RESIDENTIAL END USES OF WATER STUDY 2013 UPDATE

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RESIDENTIAL END USES OF WATER STUDY UPDATE

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CONVERSION FACTORS

	GAL	CF	CCF	KGAL	AF	MG	M^3	L
GAL	1	0.1337	$1.337x10^{-3}$	$1.0x10^{-3}$	$3.069x10^{-6}$	1.0×10^{-6}	0.0038	3.785
CF	7.48	1	0.01	$7.48x10^{-3}$	$2.296x10^{-5}$	$7.48x10^{-6}$	0.0283	28.31
CCF	748	100	1	0.748	$2.296x10\text{-}^{3}$	$7.48x10^{-4}$	2.83	2831
KGAL	1000	133.7	1.337	1	$3.069x10^{-3}$	1.00x10-3	3.785	3785
AF	325,851	43,563	435.6	325.852	1	0.326	1233.5	$1.232x0^{6}$
MG	1×10^{6}	133,7	1337	1000	3.069	1	3785.44	$3.785x10^{6}$
M^3	264.17	35.32	0.3532	0.26417	$8.107x10^{-4}$	$2.64x10^{-4}$	1	1000
L	0.264	.035	.00035	.000264	$8.107x10^{-7}$	$2.64x10^{-7}$	.001	1

Note: multiply number of units in column 1 by the number in the body of the table to convert to units shown in row 1, for example: 10 MG x 3.069 = 30.69 AF.

FOREWORD

The Water Research Foundation (Foundation) is a nonprofit corporation dedicated to the development and implementation of scientifically sound research designed to help drinking water utilities respond to regulatory requirements and address high-priority concerns. The Foundation's research agenda is developed through a process of consultation with Foundation subscribers and other drinking water professionals. The Foundation's Board of Trustees and other professional volunteers help prioritize and select research projects for funding based upon current and future industry needs, applicability, and past work. The Foundation sponsors research projects through the Focus Area, Emerging Opportunities, and Tailored Collaboration programs, as well as various joint research efforts with organizations such as the U.S. Environmental Protection Agency and the U.S. Bureau of Reclamation.

This publication is a result of a research project fully funded or funded in part by Foundation subscribers. The Foundation's subscription program provides a cost-effective and collaborative method for funding research in the public interest. The research investment that underpins this report will intrinsically increase in value as the findings are applied in communities throughout the world. Foundation research projects are managed closely from their inception to the final report by the staff and a large cadre of volunteers who willingly contribute their time and expertise. The Foundation provides planning, management, and technical oversight and awards contracts to other institutions such as water utilities, universities, and engineering firms to conduct the research.

A broad spectrum of water supply issues is addressed by the Foundation's research agenda, including resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide a reliable supply of safe and affordable drinking water to consumers. The true benefits of the Foundation's research are realized when the results are implemented at the utility level. The Foundation's staff and Board of Trustees are pleased to offer this publication as a contribution toward that end.

Roy L. Wolfe, Ph.D.
Chair, Board of Trustees
Water Research Foundation

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Executive Director
Water Research Foundation

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The Project Advisory Committee consisted of:

- Mr. David Bracciano, Demand Management Coordinator, Tampa Bay Water
- Mr. Doug Bennett, Water Conservation Manager Southern Nevada Water Authority
- .Ms. Mary Ann Dickenson, Executive Director, Alliance for Water Efficiency
- Mr. Warren Liebold, Director of Conservation, New York City

The following water agencies participated as Level 1 sites:

- The Denver, Colorado Water Department
- The City of Fort Collins, Colorado, Water Department
- The City of Scottsdale, Arizona Water Department
- The San Antonio, Texas, Water System
- The Clayton County, Georgia, Water Authority
- The Toho, Florida Water Authority
- The Region of Peel, Ontario, Canada
- The Region of Waterloo, Ontario, Canada
- The City of Tacoma, Washington, Water Department

The following water agencies participated as Level 2 sites,

- City of Aurora Colorado Water, Department
- City of Austin, Texas
- City of Chicago, Illinois
- City of Henderson, Nevada
- City of Mountain View, California
- City of San Diego, California
- City of Santa Barbara, California
- City of Santa Fe, New Mexico
- Cobb County Water System, Georgia
- Colorado Springs Utilities, Colorado
- Town of Cary, N.C.
- EPCOR, Edmonton, Alberta, Canada

- Miami-Dade Water & Sewer, Florida
- Otay Water District, California
- Philadelphia, Pennsylvania Water Department
- Portland Water Bureau, Oregon
- Regional Water Authority, Connecticut

Member of our Staff

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- Ms. Leslie Martien, data analysis
- Ms. Renee Davis, data analysis and report writing
- Mr. Will DeOreo, data analysis, GIS analysis of landscapes
- Ms. Jane DeOreo, data analysis and GIS

Our Research Partners:

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    - Dr. Jack Kiefer
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EXECUTIVE SUMMARY

As one investigates residential water use using increasingly detailed data sets one obtains information on the patterns of use that are correspondingly more detailed. Some basic information can be obtained from annual data; more can be learned from seasonal and non-seasonal data, and so on. Each more detailed data set contains less noise and more information. Ultimately, the most detailed information can be obtained when household water use is disaggregated down to the end use level. This allows the key types of water use to be studied individually, and limits the degree to which noisy data in one type of use interferes with the analysis of use in another. Having more detailed data also increases the number and types of metrics that can be used to assess the patterns and efficiency of water use. This is what the REUWS2 attempts to provide for water researchers in the United States, Canada, and around the world based on extensive new data collected between 2011 and 2013 and compiled data from historical studies dating back to the original REUWS1 from 1999.

OBJECTIVES

There were several objectives of this study. They all related to obtaining updated information on single family residential water use at a very detailed level. The overall objective was to understand how much water single family households currently use for the major end uses of water, and what factors affect, and predict these uses. Data were to be collected from customer billing databases, individual surveys of customers and utilities, census and economic sources and flow trace data obtained from the customers' water meters that was disaggregated into end uses. In addition to data from the main water meters a group of 110 homes was equipped with separate meters on the feed lines to their water heaters. This allowed parallel analyses of hot water use to be performed in those houses. Outdoor use of water was to be analyzed on an annual basis in order to understand both the volumes of water that customers were using for landscape uses and the ratio of the applied water to the theoretical irrigation requirements based on the landscape type and the local evapotranspiration (ET). Finally, the data were to be organized into databases from this statistical analyses could be created and econometric models of water use developed in order to identify the factors that affected indoor and outdoor water use in the group.

BACKGROUND

In most large municipal water systems residential water use makes up the majority of all water deliveries. If only billing data are available it is difficult to determine how much water the customers are using for uses such as toilet flushing, clothes washing, faucet use, showering, irrigation etc. It is also difficult to determine how much water is being lost in the homes due to leakage. Having only aggregated data makes it difficult to determine how efficient the current water use is and how much potential savings are available from demand management and water conservation programs. As mentioned above, obtaining highly detailed information on random samples of customers, including 10-second interval flow traces, allows the water use in the homes to be disaggregated into individual water use events, each of which can be classified as to its fixture type, start time and date, duration, volume, peak flow and mode flow. Having data at this level of detail, in combination with survey and other information on the homes allows the water use to be measured in many more ways than can be done from just billing data. For example, from monthly billing data it is possible to estimate non-seasonal water use, which can serve as a proxy for indoor use, even though non-seasonal use frequently includes irrigation occurring during the winter period. Nonetheless, non- seasonal use can use used as a metric to evaluate indoor use, and even compare it to benchmarks of efficient indoor homes. Disaggregating end-use data allows one to examine the full range of water use patterns and to determine, during the logging period, actual indoor use, excluding any irrigation events, measurements of gallons of water used per day for each end use (including leakage) and a range of efficiency data such as gallons per flush for toilets, gallons per load of clothes washers, flow rates for showers and faucets, and daily leakage rates.

The data collected as part of this study included information on hot water use in 110 homes. This allowed the types of uses that are responsible for the bulk of hot water use to be identified and the quantities of hot water used for each type of fixture and appliance. This includes how many gallons per day are used for hot water by uses such as showers, baths, dish washers and faucets. Since temperature of the inflow water and hot water from the tanks was measured it allowed the total energy use for water heating to be calculated. At the event level the data allowed the volumes, durations and flow rates of each hot water draw to be used to simulate the operation of hot water systems, and this was done by the Tacoma Power utility, which used their data to analyze the operation of heat pump water heaters.

Outdoor water use is much more variable than indoor use, but is still related to a series of measurable parameters such as irrigated area, plant type, local weather, income and what type of irrigation system is present. In addition, there are local cultural norms that influence whether or not people are inclined to irrigate their yards, or to accommodate to available rainfall. Investigating these relationships was part of the study as well.

Since the REUWS1 study in 1999 there have been a series of studies done on single family homes covering a wide range of geography, climate, fixture types and economics. Assembling the data from these studies to allow for a comparison in water use over time was something that the data made possible. As efficiency standards for items like toilets, faucets, showers and clothes washers have increased over time indoor residential demands have decreased.

APPROACH

The report contains a chapter devoted to explaining the research methods in detail. The chapter starts with a description of the overall study organization and then describes how each major task was accomplished, from obtaining information from the agencies, implementing the survey, collecting and analyzing the data, and presentation of results.

The research approach was centered on the concept of selection of random samples of single family customers, and then obtaining highly detailed information on their water use, demographics, the physical nature of their houses and landscapes. The water use information (down to the end-use level) was then assembled into databases from which descriptive statistics could be prepared, metrics examined against benchmarks and models created to identify what factors were most influential in explaining water use.

Each participating water agency provided the research team with information on their customer base. Billed consumption reports were provided which showed the number and categories of accounts in the system and their water use over a multi-year period. The agencies also provided information on their water conservation programs, drought and conservation plans, budgets, staffing levels, and water and wastewater rates.

Random samples of 1000 single family customers were then selected from the billing databases for each agency. The monthly billing data for each of these was tabulated and the sample was checked to verify that its water use was similar to the population from which it was drawn. This sample, called the Q_{1000} was used to send surveys and ultimately to select the homes for data logging in the level 1 sites. The level 2 agencies did not participate in the data logging, but only in the customer surveys.

After the Q_{1000} samples were selected surveys were mailed to 1000 homes in each of the level 1 sites (a total of ~9000 surveys) and to 5000 homes from the combined Q_{1000} samples from the level 2 sites. A total of 14000 surveys were mailed out in order to obtain information on a wide range of topics as described in the chapter on survey results. The results from the surveys served as inputs for water use analyses and as part of the survey response tables.

After the returned surveys were tabulated samples of approximately 100 homes were selected from each of the level 1 sites for data logging, and 10 homes were selected to also receive a hot water meter (Tacoma expanded their hot water sample to 37 homes so that they could do the heat pump simulation.)

Aerial photos were used to analyze the landscapes on each of the homes selected for logging. This supplied estimates of landscape area, which was combined with local weather and ET data to generate estimates of the annual irrigation requirement for the landscapes. (Pools were included as parts of the landscape.)

Visits to the sites for data logging took place from February 2012 through January 2013, and analysis of the trace files was completed by March of 2013. Summaries of indoor and landscape water use were prepared and put into tabular form for analysis in conjunction with the survey and other data collected for the homes.

Descriptive statistics on the results were prepared and mathematical (regression) models were created to search for factors that affect residential water use. The data from the combined studies were used to explore metrics to better describe water use and benchmarks for comparing residential water use to accepted efficiency standards.

The report describes the conservation staffing and practices reported by the agencies. The largest staff was in San Antonio, with 21 full time equivalents

LITERATURE REVIEW

The report contains an extensive literature review that covers the period from the 1984 HUD study to the current study. The literature review explains how the industry was calling for better information on the end uses of water for purposes as diverse as water conservation planning, integrated resource planning, sizing home water treatment systems and correctly sizing service lines and meters.

The first end-use studies approached the problem by attempting to install individual sub-meters and data loggers on all of the water supply lines in the home and wiring these to a central data storage unit. This was an accurate approach, when all of the equipment was working properly, but it was intrusive, expensive and difficult to implement. In 1994 the study done by Aquacraft in Boulder, CO showed that a very good estimate of end uses could be obtained using a single high resolution data logger attached to the main water meter of the customer meter. This led to the first Residential End Uses of Water Study (REUWS1) that was published by the Water Research Foundation in 1999.

The literature traces the many subsequent studies that have been done in North America, around the world on single family, individually metered multi-family homes. One of the most interesting aspects of some of the recent studies outlined in the literature review is that many of them include data collection on high efficiency homes, which were either designed and built for water efficiency or were standard homes that were retrofit with high efficiency fixtures and appliances. This has allowed results from the various studies to be used to generate benchmarks of residential water use efficiency, which is a topic discussed in its own chapter.

RESULTS

The most useful results from the project were generated from the surveys, billing data, flow trace data, and the various statistical analyses and models that were derived from them. We have summarized some of the more salient and interesting results here.

Results from Surveys

Approximately 14,000 surveys were mailed out to customers as part of this study, and each of the 26 participating water agencies was also surveyed for information relevant to their operations.

The surveys sent to the agencies provided a variety of information. They included questions on the numbers and types of customers and the billed consumption to each. They also included information on the types of conservation practices in place and if any water use restrictions were in place during the logging period or billing year.

The surveys showed that the study group included a wide range of system sizes. The average number of single family customers served by both the Level 1 and Level 2 sites was 141,628, and this ranged from a low of 11,802 in Mountain View, CA to a high of 392,639, in Philadelphia, PA.

Information on rainfall and ET were collected as part of this task, although most of this came from NOAA or other sources. Rainfall ranged from a low of 10.8 inches in Scottsdale, AZ to a high of 52.0 inches in Toho, FL. During the billing year of 2010 that was used for the billing and outdoor use analysis two out of the nine Level 1 sites (Toho and Clayton County) were on mandatory water use restrictions. San Antonio, TX was on drought restrictions in 2010, but data for 2008 were used so that the drought impact could be avoided. Thus the majority of the study sites were not impacted by drought during the study year.

The vast majority of the study sites relied on surface water as their predominant supply, but two agencies, Miami and Toho, listed only groundwater as their main supply. Two agencies, Austin and Santa Barbara reported using desalinated water as part of their supply and several also included reclaimed wastewater and non-potable raw water or rainwater harvesting in their supply systems.

Prices for water and water rates were important components of the econometric modelling effort. The agency surveys provided information on these topics. The inclining block structure was the most common rate structure reported. The report goes into great detail in describing the rate structures in the agencies. Average rates and marginal rates are reported for each. In addition the effects of fixed charges for water were shown to create a negative impact on the cost of larger volumes of water, so that agencies with large fixed charged had lower average costs for water in their top tier than in the 5 kgal tier, even if they had nominal increasing block rates. The top marginal rate in the study group was $17.14 in Santa Fe NM, and the lowest marginal rate was $2.01 in Chicago. The average marginal rate was $6.16.

There were a wide range of staffing and budgets for the conservation programs in the group. The average number of staff members was 6; the largest staffs were in in San Antonio and Austin, TX, with 21 full time equivalents, followed closely by Denver, CO with 20. The staff numbers varied down to less than 1 fte. Budget levels were just as varied. The average budget was just over $3 million; the largest budget was over $11 million in Denver, and the smallest budget was $0 in Chicago.

The report summarizes the types of indoor and outdoor conservation practices in place in the Level 1&2 sites. The types of indoor conservation measures in use by the study group are summarized in Table 23. The most common programs involve replacement of fixtures and appliances and the methods by which this is done range from rebates to full service replacements by the agencies. The only appliance that has not been included for replacements or rebates is the dishwasher, for which only a single agency offers rebates, and one other agency includes as part of its education program.

Table 24 summarizes the outdoor conservation programs being offered by the study group. These include smart irrigation controllers, restricted watering days, water efficient landscape programs, audits, water budgets and education programs.

Table 25 in the report summarizes the types of information that the agencies provide to their customers to assist with management of irrigation water use. A total of 10 (38%) of the agencies use or provide ET information. Eighteen of the agencies (63%) allow their customers to read their water meters directly in order to track their water use, but only 2 agencies (8%) provide any type of device capable of providing direct meter readings in the home on a real time basis.

Virtually all of the agencies have water loss control programs and most of them follow the AWWA Manual 36 audit procedures in preparing annual accounting. All but one of the agencies have an active leak detection program, and all of them have active meter testing programs. All of this is outlined in Table 28 of the report.

The customer survey contained a total of 47 main questions. Most of these included sub-questions so the total number of total responses in the survey is much larger than this. Eighteen of the questions related to hardware found in the homes, 9 related to demographic information, 13 dealt with behavioral issues, 2 were geographic, 3 asked for judgments from the customers and 2 asked about alternative water supplies that might be present in the home. The responses from the customer survey have been summarized in Table 30 through Table 41 of the report.

Some of the interesting results from the survey included the fact that 16% of homes do not have a dishwasher, and 67% of them report having a high efficiency clothes washer. It was somewhat surprising that an average of 13% of the homes had a recirculating hot water system to reduce the wait times for hot water, and in one site, Scottsdale, AZ 30% of the homes had these devices installed.

In most sites less than 10% of the homes had swimming pools, but in three sites: Scottsdale, Toho and Waterloo pools were present in 18% or more of the homes. Scottsdale, as one would expect, had over 55% of the homes with a pool. See Figure 34 for this breakdown.

Table 36 summarizes information on evaporative coolers, humidifiers and whole house water treatment (usually water softeners). Overall, only 6% of the homes had evaporative coolers (Denver was the largest with 23%), 19% of the homes had whole house humidifiers, with Peel on top with 57%, and 13% of the homes had water softeners, for which Waterloo had the highest percent at 51%.

Around 60% of the homes reported little or no wait for hot water, and 40% reported a “pretty long” to “very long” wait. Nearly 75% of the homes heated water with gas, and 22% used electricity. The rest either did not know or used solar or propane.

The average number of persons per household in the study group was 2.59, and this varied from a low of 2.21 in Scottsdale to a high of 3.43 in Peel.

The site with the highest amount of education was Fort Collins, CO, where over 45% of the households had a graduate or professional degree. Overall around 30% of households in the group reported advanced degrees. Clayton County, GA had the fewest advanced degree holders with less than 15% of homes reporting positive for this.

The median reported income for the group was around $50,000. The site with the highest reported income was Scottsdale, AZ, where approximately 18% of the respondents reported incomes of more than $200,000, and the site with the lowest income was Toho, FL, where none of the respondents reported incomes in this bracket. The breakdown of respondents falling into each of the income brackets is shown in Figure 37.

The survey asked several questions to elucidate information about residents' behavior patterns. These questions covered a range of water use habits. Perhaps some of the most interesting questions related to water conservation. One question asked if the household had taken any action to conserve water in the last few years. A clear majority (73%) said they had. These results are shown in Table 39. If survey respondents reported conserving, they were asked what actions they had taken. Table 40 details some of these responses. Study-wide, the most common (72%) action was to avoid irrigating during the heat of the day. Over half (52%) of people reported taking short showers.

Judgment questions on the survey requested information on residents' opinions of water rates, conservation, and drought. When asked whether their community was experiencing drought, respondents could choose among five responses ranging from no drought to severe drought.

Responses to this question were fairly evenly split at many sites and for all combined answers (Figure 41). However, a majority of Tacoma, WA respondents said their community was not experiencing drought. Peel, ON and Clayton County, GA respondents' most common answer was that there was no drought in their area. Tacoma's responses agree with the U.S. Drought Monitor (Figure 42). Other communities' perception of drought and their actual level of drought level, based on the North American and U. S. Drought Monitors, are shown in Table 42.

Overall, 70% of the survey respondents reported that they irrigate their landscape. This percentage was the highest in drier, western site such as Denver, Scottsdale and Fort Collins. The percentage of irrigators was lowest in the more humid area in the east, such as Clayton County, however, Clayton was the only site in which the irrigation rate was less than 50%; in the other eastern cities the percentage of irrigators was consistently over 50%.

In-ground irrigation systems were present in just over half (53%) of all survey respondents' (as shown in Table 41). The respondents were asked, if they had an in-ground system, about some of the features of those systems. Table 41 shows some of the responses. Most in-ground systems included an automatic timer / controller. Weather-based ("Smart") controllers were still relatively uncommon.

Results from Billing Analysis

The primary information obtained from the billing data were the annual, seasonal and non-seasonal water use for the customers. The annual use was just the sum of the total volume of billed deliveries to the customer during the billing year. In order to be consistent all of the data were converted to units of thousands of gallons (kgal). The non-seasonal use was generally calculated as the average use during the winter quarter (Dec, Jan, Feb), and then prorated to the year. The seasonal use was the difference between the annual use and the non-seasonal use.

There was a considerable variability in these uses, but more-so in the seasonal use than in the non-seasonal use. As shown in Table 45, the annual water use averaged 88 kgal, and ranged from a low of 44 kgal to a high of 175 kgal. The seasonal use averaged 30 kgal and ranged from 4 to 83 kgal per year. Non-seasonal use averaged 58 kgal (159 gpd) and ranged from 34 to 129 kgal. Scottsdale, AZ was the highest non-seasonal use, but this was due to the fact that the community is so heavily occupied during the winter months, and relatively deserted during the summer. Non-seasonal use can be misleading in areas with this type of occupancy pattern. It can also tend to over-estimate indoor use when used in areas, like Scottsdale, with significant "winter" irrigation. Per capita non-seasonal use averaged 70 gpcd and ranged from 43 to 164 gpcd, with Scottsdale again being the outlier.

Results form End Use Analysis

The results from the end use analysis provide a much more accurate and detailed picture of the water use than do the billing data. Where non-seasonal use includes winter irrigation, indoor use from the flow trace analysis includes only actual indoor uses (plus leakage). As one would expect, indoor use from the logging samples was lower than non-seasonal use. Indoor use averaged 138 gpd, where non-seasonal use was 159 gpd. Indoor use in the REUWS2 was also significantly lower compared to the REUWS1 study. To demonstrate this we have copied Figure 48 in the body of the report as Figure 1 for the summary.

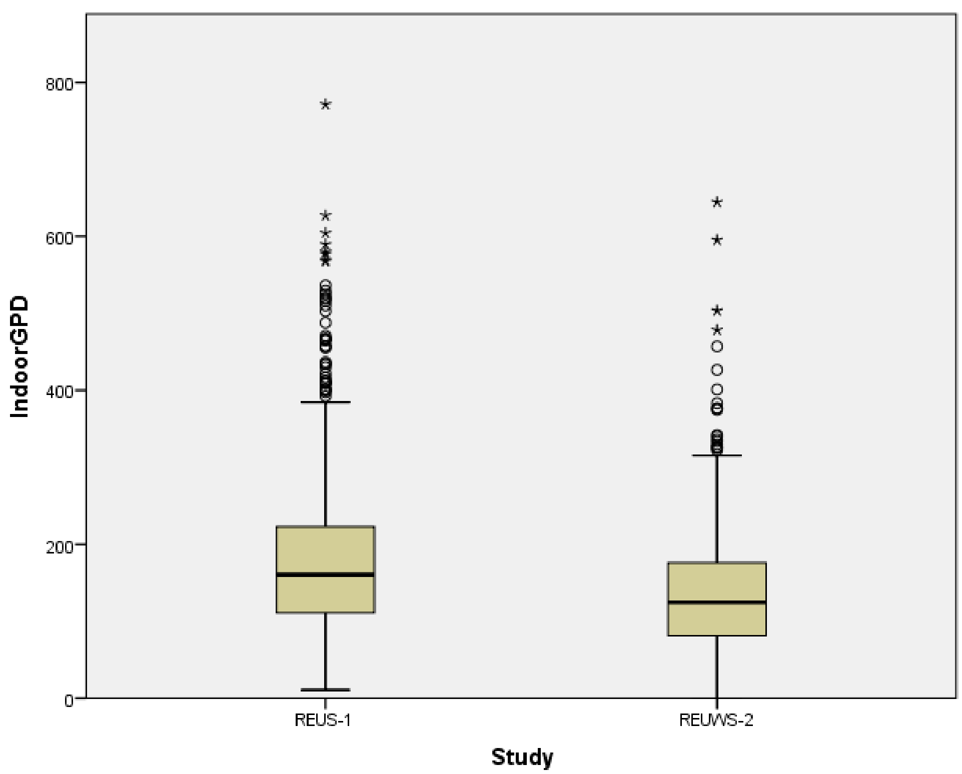

Figure 1: Box diagram comparison of REUWS2 to REUWS1 indoor use

Per capita use was also lower in the REUWS2 study. Where per capita use was over 70 gpcd in REUWS1 it was closer to 52 gpcd in REUWS2. The relationship between per capita use and the number of residents in the home was found to decrease, as it did in REUWS1. Figure 53 in the report shows that with one person in the home the per capita use was 78 gpcd, but with 6 persons present per capita use dropped to 38 gpcd. The corollary to this is that household use does not increase linearly with the number of residents present. This is such an important concept that it is worth reproducing Figure 52 below.

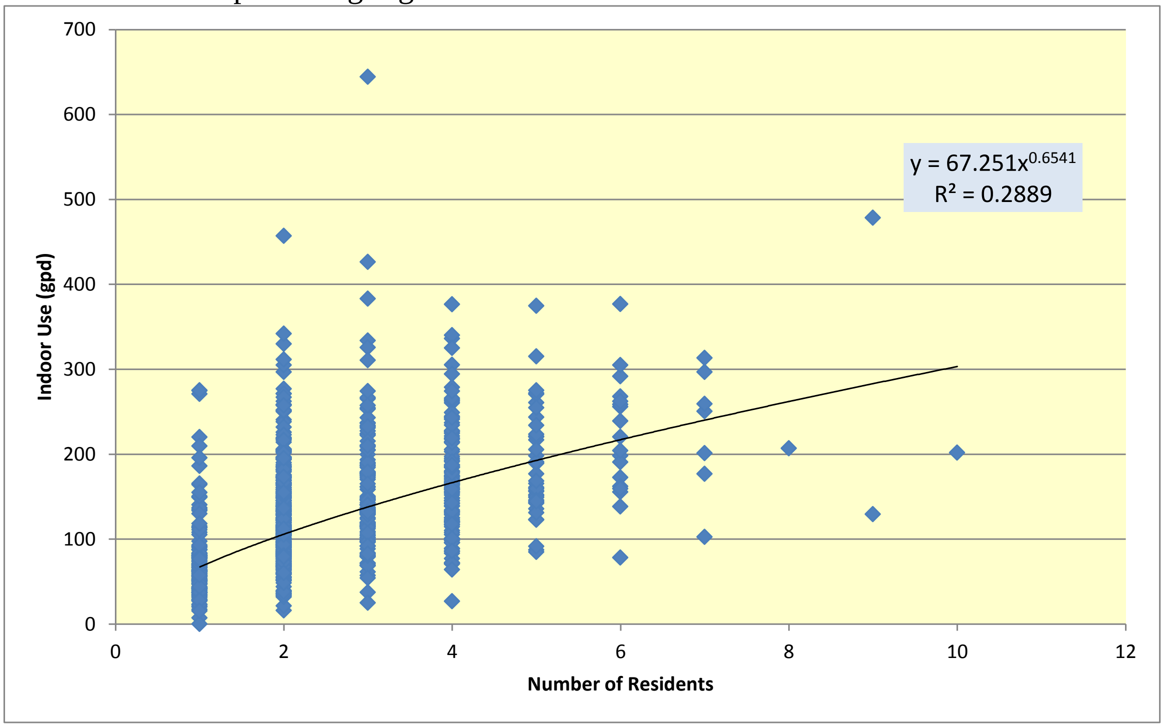

Figure 2: Indoor household use versus number of residents

The data for individual end uses of water, shown in Figure 3 is also worth reproducing since it shows that for the eight end-uses of water identified for indoor uses the only two that have shown an unqualified reduction in use are clothes washers and toilets. The reduction in shower use is on the borderline. While the average use for the other categories has dropped, which is suggestive of a change, the means are all within the 95% confidence interval of each other, so while the means may have dropped this drop cannot be said to be significant at the 95% confidence level. This is not an unexpected result since clothes washer, toilets and showers are the three uses that have been the object of the most concerted efforts at conservation, and they are uses that are most amenable to mechanical fixes. Uses that are volume driven, like many faucet uses or behavioral appear harder to modify through device design. Leakage events fall into a special category, and have been analyzed as though they were indoor events, but in fact they result from a combination of indoor and outdoor malfunctions from devices like toilets, faucets, hose bibs, pools. In thinking about residential water use leaks deserve special attention since they are “uses” of water that generate no real benefit to any user, except perhaps to the degree that recharge groundwater or add to base flows in wastewater systems.

The report includes data on per capita uses as well, which paralleled the household uses. Since the number of residents in the homes was very similar between the REUWS1 and REUWS2 the changes in water use that occurred in REUWS2 were not the result of differing numbers of persons per household.

