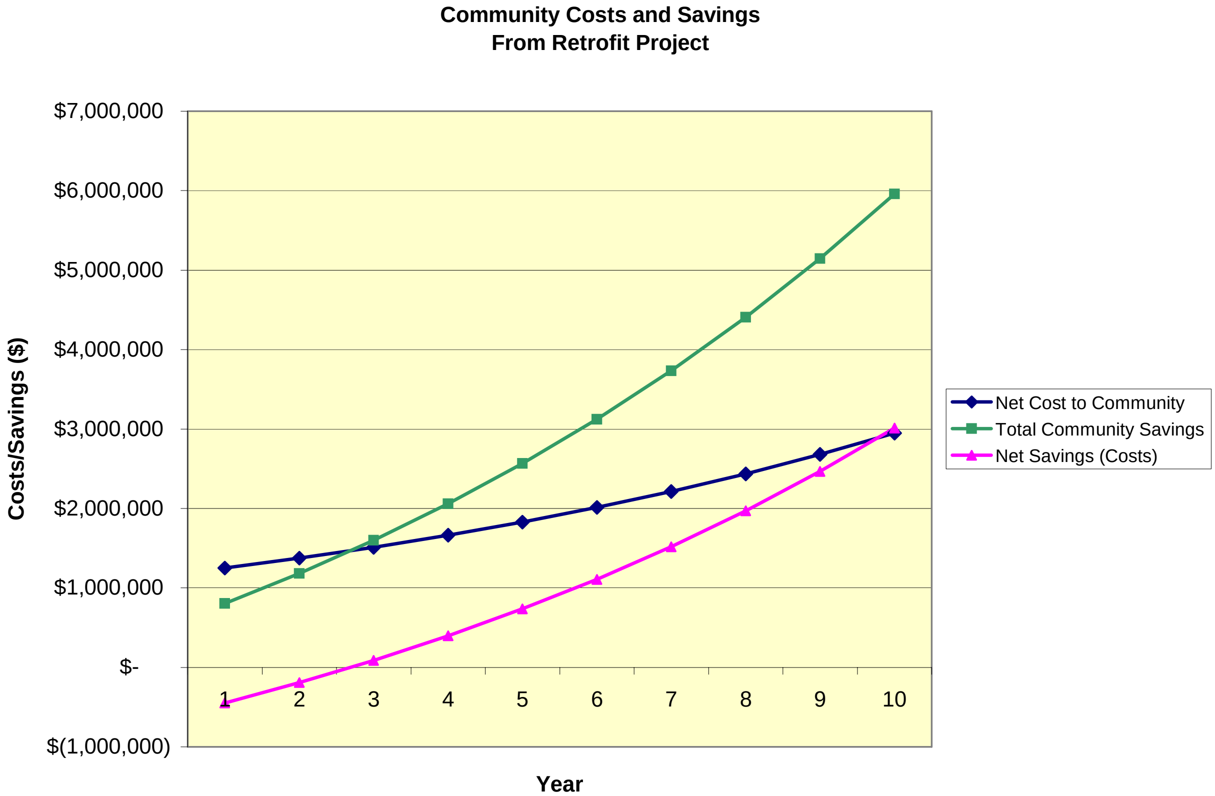


Figure 7.1 Annual costs, savings and net savings for community retrofit program

CHAPTER 8 CUSTOMER RESPONSES AND ACCEPTANCE OF NEW TECHNOLOGY

This section summarizes the salient responses from the customers about their attitudes towards the new products and will compare these to those they expressed prior to the retrofit. It emphasizes the overwhelming opinion expressed by the participants that these new products were an improvement over the old ones, including the ULF toilets.

PARTICIPANT RESPONSE TO RETROFIT PRODUCTS

In addition to evaluating products for their ability to save water they were also evaluated for customer satisfaction. Poor product performance is often a major concern with water conserving products and has made their acceptance more difficult. For example, anecdotally, ULF toilets have been thought to use more water than standard toilets because of a need for double flushing. Poor performance, leading to low customer satisfaction, increases the risk that fixtures and appliances will be replaced with products that do not achieve the level of water conservation desired by the utilities.

Toilets

Study participants were asked a variety of questions about their new toilets designed to assess how well they worked, how often they clogged, the frequency of double flushing, the level of maintenance, and overall satisfaction level. They were asked to rate their toilets in six different categories and overall on a scale from 1 –5 (1 = unsatisfied and 5 = completely satisfied). Overall, customers were pleased with their ULF toilets. Eighty seven percent indicated that they liked their ULF toilets as well as or better than their old non-conserving toilets and 84 percent would recommend them to a friend. Table 8.1 shows the comparison of pre and post-retrofit toilets in six categories and overall performance for the three study sites combined.