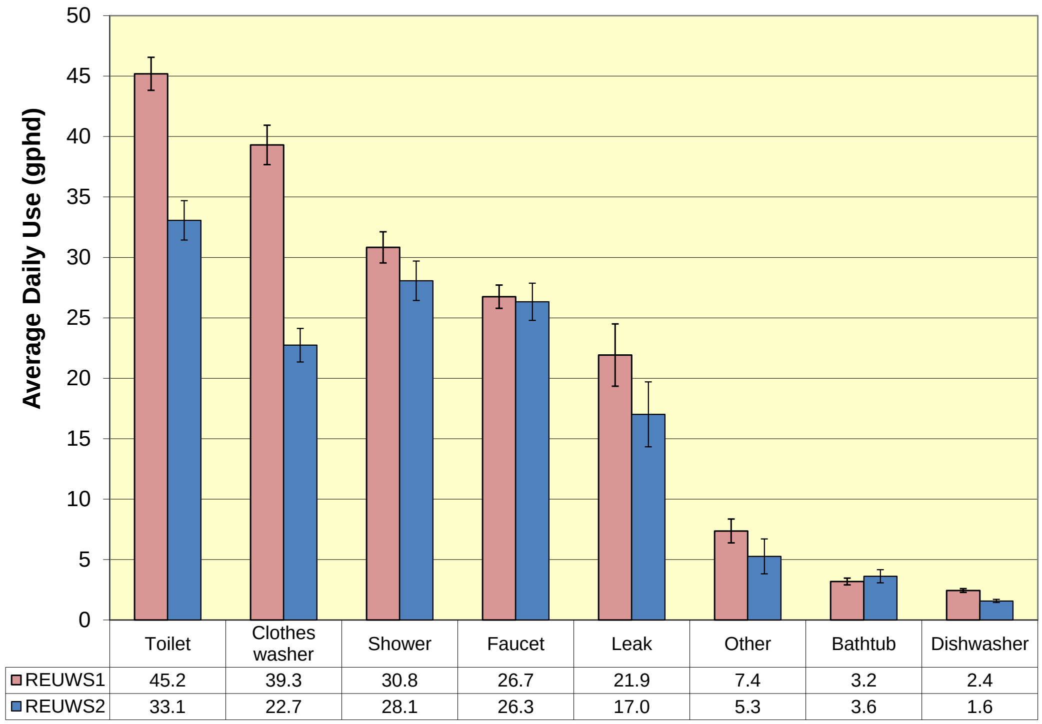

Figure 3: Comparison of indoor end uses for REUWS2 and REUWS1

There are sections in the body of the report that describe the use statistics of each of the categories of indoor use. There are tables that show frequencies of use, volumes per use, flow rates and other statistics. An example of a table for toilets is shown in Table 1. This table shows that while the parameters such as persons per house and flushes per person per day have remained stable, the volume of water used for toilet flushing in the homes has decreased by approximately 12 gallons per household per day, and the average flush volume has decreased by approximately 1 gallon per flush, which represents a 27% reduction.

Table 1: Summary statistics for toilet use

	REUWS2	REUWS1
Number of houses logged	762	1187
Total number of flushes recorded	124,611flushes	348,345 flushes
Total number of days logged	9659 days	28013
Average number of residents per home	2.6	2.7
Total volume of water devoted to toilet flushes during the logging study	318,049 gal	1,266,655 gal
Average flushes/household per day	13 flushes/household/day	12.4 flushes/household/day
Average flushes per person per	5.0	4.6

	REUWS2	REUWS1
day		
Average flush volume	2.6 ± .01 gal	3.65 ± .06 gal
Average daily use for toilet flushing	33.1 ± 2 gpd	45.2 gpd
Median daily use for toilet flushing	29 gpd	43 gpd
% of Flushes < 2.2 gal	51%	16%

One of the more interesting figures in the report is the comparison of the distribution of the individual toilet flushes recorded during the logging periods for the REUWS1 and REUWS2 studies. This has been copied in Figure 4. This figure clearly shows the dramatic change in toilet flush volumes that have occurred in random populations of homes between the two studies. In the REUWS1 data there was a hint of a peak of flush volumes under 2 gallons, but in the REUWS2 study this peak now predominates to the degree that there is no longer a clear peak in volumes above the 2 gallons volume.

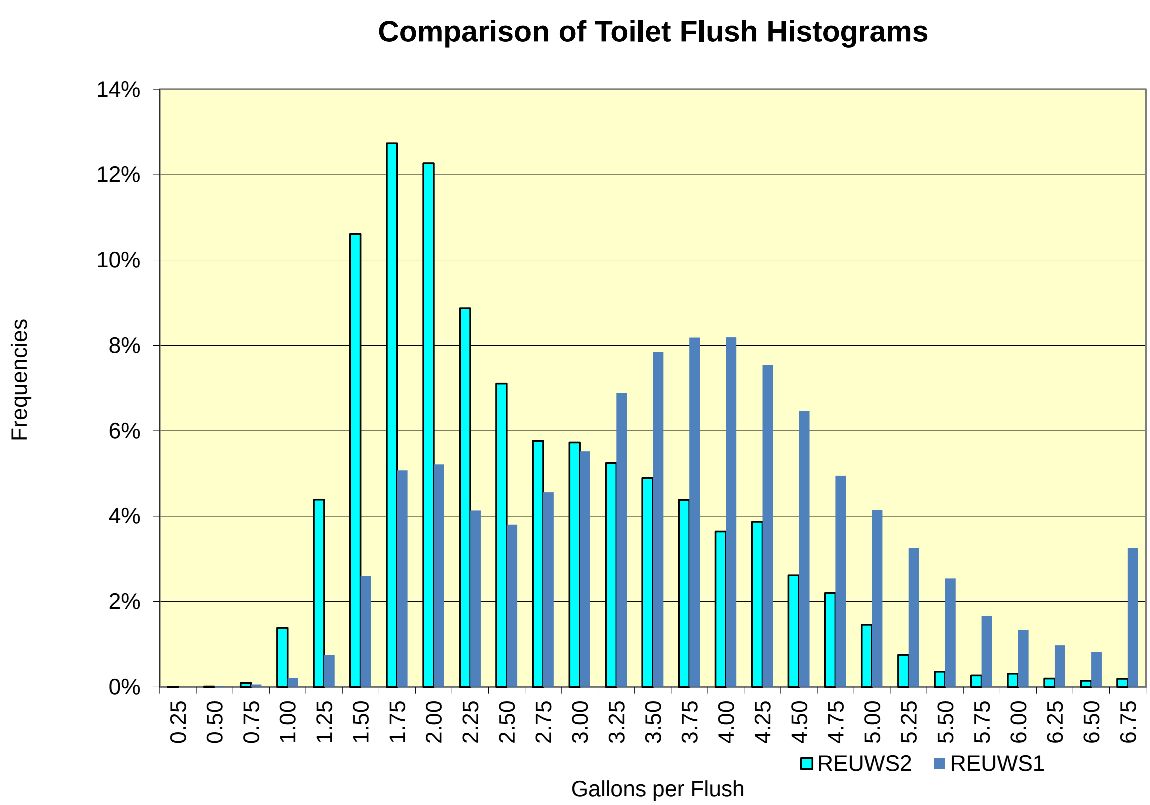

Figure 4: Comparison of toilet flush distributions between REUWS2 and REUWS1

Another interesting and useful set of data are shown for toilets in the report that shows how the percentages of low volume toilet flushes varies across the study group. This is shown below in Figure 5. When the percentage of toilet flushes that are 2.2 gallons or less in each home are determined, the data show that as of the date of the REUWS2 there were clustered at the extremes, with roughly 27% of the homes having few flushes less than 2.2 gpf, and 33% of the homes having most of their flushes using less than 2.2 gpf, and the remaining homes somewhere in the middle, with a mixture of flush volumes.

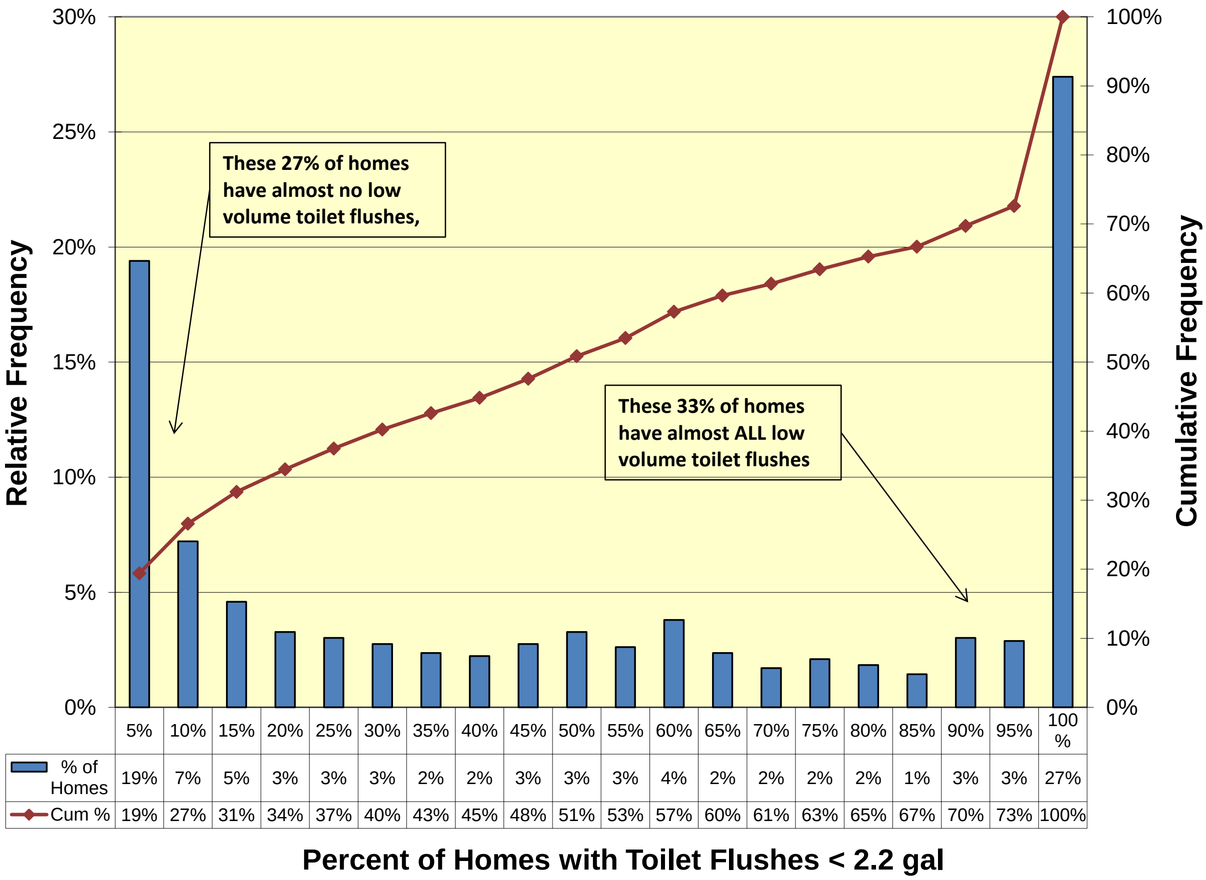

Figure 5: Toilet heterogeneity diagram

The information on showers for the study showed a remarkable degree of similarity to the data from the REUWS1 study. The average number of showers per person per day was 0.69 in this study, compared to 0.66 in the previous one. The average shower volume was 15.8 gallons in this study, compared to 16.7 in the previous one. The duration of showers in both studies was the same, at 7.8 minutes per shower. The average flow rates for showers was 2.1 gpm in this study, compared to 2.2 in the first. The average daily use for showering dropped slightly from 31 to 28 gphd. Altogether, the results on shower use do not suggest that a major change in water use for showering has occurred since 1999. The statistics on showers use is shown in Table 52.

Faucet use is also similar between the two studies. The average daily use for faucets was 26.3 gpd for this study and 27 gpd for REUWS1. The median daily uses were 22.5 and 23 gphd respectively. The vast majority of faucet events were short duration and low volume. 99.9% of all faucet events used less than 10 gallons of water, and the average use in this bin was 0.5 gallons per event. The average duration for faucet events was 30 seconds, and the median duration was 20 seconds. The flow rates for faucet use were low, with 95% of all faucet uses flowing at 1.4 gpm or less. The faucet use was compared between homes with dishwashers and homes without. In previous studies homes with dishwashers had lower faucet use than homes without them, but in this study the faucet use was identical in homes with and without dishwashers.

Clothes washers were the other category of use that showed an unambiguous reduction in water use. While the average number of loads of clothes per day stayed the same, the average gallons per load dropped by 25% from 41 to 31 gallons per load. The average daily use for clothes washing dropped by 16.6 gphd, from 39.3 to 22.7 gphd, a reduction of over 42%, which is really remarkable. Table 57 gives the statistics for clothes washers.

Bath tubs and dishwashers are minor players in residential water use. Together they account for less than 6 gphd. As mentioned above, dish washers were not associated with lower faucet use in this this study, which is disappointing, since one would expect an appliance that washes dishes with so little water to save faucet use that is used for manual washing.

Out of the 762 homes in the indoor logging group 662 registered some leakage. It is somewhat surprising that there were 100 homes in the group that did not register any leaks, given how easy it is for a small leak to appear in a trace. Houses with zero leakage have very tight plumbing systems.

Leakage is a heavily skewed type of category. The average leakage for the group was 17 gallons per household per day, but the median rate was only 4.3 gphd. This means that half of the homes had leakage of 4.3 gpd or less and a few homes had very high leakage rates that raised the average for the group. Figure 6 presents the distribution of household leakage, which shows that two thirds of the homes in the study group had 10 gpd or less of leakage recorded during the logging period. Ninety percent of the homes had leakage rates of 50 gpd or less.

The homes at the bottom end of the leakage distribution may make up the bulk of the homes, but they do not contribute the majority of the leakage. The two thirds of the homes below 10 gpd of leakage account for only 17% of the total volume of leakage recorded in the study group. This is shown in Figure 7. In this figure the impact of the homes with larger leakage rates is very clear in terms of the percentage of the total leakage volume they represent. Based on their numbers, shown in Figure 6 they appear insignificant, but in terms of their volume they are important. The top 1/3 of the leaking homes accounted for 83% of the leakage volume, and the top 10% of the leaking homes accounted for 53% of the leakage volume. This means that the overall leakage could be cut in half if the leaks in one out of ten homes could be eliminated. That alone, would reduce household use by 8 gphd, which would be a 6% reduction in overall indoor water use for the group.

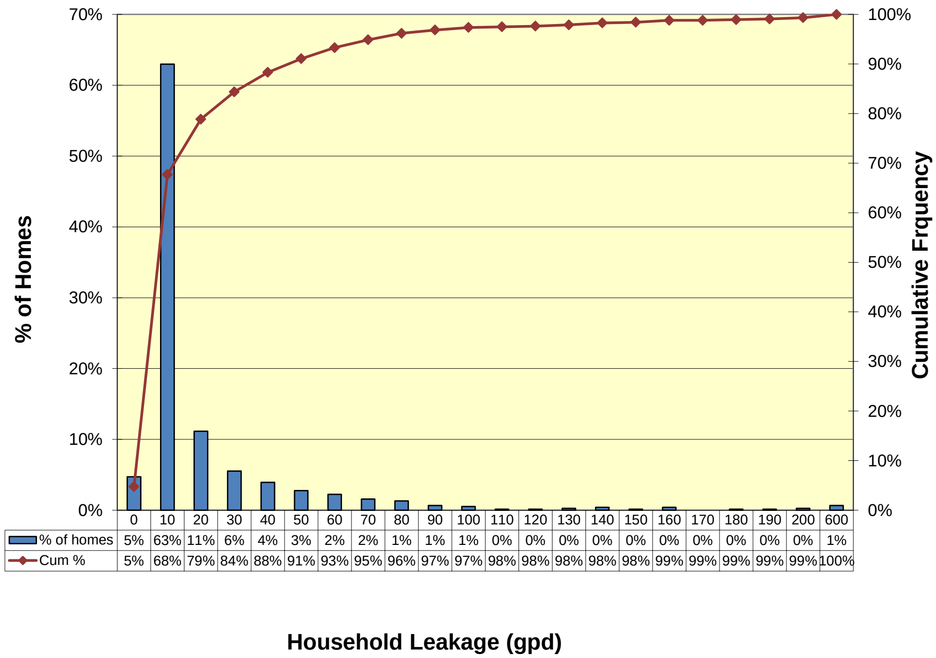

Figure 6: Distribution of homes falling into leakage rate bins

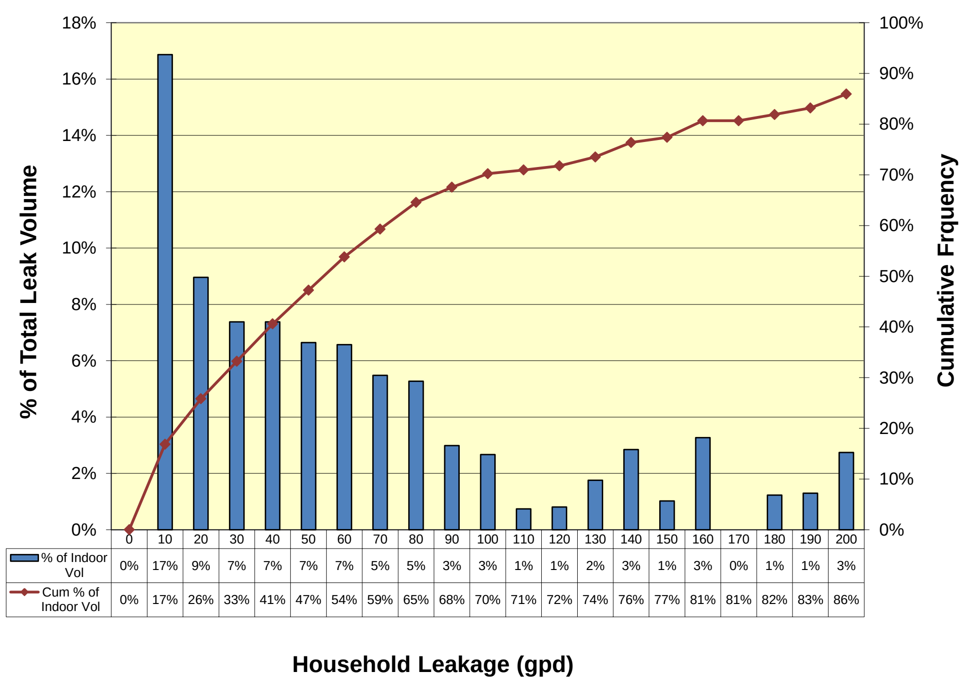

Figure 7: Distribution of leakage rates as a percent of the total leakage volume

Hot Water Use

During the logging periods the houses used an average of 138 gpd of water for indoor uses, and 46 gpf of this, 33%, was for hot water. Figure 8 shows how the hot water use was divided among the end uses. The two largest categories of hot water use were showers and faucets.

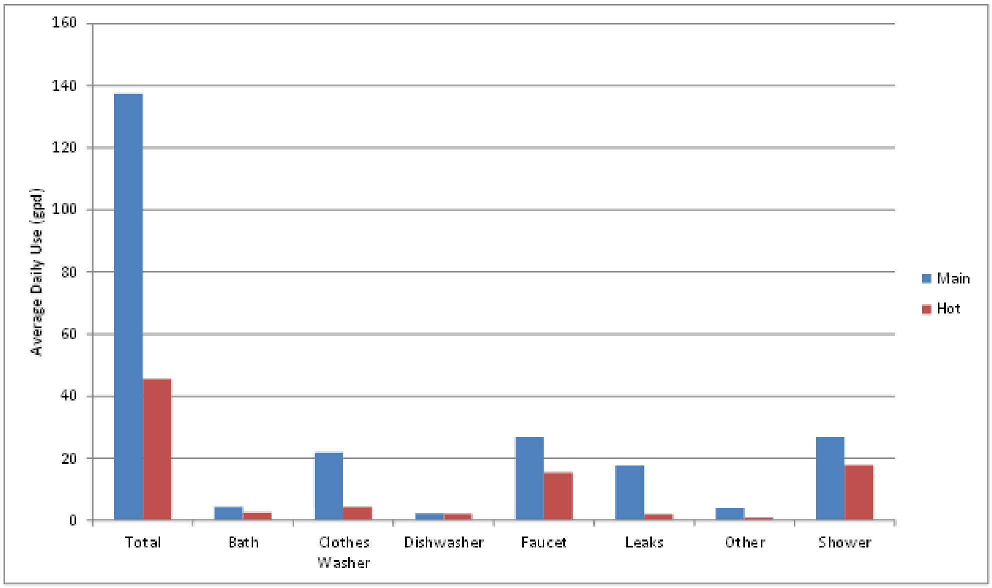

Figure 8: Comparison of main meter and hot water meter use by end use

The temperatures of the hot and cold water were measured during the home visit making it possible to derive estimates of the energy required for water heating. This information is presented in Table 65. The average monthly energy requirement for water heating in the homes was 753,000 BTU and this ranged from a low of 322,000 in Scottsdale to a high of 1.1 million BTU in Tacoma.

Frequency tables were prepared for hot water draws for showers and faucets and are presented in Table 66 and Table 67. These tables show the number of percentage of events falling within duration bins from 20 seconds up to 1500 seconds.

Hot water use was found to vary with the month of the year in which logging occurred. The peak period for hot water use was November through February. There was a distinct drop off in how water use from March through October. The monthly use data are shown in Figure 75.

Outdoor Use

Outdoor use was analyzed for each home on an annual basis by taking the difference between annual use and indoor use as the annual outdoor use. By outdoor use is meant water used for automatic irrigation and large uses for things like major pool filling and hose irrigation. Smaller faucet uses that may be for outdoor purposes such as car washing, or topping off of pools, would be included in the faucet category as indoor uses. In general, the outdoor use category is primarily for irrigation.

The actual irrigation use was compared to the estimated theoretical irrigation requirement (TIR) determined for each lot based on the irrigated area, plant types and local ETo for each. Allowances were made for reasonable irrigation efficiencies based on well-maintained systems so that the theoretical irrigation requirement could be used as a benchmark for the expected maximum irrigation use needed to satisfy the full plant water requirements. There is no norm that requires any property owner to apply the full irrigation requirement, and many residents made no attempt to irrigate to this level. The norm, however, assumes that if a resident elects to irrigate no more than the theoretical requirement should be applied to the landscape. Application of more than this amount constitutes excess irrigation. The savings from irrigation management would come from reducing excess irrigation while leaving the deficit irrigation alone.

The water requirements were also determined for landscapes composed of only cool season turf, which was referred to as the reference requirement. This parameter showed the amount of water needed to satisfy ET for a 100% lawn landscape. By taking the ratio of the actual irrigation requirement (based on the actual landscape) to the reference requirement the landscape water requirements could be classified according to the percentage of the reference ET (ET_o) they required. This was referred to as the Landscape Ratio. Overall, the average landscape ratio was 97%, which means that the landscapes were very close to the reference value. The lowest landscape ratio was found in San Antonio at 65% and the highest was in 1.13 in Toho. The landscape ratio only refers to the theoretical irrigation requirement relative to ET_o, and does not indicate the amount of water that was actually applied to the landscapes by the residents. The values for the landscape ratios for each study site are shown in Table 71.

The average lot size for the study group was 9831 sf. This ranged from a low of 5396 sf in Peel to a high of 16,797 in Scottsdale. The average area that was classified as landscaped was 5826, or 60%, and this ranged from a low of 2494 in Peel to a high of 11,195 in Clayton County. Note that because of the overlap of landscapes into street rights of way the landscape area can extend beyond the lot lines, and in the case of Clayton County this resulted in the average landscape area being slightly larger than the lot, which was an unexpected outcome, but one that made sense based on the land use.

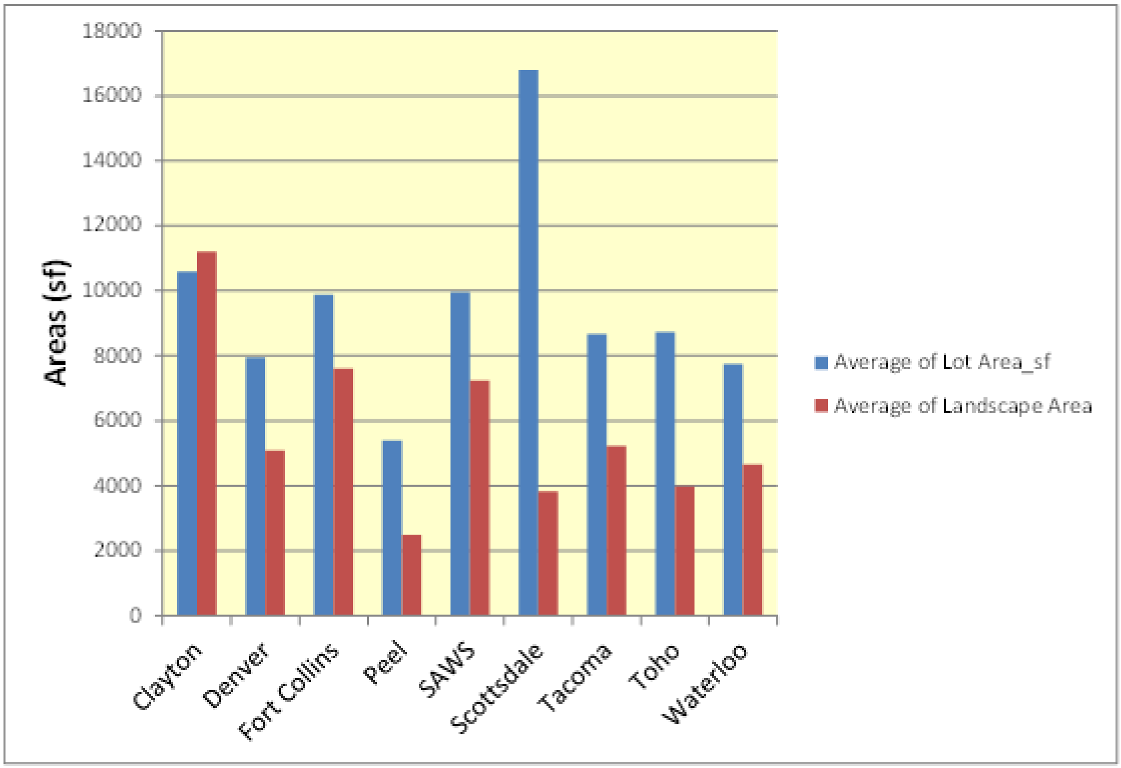

Figure 9: Lot and landscape areas

In terms of irrigation efficiency and water use the key parameter is the application ratio, which is the ratio of the actual irrigation use to the TIR. An application ratio of 1.0 indicates that precisely the "correct" amount of water is being applied to the landscape. When the application ratio is less than one then deficit irrigation is taking place, and inversely an application ratio greater than 1.0 indicates excess irrigation.

The application ratios in the study sites varied widely as shown in Table 2. The site with the lowest amount of irrigation was Clayton Count, which applied an average of just 19% of the theoretical irrigation requirement. Scottsdale, was the heaviest irrigator, with an average application ratio of 131%, this was the only site with a ratio greater than 1. The overall average application ratio was 58%. This table demonstrates that the preponderant state of irrigation application is towards deficit irrigation not excess.

Table 2: Average of individual values for TIR, actual use and application ratios

Site	Number	Average of TIR_kgal	Average of Outdoor_kgal	Average of Application Ratio[1]
Clayton	103	138	19	19%
Denver	95	99	77	87%
Fort Collins	88	175	55	34%
Peel	69	38	24	82%
SAWS	98	147	61	46%
Scottsdale	111	122	120	131%
Tacoma	107	61	27	55%

Toho	95	120	33	39%
Waterloo	72	67	13	21%
Overall means	838	110	50	58%

[1] These are the average for the individual home ratios and will not be equal to the ratio of the averages in columns 2 and 3.

More detail on the pattern of irrigation application on the 838 homes in the group is shown in Figure 10, which shows the distribution of the application ratios of each of the homes. This figure shows that 83% of the homes, 696 homes, were applying the TIR or less. This means that the total available volume of excess irrigation use was occurring in 17%, or 142, of the homes.

This result shows different numbers in terms of numbers, volumes and percentages from other studies discussed in the literature review, but the pattern of the distribution of ratios demonstrated in the figure is the same that has been seen in all of the studies. When it comes to irrigation use there is a consistently a relatively small number of homes which account for the large percentage of the total excess use.

The volumes of irrigation have been calculated in two ways: as excess and net use. In calculating the excess use the difference between the actual use and the theoretical requirement is calculated for each lot, but the value is not allowed to drop below 0, so where deficit irrigation is occurring (i.e. where the excess use is a negative number) this is treated as a 0 excess. When calculated on a *net* basis the actual algebraic value is used. This means that homes with a negative application offset the excess values. The results of these two approaches are very different and are both significant.

Table 3 shows the average volumes of excess and net irrigation at each of the study sites. There was a total of 6,880 kgal of *excess* use in the 838 homes of the study group, but this occurred in total of only 142 homes (17% of the total group). When calculated on the basis of excess use the average volume comes to 8.21 kgal of excess use over the entire group, but the average excess use on the homes where it was occurring was 48 kgal per home. This is a case where the mean value is misleading in that it implies an evenly distributed excess use pattern of just over 8 kgal per home per year, when what is really happening is that 83% of the homes are at or below their appropriate application rates and 17% of the homes are over irrigating by an average of 48 kgal per home. The consequences of this is that if the excess irrigation could be eliminated where it is occurring the average reduction in use would be 48 kgal per home on the 142 homes that were in the excess group, but the average reduction for the group as a whole would be 8.2 kgal.

The sum of the *net* irrigation volumes was -50,440 kgal. On the basis of net application this means that when the net volumes of excess or deficit irrigation were summed the total was a negative 50,440 kgal, and furthermore, if the entire group's water use was brought to the TIR at each site, as might be done with weather based irrigation controllers, the total water use would increase by over 50 million gallons, and the average change in use per home would be an increase of over 60 kgal. This has important implications for design of irrigation conservation programs.