Table 8.1 Toilet satisfaction rating of the combined groups pre and post retrofit

Rating Category	**Combined**	
	Pre-Retro (n=96)	*Post-Retro (n=94)*
Bowl cleaning	3.44	4.07
Flushing performance	3.47	4.33
Appearance	3.36	4.67
Noise	3.27	4.62
Leakage	3.77	4.70
Maintenance	3.66	4.61
Overall average	3.50	4.50

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

Clothes Washers

Although the water savings achieved by retrofitting clothes washers is significant, many customers are reluctant to spend the additional money necessary to purchase a more efficient model. Study participants were asked if they would be willing to pay a premium of $150 to get an equivalent quality, conserving washer. Twenty four percent said they would not be willing to pay the extra money and 13 percent were unsure. However, when asked if they liked their new clothes washer better than their old one 84 percent said that they did and 91 percent would recommend it to a friend.

Participants were asked to rate the performance of their new machines in eight categories ranging from cleaning ability to reliability and noise level. These results were compared to responses from an earlier survey where the same questions were asked about their old clothes washers. The responses are shown in Table 8.2. The new clothes washers rated better than the old ones in all categories and none of the category ratings was below 4.5.

Table 8.2 Clothes washers satisfaction rating of the three study groups pre and post-retrofit

Rating Category	Combined Study Groups	
	Pre Retro (n=96)	*Post Retro (n=94)*
Cleaning of clothes	4.00	4.75
Reliability	4.34	4.74
Noise	3.18	4.63
Moisture content of clothes	3.56	4.67
Cycle selection	4.09	4.65
Capacity	4.16	4.56
Wash cycle time	NA	4.53
Detergent use	NA	4.59
Overall average	3.88	4.64

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

Showerheads

The concern that is often expressed about low flow showerheads is that they the flow will be inadequate and yet following the retrofits the average rating for water flow in the three groups was 4.4 on a scale of 1 – 5 (1 = unsatisfied and 5 = completely satisfied). Seventy three percent of participants said they would recommend their new showerheads to a friend and 73 percent liked it better than their old fixture. Table 8.3 shows how showerheads were rated in five categories.

Table 8.3 Showerhead satisfaction rating of the three study groups combined

Rating Category	**Combined** *(n=90)*
Water flow	4.40
Flow pattern	4.39
Appearance	4.66
Clogging	4.75
Adjustability	4.36
Overall average	4.51

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

Faucets Aerators

The one feature that most often affects customer satisfaction with faucet aerators is the flow rate. This is due at least in part to the fact that many tasks utilizing faucets require a set volume and flow reduction can increase the amount of time required to accomplish these tasks. Filling a large pot at the kitchen sink is just one example of a task that would be affected by faucet flow rates. In Tampa, where kitchen and bathroom faucet aerators were rated separately, kitchen aerators received the lowest ranking of all of the rating categories in all three groups. Nevertheless, Table 8.4 shows that although the water flow rated the lowest of the four evaluation categories it still achieved a better than average rating of 4.02. Although, generally, participants were satisfied with their new faucet aerators and 68 percent would recommend them to a friend, only 39 percent said they liked their new aerators better than their old ones.

Table 8.4 Faucet aerator satisfaction rating of the three study groups

Rating Category	**Combined (n=105)**
Water flow	4.02
Flow pattern	4.25
Appearance	4.58
Clogging	4.57
Overall average	4.36