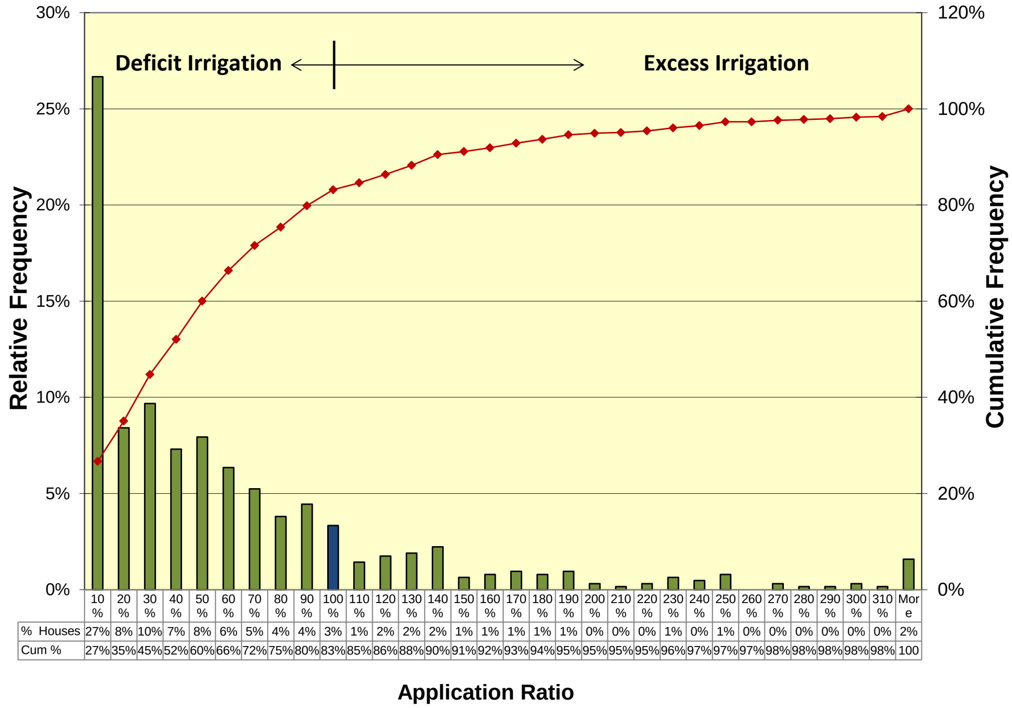

Figure 10: Distribution of application ratios for all study homes

Table 3: Volumes of excess and net irrigation (N=838)

	Data	
Site	**Average of Excess Irrigation (kgal)**	**Average of Net application (kgal)**
Clayton	0.18	-119.54
Denver	12.92	-22.49
Fort Collins	0.00	-119.92
Peel	6.42	-13.91
San Antonio	3.80	-85.31
Scottsdale	34.38	-2.62
Tacoma	5.24	-33.62
Toho	3.21	-87.30
Waterloo	1.95	-54.66
Average Volume	8.21	-60.19
Total Volumes	6,880	-50,440

Diurnal Use

Figure 11 shows the percent of total indoor water use that each of the end-uses accounts for during over the course of the day. As one would expect showers and toilets are the first uses to drive demands and these are followed by faucets, clothes washers. Leaks and other uses tend to be more evenly distributed. Bath tub use shows a small peak in the morning and a larger peak in the evening, as one would expect.

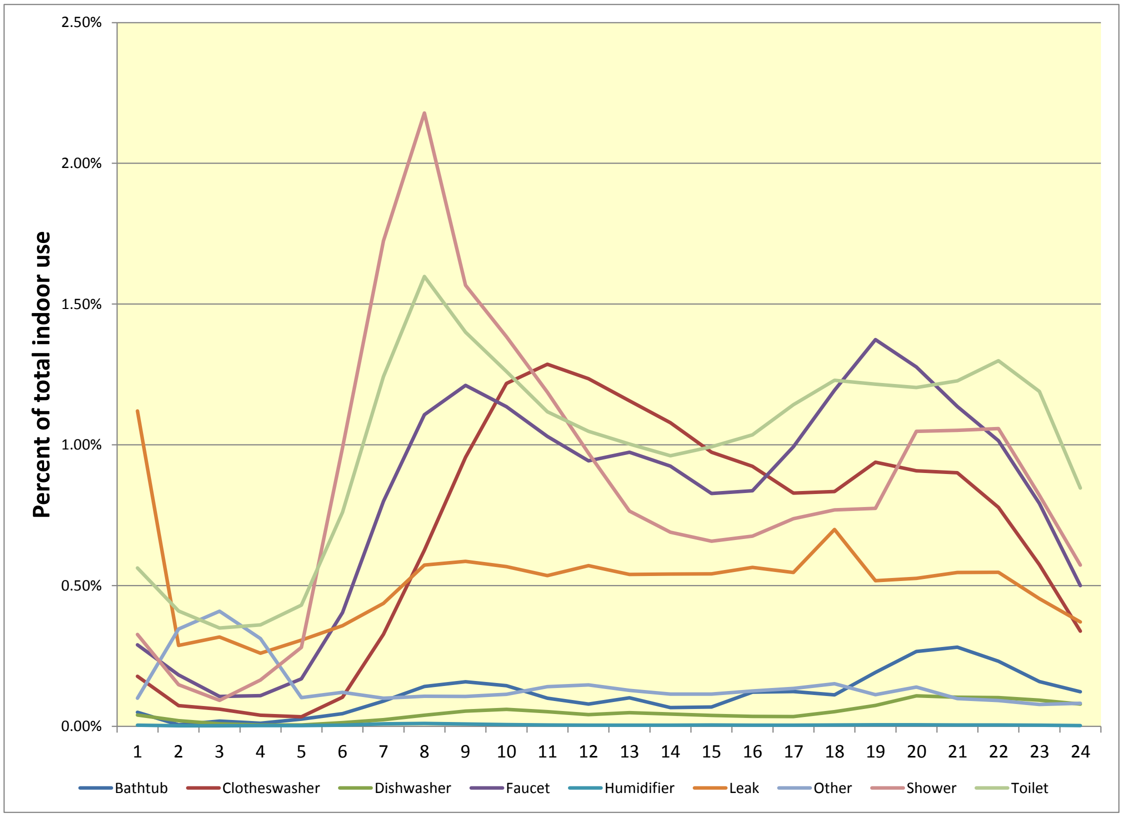

Figure 11: Hourly percent of total indoor use represented by end uses

Models of Water Use

Models of water use were developed from a combination of the water use summary data and the survey information. The model selection process can be characterized as an iterative search for statistically significant relationships governed by some guiding principles and constraints:

- Test and include variables that directly measure or serve as proxies for willingness and ability to pay
- Test and include variables that directly measure or serve as proxies for water requirements
- Increase sample sizes by relying on variables with fewer missing values
- Test and include variables (where possible) to distinguish the effects of efficient water-using technologies
- Seek model parsimony by explaining water use variability with an efficiently small set variables
- Assess parameter estimates by the sign and magnitude of estimated coefficients, as well as statistical significance.

Models were developed for indoor and landscape use separately since these two types of uses are driven by different sets of variable. The model for indoor use contained 9 variables, which were found to best explain indoor use from the available data from this data set:

1. Persons residing at the home (+.748)

2. Persons under age of 12 in home (-.186)
3. Size of the lot (+.122)
4. Presence of a swimming pool (+0.082)
5. Sewer Rate (-.112)
6. Presence of efficient toilets (-.174)
7. Presence of efficient clothes washer (-.073)
8. Presence of whole water softener (+.155)
9. Presence of hot water on demand (recirculation system) (-.109)

The list of variables also shows the coefficient for the variable. The sign of the coefficient shows the direction that water use changes as the variable changes. Positive signs indicate that water use increases with the variable and negative signs indicate that water use decreases as the variable increases. It is noteworthy that the presence of children in the home has a negative sign, which is an indication that children account of less water use than do adults. The reason that the presence of a swimming pool affects the indoor model is that much water use associated with a pool, such as topping the pool off, appears in the faucet category, and it is impossible to determine which faucet uses are for pools as opposed to other uses, so pool use tends to increase faucet use and indoor use. It is also interesting that the presence of a whole house water treatment system, (i.e. a water softener) was linked to a 15% increase in indoor use, while the presence of a hot water recirculation system was linked to a 10% reduction in indoor use.

An example of how the indoor model can be used to create estimates of water use is shown in Table 84 of the body of the report. This table shows that when the values for the variables from the study group are use with the coefficients from the model it predicts an average household water use of 138 gphd and per capita use of 53 gpcd, which matches the observed values. By changing the assumed values for the parameters one can use the model to estimate how household water use will respond. For example, if the percent of homes with efficient toilets and clothes washers were brought up to 100% the model predicts a reduction in household water use from 138 gphd to 119 gphd, which is equivalent to approximately 7 kgal per year per home.

A second model was prepared for the outdoor use data. For outdoor use there were two relationships presented: one for the fraction of residents expected to be non-irrigators (i.e with zero landscape use), and one that predicted the expected volume of annual landscape water use.

The following variables (with their coefficients) were identified as best predictors of the percent of non-irrigators in the population:

1. The high temperature of the site (-.254)
2. The precipitation (.036)
3. The volumetric price for water above 10 kgal (.066)

The variables (and their coefficients) that were found to be best as explaining landscape use were:

1. Number of children <12 yrs (-.3163)
2. Size of the parcel (.611)
3. Percent that is irrigable (.361)
4. Whether home was built after 2006 (.906)
5. Price for water at 10 kgal (-.904)
6. Average annual max temperature (-.875) during logging period

7. Total precipitation during logging period (.772)
8. Presence of swimming pool (.326)
9. Presence of drip irrigation (-.215)
10. Presence of in-ground irrigation (1.134)
11. Absence of turf in landscape (-.436)
12. Rain barrel in use (-.855)

Most of the variables in the landscape model are intuitively clear in terms of their impact on water use. The fact that young children tended to decrease landscape use was noteworthy. Also, the fact that newer homes tended to use more water for landscape to such an extent was interesting. The largest single factor that impacted landscape use, however, was the presence of an in-ground irrigation system, which is as one would expect. It is not clear why the presence of a rain barrel had such a strong negative impact. This could have been due to the fact that people with rain barrels were more water conscious than people without.

Benchmarking and Estimates of Conservation Potential

One of the advantages of obtaining highly disaggregated data is that it provides the analyst with a wider range of metrics of how water is used. Instead of just having a few coarse metrics based on annual, seasonal or monthly use, the end use data give information on daily, hourly and water use by individual events. This gives an entire spectrum of use data that allow water use to be characterized with a high degree of specificity and accuracy.

This chapter of the report presents information on the various types of metrics that the data provide and then discusses how benchmarks for efficient use can be developed that allow estimates to be made of the potential for water conservation in the study group. The chapter begins with a more detailed analysis and comparison of billing data, and generates a series of metrics for residential water use that follow the Water Conservation Metrics Guidance Report (AWWA 2010).

The chapter points out that due to the wide diversity of the types of customers and their individual water use patterns it is virtually impossible to develop any type of meaningful water use benchmark from simply the total water deliveries and the number of customers in the system. Benchmarking requires some level of uniformity in the customers being investigated.

It is normally possible to determine the total deliveries and number of residential accounts in the system, so it usually possible to develop an average annual use metric (AUM) for at least the residential and non-residential customers. The AUM metric was 88 kgal/acct/year, or 241 gpad for single family customers, and at 2.6 persons per home this is equivalent to 95 gpcd (359 lpd) for indoor and outdoor uses.

The benchmarking chapter goes into some discussion of the factors that explain the observed variability in the annual use metrics. One such example is the affect that annual precipitation has on water the annual use metric. A simple scatter plot of AUM versus annual precipitation shows that this parameter explains nearly 60% of the variability in annual water use among the sites. This makes perfect sense since annual use includes both indoor and outdoor use.

After concluding that billing data by themselves is a poor way to develop reliable efficiency benchmarks the benchmarking section investigates whether the observed reductions in residential water use are due to real changes in use based on higher efficiency devices, or only apparent changes due to modifications in the rates of use or number of persons in the homes.

There are several tables devoted to this process. The analysis, in Table 92, shows that the difference in water use that can be attributed to changes in occupancy or use rate is negligible. By applying two levels of efficiency benchmarks to the use for each study site the analysis shows the anticipated household use for each site based on their current use, use assuming efficient appliances are used and assuming ultra-efficient appliances are used. This information is summarized in Figure 12

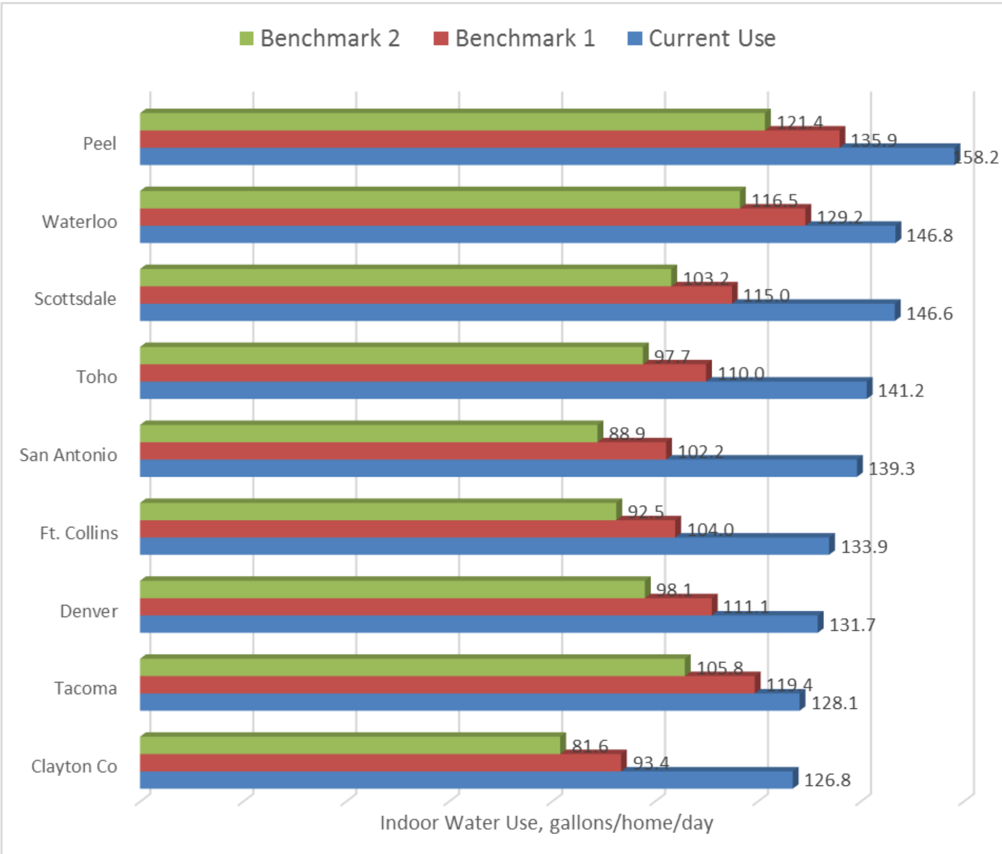

Figure 12: Estimated household use by study site for current use efficient and ultra-efficient use benchmarks

The household water savings projected from the study data are the difference between the current use and the projected use at the selected efficiency benchmark. Assuming that the ultra efficient benchmark is the most reasonable one to use, since it corresponds to the most recent standards, the projected water savings, shown in average 38.5 gpad, or 14 kgal per year. This represents as savings of approximately 16% of the baseline annual use of 88 kgal/yr (see Table 45) or ~30% of the average indoor use of 138 gpad (see Table 47).

Table 4: Projected indoor water savings

Site	Low Savings (gpad)	Hi Savings (gpad)
Clayton Co	33.4	45.2
Tacoma	8.7	22.3

Denver	20.6	33.6
Ft. Collins	29.9	41.3
San Antonio	37.1	50.4
Toho	31.2	43.5
Scottsdale	31.7	43.4
Waterloo	17.5	30.2
Peel	22.3	36.8
Average (gpad)	25.8	38.5
Annual (kgal/yr)	9.4	14.1

The situation with establishing benchmarks for outdoor use is much more complicated than for indoor uses since outdoor use is so varied from site to site, and is affected by unpredictable variables such as weather. Customer behavior is also wildly divergent and tolerance for under-irrigated landscapes can be high. What does not change from site to site is the pattern where a few customers account for the bulk of the over irrigation, and most customers are content to apply significantly less than horticultural theory predicts as the "correct" application. The data support the proposition that overall outdoor savings on the order to ~8.2 kgal per account are achievable for the study group, which represent an average of 16% of the base outdoor use or or 8% of baseline total annual use. The key, though, is that these savings will come from only around 17% of all customers.

CONCLUSIONS

The overall conclusion of this study is that if one wishes how much water a typical North American home requires the question should be qualified with the phrase "for what purpose?" What starts out as a dizzying array of values for annual use begins to show consistent patterns when the uses are disaggregated. The research team offers some of the salient conclusions that we draw from each of the topic areas.

From the Agency Surveys

The nine Level 1 study sites included in this project were located in a diverse set of climate types. There were 2 in humid, sub-tropical zone, 2 in the humid continental zone, 2 in the warm oceanic zone, 2 in the cold semi-arid zone, and one in the warm dessert zone. The maximum mean monthly temperatures In the group ranged from around 68 ^{o}F to 92 ^{o}F, and the minimum monthly temperatures ranged from around 20 to 60 ^{o}F It is not surprising then that outdoor water use patterns were also very diverse.

In most cases the water use for the Level 1 study sites was not impacted by drought restrictions during the study year. Two sites, Peel and Toho had mandatory outdoor restictions limiting irrigation to 1 or 2 days per week during 2010. San Antonio also had restrictions, but billing data for 2008 were used for the study (for determining outdoor use), which was free from restrictions. None of the other sites reported any outdoor use restrictions in place during 2010.

When the total billed consumption from 2006 through 2010 is plotted for the participating agencies the general trend in use was downward over the period.

The most common form of rate structure found in the group was the increasing block rate, with the most common number of blocks being 4 and the average volume in the first block being 6 kgal.

Many agencies include fixed charges as part of their water bills. The effect of these charges is to make the average rate in $/kgal decrease as customers increase their use—even though they may pay an increasing block for water use. There were only five agencies in which the average cost of water was greater in the top tier than in the first tier.

When fixed charges are excluded the average marginal price for water in the top tier of consumption averaged $6.16/kgal and ranged from $2.01 (in Chicago) to $17.14 (in Santa Fe).

There was only a single agency that did not have a budget for water conservation. The average number of staff reported in water conservation was 6 and the average budget was just over $3million.

Most of the agencies reported that they view water conservation as a method of increasing the reliability of their system, and they track the impact that their conservation programs have on annual household and/or per capita water use. By tracking costs and benefits of water conservation the agencies can evaluate demand management on an equal basis with supply site options. From this one has to conclude that the skepticism that was present about the efficacy of water conservation during the preparation of the first REUWS study has disappeared.

Every agency in the study group reported having an active water loss control program and in almost all cases they use the AWWA M36/IWA accounting procedure for estimating losses.

From the Customer Surveys

The results of this study indicate that approximately 1 in 3 households who received a survey took the time to fill it out and return it. Given the fact that this was a five page document this response rate is excellent and shows that people will make an effort to assist in this type of research.

On average, the number of residents per home has remained stable since the first REUWS. There was an average of 2.6 persons per household in this study compared to 2.8 persons in REUWS1.

Two thirds of the homes reported having a high efficiency clothes washers and the flow trace analysis showed that approximately half of the homes had clothes washer load volumes of less than 30 gpl. This makes sense since it is possible to operate a nominally high efficiency washer with settings that will use more than 30 gallons. Also, some residents will naturally be uncertain about exactly what type of washer they may have so some miss-reporting is expected.

The average number of toilets in the homes was 2.5, in REUWS1 the average was 2.3.

A surprising number of homes reported having recirculation pumps on their hot water lines in order to reduce the wait for hot water at the tap. The site with the greatest number of these devices was Scottsdale, where 30% of the homes reported having one.

There was not any site in which swimming pools were absent. Fort Collins and Denver had the lowest percentages of homes with pools and Scottsdale and Toho had the highest.

On average around 30% of the homes in the group did not irrigate their landscapes at all. Sites in the humid climates tended to have less irrigation which sites in the drier climates Denver, Fort Collins and Scottsdale had the highest percentage (>90%) of irrigators.

When people reported irrigating around 25% said they watered exclusively by hand and the rest had at least a portion of their landscape under an automatic irrigation system. This equates to around 53% of all homes that were equipped with in-ground irrigation systems. In the REUWS1 study the percent of homes with in-ground systems was 41%. We would not draw any conclusions from this since the nature of the study groups was different in the two studies with respect to climate.

One thing that can be concluded from the information on irrigation controllers is that significantly more systems are equipped with weather based or smart controllers. In some sites overs half of the customers reported having smart controllers.

Indoor uses have clearly declined over time, primarily as a result of the introduction of high efficiency toilets and clothes washers. These two categories of indoor use have shown unambiguous decreases.

Water use for the other indoor categories has also shown decreases, but these are not as statistically robust as those for the toilet and clothes washer categories.

Customers showed a fairly good understanding of the drought situations in their area. There are five levels in the office drought monitor report (no drought, mild drought, moderate drought, severe drought and extreme drought. In most cases the customers were within one level of the official status in their understanding. That is, if the official status was moderate, the customers tended to either rate the drought at moderate or mild.

From Water Use Statistics

The average annual water use for the Level 1 and 2 sites was 88 kgal (333 M^3), which is equivalent to 241 gpad (910 lpac) or 95 gpcd (359 lpcd) for all uses. The range of annual use was from 44 kgal to 175 kgal per account (166 to 662 M^3/acct).

Indoor use averaged 138 gpad (521 lpad) or approximately 53 gpcd (200 lpcd). (This includes leakage, which is really not a "use" of water, and is considered equivalent to a parasitic load in an electric system.)

The relationship between household water use and the number of residents is not a linear one, but follows a power curve Indoor use = $67.3 \cdot Res^{0.654}$ (gpd). Knowing this is important in order to avoid over estimating domestic demands for larger households.

Indoor use has declined significantly since the REUWS1, from 177 gpac (670 lpac) in the former to 138 gpad (521 lpad) in the latter.

The two main driving forces in the observed reduction in indoor use were toilets and clothes washers, both of which showed statistically significant reductions.

There were decreases in use for the other indoor categories, but these were not statistically significant. Even though these changes were not statistically significant (at the 95% confidence level) the fact that reductions were seen in virtually all categories is suggestive that real reductions are occurring.

The largest reductions in water use were seen in clothes washer use and toilet use. The smallest changes were in the shower and faucet categories. The fact that the categories of use that are based on behavior showed the smallest changes suggests that even with more efficient showerheads and faucet aerators there is a base use level, below which it is difficult to drive demands.

The usage rate for toilets and clothes washers did not change significantly between REUWS1 and 2, so we know that the observed changes in the daily use are not due to changes in how frequently people are washing clothes or flushing toilets.

In the REUWS1 study only 16% of all flushes were in the efficient range (<2.2 gpf 8.3 lpf), but in the REUWS2 study 51% of flushes were in this range. The average flush volumes dropped from 3.66 gpf (13.8 lpf) to 2.60 gpf (9.8 lpf).

In the study group there were around 30% of the homes with very few flushes in the efficient range, implying that these homes are equipped exclusively with older, inefficient toilets. At the same time there were around 33% of the homes that appear to be equipped exclusively with efficient toilets. The remaining homes contain a mixture of old and new toilets.

The average number of showers per household per day was precisely the same in both the REUWS1 and 2 studies—1.8 showers per day. The duration of the showers was 7.8 minutes in both studies. The average flow rate for showers was slightly lower, at 2.1 versus 2.2 gpm (~7.9 lpm). Overall, except for houses with ultra-efficient showers there was no observable change in shower use between the two studies.

Between the two studies over 1.5 million faucet events were logged, which accounted for over 1 million gallons of water use. The number of faucet uses per day per person was between 15 and 20 uses, and the average daily use for faucets was 26-27 gpad (~100 lpad). Ninety percent of all faucet events were less than 90 seconds in duration and used less than 1.2 gallons of water. Overall, it was not possible to detect a significant change in miscellaneous faucet use between the two studies.

Clothes washer use in terms of loads per day was virtually identical between the two studies, but the volume of water required for a load dropped from 41 to 31 gallons (155 to 117 liters). Water efficient clothes washers have been critical at reducing domestic water use.

While dish washers do not account for a large percentage of total domestic use the volume of water used for a load of dishes has dropped significantly. In REUWS1 an average load of dishes used 10 gal (37.9 l), while in REUWS2 an average load consumed 6.1 gal (23 l), which is a 40% reduction.

In this study the presence of a dish washer had no impact on average faucet use.

Bathtub use is infrequent. On average a bathtub filling was recorded only once every 5.5 days, but in most houses no tub use was recorded at all. The average volume of water per bath was 20 gal (76 l).

The data on leakage are clear: a small percentage of homes contribute the bulk of the leakage. Two thirds of the homes in the study were leaking at 10 gpd or less, but these accounted for just 17% of the total volume of leakage. The one third of homes with leakage greater than 10 gpd accounted for 83% of the total leak volume. The top 10% of homes were leaking at more than 50 gpd, and they accounted for 53% of all leakage.

The large leak volumes were associated with continuous low flow rate leaks, not short intermittent leaks. If plumbing controls or AMI systems could identify homes with continuous low flows the leakage rate could be cut in half.

Homes in the study group used an average of 45 gpd (170 lpd) of hot water, which represents approximately 1/3 of the total water us in the home.

The biggest two users of hot water in the home were showers and faucets. Clothes washers used less than 5 gpd of hot water.

On average the homes used 753,000 BTU/month for water heating during the study.

Hot was use was found to increase during the winter months.

Outdoor use was similar to leakage in the degree to which the use was skewed by a few heavy users. Overall, the ratio of actual landscape use to theoretical requirements was 58%, but only 20$ of the homes in the study group were over-irrigating. This means that the entire conservation potential from improve landscape management (as opposed to wholesale changes to landscape such as turf removal) is expected to derive from just 20% of the customers.

Because so many homes are under-irrigating any general attempt to bring everyone into compliance with ET requirements (such as with WBICs) could lead to major increases in landscape water use. The data collected as part of this study clearly suggest that irrigation programs must be targeted to customer who are heavy users of landscape water.

The diurnal use pattern for indoor uses follows the typical two peak pattern, with a large peak occurring in the morning and a smaller peak occurring in the evening.

Showers and toilets drive the morning peak while faucets and toilets drive the evening peak.

From Models

The regression models prepared from the study data showed that the most important predictor of indoor water use was the number of persons residing in the home.

Children account for a lower water use than do adults.

Indoor water use rises with the size of the lot and with the presence of a swimming pool, and both of these may be the effect of additional faucet events occurring for pools and landscape use which are classified as indoor use by the analysis.

The cost for water was not found to be a determinant for indoor water use, but the cost for sewer service was.

High efficiency toilets and clothes washers were found to decrease indoor use, as was the presence of a hot water circulation system for on-demand hot water.

If the three variables that were found to decrease indoor water use: high efficiency toilets, clothes washers and hot water systems were all set to 100% saturation the model predicts that the household use for the group would decrease from 138 gpd to 108 gpd, or from 53 gpcd to 41.5 gpcd—a 21% reduction in indoor use.

The model does not deal with leakage rates explicitly, but if leakage control system could be implemented household use could easily drop below 100 gpd.

The regression analysis for outdoor, landscape uses found that the chief predictors of outdoor use for landscape were the size of the parcel, the percent that is irrigated, whether the home was built after 2006, the local weather and the presence of a pool or in-ground irrigation system. The model did not deal with the presence of excess irrigation explicitly.

Since most of the terms in the outdoor model are related to factors that the utility can not control it is difficult to use it to predict conservation potential. The factors that could be controlled in the model are the percent of the lot that is irrigable, which could be limited, the presence of a pool, which could be discouraged, and the presence of an in-ground irrigation system. Of the three, the only item which really lends itself to regulation is the percent of the lot that is irrigable, or in turf. Local agencies could require landscapes to be less turf intensive and have less irrigated area. It seems improbable that banning pools or in-ground irrigation systems would gain much favor.

The un-named item in this list is eliminating or reducing excess irrigation. As discussed in the benchmarking section, elimination of excess irrigation is the single biggest source of landscape conservation available.

From Benchmarks

By examining the current water use patterns in light of known benchmarks based on levels of efficiency of indoor and outdoor use it is possible to derive estimates of potential water conservation savings.

By use of the benchmark method the target level of indoor use was shown to be 96 gpad and this assumes no change in the average leakage rate, but it does assume that over time water sense standard fixtures and appliances will be fully utilized.

Given the fact that both modelling and benchmark analysis both point towards indoor domestic use around 100 gpad makes this a very compelling planning value. If leakage could be addressed then indoor use as low as 90 gpad is not unreasonable.

Starting from the existing indoor use of 138 gpad a reduction to 100 gpad represents a 27% reduction in indoor use over time from current levels, and a reduction of approximately 44% compared to the indoor use levels from the REUWS1 study, of 177 gpcd.

The benchmark for outdoor use is based on elimination of excess irrigation where it is occurring while leaving the deficit irrigators to carry on. If excess irrigation could be eliminated in the study group then the average outdoor use for the entire study group would drop by 8.2 kgal. (It would decrease by ~48 kgal on the homes that were over-irrigating.)

A savings of 8.2 kgal/year in outdoor use represents a 16% reduction.

It is really not possible to project these precise savings volumes onto the country as a whole since irrigation rates vary so much. It is necessary to do local studies of irrigation use for each community in order to get savings estimates that pertain to any particular service area.

APPLICATIONS/RECOMMENDATIONS.

The end use data collected for this study has been used by water agencies, universities, regulatory bodies and code developers and manufacturers for a myriad of purposes. The most common use of the data has been for developing planning models of residential water demands. Many demand models rely in information on the number of uses per day for each fixture and appliance in the home, and their volumes in order to estimate household demands. The data from this study, like its predecessor, provides this information.

Knowing the flow characteristics for devices of a range of efficiency allows benchmarking to be done, which provides an excellent way of both gauging the current level of efficiency of the service area customer and in making estimates of remaining water conservation potential, which is necessary for system planning.

The water use data from the study provide a baseline against which the impacts of various water conservation programs can be tested. These include things like faucets, toilets, hot water systems, leak detection devices and other conservation devices that have yet to be discovered.

The data on percentages of homes that meet efficiency criteria for toilets, clothes washers and showers has proved useful for design of residential retrofit programs and in evaluating the effectiveness of programs after their implementation. This information also helps determine which programs should be emphasized and which might be discontinued.

The State of New Mexico, Office of the State Engineer, has used the flow trace data and database of residential water use as part of its system for granting groundwater permits which require household and per capita water allocations based on the current levels of efficiency. These were extracted from the high efficiency homes in the data set.

The outdoor use data shows how the customers are actually applying water to their landscapes as opposed to how they are believed to be applying water. Knowing that the bulk of customers are under-irrigating, and that the bulk of waters savings from improved irrigation management will come from a small number of heavy users should have a major impact on the types of landscape conservation programs that are implemented, i.e. targeted programs.

The mathematical models derived from the data are useful in understanding which factors best explain and predict water use, and how changing each of the explanatory variables is likely to change the use of water. These models provide information on the parameters, the direction of their impact on water use and the relative magnitude of their impact. They also help point away from factors that do not have a good explanatory value for water use. The models also help elucidate the elasticity of water use with respect to the parameters.

A huge amount of work went into design and implementation of the surveys. These surveys, sent to random samples of single family water customers, provide a representative picture of the demographics, physical characteristic, types of fixtures and appliances present in the homes and attitude of the customers. The fact that the surveys were all conducted within a short period of time provides a contemporaneous snapshot of customers, across the United States and Canada.

An area where several entities have used the data is in mining the raw event files. For example, the Water Quality Association used event data from the REUWS1 study to determine the actual volumes and flow rates of domestic uses so that they could design water filtration systems that match the actual demand patterns and are not over-sized.

Tacoma Power actually expanded the hot water portion of this study in order to obtain hot water trace data for simulating the operation of heat pump water heaters. By knowing the timing, volume and flow rate of each hot water draw Tacoma Power was able to determine how much of the hot water use would be supplied by the heat pump portion of the system and how much would require use of the resistance element of the (electric) water heater.

The international association of plumbing and mechanical officials (IAPMO) has used the flow trace data from the historical data to update the Hunter method of determining peak water demands based on real, empirical, data on the frequency of water use events,(by fixture), their duration and peak flow rates. This allows the actual hourly probabilities that a given fixture or appliance will place a demand on the water system in a given hour of the day, which can then be used to determine the probably peak flow that the system sill need to accommodate for that device. This should lead to much better meter supply pipe and service line sizing, and avoid the chronic over-sizing that the original approach engendered.

Another promising area that the research opens up is the use of monte carlo simulation techniques for predicting demands. In this approach rather than relying on regression analysis, the daily use data for each fixture type are used to generate probability distributions of demands, which are then sampled repeatedly to generate a range of probable demands that match the underlying distributions obtained from the end use data. This mechanistic and deductive approach is far less data intensive, and can reproduce the full range of demands within the range of the probability distribution. (See Cahill, 2013)

There are many areas where future research could help amplify and clarify the results of this study. One of the most interesting would be to sample from only homes in the top ~20% of single family users. The data show that the majority of savings are expected to come from a small number of homes. So, obtaining better information on the sources and explanations for high water use would be very helpful in designing water conservation programs.

Another repeated observation from this study and all previous end use studies is the consistent presence of very long duration events that have been classified as leaks in a small number of homes. In most cases where survey data are available there is nothing in the survey that would explain a constant flow of water (lasting for days at a time) except a leak. It would be very interesting and useful to do follow up interviews and perhaps additional data logging on a group of homes that have been identified as large leakers. For example, in the present study it was found that just 21 homes accounted for over 30% of the total leakage in the group. Follow-up studies on these homes could help shed light on whether the events that were classified a leaks in the study are actually leaks or something else that gave the appearance of leaks.

Simply repeating this study on a ten year basis would be very helpful in seeing how water use patterns are changing in random samples of homes. One of the most interesting parts of the current study was in seeing how water use changed since the first study from 1996-1999.

Another interesting variation of the study would use data loggers that use cell phone network to transmit the data to a server rather, and to leave them in place for a long period of time on samples of high water use homes. Data from the loggers would be analyzed and information sent to the residents informing them of they consumption (relative to a budget that each would be given), and would notified fo leaks in a near real time basis. The goal of this would be to determine if customers are willing and able to modify their consumption patterns when provided with benchmarking information and information on which they can act to regulate their water use.

Since the flow trace analysis technique has been used in several countries around the world it would be interesting to collect as many of these studies as possible and compare the results to see how domestic consumption varies by geographical area.

MULTIMEDIA

The element of the project that lends itself to multi-media publication is in the database files. These are currently on a limited access website from which authorized users can download them. They could also be published on CD-ROM, but the final decision about this has not been made by the Research Foundation.

INTRODUCTION AND GOALS OF PROJECT

In 1996 the then AWWA Research Foundation, now the Water Research Foundation (or The Foundation), undertook a study of the end uses of water in single family residences. This study was established in recognition of the need for more precise information on how much water was used in single family residences for individual end uses. In 1993 a task force of water conservation officials enlisted by the Foundation listed the need for end use data as their number one research priority at that time. So, the solicitation of proposals to do this study was a natural response to the real need for information expressed by the professionals on the advisory committee.

Needing the data and being able to collect it in a practical manner are two different things. It also happened that approximately the same time period in which the need for the data was being highlighted (the mid 90's) two other things were happening in parallel: the Heatherwood study (Aquacraft 1994) was showing that high resolution flow data could be obtained from magnetically driven small water meters, and that these data could then be disaggregated into end uses, and secondly, data loggers came onto the market that were able to collect these data and were small enough, and rugged enough to survive placement in water meter pits.

The fact that the hardware and software were available in 1995 for collecting flow trace data from residential water meters and disaggregating them into individual end use events meant that it became practical to conduct a large scale research project on residential end uses of water in North American homes and make this information available to water planners. This study took the form of the Residential End Uses of Water Study (REUWS), which began in 1996 and was published by the Water Research Foundation in 1999 (Mayer et al, 1999).

The original REUWS study was based on a methodology of selection of random samples of customers, and obtaining very detailed information on their physical and demographical characteristics and their water use. From this information detailed statistical analyses were prepared and mathematical models of water use created which then allow the results to be extrapolated to other similar populations. The idea of both studies was not to assemble a sample that represented the entire North American population of single family water customers. Rather, the objective is to obtain a large and diverse sample from which the relationships between a manageable set of explanatory variables and water use can be established by modeling. The models then could be used to predict the effect of things like replacements of fixtures and appliances, or the presence of pools or sprinkler systems on water use.

Single-family residential customers comprise the largest individual demand sector for most North American water providers. Consequently, understanding where and how much water is used in single-family homes is essential information for the water community. Everyday water use patterns of residential customers are key drivers of overall utility demands and have been the subject of scientific research since the 1940s. Changes in residential water use are important to detect and quantify because these changes can significantly alter the overall demand patterns for the water provider. Failing to properly adjust demand forecasts to account for changes at the household level can lead to serious over-investment in expensive water supply and treatment projects. The fundamental goal of this research project (REUWS2) was to update and expand the Water Research Foundation's (WaterRF) 1999 Residential End Uses of Water study (REUWS1) with new information obtained nearly 20 years after the original study data were collected in order to see how demand patterns have changed over time.

The REUWS2 addresses water uses at the end use level. "End uses" of water refer to a set of fixture and appliance types that can identified through flow trace analysis. As discussed in the Methodology chapter these include both very specific fixtures, such as toilets, clothes washers and automatic irrigation timers that can be readily identified, and less specific uses such as miscellaneous faucet uses and leaks that can be identified by the flow characteristics, but cannot be precisely pinned down as to the location or exact intention of the use. The result of the analysis is a breakdown of water use into the major categories of use such as toilets, showers, clothes washers, faucets, lawn watering, etc. Accurately measuring and modeling the residential end uses of water and the effectiveness of conservation efforts is essential for planning and managing urban water systems. Understanding where water is put to use by the consumer is critical information for utilities, planners, and conservation professionals.

The 2014 *Residential End Uses of Water Update* adds to understanding of urban water use patterns in North America and measures important changes in residential water use patterns that have occurred over the 15 years since the REUWS1. The REUWS2 updates and expands upon previous research by measuring water use patterns in 762 randomly selected households from 9 urban areas in the United States and Canada. Water use was monitored in these homes for approximately two week each and historic consumption data from billing records were available for several prior years. Individual end uses of water such as toilet flushes, showers, clothes washers, faucets, dishwashers, leaks, etc. were disaggregated using the flow trace analysis techniques developed by Aquacraft. The research team, led by Aquacraft, followed the same basic analytic approach to the research that they used in the REUWS1.

The products of the 2014 *Residential End Uses of Water Update* research effort include:

- Average annual, seasonal, and non-seasonal water use from 23 water providers in the U.S. and Canada.
- Disaggregated end use data from 762 homes from 9 water providers in the U.S. and Canada.
- Benchmark comparisons of water use between the REUWS1 and the 2014 REUWS Update.
- Information on the saturation rate of water efficient fixtures and appliances.
- Analysis of residential leakage patterns.
- End use measurement of hot water use by end use in 110 homes.
- Landscape and outdoor use analysis from 762 homes.
- Analysis of the socio-economic factors that influence water use.
- Predictive models of water use.
- Assessment of conservation potential and benchmarking.
- A literature review of end use research from around the world and bibliography.
- A research database of the billing, survey and end use data developed for the study, and from key historical studies, going back to the REUWS1 that will be available to researchers for additional studies.

This report summarizes the methodology and important findings of this study and presents a number of analyses based on the database assembled over the course of the study. However, it would be impossible for this report (or any report) to exhaust to possibilities of analysis presented by the extensive database collected over this two year research effort. It is anticipated the data resource developed in this study will be utilized to expand and enhance future research efforts as well.

This report represents a time and place snapshot of how water is used in single-family homes in numerous North American locations. Similarities and differences among "end uses" were tabulated for each location, analyzed, and summarized. Great care was taken to create a statistically significant representative sample of customer for each of the participating water utilities. However, these sites all volunteered to participate in the project and no effort was made to determine is these sites are statistically representative of any or all North American locations.

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

The diversity of the water use data found over the research locations illustrates the importance of utility specific information on how individual behavior and household technology influences home water use. This report also reveals striking similarities in water use patterns between study locations. The measurements of water used by fixtures and appliances like toilets, washing machines, showers, dishwashers, faucets, and fixture leaks should have significant "transfer" value across North America to similar regions and communities. The predictive models developed as part of this study to forecast indoor demand significantly increase the confidence in explaining the water use variations observed. The major benefit of modeling is to provide a predictive tool with a high transfer value for use by utilities that did not participate in the actual research.

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

1. The accuracy of the billing consumption histories provided by participating utilities
2. The accuracy of the water meters from which the raw data were obtained, especially at very low flow rates.
3. The accuracy of mail survey responses.
4. The timeframe of monitoring capturing "representative" indoor water use for each home.
5. The exact cause of many continuous leak events that occurred in a small number of homes, but represented such a large volume of water that they raised the average leakage rates for the entire study group.
6. The precise location of many small leak events was impossible to determine so they were grouped as leaks and included as part of the indoor uses. In fact some or many of the leaks may have been associated with irrigation systems, swimming pools or outdoor hose bibs.
7. The exact place of use of many faucet events, which may have been for one of many indoors uses or for outdoor uses such as plant watering or car washing. These events, like leaks were all labeled as “faucets” and modeling was used to elicit the factors that impacted faucet (and leak events).

LITERATURE REVIEW

INTRODUCTION

Water use in homes and buildings has been the subject of scientific research in North America since the 1940s. Single-family homes typically use the most water of any customer sector of North American water utilities and that is why the water demands of the single-family residential sector are of significant interest and importance to the water industry. Since 1994, interest in the end uses of water has intensified as the Energy Policy Act of 1992 (DOE 1992) and other codes and standards measures have reduced toilet volumes as well as shower and faucet flow rates and as urban water demand management programs have become a focus for some water utilities.

The most significant residential end use study conducted in North America until now is the over the Water Research Foundation's 1999 Residential End Uses of Water (Mayer et. all. 1999). The 1999 Residential End Uses of Water (or REUWS1 for short) provided detailed information on residential water use patterns and efficiency levels in a sample of 1,188 homes. Since publication of this landmark report, many other residential end uses studies have been conducted around the world to help improve understanding of water demands and the factors that influence water use. Over the past 15 years, interest in residential water use around the world has grown and significant end use studies have now been undertaken in Australia, Great Britain, Spain, New Zealand, Cyprus, Jordan, the United Arab Emirates, and many other countries.

The primary goals of most residential end use studies have been to determine how much water is devoted to the primary end uses (such as toilets, clothes washers, showers, faucets, and irrigation), the level of water efficiency that has been achieved, and to delineate the key factors that affect the end use patterns. Billing data analysis, customer interviews, surveys, home audits, retrofit studies, and more recently flow data recorders and flow trace analysis software, are among the tools that have been used by utilities to evaluate customer demands and estimate the effectiveness of conservation measures.

The 1999 Residential End Uses of Water pointed out that, "Accurately measuring and modeling the residential end uses of water and the effectiveness of conservation efforts has been the Achilles heel of urban water planning for many years. Understanding where water is put to use by the consumer is critical information for utilities, planners, and conservation professionals." (Mayer, et. al. 1999).

Today we understand much more about how and where water is used in residential housing than we did in 1999, but end use research remains and important topic because of the changes in water use that have been brought about by water efficiency efforts. End use studies are an effective way to benchmark progress in water efficiency and to improve understanding of the conservation potential the remains yet to be achieved.

This literature review describes the history of end use studies and places in historical context the methods developed Aquacraft over the past 20 years that have been adapted world-wide to conduct water use research. These are the same methods were used to conduct the 2014 Residential End Uses of Water Update.

HUNTER CURVES

An interest in peak demands spurred some of the earliest published demand monitoring efforts. In 1940 an engineer name Roy Hunter developed peak demand profiles for the National Bureau of Standards (Hunter 1940). These profiles are known today as the "Hunter curves" and demand curves derived from Hunter's work can still be found in AWWA manuals of practice used for sizing meters and service lines (AWWA 2014). The Hunter curve approach applies an understanding of the water uses and peak fixture flow rates within a building along with theoretical estimates of the frequency of fixture use and the probability of simultaneous use to derive estimates of the peak instantaneous demands for water in buildings. This approach has been widely adopted and applied for the purpose of sizing service lines and water meters across North America since 1040.

There have been significant changes in water use patterns over the more than 70 years since Roy Hunter first published his pioneering, but the basic method he developed has endured. Recent changes to plumbing fixtures and appliances brought about by national and state codes and standards have reduced volumes, flow rates, and the duration of individual fixture flows in buildings of all sizes. These changes have reduced peak instantaneous demands and reduced the probability of simultaneous water uses. Unfortunately the water industry has been slow to update the demand curves used for meter sizing and as a result, meter and line sizing calculations are frequently based upon assumptions that include old volume and flow patterns (AWWA 2014).

The importance of flow profiles (i.e. high resolution time series flow rates that allow individual uses of water to be identified) was recognized in the years following Hunter's pioneering work. By the mid 1970's water utilities across the U.S. deployed mechanical flow monitors with circular chart recorders to measure flow profiles from individual water meters. The resulting flow diagrams, frequently referred to as "flow traces" since a pencil was used to physically trace the flow on a piece of circular graph paper, allowed actual peak demand information to be collected from meters serving specific customers, whose size and other characteristics were known. The first edition AWWA Manual 22 Sizing of Service Lines and Water Meters used data from these empirical observations to revamp the original Hunter curves to estimate peak demands (AWWA 1975).

1984 HUD STUDY

In the 1970s and 1980s population increases coupled with episodes of severe drought necessitated utilities to adopt policies and programs to manage water demands through conservation and efficiency. Questions about the efficacy and longevity of the water savings heightened interest in new research and approaches for measuring water use patterns at the end use level. As new water supplies became both more difficult to find and expensive to obtain, water providers began to see water conservation as an economic way to delay or eliminate the need for costly new water supply projects. AWWA's 1981 Water Conservation Management handbook was one of the first professional publications to describe utility-scale water conservation program methods (AWWA 1981).

In 1984 the US Department of Housing and Urban Development (HUD) published a study on residential water use conducted by Brown and Caldwell. The landmark Residential Water Conservation Projects---Summary Report was one of the first research studies to measure the end uses of water in residential structures by instrumentation (Brown and Caldwell 1984). This national study of 200 homes culled data from studies conducted in California, Colorado, Washington D.C., Virginia, Georgia, and Virginia to provide baseline water use information as well as estimates of potential savings from conservation efforts at the household level. The text of the report identified the essential problem that had been vexing water professionals regarding residential usage patterns:

"Although testing has established water use for residential plumbing fixtures and water conservation devices under laboratory conditions, estimates of water and energy savings with reduced-flow fixtures and devices have been based upon very different assumptions regarding typical duration of fixture use, flow rate, temperature, and frequency of use. As a result, estimate savings found in the literature for water-saving fixtures and devices span a range of nearly 300 percent." (Brown and Caldwell 1984)

Results from the 1984 Brown and Caldwell study offered a great improvement in the understanding of water use patterns and potential savings from water efficient fixtures. Of significance was the finding that water savings from fixture retrofits did occur, but in many cases the actual savings were less than what was predicted from theoretical calculations (Brown and Caldwell 1984). The study findings also suggested some of the savings found initially tended to decrease with time. The applicability of the HUD study results to the general public was somewhat limited by the research methodology where by participation in this study was voluntary. In addition the equipment used to measure water use required significant intrusion into the normal operation of the homes. These issues brought forward the importance of developing accurate and unobtrusive ways to measure water use and water savings from random samples of customers, but it would be seven years until publication of another significant residential end use study.

A 1990 study by Cameron published in Water Resources Research employed a discreet choice model and survey to estimate the impact of a residential retrofit program, but the sample size in the study was quite small (Cameron, et. al. 1990). Water utilities were interested in better understanding the water use patterns of their customers, but a research methodology that could be inexpensively applied to larger random samples of customers had not yet been developed.

NEW APPROACHES IN THE 1990'S

The 1990s saw the ascent of the Internet and the explosion of micro-computing technology. These innovations enabled significant advances in the measurement and analysis of urban water use patterns. In 1991, the Stevens Institute of Technology published the results of a residential end use study conducted in the Oakland bay region for the East Bay Municipal Utility District (Aher et. al. 1991). The Stevens Institute study involved an elaborate data collection apparatus of individual sensors and loggers placed on targeted fixtures and appliances to measure end use frequency and volumes. The research methodology enabled disaggregation of water use data into component end uses such as toilet flushes, clothes washer cycles, and individual showers. Results from the Stevens Institute study showed that disaggregating residential water use into end uses increased the accuracy of water use measurements and water savings calculations (Aher et. al. 1991).

Researchers quickly realized that disaggregated end use data offered significant benefits for understanding the impacts of water conservation programs, technology, and behavior. By measuring water use from each fixture and appliance separately, it became possible to control for changes in one water use category such as toilets and to keep these changes from masking changes in water use in another end use category such as showers. This enabled researchers to evaluate multiple water efficiency efforts simultaneously, without fear of under or over-estimating impacts. It was also discovered that disaggregated data reduced the inherent variability in the water use for each end use category. Reducing the noise in the measurements within each end use category made it possible for researchers to detect smaller changes in water use with less data. While the Stevens Institute work represented a significant advance the process of collecting and analyzing the water use data itself was cumbersome, intrusive, and expensive making it difficult to expand the approach to large and diverse random samples.

A 1993 study conducted in Tampa, Florida by a team of water engineers offered a significant step forward in the evaluation of the retrofit impacts on residential water use (Anderson et. al. 1993). In this study what the authors referred to as "an extensive array of electronic water meters, pressure transducers, and event counters" were installed on 25 homes in Tampa. Water uses were monitored for 30 days continuously to obtain baseline demand data. Next, the researchers replaced the toilets and showers in all 25 homes and the 30-day data collections process was repeated. The authors pointed out that collecting these data was necessary to fully measure the impacts of the retrofit and to properly account for variability in human behavior. The methodology used in Tampa could account for toilets flushed more frequently and could measure if more time was spent in the shower after the retrofit. Using this methodology, the authors of the 1993 Tampa study successfully measured an actual reduction in water use in the study homes of 7.9 gallons per capita per day (gpcd) which amounted to 15.6% indoor use savings (Anderson et. al. 1993).

The Stevens Institute and Tampa studies demonstrated the power and utility of disaggregated end use data. The 1993 AWWA publication Evaluating Urban Water Conservation Programs: A Procedure's Manual, offered a strong argument for the necessity of this type of information:

"A meaningful assessment of the current efficiency of water use cannot be made without separating indoor and outdoor uses into their various end uses. Furthermore, knowledge about the end sues of water and their relative contributions to water use in the service area would allow conservation planners to more effectively target conservation programs to particular end uses and to make more accurate estimates of potential water savings. Unfortunately, up to now, very few measurements of actual water use for various indoor and outdoor activities have been made." (Dziegielewski et. al. 1993).

The need for end use data was clearly established and technological breakthroughs in hardware and software were about to make it easier and less expensive to obtain.

FLOW TRACE ANALYSIS

In 1979, Water Resources Research published "An analysis of residential demand for water using micro time-series data" by Danielson which is one of the earliest studies to investigate using high resolution time series data to measure residential water use patterns (Danielson, R., 1979). The development of battery powered flow data recorders in the 1980s and 90s provided a technological breakthrough for utilities and researchers interested in measuring instantaneous flows from water meters. Flow recorders, such as the Meter-Master 100 from the F.S. Brainard Company shown in Figure 1, attach directly to a magnetic drive water meter and record flow my measuring magnetic flux as water flows through the meter and internal magnets in the meter spin and change polarity. These portable flow recorders could be easily installed on any magnetic drive water meter and flow data could be recorded at frequent intervals like every minute or every 10 seconds.

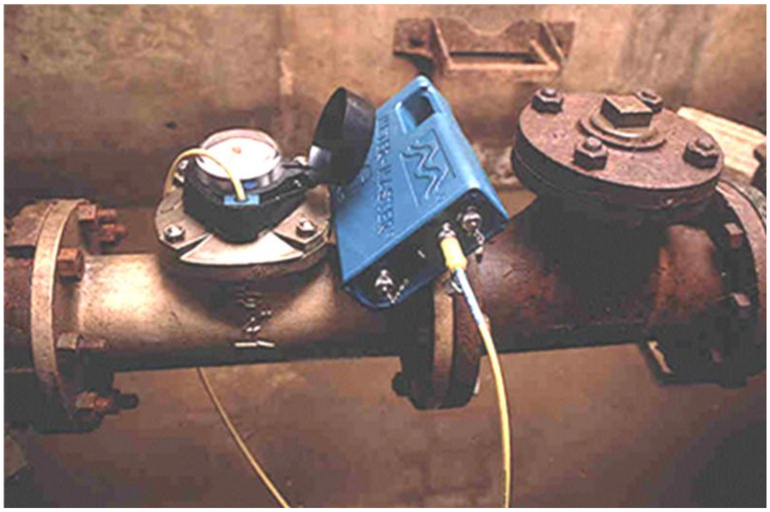

Figure 1: Meter-Master flow recorder installed on a magnetic drive water meter. (Photo courtesy of the F.S. Brainard Company)

A 1993 WaterRF study titled Residential Water Use Patterns employed portable flow data recorders to calculate typical residential flow rates, hourly consumptions, and seasonal usage patterns (Bowen et. al. 1993). However, this study did not record flows at a high enough frequency to measure individual end uses.

In 1993, William DeOreo of Aquacraft began disaggregating water use in his own home in Boulder, Colorado using a Hall Effect sensor and battery powered data logger. DeOreo discovered that by recording flows every 10 seconds and graphing the resulting “flow trace” data on a personal computer he could easily distinguish between different water uses including toilets, showers, clothes washers, irrigation, faucets, and leaks.

HEATHERWOOD STUDIES

Paul Lander was the City of Boulder’s Water Conservation Coordinator in 1993 and he quickly understood the value of the end use data DeOreo had collected from his own home. Lander agreed to fund a study to evaluate the feasibility of using a single data logger attached to a customers’ water meter to study end uses. Peter Mayer, a graduate student of civil engineering at the University of Colorado was recruited to work on the project.

The Heatherwood neighborhood in Boulder was selected for the study and a sample of 16 participating homes in the area were studied at various times during 1994 (DeOreo and Mayer 1994), (Mayer, P.W. 1995), (Mayer and DeOreo 1995). The study used was conducted in the Heatherwood neighborhood of Boulder, Colorado. In this study a battery powered data logger wired to a Hall effect sensor was attached to each customers’ water meter and left in place for a week or more. The design of the meter and magnetic coupling provided approximately 80 magnetic pulses per gallon of flow, a high level of resolution that enabled the research team to discern small differences in flow rate (DeOreo and Mayer 1994), (Mayer 1995). The data logger produced a record of water flows (referred to as a “flow trace” because of the original mechanical paper and pencil approach it replaced), at ten second intervals, of sufficient accuracy, to allow all of the major end uses of water in the home to be identified through visual inspection. The flow traces were manually disaggregated by Mayer using a DOS-based software program provided by the Rustrak data logger company and then entered into an Excel spreadsheet for statistical analysis.

The results of the 1994 Heatherwood research effort were so promising that Lander and the City of Boulder decided to fund additional research in 1995. A select group of homes from the initial sample of 16 were chosen to be retrofit with high-efficiency fixtures and appliances including ULF toilets and the first generation of high efficiency clothes washers. The data collection process was repeated and the impact of the retrofits measured (DeOreo, Heaney, and Mayer 1996), (DeOreo, Lander, and Mayer 1996a,b), (Mayer, Heaney, and DeOreo 1996).

The City of Westminster, Colorado, a suburb northwest of Denver, has also played an important role in the development of residential end use studies, although they have not participated in any of the national research conducted by Aquacraft. In the mid-1990's Westminster funded two Aquacraft residential end use studies which were conducted on small samples of 20 - 30 homes (Aquacraft, Inc. 1998). It was during these early Westminster studies that Aquacraft first developed and tested the Trace Wizard software (Mayer and DeOreo, 1996).

1999 RESIDENTIAL END USES OF WATER

In 1993 the American Water Works Association Research Foundation (now WaterRF) convened a meeting of water conservation planners and experts to identify future research needs for the industry (Nelson, J.O., 1993). The top research need to emerge from that gathering was to obtain better information on the residential end uses of water. In response to this request, WaterRF funded a comprehensive study of water use patterns in single family customers in North America and a team lead by Aquacraft that included funding and support from 22 municipalities and utilities is the US and Canada was selected to conduct the work. The project was started in 1996 and research was completed in 1998.

Residential End Uses of Water, published in 1999 by WaterRF, assembled historic consumption data from 12,000 residences, survey data from 6,000 households, and detailed end use data from 1,188 single-family houses in 14 cities in the US and Canada (Mayer et. al. 1999). The REUWS1 used a random sampling approach to select participants and significant effort was made to obtain data from large, representative samples of customers in each of the service areas covered.

Key findings from the study that are frequently cited include (Mayer et. al. 1999):

- 69.3 gpcd - average daily per capita indoor water use
- Leaks accounted for 13.7% of indoor use
- 3.48 gallons per flush – average toilet flush volume
- 5.05 flushes per person per day – average flushing frequency
- 17.2 gallons per shower – average shower volume
- 8.2 minutes – average shower duration

An electronic version of the REUWS1 is available for free download from the WaterRF – www.waterrf.org.

Two key technological innovations fostered the success of the REUWS1. First was the development of the Meter-Master© 100EL flow data recorder from the F.S. Brainard Co. This compact battery powered flow recorder had sufficient memory to record about 15 days of flow data at 10-second intervals. Aquacraft purchased 110 of these flow recorders to conduct the REUWS1. The second innovation of the REUWS1 was the creation of Aquacraft's Trace Wizard© software for disaggregating flow traces into component end uses.

Prior to the REUWS1 Aquacraft had started developing a software program that could speed up the detailed analysis process of disaggregating a residential flow trace into component end uses, but once the REUWS commenced a professional version of Trace Wizard was developed. Trace Wizard water use analysis software was used to disaggregate all of the flow trace data collected in the REUWS1. This software has now been put to use across the globe from Australia to the Middle East to Europe for disaggregating water use flow data into component end uses. Early versions of the Trace Wizard program were limited in their ability to disaggregate simultaneous end use events without accessing the original database – a cumbersome and time consuming process. Subsequent improvements eliminated the difficulty of simultaneous event disaggregation and Aquacraft's Trace Wizard software is currently in version 5 (Aquacraft 2013).

As with any new data measurement technology, questions were raised regarding the accuracy and reliability of data-loggers to measure volumetric end uses. Several independent tests of this technique have been conducted and all have shown that it is a reliable method for measuring volumetric water uses. An independent 2004 study found that discreet toilet events can be accurately quantified at the 95% confidence level plus or minus 3% of the mean volume with this technology (Koeller and Gauley 2004).

The 1999 Residential End Uses of Water study stands as an important benchmark for water use and for water use research. The highly detailed data included in the REUWS1 enabled more accurate demand forecasting and conclusively demonstrated the impact of water efficiency measures. The results of the REUWS have been put to use over the past 15 years to establish demand benchmarks, measure the impacts of water conservation programs, and forecast future water use patterns. The scientific approach and innovated methods employed in the REUWS1 set a new standard for water demand research and set off a flurry of end use research across the globe.