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

CHAPTER 9 NATIONAL IMPLICATIONS

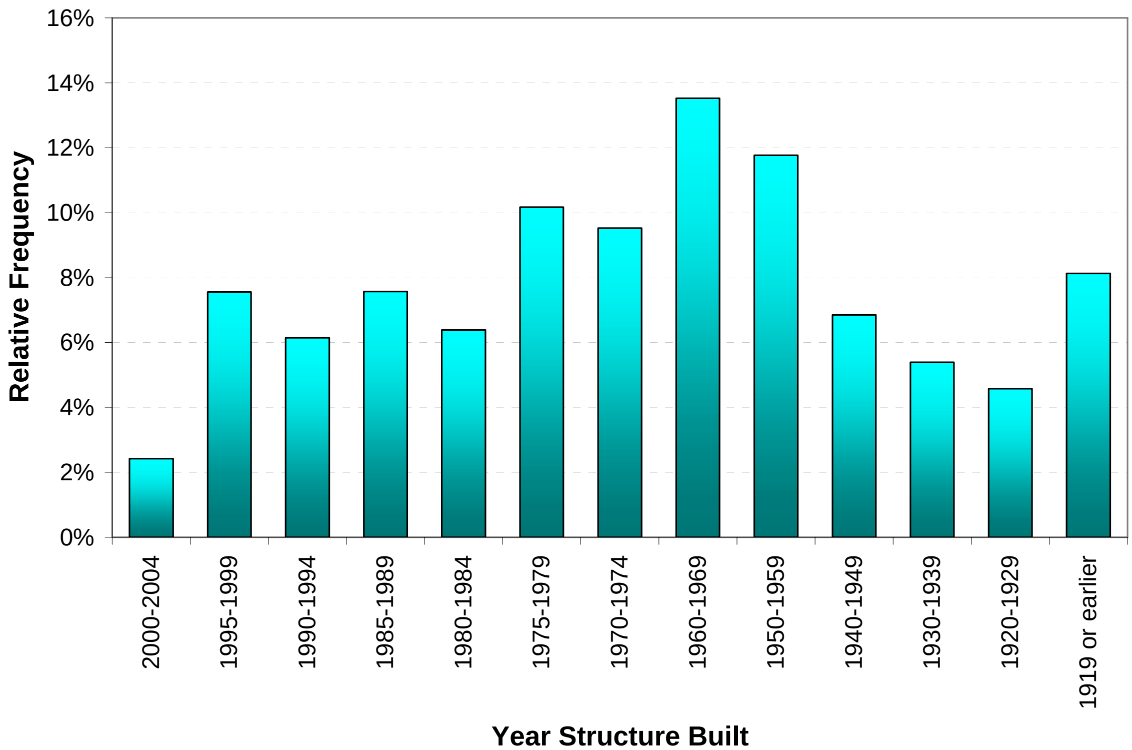
The results of this study show that domestic water use could be reduced by approximately 0.1 acre feet of water per home, based just on indoor uses. While this study did not deal with multi-family housing, data from the literature suggests that savings from retrofitting multi-family households can be expected to amount to at least half of those from the single family homes. Data from the 2001 American Housing Survey[5], sponsored by the U.S. Department of Housing and Urban Development and conducted by the U.S. Census bureau indicates that there are 74,434,000 single family homes in the United States and these make up 70% of the housing. Multi-unit housing, housing which consists of two or more units, constitutes another 23% of housing and the remaining 7% are manufactured or mobile homes as shown in Table 9.1.

Table 9.1 Number and percentage of housing units in the United States

Housing Type	**Total Number of Units** (numbers in thousands)	**Percent**
1 unit	74434	70%
Multi-unit, 2 or more units	24610	23%
Manufactured and mobile homes	7219	7%
Total	106261	100%

One consideration in assessing water use in homes as well as the benefit of subsidizing fixture replacement is the age of the home. Homes built after 1994 are required to install low flow fixtures including toilets, faucet aerators and showerheads. Older homes are less likely to have these low flow devices installed and many homes will have fixtures and appliances that are near the end of their useful life. The median year in which these homes were built is 1970 and only 10 percent or 10,595,000 homes were built after 1994 and 45 percent were built between 1950 and 1979. Figure 9.1 shows the distribution of housing age in the United States

Figure 9.1 Distribution of housing age in the United States



The results of this study show that, on average, non-conserving single family homes use 175 gallons of water per day for indoor use. At the rate of 175 gallons of water per day single family homes use 4.8 billion kgal or 14.6 million acre-feet of water nationally in the course of one year. Multi-family homes use another 786 million kgal (87.5 gpd) or 2.4 million acre-feet. While manufactured and mobile home households are a small percentage of the housing because their water use is approximately 155 gpd, similar to that of single family homes, they consume another 408 million kgal or 1.3 million acre-feet annually. By installing water conserving fixtures and appliances the average daily usage in single family homes can be reduced from 175 to 106 gallons per household per day. The reduction of average household use by 69 gallons per day results in national savings of 1.7 million kgal or 5.3 million acre feet annually. While less dramatic, reductions can also be achieved by retrofitting mobile homes and multi-units households. Even homes built after 1994 can increase their water savings with the installation of water conserving clothes washers. These savings decrease the demand on utilities for both drinking water supply and wastewater treatment and could provide indoor water for additional single family households nationally, each year, without the need to pump, treat or store additional water.