The REUWS report has become one of the all-time best sellers for WaterRF and the end use data collected for the study has been a rich treasure trove for ongoing research into water demands. A follow-on study, Commercial and Institutional End Uses of Water was published by WaterRF in 2000 (Dziegielewski, et. al. 2000).

END USE RESEARCH: AUSTRALIA AND NEW ZEALAND

In the water stressed continent of Australia, residential end use studies were conducted starting in 1998 in Perth, Western Australia. Published in 2003, the Domestic Water Use Study in Western Australia 1998-2001 included end use data from 120 homes in which water use was monitored continuously for more than a full year (Loh and Coghlan 2003). In this study, monthly billing data from a sample of 600 homes were also obtained to validate the results of the end use analysis. The flow trace analysis portion of this study was conducted using the Aquacraft methodology of recording flows every 10 seconds and disaggregating the resulting flow trace using Trace Wizard software (Loh and Coghlan 2003). The study confirmed that the flow trace analysis methodology was capable of accurately determining the percent of showers, toilets and clothes washers falling into normal and high-efficiency categories and these results were confirmed by in-home audits (Loh and Coghlan 2003). This research project which combined both flow trace analysis and in-home audits, provides further validation of the flow trace technique as a tool for measuring both the volumes used by individual end uses and the efficiency levels of the fixtures and appliances found in the homes. The data set from the Perth study has proven to be a rich resource for Australian water researchers in the years following the completion of work.

On the east coast of Australia, interest in residential end use studies was spurred by Dr. Stuart White and the Institute for Sustainable Futures in Sydney. White and Fane's 2001 paper, "Designing Cost Effective Demand Management Programs in Australia" points out the importance and utility of end use data (White and Fane 2001). The Institute for Sustainable Futures has played important leadership and support roles in many of the end use research projects conducted in Australia since 2001.

Yarra Valley Water is Melbourne's largest water and sewerage business, providing water supply and wastewater treatment services to over 1.7 million people and over 50,000 businesses in the northern and eastern suburbs. Starting in the late 1990s, Yarra Valley Water, led by Demand Forecasting Manager Peter Roberts, embarked on three end use studies that employed the Aquacraft flow trace analysis methodology and Trace Wizard software. Through this research, Yarra Valley discovered the benefits end use analysis when compared to surveys, as a tool for developing predictive models (Roberts et. al. 1999, 2004, and 2005) Roberts and his co-researchers found that flow trace analysis was more accurate and more cost effective than other data collection methodologies Yarra Valley had employed.

The first Yarra Valley end use study, the 1999 Residential Forecasting Study, utilized a telephone survey of 1,000 Yarra Valley Water single-family customers coupled with metered consumption data to better understand water use patterns (Roberts et. al. 1999). It provided detailed information on customer water use patterns, end uses, behavior, and penetration rates of conserving fixtures and appliances. One of the limitations of this study was the inability of customers to provide information about fixture efficiency, for example whether or not the home contained standard vs. efficient showerheads or 6/3 or 9/4.5 liter dual flush toilets (Roberts, et. al. 1999).

The 1999 Residential Forecasting Study was followed by the Yarra Valley Water 2003 Appliance Stock and Usage Pattern Survey which was designed to improve upon the 1999 study. In-home surveys were performed by a team of trained technicians who obtained detailed customer information. This approach provided verification of the penetration of efficient appliances in 840 homes in the Yarra Valley service area. Peter Roberts explained the problems Yarra Valley had experienced with earlier methods that only used surveys to obtain customer level data: "Surveys are expensive and they are always at risk of yielding non-representative samples due to disproportionate refusal rates by certain segments of the residential population. Furthermore, these surveys provide only limited information about things like the rate at which water-wasting plumbing devices are replaced by their water-conserving alternatives." (Roberts, et. al. 2004).

Yarra Valley took their research further by selecting a sub-sample of homes for a detailed end use study. About 100 of the 840 homes in 2003 Yarra Valley Appliance Stock study were selected to participate in the Residential End Use Measurement Study which built upon the earlier work, (Roberts, et. al. 2005). In this study, flow data recorders were used to measure flows every 10 seconds and the resulting flow traces will sent to Aquacraft to be disaggregated into component end uses with Trace Wizard software (Roberts, et. al. 2005). The results from the 100 home end use sample were compared to the 840 in-home surveys and the results showed remarkable consistency (Roberts, et. al. 2005). The 100 home end use study also provided information about leakage, fixture replacement, and behavior that was not yielded by the survey methodology. The value of the research was established.

> *"The findings (from the end use study) have enabled Yarra Valley Water to establish a robust end use modeling capability. In addition the end use measurement has also enabled more informed design and assessment of various demand management programs and provided a valuable data set from which to provide customers with informative usage data via their quarterly account statement."(Roberts, et. al. 2005).*

In 2007, Mathias Heinrich published residential end use results from a study on 12 single-family homes on the Kapiti Coast of New Zealand. This study also used flow data recorders and Trace Wizard software. Even with a small sample size, the results were remarkably useful and Heinrich found unique ways to describe the repeatability of the results. By lining up the 10 second flow characteristics of multiple flushes of the same toilet as shown in Figure 2, he demonstrated why the pattern recognition component of flow trace analysis has proven so powerful.

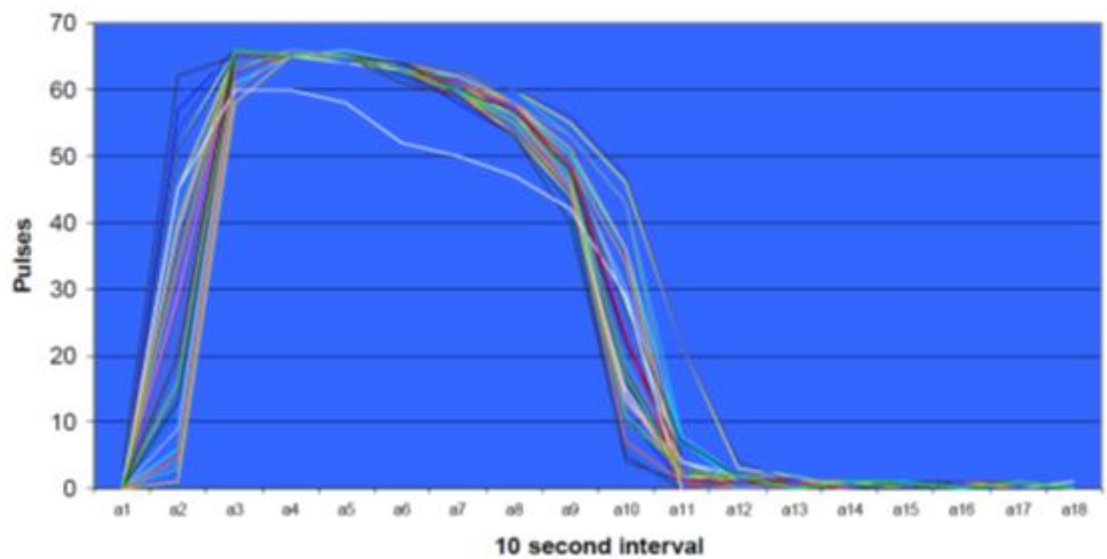

Figure 2: Repeated flush patterns of the same toilet (from Heinrich 2007)

The next major Australian residential end use studies were conducted by faculty and students from Griffith University and the Gold Coast Water Company, located just south of Brisbane. Spurred by severe drought in the Murray-Darling river basin, Gold Coast Water invested in water conservation measures and research to better understand demands and develop solutions to the crisis. A series of end use research studies were conducted by Dr. Rachelle Willis and Dr. Rodney Stewart and their team using the Aquacraft methodology and Trace Wizard software as the primary analytic tool.

A study conducted in 2007 and 2008 measured water use in 151 homes in the Gold Coast Service area, some of which were equipped with a dual plumbing system for gray water (Willis, R. et. al. 2009). This study found an average water use of 42.0 gallons per person per day including outdoor irrigation which amounted to just 12% of water use (Willis, R. et. al. 2009). Leaks accounted for just 1% of average daily use. This research also confirmed that income was a strong determinant of water use and higher income households were likely to use more water (Willis, R. et. al. 2009).

Subsequent research from Griffith University leveraged these and other end use data to measure behavioral response to shower devices and home information dashboards (Willis, R. et. al. 2011), (Stewart, R. et. al. 2011), and (Beal, C. et. al. 2011b). Key results from end use research in South East Queensland were published in 2011 by Beal and Stewart in the South East Queensland Residential End Use Study: Final Report (Beal and Stewart, 2011a). Researchers at Griffith University and the University of Queensland continue to be among the most active in conducting residential end use research and publishing the results.

TARGETED END USE STUDIES IN THE U.S.

In the U.S., interest in end use research expanded after the publication of the 1999 Residential End Uses of Water as utilities and researchers came to understand the potential applications of the flow trace analysis techniques developed by Aquacraft as well as other research methods. In 1998, the Maytag Corporation retrofit the entire town of Bern, Kansas with high efficiency clothes washers and metered water use directly at the washer to measure the impacts. The Bern study employed direct measurement of flow at the fixture rather than the flow trace analysis approach and the water savings results were used in a TV commercial and published by the research team (Tomlinson, L. et. al. 1998). Water utilities and the federal government were interested in measuring the impact of different water efficiency efforts. Starting in 1998 and moving forward, the methods and software developed by Aquacraft were used to examine specific water efficiency program impacts and measures in Las Vegas, Tucson, Seattle, Oakland, and Tampa.

In 1999, Aquacraft and the Southern Nevada Water Authority published results of a residential end use study of 100 homes participating in the Las Vegas area Xeriscape conversion program in which customers were paid to remove turf landscape and replace it with water-wise landscape elements (Aquacraft, Inc., 1999).

In 2000, the City of Tucson participated in a residential end use study of conducted by the Water Research Center at the University of Arizona. In this study, customers who received a toilet rebate for purchase of early-model ULF toilets in 1991 and 1992 were identified and their water use monitored and analyzed using Aquacraft's flow data recorders and Trace Wizard software (Henderson and Woodard, 2000). End use data from approximately 170 toilet rebate recipients were obtained and the results, "revealed that nearly half of aging low-consumption toilets had problems with high flush volumes, frequent double flushing, and/or flapper leaks." (Henderson and Woodard, 2000). The end use data collected and analyzed showed that the average flush volume for all low-volume toilets installed in the selected study homes toilets was 1.98 gallons per flush, or about 24 percent higher than 1.6 gallons per flush they were designed to use. In addition, 26.5 percent of households have a toilet that flushed with an average volume exceeding 2.2 gpf (Henderson and Woodard, 2000).

The findings from the Tucson field study confirmed what lab research conducted in in Southern California in 1998 had revealed: Some common toilet cleaning chemicals cause degradation of toilet flappers and some after-market toilet flappers provide a poor fit thus contributing to increased leakage and flushing volumes (Metropolitan Water District, 1999), (Henderson and Woodard, 2000). The Tucson study showed how end use data could be used to answer specific questions about water efficiency programs, technology, and impact.

As the value of end use data and research became more apparent, John Flowers an engineer with US EPA who helped gain approval for the water efficiency components in the 1992 Energy Policy Act, secured grant funding for a trio of Aquacraft residential water conservation retrofit studies over a three-year period. Research was conducted in Seattle, Washington, Tampa Bay, Florida, and the East Bay Municipal Utility District, California from 2000 to 2003. The resulting three individual retrofit studies, and combined retrofit study final report provided useful information on the effectiveness of water conserving fixtures and appliances in reducing indoor water use (Mayer, et. al. 2001), (Mayer, et. al. 2003), (Aquacraft, Inc. 2003),(Aquacraft, Inc. 2004). The results of this study were influential in estimating the potential impact of the WaterSense program as it was being developed by the US EPA.

In the EPA retrofit studies, baseline water use data were collected from a combined sample of 96 homes located in Seattle, the Tampa Bay area, and East Bay Municipal Utility District in California. From these data the household and per capita usage of toilets, showers, clothes washers, dishwashers, faucet use, leakage, and other indoor uses were determined (Aquacraft, Inc. 2004). Next, the same set of homes were retrofitted with conserving toilets, clothes washers, showerheads, faucet aerators, and hands free faucet controllers. After allowing a settling in period of six months, water use was once again measured with flow recorders and Trace Wizard software and the household and per capita uses were reexamined. The results showed a significant reduction in indoor water use of 39% in the homes that were retrofitted with conserving fixtures and appliances (Aquacraft, Inc. 2004a). Results from this series of studies have been used to establish benchmarks for water use with current high efficient technology and as a measuring stick for gauging progress of utility sponsored water efficiency programs.

Seattle Public Utilities' (SPU) Water Conservation Manager, Al Dietemann, was an early endorser of the flow trace analysis approach to measuring end uses and Seattle was a participant in the REUWS1 and in the 2004 EPA retrofit studies. In 2004, SPU hired Aquacraft to conduct a market penetration study using flow trace analysis to assess the percentage of homes in Seattle that were equipped with high efficiency fixtures and appliances (Aquacraft, Inc., 2004b). The Seattle Market Penetration Study was one of the first end use studies conducted specifically for the purpose of assessing the level of water efficiency achieved in a random set of single-family homes.

CALIFORNIA RESIDENTIAL BASELINE AND EPA NEW HOME STUDIES

California has been a national leader in water demand management and conservation since drought struck the state in the 1970s, spurring one of the first growth spurts in water conservation programs and measures (Mayer, P. 1995). California water efficiency and demand management received elevated importance when in 2008 Governor Arnold Schwarzenegger adopted a statewide goal of reducing per capita demand by 20% by the year 2020 (State of California, 2010). By 2008, a consortium of California utilities had already embarked on an ambitious residential end use study with Aquacraft, led by Fiona Sanchez, Conservation Manager at the Irvine Ranch Water District (IRWD). The project became the second largest baseline residential end use study conducted to date, after the REUWS1.

The California Single Family Water Use Efficiency Study was finally published in 2011, but actually began in 2004 when a group of California water agencies, led by Irvine Ranch Water District applied for a grant from the California Department of Water Resources to fund a baseline residential end use study to expand on the REUWS1 and include data obtained entirely from samples of homes within the State of California. Eventually this grant request was approved and Aquacraft commenced work on the study in 2006 with the support of 10 participating California water agencies (DeOreo, et. al. 2011a).

The California Single Family Water Use Efficiency Study provided detailed water use data on a statewide sample of approximately 700 single family homes spread across 10 water utility service areas around the state and delivered an updated snapshot of water use patterns (DeOreo, et. al. 2011a). The results showed the current penetration rates of conserving fixtures and appliances across meeting or exceeding established conservation standards across the state and in specific markets. The 2011 California study also provided an updated benchmark for progress on water use efficiency in California and offered a useful comparison with demands from California obtained as part of the REUWS1 (DeOreo, et. al. 2011a), (Mayer, et. al. 1999). From these data, water planners in California were able to estimate how much untapped water conservation potential existed in largest urban customer category.

In 2005, momentum was gathering across the US for a national water efficiency program that could act in parallel with the US EPA and Department of Energy's Energy STAR program. This ultimately led the US EPA to create the WaterSense program in 2007, but before this development was complete, the EPA worked with the Salt Lake City Corporation to fund a benchmarking study of water use in new single-family homes (US EPA, 2007), (Aquacraft, 2011b) . The study, Analysis of Water Use in New Single Family Homes was conducted by a team led by Aquacraft and completed in 2011 (Aquacraft, 2011b). Working with nine participating utilities from across the U.S., the 2011 EPA New Home Study was designed to measure typical water use patterns in "standard" new homes, built after January 1, 2001 to the water efficiency level established through the 1992 Energy Policy Act, and "high-efficiency" new homes that were built during the study period to match the emerging WaterSense specification for highly efficient new homes. (DeOreo, et. al. 2001b). Results this study found that "standard" new homes use about 21% less water indoors than the existing housing stock – largely due to the impact of federal plumbing codes and appliance energy performance standards. A small set of "high-efficiency" new homes built to meet the WaterSense standard used about 38% less water indoors than the existing housing stock and about 21% less water indoors than the "standard" new homes (DeOreo, et. al. 2011b). Results from this study were useful in establishing that the WaterSense new home specification was capable of reducing water use by 20% in new homes (US EPA 2009).

END USE RESEARCH IN EUROPE AND BEYOND

While some of the largest residential end use studies have been conducted in the U.S., Canada, and Australia, a number of studies have been successfully conducted in Europe and the Middle East.

The most significant end use research in Europe has been produced by a group led by Francisco Cubillo, Deputy Director of Research, Development and Innovation for Canal de Isabel II based in Madrid, Spain. According to Cubillo:

> *"Canal de Isabel II undertakes research on micro-use to develop reliable scenarios about the effect of temperature and daily rainfall on water consumption in individual homes. Results can be seen by specific use – showers, washing machines, toilets, faucets, dishwashers, irrigation, swimming pools and leaks – to identify customers' climate sensibility through their end uses. The information is applied in designing and implementing water infrastructure action plans." (Cubillo, F. 2003).*

Cubillo and his team uses a flow trace analysis approach similar to the methods developed by Aquacraft to measure “micro-use”, but they their own hardware and software to conduct the analyses.

In South Africa, a number of water use benchmark and end use studies have been conducted by H.E. Jacobs and J.E. Van Zyl that use both measurement and statistical modelling approaches to determine where and how water is being used in residential and non-residential buildings (Jacobs, H.E. 2007), (Van Zyl et. al., 2003), (Van Zyle et. al. 2006).

In the Middle East, end use research has been conducted in Saudi Arabia and more recently in the United Arab Emirates and Jordan (DeOreo, W.B. 2011). In Jordan, researchers developed new approaches for measuring end uses that included installing a new water meter on the outflow pipe of the roof tank at selected residences and then using a flow recorder and Trace Wizard to disaggregate water use from the resulting flow trace (DeOre, W. B. 2011).

Other regions that have conducted small to medium scale residential end use monitoring include Brazil, Cyprus, and the United Kingdom.

RECENT END USE RESEARCH IN THE U.S.

Recent end use research in the United States has largely been carried out by Aquacraft, Inc. using the same flow recorder technology and Trace Wizard signal processing software they have been developing and improving upon since the early 1990s.

In 2008, Aquacraft completed the first ever end use study of multifamily housing for IRWD – Analysis of Water Use in Multifamily Housing. This study was conducted by IRWD for the purpose of establishing more accurate indoor water budgets for their innovative water budget-based rate structure (DeOreo and Hayden, 2008).

A project funded through the federal American Recovery and Reinvestment Act (ARRA) stimulus program studied the impact of high efficiency retrofits on a set of single family homes in Albuquerque, New Mexico. Conducted by Aquacraft, this study evaluated the impact of local rebate programs and then measured the impact of retrofitting high efficiency fixtures and appliances including WaterSense labeled toilets, showerheads, and faucets (Aquacraft, Inc. 2011). In the end use component of this study, the project team first measured baseline water use in a sample of 209 single family homes to establish baseline demand patterns. Then a full indoor retrofit was completed at 31 homes which included toilets, clothes washers, showerheads and faucets. The results showed that the after the retrofit, the households used about 27% less water on average indoors. The savings were mostly due to the toilets, clothes washers, and a reduction in leakage (likely due to the toilet retrofit). In this study, the shower and faucet retrofits did not result in a statistically significant change in water use (Aquacraft, Inc., 2011).

The City of Westminster, Colorado teamed with Aquacraft to conduct a residential demand study in 2011 in conjunction with their water conservation planning effort. This study measured water use at a random sample of 60 homes in Westminster and helped the City determine which conservation program measures should be included in the water conservation plan developed in 2012 (Mayer and Feinglas, 2012).

RESEARCH METHODS

This section of the report provides a summary of the research methods used for the study.

OVERALL STUDY ORGANIZATION

This study was organized around the principal that detailed data collected from random samples of single family water customers can provide information from which useful water use projections can be made to other groups of single family residential customers for which information is known or estimated for key explanatory variables. The detailed water use and demographic information on the samples can be analyzed mathematically in a way that allows projections of water use to other groups of single family customer. The overall organization of the study is illustrated in Figure 13. Each box on the flow chart represents a major work element of this residential end use analysis. Details are provided below.

Before any of the work discussed below could take place the first step was to solicit a set of water agencies from the United States and Canada to participate in the study. This was done by sending out emails and making telephone calls to agencies around the country which were known to have an interest in demand analyses of this type. Two levels of participation were offered to the agencies: Level 1 involved a complete customer analysis including surveying, billing data analysis, data-logging and landscape analysis; and Level 2 which was confined to just surveying and analysis of billing data. Efforts were made to obtain as geographically diverse a sample as possible, but no attempt was made to assemble a group of utilities that represented a scientific "match" to the entire universe of municipal water agencies in North America. Doing this, was practically impossible.

OBTAIN INFORMATION FROM UTILITIES

After the study groups were assembled, the first step in the research process was the collection of the key information from each utility needed to conduct the study. Work started on the project in May of 2011. In June of 2011 a data request was sent to each of the Level 1 and Level 2 utility participants. There were a total of 9 Level 1 utilities in the study. Each of these provided a Q_{1000} sample of billing data for their single family customers. Each of the 1000 homes in the sample was sent a survey, and a group of 100 homes was selected from the survey respondents in each Level 1 site for data logging. There were a total of 17 Level 2 sites in the study. Each of these provided a Q_{1000} sample. All of the Level 2 survey respondents were grouped, and a single sample of 5000 homes was randomly selected to receive a survey.

The data request was divided into three parts:

Utility Information Part 1 – Selecting the Sample of 1,000 SF customers (Q1000)

Each of the 26 participating agencies was sent a set of instructions for selecting a random sample of single family homes from their 2010 billing database. This sample was checked to ensure that it was statistically similar to the population of single family homes. After this check was completed the data were sent to the research team for use in surveying and data logging.

The Q_{1000} data also included customer information and information on the meters located at the site.

Utility Information Part 2 – Utility and Program Information

Several other pieces of information were requested from each of the participating utilities. These included contact names and information, conservation staff sizes and budgets, information on water and wastewater rates, and information on the types of water conservation programs in place at the agency. The agencies were also asked to provide information on the types of water sources they utilized, whether they had a good local weather station for ET data, and to provide copies of recent conservation and drought plans. The final question was an open ended request for any site specific information that the agency wanted the researches to be aware of that might have a bearing on the study.

Utility Information Part 3 – GIS and parcel level data (Level 1 sites only)

Aerial photos and parcel shape files were requested from each of the Level 1 sites so that the irrigated areas and landscape plant types could be determined for each of the logged homes. This allowed estimates to be made of the theoretical irrigation requirements for each home. The annual outdoor use for the homes was then compared against the theoretical requirements in order to determine the ratio of the actual to the theoretical applications, and the volumes of excess or deficit irrigation.

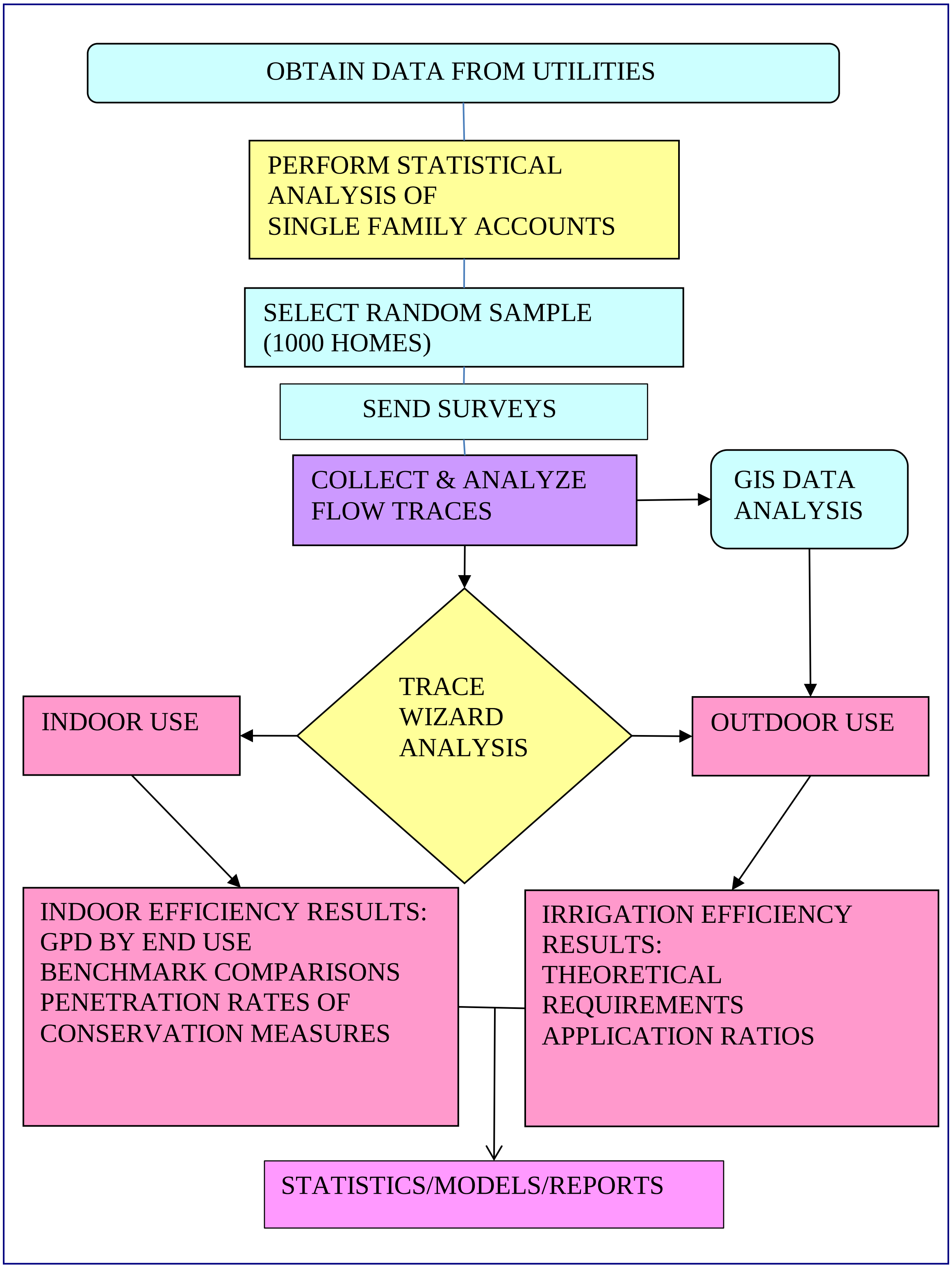

Figure 13: Organization of Study

SURVEY IMPLEMENTATION

After the billing and customer information had been obtained from each of the 26 sites, and the necessary statistical tests and sampling of the Q_{1000} done, the next critical step was the implementation of the customer survey. This survey was similar to others that have been used in previous end use studies, but had some questions that were unique to this study. In addition, each of the Level 1 sites had the opportunity to submit questions to be sent to just their own customers on issues that were considered of local interest.

Each survey was identified with a survey ID code which was linked to the customer information and billing database. The survey ID provides a unique identifier for all houses that were mailed a survey. Houses selected for data logging were assigned a separate keycode ID, which identifies all houses that were part of logging groups. After the data logging was complete the survey ID's and keycodes were linked so that all of the information for each home could be accessed.

The results from the surveys were used in two ways: first in combination with the annual and seasonal water use information from the billing information, and second, in combination with the data logging results. In both cases mathematical models were developed to search for relationships between the survey results and the billing and/or end use data.

Homes for data logging were selected only from survey respondents so that the survey results were available for all of the homes in the end use database.

SELECTION OF LOGGING GROUPS

The logging groups were selected from the survey respondents in each of the Level 1 study sites. Each survey home was identified with a unique logging code, referred to as a Keycode. Because the surveys were sent out prior to the selection of the logging groups they were identified with a separate survey ID identifier. The Keycode was linked to the Survey ID so that the end use data obtained from the data logging could be linked to the billing and survey data identified with the Survey ID's. Consequently, there were two ID's used to identify customers in the study: the Survey ID, which was assigned when the surveys were mailed out, and the Keycode that was used to identify homes selected for data logging (either as primary sites or back-ups).

Each of the surveys was assigned a Survey ID code, which identified the survey in relationship to the customer information and billing data. When surveys were returned a sample of 100+ were selected for data-logging. Each of these homes was assigned a keycode, which identified the homes from the logging sample. The Keycodes were linked to the Survey ID's so that data from the surveys could be used for the water use analysis. The Keycodes all had a common format: YYSNNNN, where the first two digits represented the year in which the data were collected, the S indicated that the data came from a single family account, and NNNN represented a number assigned in sequence from 0001 to 9999 for all keycodes assigned in the single family group during the year. Extra keycodes were assigned in order to allow for alternate logging homes in case some houses had to be rejected for any reason.

Table 5: Keycode assignments

NO.	Level 1 Agency	Survey ID Range	Keycode Range
1	Denver, Colorado	521,000-999	12S101-226
2	Fort Collins, Colorado	530,000-999	12S230-360
3	Scottsdale, Arizona	552,000-999	12S370-489

NO.	Level 1 Agency	Survey ID Range	Keycode Range
4	San Antonio Water, Texas	541,000-999	12S500-609
5	Clayton County, Georgia	511,000-999	12S701-810
6	Toho Water Agency, Florida	571,000-999	12S820-917
7	Region of Peel, Ontario	611,000-999	12S1001-1122
8	Region of Waterloo, Ontario	521,000-999	12S1201-1319
9	Tacoma Water and Power, WA	561,000-999	13S101-215

SELECTION OF HOT WATER GROUPS

One of the new aspects of this study compared to the original REUWS study was the addition of a subset of homes within the logging groups to have data obtained on their hot water use. In all sites, except Tacoma, 10 homes were selected for hot water logging. In Tacoma a total of 37 hot water homes were selected, since Tacoma power wanted to have more hot water data in order to simulate operations of electric heat pump water heaters. This brought the total number of hot water homes to 117 for the entire study.

Each of the homes in the hot water group was selected from the logging group by invitation. Letters were sent to the homes in the logging group asking who would be willing to have a water meter installed on the inlet line to their water heater, and then have this meter data-logged at the same time as was the main meter. A group of 10 homes, plus a couple of back-ups, were selected and plumbers were contracted to install the meters.

At the time that the technicians visited the homes to install the data loggers on the main meters, which, except for the Canadian sites, were located outside the house on a property line, a separate data logger was installed on the feed line to the water heater, which was normally located inside the home or in the garage. This required setting up an appointment with the owner and gaining access to the home. Once inside the home the technicians took a few minutes to verify the types of toilets and clothes washers present in the home (so that this could be compared to the results from the surveys) and to measure the temperature of the inflow and outflow water at the water heater.

The result of the logging were two simultaneous flow traces: one from the main water meter and one from the hot water meter that could be analyzed side-by-side in order to disaggregate water use from each meter, so that both total water use and hot water use could be broken down by end use.

LANDSCAPE ANALYSIS

The landscapes for each study home were analyzed by obtaining parcel shape files and imagery for each of the level 1 study sites. Generally, both of these pieces of information were made available by the water agency, the GIS department of the local government, or from other public sources. In some cases it was necessary to use other sources for the aerial imagery, but in all cases the research team was able to obtain good quality color images, generally at 6” resolution, for each study site.

The addresses for the logging groups were located on the aerials using the parcel files. An analyst then manually traced out the portions of each lot that were part of the vegetated landscape. Each landscape area was identified by its keycode, area and ground cover.

Irrigated Areas and Efficiencies

Each plant type was assigned an irrigation efficiency based on whether it would be expected to have a spray or drip system. The combined factors were calculated as the crop coefficient/efficiency. Open water surfaces on the property were treated as quasi irrigated areas and assign a species coefficient and irrigation efficiency so that a reasonable water allocation could be determined for them. The irrigation efficiencies were based on reasonable estimates of target efficiencies for well-designed and maintained systems. The analysis was aimed at determining what the landscapes should require based on good practice; not on what they might require in less than a good state of repair and operation.

Table 6: Landscape parameters

Ground Cover	Species Coefficient	Irrigation Efficiency Allowance	Combined Factor
Entire Lot	NA	NA	NA
Non-Turf Plants	0.65	71%	0.92
Pool or Fountain	1.25	100%	1.25
Cool Season Turf	0.80	71%	1.13
Warm Season Turf	0.60	71%	0.85
Vegetable Garden	0.80	71%	1.13
Xeriscape	0.30	90%	0.33
Non-irrigated Ground	0	0	0

Landscape Ratios

The landscape ratio for each lot was calculated as the ratio of the theoretical irrigation requirements to the reference requirements (based on ETo). Since the theoretical irrigation requirement takes into account both plant types and irrigation efficiencies it is analogous to the maximum water allocation calculation. A landscape ratio of 0.70 means that that landscape requires no more than 70% of the ETo. It should be noted that even if the landscape ratio is 0.7 or less it can still be over-irrigated so that the actual use exceeds its allowance. Conversely, a landscape ratio may be greater than 0.7, but if it is deficit irrigated, it may not exceed the maximum allowance. The landscape ratio is just an indicator that the water requirement of the landscape based on its design.

Theoretical Irrigation Efficiencies

The theoretical irrigation requirement (TIR) is a measure of the water requirement of the landscape based on whatever plant material and areas were present at the time of the analysis. The TIR was calculated for each lot using the areas for each plant type on the lots with the ET data and efficiency allowances shown above. The Net ETo was determined for each site based on the best available weather data. Net ETo was determined by doing daily soil moisture analyses from sample weather stations. The daily ETo and daily rainfall for the billing year were input, and only rainfall that reduced ETo either directly or via soil moisture storage was counted as effective. This excluded rainfall that fell in excess of the soil moisture capacity, soil uptake rates, or which was such a small quantity that it would not be expected to enter the root zone. In the northern sites, rainfall was found to reduce ETo by 25%, while in the southern sites the net ET was just 9% less than the gross ETo.

The Net ETo was then converted from inches to gallons per square foot using the conversion factor 1 inch = 0.624 gpsf. The area for each landscape sub-area was then multiplied by the Net ETo and the crop coefficient for the plant material. The result was divided by the allowed irrigation efficiency for a well-designed and maintained irrigation system to arrive at the TIR.[1]

The equation used for estimating the TIR for this study was:

$$TIR = 0.624 \times ETo_{net} \times \sum_{i=1}^{n} \left[\frac{A_i}{Eff_i} \times K_{zi} \right]$$

Where:
TIR= theoretical irrigation requirement (gal)
0.624= converts from inches of ETo_{net} (Net ETo) to gallons per square foot
ETo_{net} = reference ETo (inches) minus effective rainfall (inches)
n= number of zones in the landscape
i= individual zone
A_i= area of individual zone (sf)
Eff_i = irrigation efficiency allowance of individual zone
K_{zi}= zone coefficient for individual zone = $k_{species}$ x $k_{density}$ x $k_{microclimate}$

Estimation of Annual Outdoor Water Use

When only a single water meter is present there is no completely accurate method of separating indoor and outdoor uses. In most cases having indoor use from the flow trace analysis gave good results, but not always. Use of minimum month or average winter consumption as a proxy for indoor use is reasonable. In areas where irrigation occurs on a year round basis it can lead to an over-estimation of indoor use.

The outdoor water use for each lot was estimated by taking the annual water use from the billing data and subtracting the best estimate of annual indoor water use, obtained mainly from the projected indoor use from the logged data. In some cases the indoor use during the logging period did not give the best estimate for annual indoor use, for instance if no one was home during the logging period. In cases where the logged indoor use did not appear to give the best estimate of the annual indoor use, then the minimum month water use was used as a proxy for indoor use. Due to the necessary lag time between sample selection and data logging, the logging data were usually not collected in the same year as was the billing data. Indoor use tends to be

[1] There was some discussion of using irrigation efficiencies less than 0.71, but since this is the minimum acceptable efficiency in the MAWA calculations it was agreed in September 2009 to use 0.71. We recognize that achieving this may be a challenge for many older systems. Efficiencies for drip systems were set to 90%.

stable; therefore, use of indoor data for a period different from the billing data is not a bad assumption as long as it is checked for reasonableness, as was done.

Application Ratios

The ratio of the actual outdoor use to the TIR is called the application ratio in this study. This tells whether the landscape is being watered properly based on the actual plant material on-site. If a lot is 100 turf an application ratio of 1.0 means that it is receiving the proper amount of irrigation water for a turf landscape.

DATA LOGGING

Data logging began in Denver during February of 2012 and continued until January 2013 when the last logging was completed in Tacoma. All data logging was completed within 12 months (see Table 7).

Table 7: Data logging efforts

Study Site	Denver	Fort Collins	Scotts	San Antonio	Clayton	Toho	Peel	Waterloo	Tacoma	Total
Number Logged	100	100	100	100	100	100	79	83	100	862
Number Main	97	88	96	91	96	65	60	71	98	762
Number Hot	10	10	10	10	7	5	6	9	33	100
Days/trace	12.3	13.4	13.1	11.9	12.9	12.2	12.9	12.9	12.4	Ave=12.7
Logging Month	Feb-12	Mar-12	May-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Jan-13	12 mo.

FLOW TRACE ANALYSIS

In order to properly interpret the results of this study it is important to understand how flow trace analysis works, and consider its strengths and weaknesses. The goal of flow trace analysis is to disaggregate water use in a single-family home based on a highly precise pattern of flow over time obtained from the main water meter for the house. The key is that the main water uses, such as toilets, clothes washers, dish washers, irrigation systems, and showers in the home provide very clear flow patterns that are relatively easy to identify. Other uses, such as faucets, leaks, water treatment and pools are more ambiguous. The idea is to extract the information for the easily identified events, which leaves behind a smaller volume of water in the remaining categories. This smaller volume of water can then be analyzed statistically to examine the factors that appear to have an influence.

Flow trace is a very good tool when understood in this way, but it does involve a degree of uncertainty and random error. When one balances the information provided by flow trace analysis against the practical impossibility of sub-metering a home to provide end use information of equal detail, its value is clear. Working with flow traces and the Trace Wizard program, an experienced analyst can determine the important information related to the daily household use for the key fixtures and appliances, and can determine the efficiency levels of these as measured by their volumes of use and flow rates. Water use for categories like faucets and leaks can overlap since sometimes events produced by a faucet may appear to be a leak, and vice versa. This is where the information from the surveys can be used to identify relationships between household characteristic and the end use in question. This process can help clarify the factors that are probably linked to the use. For example, leak events may sometimes include very small faucet uses, intermittent flows for automatic pool filling, ice machine, or continuous flows from certain water treatment systems. By modeling leakage against the presence of pools, home water treatment, automatic irrigation systems etc., it is possible to see what factors explain increased leakage or leak-like events. Leakage estimates should be tempered with the knowledge that in some cases what appears to be a "leak" may be a legitimate use that requires continuous flow. These types of issues tend to work on the fringes of the data. The main body of information provided by the analysis is the core household water use patterns and efficiency levels for the household.

Each flow trace file obtained during the site visits was analyzed into individual water use events using the Trace Wizard software. During Trace Wizard analysis each event is characterized according to its end use, start time, duration, volume, maximum flow rate and mode flow rate. This is a stepwise process. Each trace is first checked to verify that the logged volume agrees with the meter volume. When the volumes agree then the trace can analyzed as is. When the volumes do not agree further investigation is required. In some cases the data logger records the data but the volume recorded differs from that of the meter by a small amount. These traces usually are used with a correction factor applied so that the volumes agree. In other cases the volume of the data logger and the meter volumes differ by a substantial amount. These traces are opened for inspection. In some cases the trace files may contain a few erroneous events, caused by infrequent electrical interference with the sensor, which causes extremely high flow rates to be recorded. If these are isolated events they can be removed manually during analysis, and the rest of the trace can be used. If the entire trace is contaminated with interference then it has to be discarded. In some cases the logger simply fails to record any data, in which case the trace is discarded and if necessary the site is re-logged. It is also not uncommon for a logger to record flow through the meter that the register fails to pick-up because of age or repair issues. In these cases the volume from the logger was used.

After the volumes were evaluated and, if needed, correction factors applied, each of the traces with usable data was disaggregated into individual events. The Trace Wizard program contains a template of indoor fixtures and appliances that serve as the starting point for the analysis. If these templates are set up carefully they can identify many of devices on the initial calculation. The Trace Wizard program is similar to an expert system in that the analyst identifies how events should be categorized according to fixture type, and then the program uses this information to find all similar events in the trace and assign them to the chosen fixture. For example, if on Day 1 of the trace a toilet is identified that has a volume of 3.5 gallons, a peak flow of 4 gpm, and a duration of 90 seconds, these fixture parameters are adopted by the analyst. The program will then find other similar events throughout the duration of the logging period that match the first event. Each of these events is labeled as a toilet with no further intervention required on the part of the analyst.

The analyst works through the flow trace to find all of the major fixtures, assigns the fixture parameters, and verifies that the fixtures have been identified successfully by the program. When multiple events occur simultaneously it may be necessary for the analyst to identify events by inspection and separate these events manually. The analyst also identifies the first cycle of all clothes washer and dishwasher events in a trace. This allows the number of clothes washer and dishwasher cycles to be grouped into loads, from which the gallons per load can be determined.

The analyst may need to evaluate other events on a case-by-case basis. Water treatment systems, pool filling, and evaporative cooling can have enough variability from one trace to another that it can be difficult to develop a template that contains all of the necessary parameters to identify them automatically. On-site regenerating water treatment systems may have similar patterns from one trace to the next, but it is impossible to have a template that accounts for all of the variability. Events such as these are identified through inspection by the analyst. Visual inspection may be necessary for identifying more common events as well. For example, if someone leaves a kitchen faucet running for 10 minutes while they wash the dishes it may look like a shower if it is flowing in the shower range. In these cases classification of the event is a judgment call supported by factors such as frequency, time of day (showers are more likely to occur in the morning) and the proximity of other events (long periods of faucet use may be followed by the dishwasher).

Each water use event in the flow trace is characterized by fixture type, flow rate, duration and volume. The analysis does not however, reveal the make or model of a fixture or appliance. The efficiency of devices like toilets, showers, and clothes washers is inferred from their measured volumes or flow rates. There may, for example, be many "standard" showerheads that flow at 2.5 gpm or less. These would be classified as "high-efficiency showers" because they meet the EPAct 2005[2] criterion, which requires a flow rate of 2.5 gpm @ 80 psi.

Toilets with flush volumes of 2.2 gpf or less were classified in this report as efficient toilets, meaning that they flush at or below a volume most likely due to a ULF or high-efficiency toilet.[3] High-efficiency toilet refers to a specific model of toilet designed to flush at 1.28 gpf or less. Toilets in this study were classified based on the measure flush volumes not their make and model. This means that an old toilet that had been modified to flush with less water would be classified as an efficient device, even though an auditor looking at it might classify it as inefficient because it was not stamped as a ULF of HET model. Conversely, there are some ULF toilets with flush volumes as high as 3+ gallons as a result of being poorly adjusted or because of a malfunction. These toilets would not be considered "efficient" in our analysis.

Following the initial disaggregation and analysis process, the trace was checked by another analyst to make sure there are no obvious errors and that events that require a judgment call seem reasonable. Once all questions are resolved, the trace is then ready for further processing, and the process is repeated on another trace. Simple traces can be analyzed in as little as 30 minutes. Analysis of complex traces may take several hours to complete. The level of complexity is normally related to the volume of water used in the home during the logging period and the frequency of events occurring simultaneously.

TRACE WIZARD IDENTIFICATION OF COMMON HOUSEHOLD FIXTURES

Trace Wizard analysis provides a visual tool for identifying individual events that take place during the two-week data logging period. The most common events found during trace analysis are toilets, faucets, showers, clothes washers, dishwashers, irrigation events and leaks. Examples of these events follow along with a description of a typical profile. While flow trace

[2] EPAct 1992: Energy Policy Act of 1992 National Efficiency Standards and Specifications for Residential and Commercial Water-Using Fixtures and Appliances

[3] The EPAct 1992 standard for ULF toilets is 1.6 gpf

analysis is not perfect it performs very well in identifying the key household end uses. There are always ambiguous events that can be categorized differently by different analysts, and these create scatter to the results.

Trace Wizard is at its best in identifying anything that is controlled by a timer or a mechanical controller. These include toilets, dish washers, clothes washers, irrigation timers and water treatment regeneration systems. Fixtures that are limited by a valve or which operate in a repeatable fashion such as showers or baths are also fairly easy to identify. The program deals with simultaneous events by splitting out the super-event from the base event. This covers the situation of the toilet flush on top of the shower or irrigation. It also has the ability to split out events that run into each other, but this requires the analyst to manually identify the point at which one event ends and another begins. This covers the situation where a faucet is turned on before a toilet stops filling.

The following sections provide some examples of how typical fixtures and appliances are recognized in flow trace analysis, and discuss issues encountered in dealing with each category of end use.

Toilets

Trace Wizard determines the time of day, the volume, the duration, the peak flow and the mode flow of toilet events. From this it is possible to draw inferences about what type of toilet might be behind the trace. However, this inference process is not perfect, and must be used with discretion. Trace Wizard cannot tell if a 3.0 gallon flush is coming from a malfunctioning ULF toilet or a modified high volume flush toilet.

There are also two ways of looking at toilets. From the perspective of a household efficiency study what is important is the actual volume of the flush, the distribution of flush volumes and the overall average gallons per flush in the home. From the perspective of a water agency that is interested in tracking the percent of all toilets that have been replaced, the key is the actual make and model of the toilet. The flow trace data can be helpful in making judgments about the market penetration rates, but it is inherently ambiguous when it comes to assigning actual toilet designs.

The other complicating factor about toilet analysis is that houses contain mixtures of different types of toilets. This makes it necessary to look at things like the percent of flushes at different volumes (toilet heterogeneity) in an effort to determine the mixture of toilets in the home. All of these techniques are used and discussed in the report.

Figure 14 is an excellent example of four toilet flush events (green) that take place over a two hour period and were identified using the Trace Wizard program. The program identifies flow events with similar properties including volume, peak flow, and duration. Also shown in the figure are faucet events (yellow) that have been separated from the toilet events and are not included in the toilet volume. The baseline flow (blue) has been labeled leakage. Although the flow rate is less than a tenth of a gallon per minute, it is continuous through the entire trace and accounts for nearly 1,400 gallons of water during the two week data logging period. In these cases the presumption is that these represent leaks unless there is evidence that the household has some sort of continuous use water device (e.g. for medical or water treatment purposes).

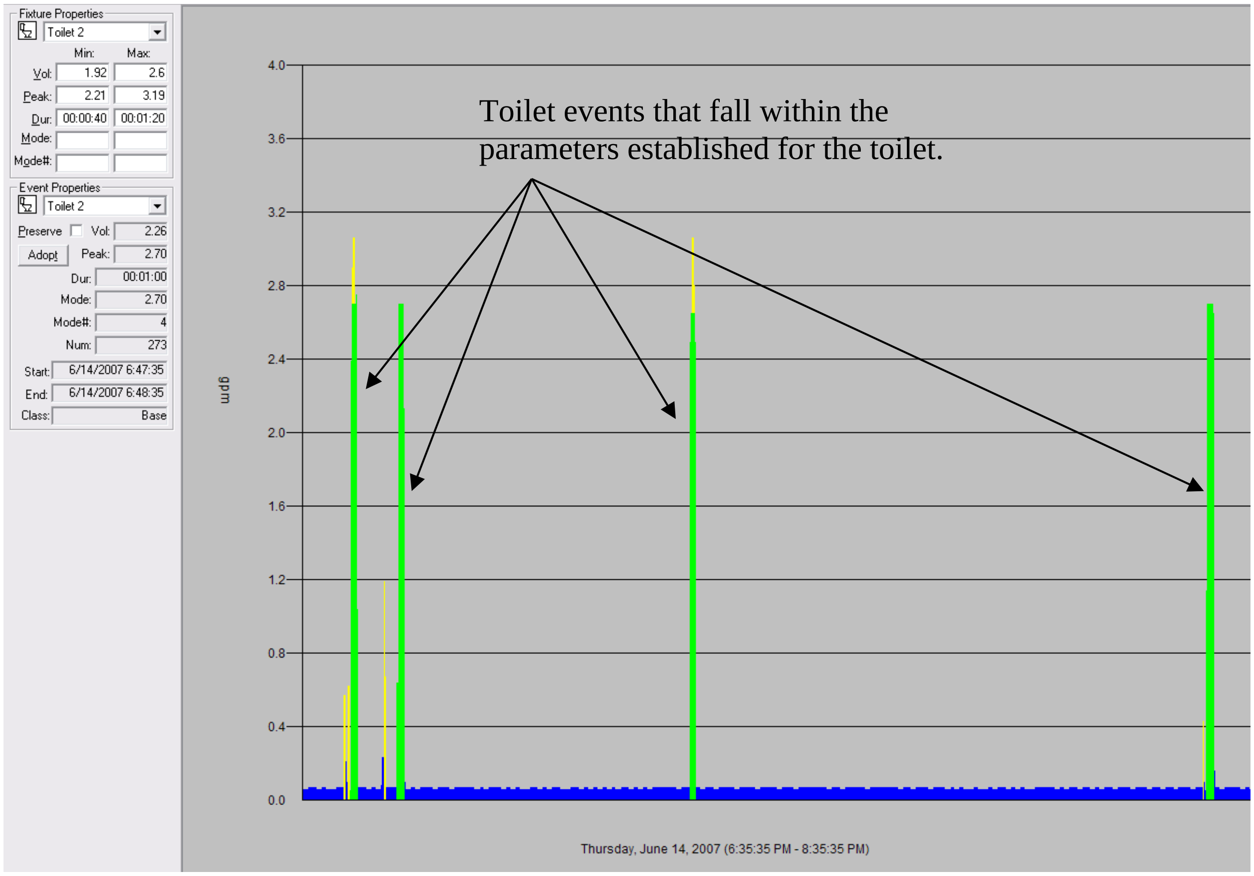

Figure 14: An example of four toilet flushes, faucet use, and baseline leak identified using the Trace Wizard program

It is not uncommon to find several different toilet profiles in the same residence. This may be the result of replacing only one of the toilets with a ULFT or HET, toilets of different brands in the home, flapper replacement, or the addition of a displacement device or some other conservation measure in one of the toilets. Figure 15 is an example of two different toilet profiles in the same home; two of the toilet flushes are from a ULF toilet and the other two flushes are from a high volume or high water use toilet with a flush volume of 2.7 gallons.

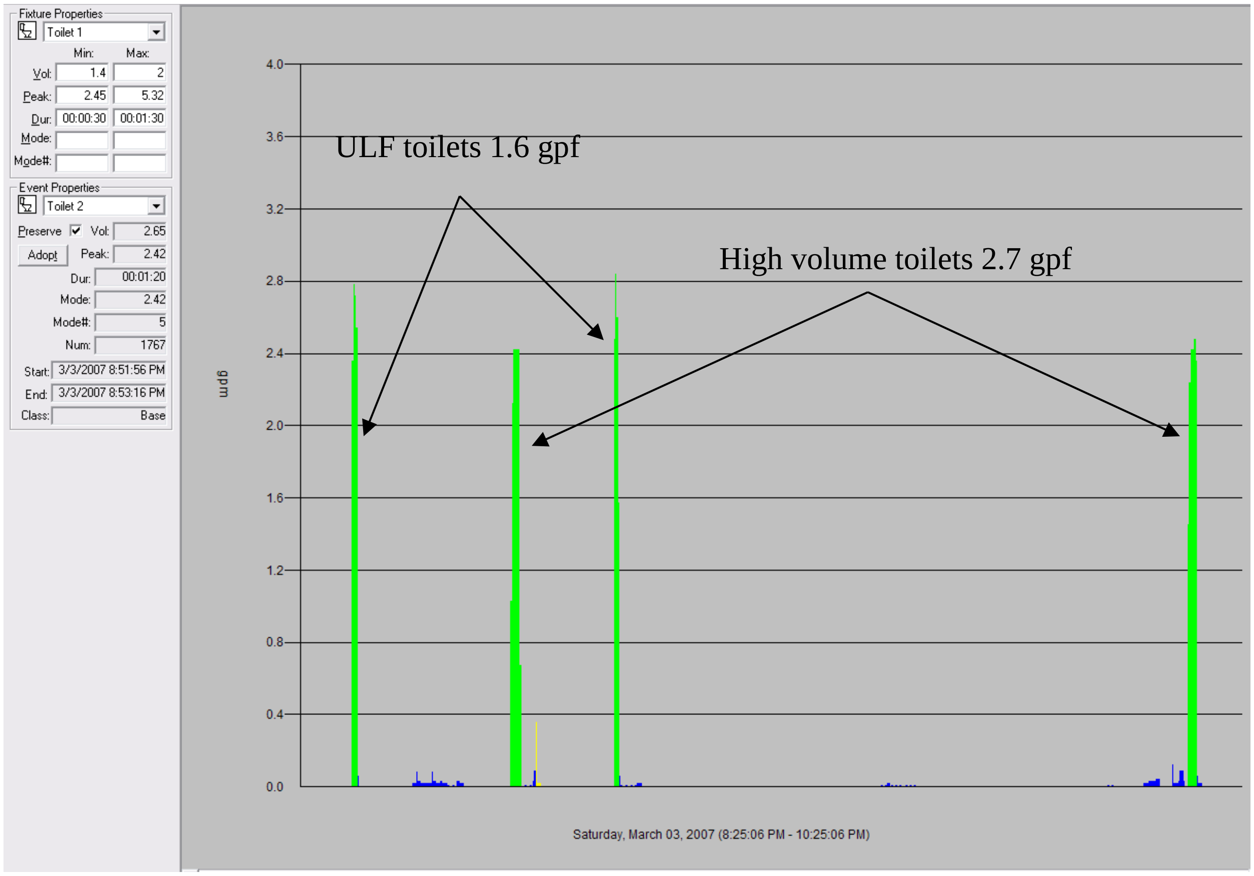

Figure 15: Four toilet flushes with two different profiles identified in Trace Wizard

Clothes Washers

Although there are many brands of residential clothes washers available, there are enough similarities in their profile to make them easily recognizable in the Trace Wizard program. Figure 16 is an example of the characteristics of a top-loading, non-conserving clothes washer, shown in light blue. Each cycle is similar in volume (22-24 gallons) and represents filling of the clothes washer tub. Cleaning and rinsing is accomplished by agitating clothing in a volume of water sufficient to submerge the clothing. The initial cycle is flagged as first cycle, which allows the total volume of the clothes washer to be calculated for statistical purposes.

This figure also shows a typical intermittent “leak” consisting of very low flow rates going on and off during the trace period. These are most likely dripping faucets or valves that “leak” at a low rate, which are very common.

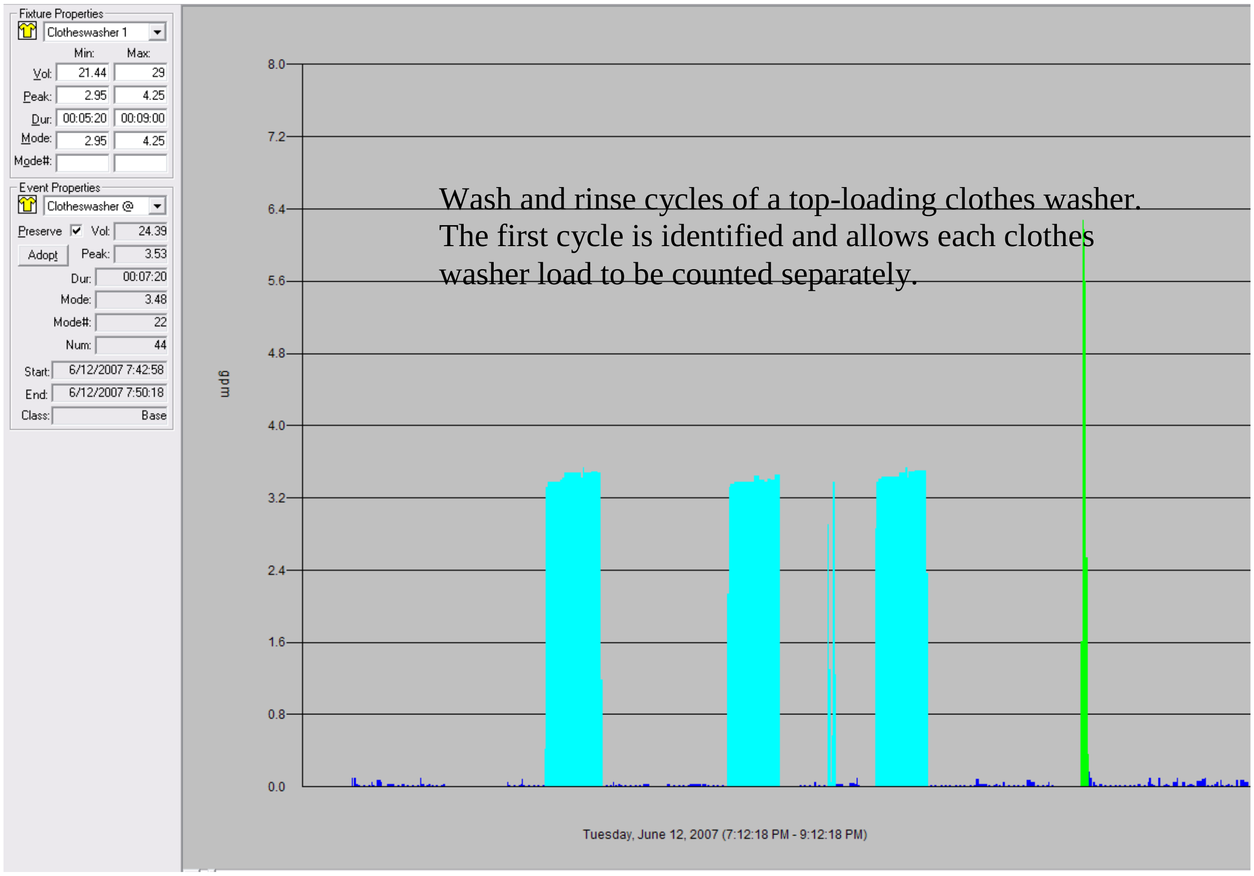

Figure 16: Typical profile of a top-loading clothes washer

High-efficiency clothes washers are designed to use less water than the standard top-loading clothes washers. They use a tumbling action that provides cleaning by continually dropping and lifting clothes through a small pool of water. The clothes washer loads, shown in light blue in Figure 17, use less than 15 gallons per load. As with a standard top-loading clothes washer, the initial cycle is flagged as first cycle, which allows the total volume of the clothes washer to be calculated for statistical purposes.