Nearly all indoor household water is eventually treated as wastewater and here too, increased demand requires more and/or larger facilities with subsequent economic and environmental impacts. “Currently, communities are investing approximately $10 billion a year in wastewater infrastructure. In most cases, the capital to make that investment is borrowed… Only rarely would a community have sufficient capital resources to fund infrastructure improvements without incurring debt.”[6] WIN, EPA, and CBO all estimate that communities will have to increase their current level of spending by as much as 100% to meet projected needs. A 1998 study performed by Potomac Resources, Inc. projected that in the next 20 years $20l billion dollars will be needed for flow-related facilities.[7] Increasingly, communities will have to bear a greater portion of these expenditures as federal subsidies are reduced.

The effect of water conservation on day to day costs of water treatment systems is fairly minimal and estimated to reduce operating costs by as little as 1 to 3% since much of the cost of treating water is fixed. [8] Wastewater treatment systems show similar reductions in O&M costs as a result of lower energy costs that result from decreased collection, influent and outfall pumping and aeration. On the other hand, depending on the source of the water, the cost of the land, and demand, the avoided cost of increasing new water supplies may vary from one municipality to another and range from $150 to $700 per acre foot per year.[9] Using an average avoided cost of $400 per acre foot the savings nationally would be as much as $2.12 billion per year.

The costs of increasing water supplies can be significant and are not simply limited to pumping costs and the cost of the chemicals to treat the water. As land becomes more valuable and concerns about the environmental impact of creating surface water storage increase, the cost of creating surface water storage rises. Areas that are heavily dependent on groundwater have seen significant declines in the water table over a period of time leading to an increase in pumping costs as well as a whole host of economic and environmental issues such as land subsidence, salt water intrusion, and loss of riparian and wetland habitat.[10]

The benefit of reducing inflows to wastewater treatment facilities is not simply the decrease in energy costs. The reduction in pollutant loading can result in other monetary and environmental benefits as well. “Yet 25 years after enactment of the Clean Water Act, much of the nation’s waters fail to meet the Act’s goals of being fishable and swimmable, and none of the nation’s cities has achieved the elimination of pollutant discharges that was originally contemplated by the Act.”[11] The use of high efficiency clothes washers provides many of these benefits. Because these washers use less water and detergent for washing not only do they use less water overall they require less energy to heat the water. They also discharge lower amounts of pollutants from detergents. Manufacturers of efficient clothes washers generally recommend reducing the amount of detergent used by half resulting in the subsequent reduction of wastewater treatment. Their design also allows for faster spin cycles which removes more water from the clothes thereby shortening drying times.

Notes:

[1] Mayer and DeOreo. *Residential end Uses of Water,* American Water Works Research Foundation (1999)
[2] Aquacraft, Inc. *Seattle Home Water Conservation Study*. December 2000
[3] Aquacraft, Inc. *Residential Indoor Water Conservation Study, East Bay M.U.D.*. July 2003
[4] Aquacraft, Inc. *Tampa Water Department Residential Water Conservation Study*. January 2004
[5] *American Housing Survey for the United States: 2001*. U.S. Department of Housing and Urban Development, Office of Policy Development and Research.
[6] www.house.gov/transportation/water/03-19-03/03-19-03memo.html. *The Subcommittee on Water Resources and Environment Hearing on Meeting the Nation's Wastewater Infrastructure Needs.* accessed June 22, 2004.
[7] Osann and Young, *Saving Water, Saving Dollars: Efficient Plumbing Products and the Protection of America's Waters.* Potomac Resources, Inc. Washington, D.C.. April, 1998
[8] Osann and Young, *Saving Water, Saving Dollars: Efficient Plumbing Products and the Protection of America's Waters.* Potomac Resources, Inc. Washington, D.C.. April, 1998
[9] Aquacraft, Inc. *National Multiple Family Submetering and Allocation Billing Program Study*. 2004
[10] Stratus Consulting, et al. *The Value of Water: Concepts, Measures, and Empirical Evidence, and Their Application to Water Management Decisions*. American Water Works Research Foundation (2004)
[11] Osann and Young, *Saving Water, Saving Dollars: Efficient Plumbing Products and the Protection of America's Waters.* Potomac Resources, Inc. Washington, D.C.. April, 1998