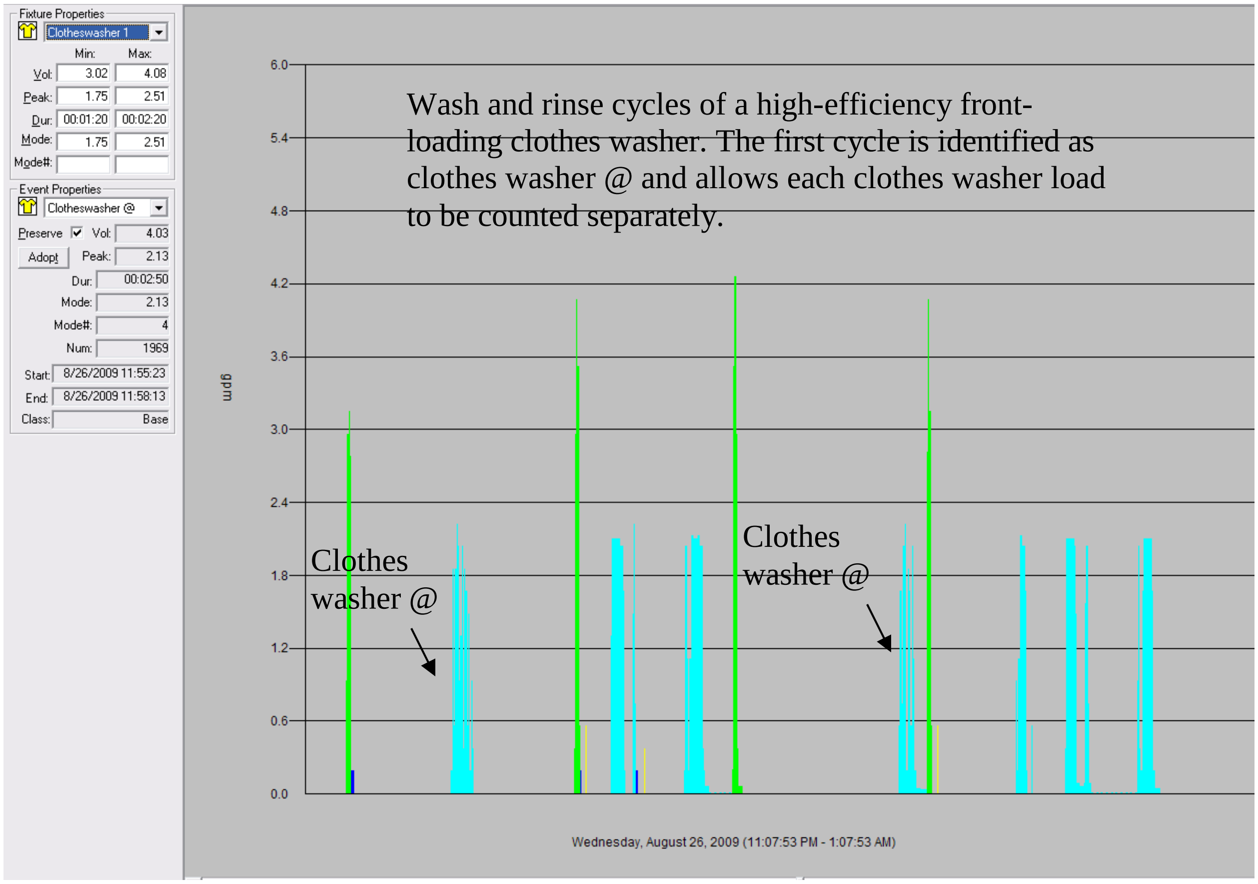

Figure 17: Typical profile of two high-efficiency clothes washer loads identified in Trace Wizard

Showers

Showers typically have one of two profiles. The profile shown in Figure 18 is representative of homes that have what is commonly referred to as a tub/shower combo, in which the shower and bathtub are operated by the same faucets. This results in a high flow when the faucets are turned on initially and the temperature is being adjusted; the diverter is then pulled and the flow is restricted by the shower head. The flow then remains constant until the faucets are turned off. The shower shown in Figure 18 has an initial flow of 5.6 gpm, which drops to 2.0 gpm for the duration of the shower. There are a number of HET toilet flush events (1.28 gpf) that occur during the two-hour time period shown in the figure, one of which occurred during the shower, and has been separated from the shower.

The second shower profile, shown in Figure 19, is typical of a stall shower where the flow goes directly through the showerhead and is therefore limited by the flow rate of the showerhead. The flow rate of a showerhead is dependent on the flow rating of the showerhead and the operating water pressure. The shower in Figure 19 is 14 minutes in duration with a flow rate of 1.7 gpm. Also shown is a clothes washer event and several toilet and faucet events.

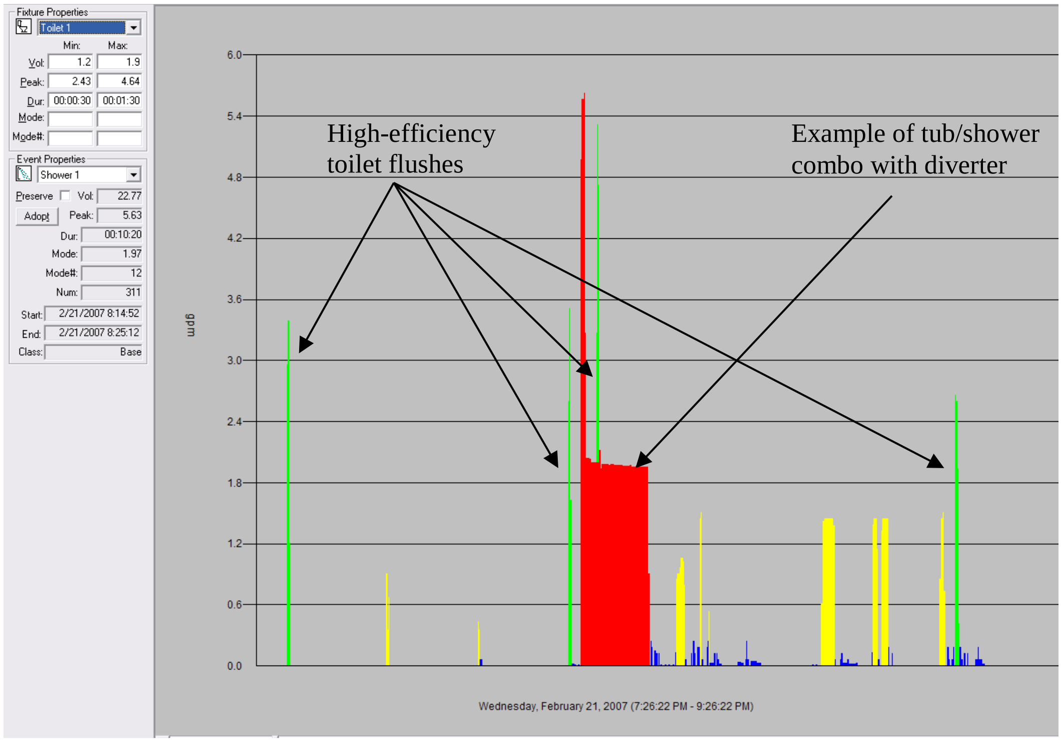

Figure 18: Classic profile of tub/shower combo with HE toilet events and some faucet use

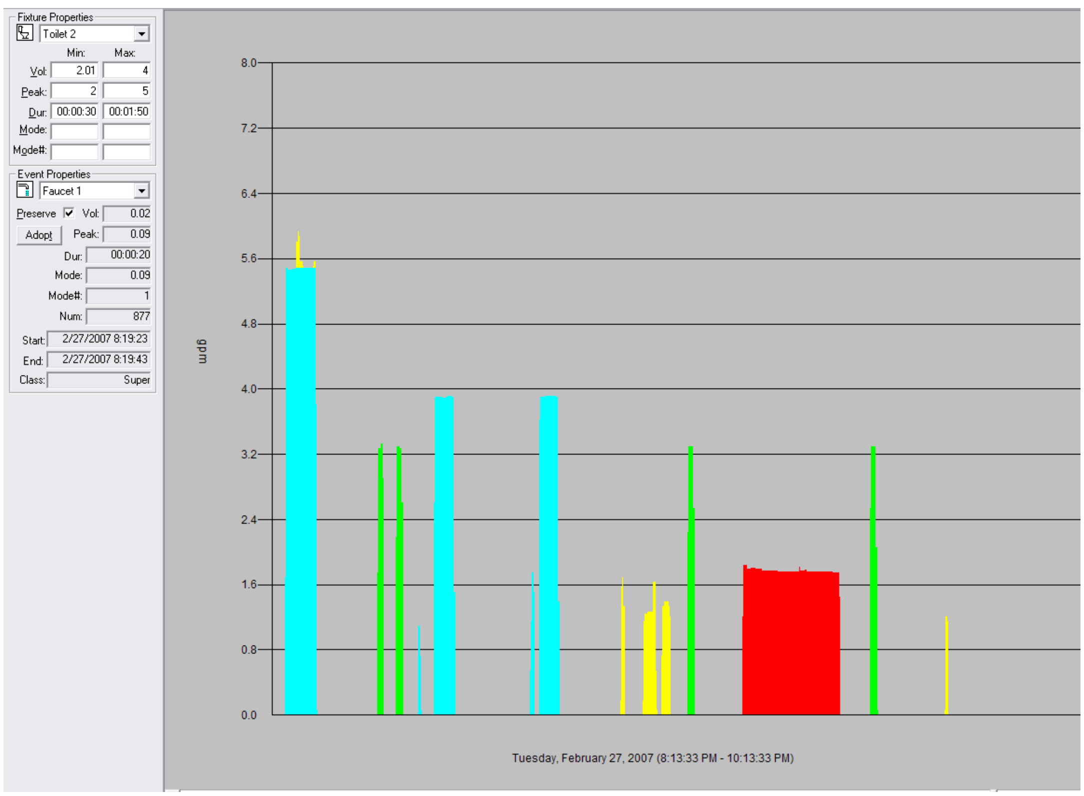

Figure 19: Profile typical of a stall shower with clothes washer, faucet, and toilet events

Dishwashers

Although dishwashers are multiple cycle events, their water use typically accounts for less than 5% of the total indoor use. Because they are cyclical and there is very little variation in the flow rate or volume of the cycles, dishwasher events are easily identifiable. And, like clothes washers, the first cycle of the dishwasher event is labeled using the @ symbol which enables the number of events to be counted. Figure 20 is an example of a dishwasher event with six cycles. Faucet use often precedes or occurs during dishwasher events as dishes are rinsed, or items are being hand washed. In the flow trace analysis the dishwasher category includes only water being used by mechanical dishwashing machines. Water used for hand-washing of dishes would be counted as part of the faucet category.

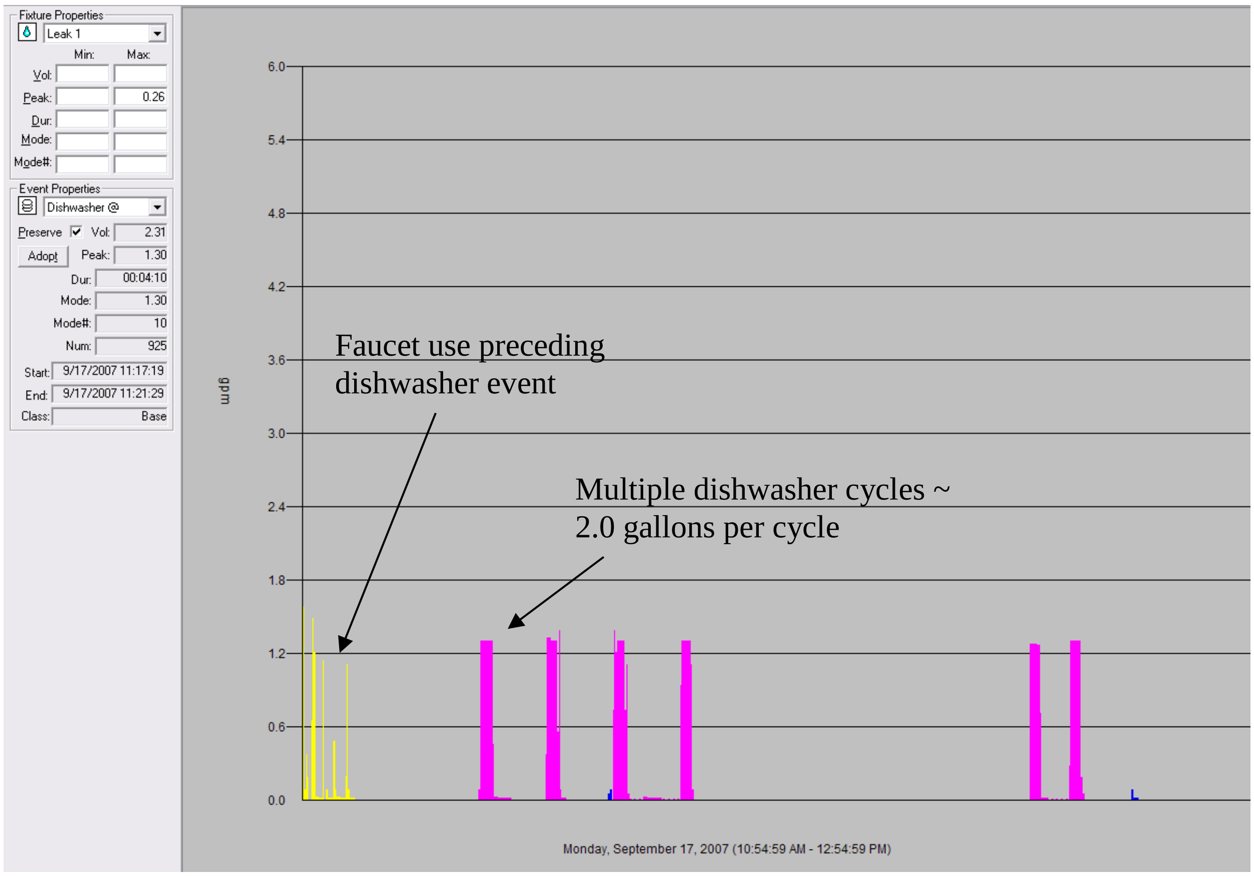

Figure 20: Multiple cycles typical of dishwasher usage

Water Treatment

There are two kinds of water treatment that need to be considered. The most common is the water softening device, which works by ion exchange. Raw water is run through a resin bed and the hardness ions (calcium and magnesium, primarily) are adsorbed onto the resin in exchange for sodium. This reduces the hardness of the water, but does not affect its total dissolved solids. Once the exchange capacity of the bed is exhausted it is regenerated by backwashing with salt water. This backwash process is the only water consumed by the process. The treated water simply flows into the water pipes for use by the occupants as needed. Figure 21 shows a typical regeneration cycle for a home water softener. These are sometime controlled with a timer and sometimes by a sensor. These types of systems are very simple to identify in Trace Wizard.

The other type of home treatment is reverse osmosis. These systems run the potable water through a membrane, which separates the water from the salt. Typically around 25% of the total water input to the system emerges as product water and 75% is wasted. Whenever water is being treated the system is using water. The flow rates are typically low, and can be mistaken for leaks. The difficulty in identifying them as water treatment as opposed to leakage is the pattern of use. If only a few gallons are produced at a time, the system will show a repeatable pattern that can be identified. For example, if once or twice a week two gallons of product water are treated for drinking and cooking this will show up on the trace as a 10 gallon event with a fairly repeatable flow rate. If the system is used to treat large volumes of water, which is rare, it will start to look like a continuous leak. Survey information that identifies houses with RO systems helps with this identification.

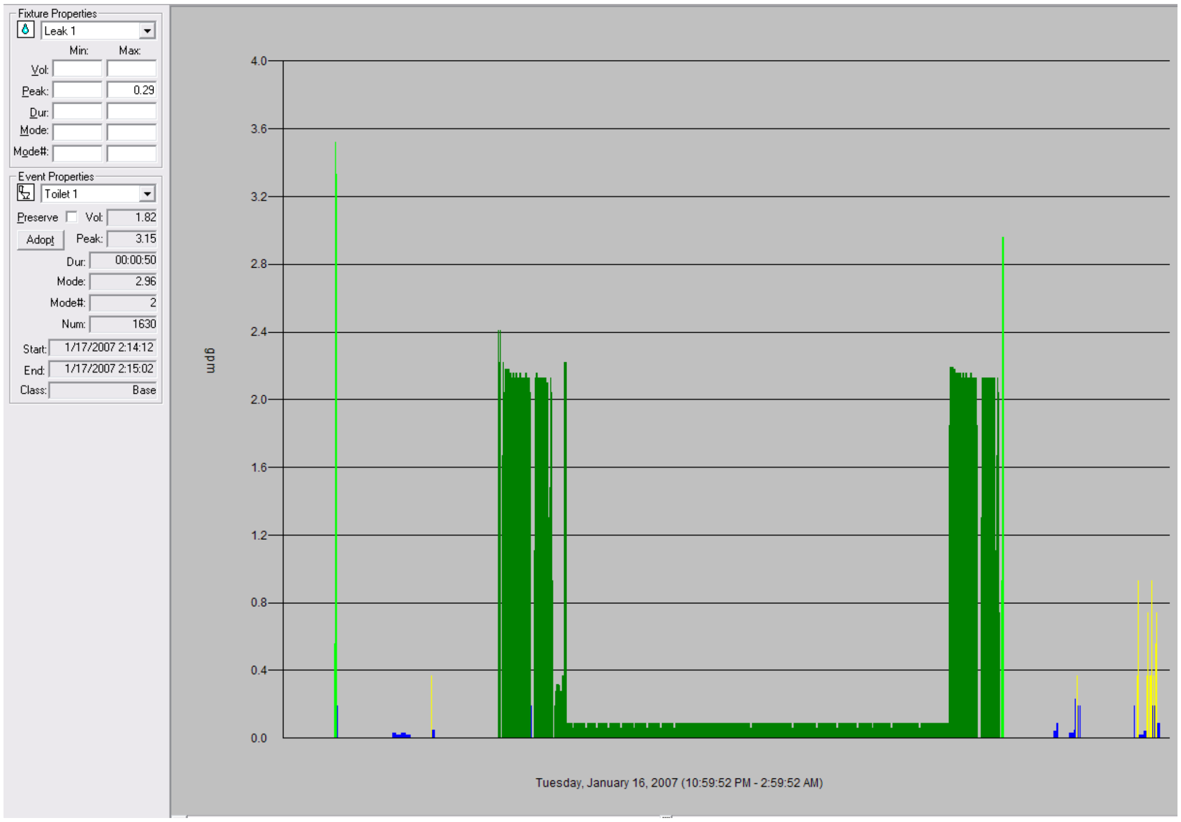

Figure 21: An example of a residential water softener in Trace Wizard

Leakage & Continuous Events

There are two kinds of leaks identified in Trace Wizard. The first type is intermittent leaks, such as toilet flappers or faucet drips and the second is continuous leaks due to broken valves or leaky pipes. Intermittent leaks are identified by their very low flow rates (too low to be faucets), association with other events that might initiate a leak, or the fact that they simply do not appear to be faucet use, and because they occur too frequently to be explained by someone standing at a sink and operating a faucet for hours at a time. Intermittent leaks are very common, and most traces contain a number of these types of leaks. The lower limit of “leak” detection is based on the ability of the water meter to register the flow. To the extent that the meters cannot register very low flows, leakage measurements would be under-estimated.

Constant leaks, on the other hand, are continuous events. In rare cases these may not be leaks at all, but instead represent a device that has a constant water demand, such as a reverse osmosis system or a once-through cooler. The presumption, though, is that these are leaks. Use of survey information can be used in conjunction with the end use data to look for correlations between leakage and fixtures in the home to see if there might be a relationship that helps clarify the source of the “leak” and leak-like events.

Figure 22 is an example of an event that is classified as leakage in the Trace Wizard program. Although the flow rate is quite low – averaging less than 0.5 gpm – over the 2 week period of the trace nearly 5,400 gallons were attributed to this event. Leakage is flow that cannot be easily classified as a typical fixture, such as use for toilet flushing, clothes washing, faucets, showering, irrigation, or other commonly found household use. Leaks can be attributable to malfunctioning fixtures such as a leaking toilet or irrigation system or due to process uses, such as a reverse osmosis system, evaporative cooling, or a non-recirculating pond or fountain. The cause of flow attributed to leakage may be discovered during a site visit or from information provided on the survey returned by the homeowner. Often, however, this information is unavailable, and the cause of leakage remains unknown. Since the “leak” category represents such an important part of single-family residential water use, looking further into the causes of these types of events would be beneficial.

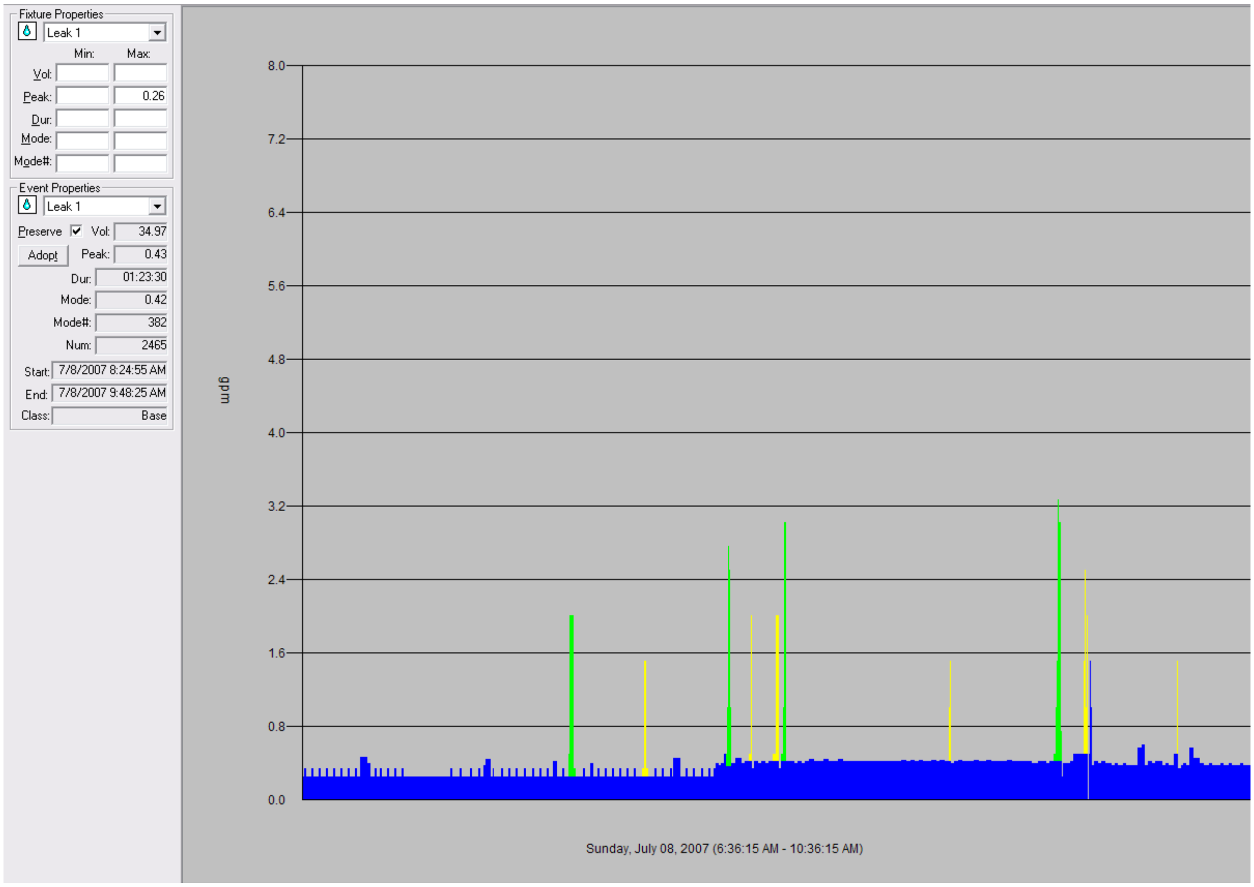

Figure 22: Four-hour period showing a continuous event classified as a leak

Irrigation

Large automatic irrigation events are the easiest to identify and are usually characterized by a large event consisting of several very distinct segments, each with its own duration and flow rate as the various zone valves open and close. Automatic irrigation is generally operated by a timer device that turns on the irrigation at a set time, on specified days, and irrigates multiple zones in sequence. The flow rate for each zone varies depending on the type and number of sprinkler heads located on that zone. Figure 23 shows an irrigation event that occurs Monday, October 29, 2007 at 1:12:10 PM. The event properties show that the volume of the irrigation event is 949 gallons with a peak flow of 18.4 gallons per minute, and a duration of 1 hour and 12 minutes. This event was repeated daily throughout the duration of the data logging period. The change in flow rate occurs seven times during the irrigation event and is indicative of different irrigation zones.

Drip irrigation is typically lower flow than overhead irrigation and may be operated manually or as a separate zone on an automatic irrigation system. Drip irrigation is generally used for non-turf type plants that require less water and less frequent watering than turf or other high water-use plants. Figure 24 is an example of a drip irrigation event with a flow rate of 2.5 gpm and a duration of 96 minutes. The total volume of the event is 190 gallons. There are several toilet flushes and some faucet use that are running concurrently to the irrigation event. A key to recognizing this event as irrigation as opposed to some other large use was the fact that it was repeated during the logging period at similar time of day.

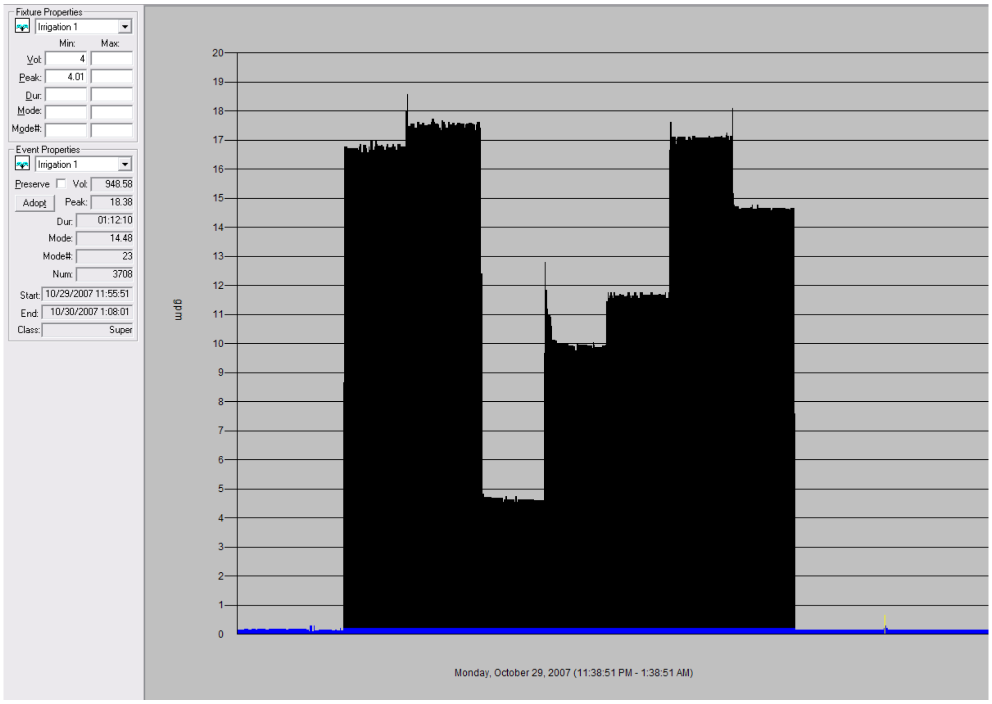

Figure 23: Irrigation event with multiple zones

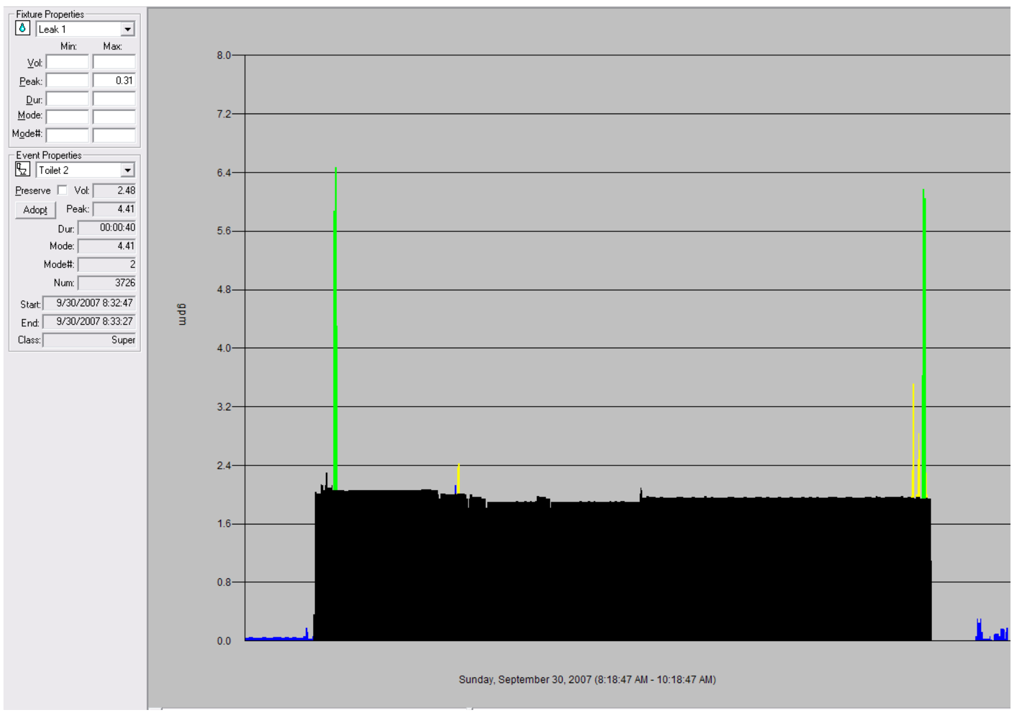

Figure 24: Trace Wizard profile of drip irrigation

Faucet Use

Basically, faucet events are generally intended to identify uses for kitchen and bathroom faucets. These include a wide range of events that are similar, with flow rates less than 2.5 gpm and durations and volumes that are reasonable with respect to what one would expect from a bathroom or kitchen sink. Exceptions to this would include flows at higher flow rates that might come from a utility sink or a bath tub with a volume too low to be a bath fill. Another quality of faucet use is their irregular and random type of pattern, with fairly short durations and low volumes. Use of faucets to hand-wash dishes while leaving the water run continuously is one of the largest types of faucet uses encountered in the analysis.

Other Uses

Events that simply do not fit neatly into any other category are listed as "other uses". They might have flow rates too large for a sink, but volumes too small for irrigation or a bath. These events are set into the category of miscellaneous other uses.

The end result of the flow trace analysis is a Microsoft Access database file with a unique keycode that identifies the home. The file for each home contains one record for each water use event along with the fixture name, volume, flow rate, start time and duration. A typical two-week trace will contain anywhere from 1,500 to 10,000 events.

DATABASE CONSTRUCTION

Summaries of the key data collected and created as part of this study was placed into one of several database tables so that they could be analyzed. This was one of the project deliverables. A total of six Xcel spreadsheets were crated to contain the project database, and these are described in the chapter devoted to the project databases. Copies of these tables are available for download from either the research team of the Foundation. These files can be used in Excel to create summaries and comparisons of the data, or can be loaded into specialized statistical programs, such as SASS or SPSS, for more advance analysis.

DESCRIPTIVE STATISTICS

Descriptive statistics were prepared for the various water use parameters investigated in the study. Typical statistics reported were means, medians ranges, and confidence intervals. Where possible, comparisons were made between the current study and the first REUWS. Many data sets lent themselves to distribution analysis, so there are many histograms in the report. Bar charts, scatter diagrams and tables of data are used throughout to report on the water use statistics. Similar analyses are presented for hot water use and outdoor use.

A closely related topic to the statistics was the development of benchmarks from the data that reflect the water use metric. The concept here is that the availability such a high amount of detailed data provides a very rich set of water use metrics with which to describe the use patterns. Comparisons of these metrics against known levels of efficiency in certain sub-sets of the data allow benchmarks, or normative levels of use to be identified for standard homes, efficient homes and highly efficient homes. These benchmarks are especially useful for conservation planning and determination of available savings from conservation.

REGRESSION MODELING

The summary tables and survey information was used to create regression models in order to examine the factors that help explain water use. Regression models use both continuous and categorical variables in an attempt to convert the data collected as part of the study into patterns of useful information about how single family water use varies with factors such as the number of persons per home, the size of the home, the presence of high efficiency fixtures and appliances, income, education and attitudes, etc.

INFORMATION ON PARTICIPATING AGENCIES

SELECTION OF STUDY SITES

Table 45 Table 8 shows the complete list of all of the participants in the study, at which level they participated, the number of single-family accounts served by each and the average number of residents per account as reported by the survey respondents. The weighting factor, shown in column four of the table is based on the percentage of the total number of single-family accounts represented by each agency. This weighting factor will be used as the basis of weighted averages, where necessary.

Table 8: Water agencies participating in REUWS 2.

Agency	Location	Level	Number of SF accounts 2010
Clayton	Georgia, USA	1	70,421
Denver	Colorado, USA	1	195,487
Ft Collins	Colorado, USA	1	27,867
Peel	Brampton, ON, CAN.	1	273,989
San Antonio	Texas, USA	1	331,853
Scottsdale	Arizona, USA	1	146,138
Tacoma	Washington, USA	1	85,288
Toho	Kissimmee, Florida, USA	1	68,021
Waterloo	Kitchener, ON, CAN.	1	55,733
Aurora	Colorado, USA	2	70,608
Austin	Texas, USA	2	189,038
Cary	North Carolina, USA	2	45,120
Chicago	Illinois, USA	2	269,698
Edmonton	Alberta, CAN.	2	220,090
Henderson	Nevada, USA	2	80,352

Agency	Location	Level	Number of SF accounts 2010
Miami	Florida, USA	2	377,846
Mtn View	California, USA	2	11,802
Otay	California, USA	2	40,994
Philadelphia	Pennsylvania, USA	2	392,639
Portland	Oregon, USA	2	153,500
RWA-CT.	Connecticut, USA	2	107,141
Santa Barbara	California, USA	2	16,919
Santa Fe	New Mexico, USA	2	26,871
Average	-	-	141,627
Maximum	-	-	392,639
Minimum	-	-	11,802
Std. Dev.	-	-	

DEMOGRAPHICS AND CENSUS INFORMATION

The communities participating in this study were varied. In some ways they were comparable and in some ways they were the same. Understanding some of the differences can help understand the context and differences in water demand. One important note about these data: the census data is based census metropolitan areas and these may not exactly match the service area of a given agency. However, gestalt of the census data can still inform about the communities and their demand for water. One major household characteristic that affects water demand is number of people per home. Table 9 shows U.S. Census data for average household size. Note that these are for all households, not just he subset of single-family homes. Overall, the Census shows slightly higher occupancy than the survey data from this study (please see Table 38 for comparisons).

Table 9: U.S. Census data from selected population profiles

Utility	Metropolitan Statistical Area	year of data	Average household size
Clayton	Atlanta-Sandy Springs-Marietta	2009	2.86
Denver	Denver -Aurora-Broomfield	2009	2.59
Ft. Collins	Fort Collins -Loveland	2010	2.42

Utility	Metropolitan Statistical Area	year of data	Average household size
San Antonio	San Antonio-New Braunfels	2009	2.92
Scottsdale	Phoenix-Mesa-Glendale	2009	2.92
Tacoma	Seattle-Tacoma-Bellevue	2009	2.86
Toho	Orlando-Kissimmee-Sanford	2009	2.77

(American Community Survey, 1-year estimates)

Single-family homes are the focus of this study. So it can be helpful to know what portion of a community's housing stock is single-family housing. The census records different types or homes, based on number of units and whether or not the unit is detached. Single-unit detached is comparable to the single-family home criteria of this study. Table 10 shows total housing units and the breakdown of single-unit detached homes. With a calculation of what percent of total stock is single-unit, detached homes. The average across all study sites is 63% of housing units are single-family detached, which validates the importance of evaluating water use patters for this sector of water users.

Table 10: U.S. Census data from selected housing characteristics

Utility	year of data	Total Housing Units	single-unit, detached	Percent single-unit detached
Clayton	2012	2,175,303	1,455,705	67%
Denver	2012	1,086,263	646,920	60%
Ft. Collins	2012	134,704	89,085	66%
San Antonio	2009	781,756	533,879	68%
Scottsdale	2009	1,737,335	1,116,083	64%
Tacoma	2012	1,478,935	874,944	59%
Toho	2009	907,080	542,548	60%

There are many characteristics that can be used to help describe a community. Possibly some of the most telling are economics. Income, which has a correlation to water demand, is captured in census data. Table 11 shows median household income for logging sites. Note that this data is from all households, not just single-family homes. Poverty is also an important parameter that can give a sense the financial limits of a community's – and a water agency's – resources, and one measure of this is also shown in Table 11.

Table 11: U.S. Census data from selected economic characteristics

Utility	year of data	Median household* income	Percentage of families whose income in the past 12 months is below the poverty level
Clayton	2009	55,464	10.3%
Denver	2009	59,007	8.7%
Ft. Collins	2009	55,676	7.7%
Peel			
San Antonio	2009	47,955	12.6%
Scottsdale	2009	52,796	10.7%
Tacoma	2009	64,028	6.7%
Toho	2009	46,946	9.8%
Waterloo			

CLIMATE AND DROUGHT

Measures of Climate

Climate sets the stage for water use, particularly outdoor use. And while weather is a key parameter in outdoor demand analysis developed in this study, climate is the baseline, long term weather norms that present the context of weather-based demand.

The Köppen climate classification is a vegetation-based empirical system. This system uses quantitated qualifiers such as temperature and dryness and gives a qualitative interpretation of biomes. Figure 25 shows a map of the climate zones for North America and Table 12 shows the climates of the Level 1 water agencies (these agencies were the ones featuring in the outdoor analysis). Looking at this table it is obvious that there is a mix of warm and cold sites as well as humid and semi-arid to desert climates in this study.

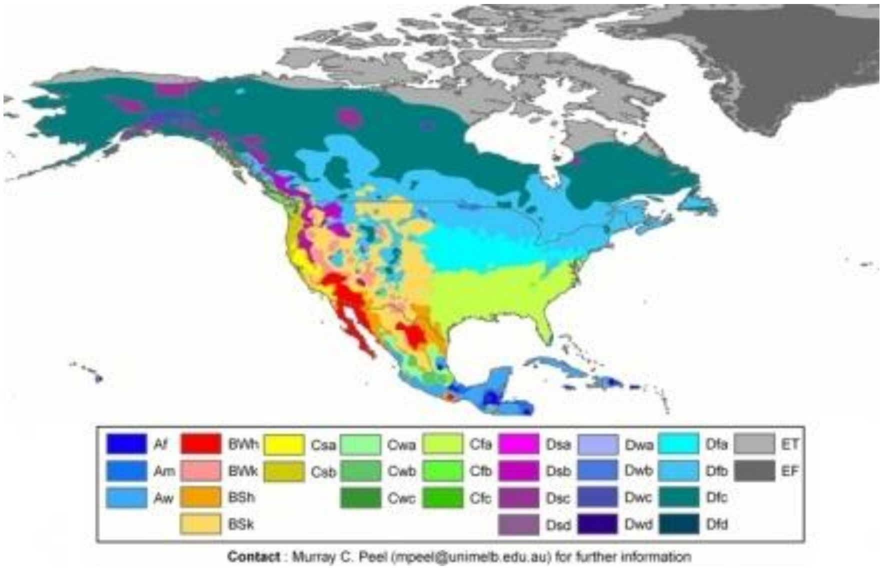

Figure 25: Climate map of North America

Table 12: Climates of participating agencies

	Köppen Class	Description
Clayton	Cfa	warm oceanic climate / humid subtropical
Denver	Bsk	cold semi-arid climate
Ft. Collins	Bsk	cold semi-arid climate
Peel	Dfa	humid continental
San Antonio	Cfa & BSh transition	humid subtropical to hot and semi-arid climate
Scottsdale	BWh	warm desert climate
Tacoma	Csb	Temperate Mediterranean climate
Toho	Cfa	warm oceanic climate / humid subtropical
Waterloo	Dfa	humid continental

In addition to the qualitative climate classifications, long-term weather averages can also be used to understand climate. The National Oceanic and Atmospheric Administration (NOAA) provides climate data. One useful set of data are the climate normal. These are defined as the 30-year (1981 to 2010) year averages. NOAA computes the monthly average temperature normal as the mean (difference) of the monthly maximum temperature normal and the monthly minimum temperature normal. Figure 26 shows these for the participating agencies.

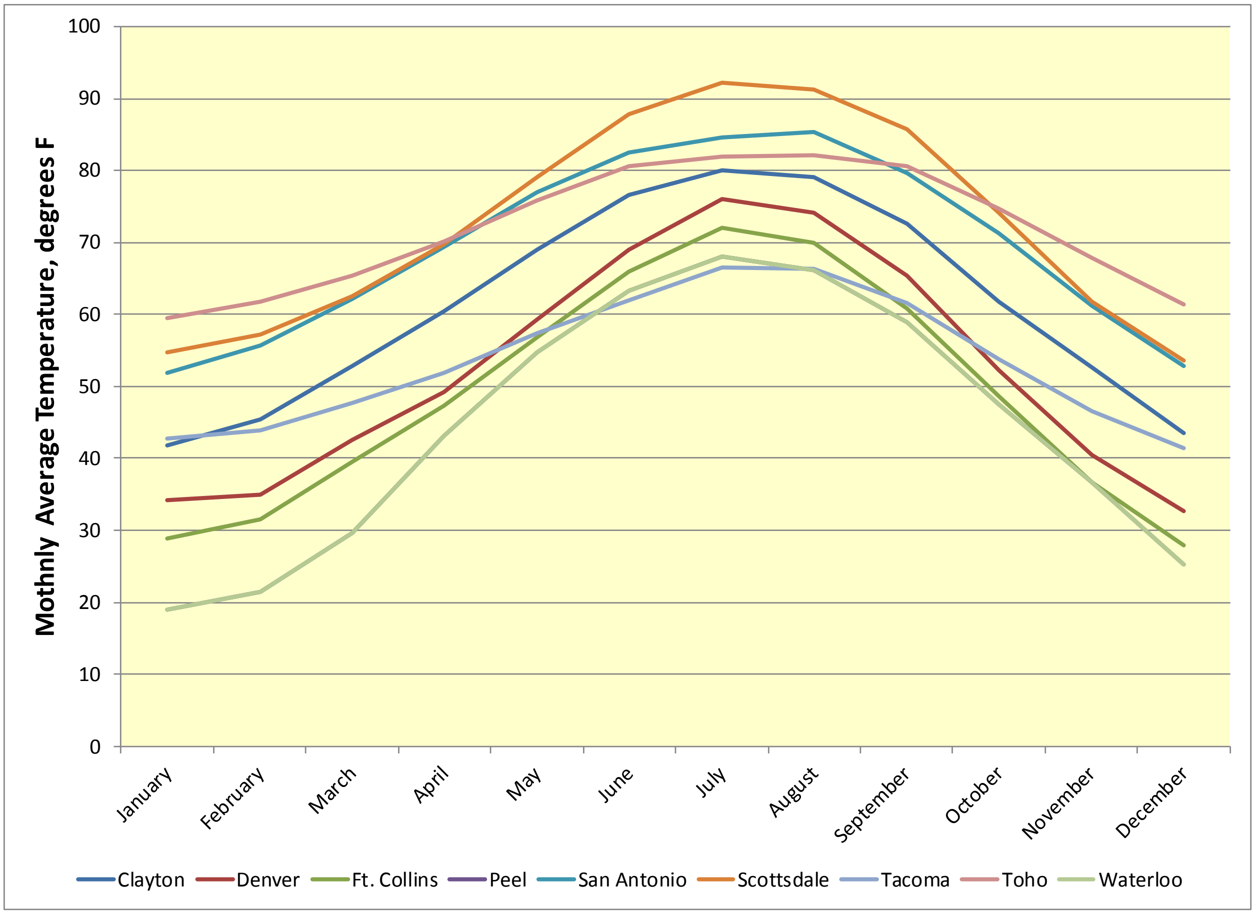

Figure 26: The monthly average temperature (°F) normal from NOAA.

Thirty-year normals of precipitation data are another important measure of climate. NOAA data are shown in Table 13. This monthly data is totaled to give some sense of annual averages. For reference, precipitation data used in the outdoor analysis is also presented. From this it can be seen how the study year (2010 in most cases) compared to the typical rainfall. Note that San Antonio and Denver were decidedly drier than average. San Antonio was in drought (discussed below) but Denver was not. Denver reported no drought during the summer but an unusually dry autumn.

Table 13: Monthly average precipitation normals, in inches, from NOAA and precipitation used in outdoor analysis.

	Clayton	Denver	Ft. Collins	Peel	San Antonio	Scottsdale	Tacoma	Toho	Waterloo
January	4.5	0.5	0.4	1.6	1.8	1.3	5.9	2.4	1.6
February	4.8	0.6	0.4	2.1	1.8	1.2	3.9	2.8	2.1
March	5.0	1.5	1.4	2.0	2.3	1.2	4.1	3.8	2.0
April	3.5	2.1	2.0	2.9	2.1	0.5	3.0	2.3	2.9
May	3.5	2.5	2.4	3.6	4.0	0.2	2.1	3.6	3.6
June	3.9	2.0	2.0	3.1	4.1	0.1	1.6	7.7	3.1
July	5.0	2.0	1.2	3.7	2.7	1.0	0.7	7.5	3.7
August	3.9	2.1	1.3	2.4	2.1	1.2	0.8	7.9	2.4

	Clayton	Denver	Ft. Collins	Peel	San Antonio	Scottsdale	Tacoma	Toho	Waterloo
September	3.6	1.3	1.3	2.3	3.0	0.9	1.3	6.3	2.3
October	3.5	1.3	1.2	2.1	4.1	0.8	3.7	3.2	2.1
November	4.0	0.8	0.7	3.4	2.3	0.9	6.7	2.2	3.4
December	3.8	0.5	0.5	2.7	1.9	1.1	5.5	2.4	2.7
Annual Total	49.0	17.1	15.0	31.7	32.3	10.3	39.2	52.0	31.7
2010	41.6	10.0	12.4	26.8	10.8	11.7	49.5	43.0	26.8

Official Drought Status

In many communities, drought evokes a response from the agency and sometimes from individuals. Individuals may alter their water demand patterns during drought or if t her is a perception of drought. Likewise, agencies may put in place voluntary or mandated water use restrictions. Such restrictions – if in place – could be expected to alter the results of this data. However, as shown in Table 14, most agencies were not in drought. San Antonio is a major exception and one that is somewhat complex.

Table 14: Official drought status

Agency	Billing data year	Official drought status	Water use restrictions in place for single family homes	Voluntary or mandatory restrictions	Please describe restrictions:
Clayton	2010				NA
Denver	2010	no drought	no	NA	Sept 2010 was very hot and dry.
Ft. Collins	2010	no drought	no	NA	
Peel	2010	no drought	yes	mandatory	Peel limited watering of lawns to once per week during restricted hours, trees, shrubs and plants every second day is allowed.
San Antonio	2008	See below	No	NA	Billing data for 2008 used to avoid drought impacts
Scottsdale	2010	no drought	no		
Tacoma	2010	no drought	no	NA	
Toho	2010	drought - extreme	yes	mandatory	Two day per week watering restrictions set forth by the South Florida Water

Agency	Billing data year	Official drought status	Water use restrictions in place for single family homes	Voluntary or mandatory restrictions	Please describe restrictions:
					Management District enforced by the Toho Water Authority in our service area.
Waterloo	2010	no drought	no	NA	

The U.S. Drought Monitor shows that significant portions of Texas have faced at least some form of drought since late 2007. Some relief was seen in late 2009 through 2010, but dry conditions returned in late 2011[4]. San Antonio in particular had several droughts since 2007[5]. San Antonio Water System relies more on the state of the Edwards aquifer than on weather-based definitions of drought as triggers for its water use restrictions. In June of 2008, SAWS began tapping into its reserve system[6]. The bottom line is that San Antonio Water System was on drought response for all or most of 2010. In an effort to get billing data that did not reflect drought restrictions, 2008 data was used in this study. This decision was a compromise between a year with fewer drought restrictions and a year that was close to the baseline year (2010) for the rest of the study.

In response to these conditions, San Antonio enacted staged drought restrictions. These measures focused attention on discretionary, outdoor use. These stages are triggered based on aquifer levels. The four stages place progressively tighter restrictions on water use. Residential restrictions include:

- Irrigation systems are limited to specific times of day and frequency. For example, during stage three, landscape watering is allowed only every other week.
- Landscape watering is only allowed morning and evening.
- Drip irrigation may be limited to certain days of the week.
- Aesthetic water features maybe limited. In stage three, use of features is prohibited unless a variance has been granted.
- Non-public swimming pools may require cover.
- Washing impervious surfaces maybe restricted and is prohibited for stage three drought.
- Residential washing of vehicles may be limited. For stage three drought, washing is restricted to assigned watering days and no street run off is allowed.

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[4] U. S. Drought Monitor, Drought Conditions (percent area): Texas http://droughtmonitor.unl.edu/DM_tables.htm?TX.

[5] “Drought sparks strict restrictions” Lubbock Avalanche-Journal 27 July 2009 http://lubbockonline.com/stories/072709/sta_471293520.shtml

[6] “State Climatologist Declares Half of Texas Is Under Drought.” San Antonio Business Journal 3 July 2008. http://www.bizjournals.com/sanantonio/stories/2008/06/30/daily28.html

CUSTOMER BASE

Size

Agencies participating in this study widely varied in size. One measure of size is total billed consumption. Figure 27 shows the total billed consumption for participating agencies for 2010. With 190,000 MG (million gallons) of billed consumption, Chicago immediately stands out. But it should be noted that this number includes wholesale and serves a population of 5.3 million. Denver, Miami, San Diego and San Antonio round out the five largest agencies. Mountain View, Santa Barbara, Cary, Waterloo and Fort Collins are the smaller five. This data can also be found in Table 16.

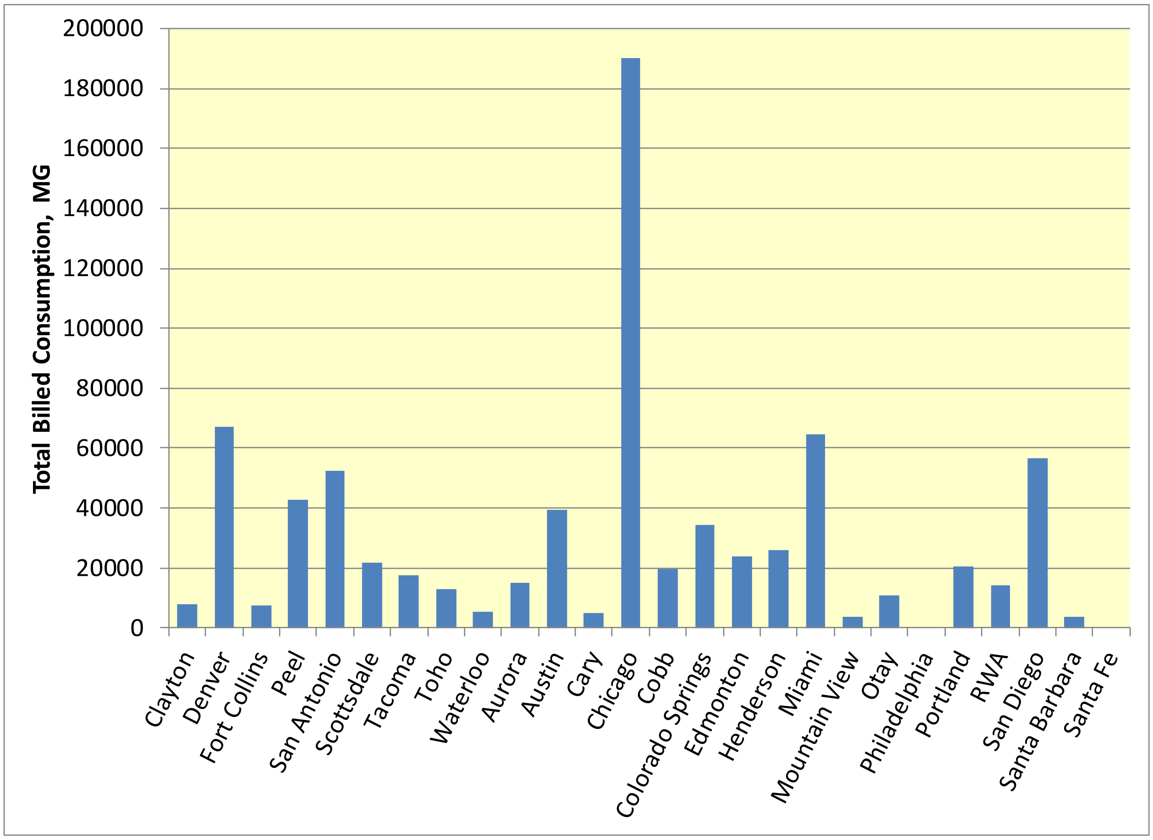


Figure 27: Total billed consumption (in millions of gallons) for participating agencies, 2010 data.

Another measure of size is population served (see Table 15). The smaller agencies, in terms of service population, are Mountain View, CA (72,800) and Santa Fe, NM (80,000). The larger agencies are Chicago, IL (5.3 million) and Miami, FL (2.3 million). Note that total volume and service population can result in different size ranks. For example, Denver has about half the population of Miami but slightly higher billed consumption (67,137 MG versus 64,430 MG). This could be due to a number of factors ranging from water use patterns, commuters and even water accounting practices.

Table 15: Population served by participating agencies.

Agency	Population served
Clayton County	279,000
Denver	1,174,000
Fort Collins	129,000
Peel	1,261,000
San Antonio	1,360,000
Scottsdale	217,385
Tacoma	317,450
Toho	Not reported
Waterloo	535,000
Aurora	325,078
Austin	886,768
Cary	152,551
Chicago	5,300,000
Cobb County	600,000
Colorado Springs	441,000
Edmonton	1,000,000
Henderson	277,502
Miami	2,288,432
Mountain View	72,800
Otay	198,616
Philadelphia	1,500,000
Portland	915,800
RWA, CT	430,437
San Diego	1,312,000
Santa Barbara	91,416
Santa Fe	80,000

Notes:
Chicago's population includes the city and 125 suburbs (47 which are wholesale direct connects).
Otay's population is 198,616 served for potable deliveries but 206,000 when including customers who are sewer only.
Portland's population includes 546,600 retail and 351,200 wholesale customers.

Sectors

Service sector breakdown is another important aspect of an agency's customer base. Figure 28 shows this breakdown for each agency from 2010-11. Given that this study focuses on single-family, it is important to have context for how much single-family use accounts for an agency's total billed consumption. On the average, 44% of total billed consumption for the study group went to single family use when counting all agencies. The median single-family share of total billed consumption is 47%.

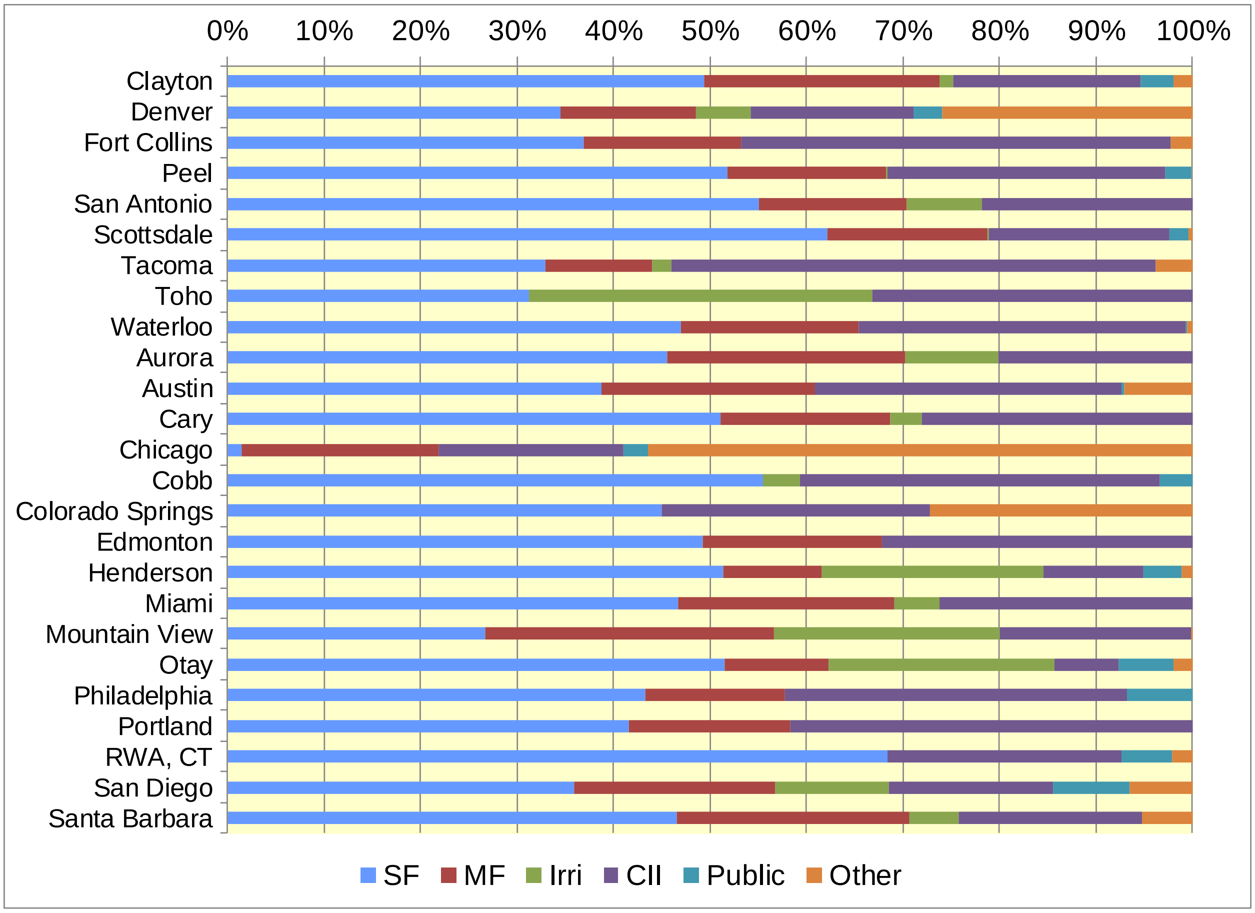


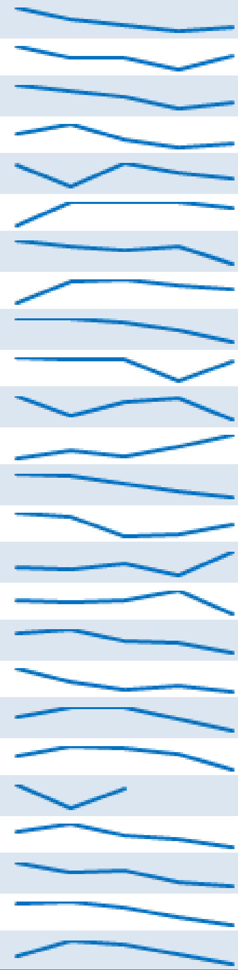
Figure 28: Billed consumption by sector as percentage of total

Trends in Expansion and Contraction

Trends in total billed consumption can also reveal if an agency is experiencing contraction or growth. Contraction can indicate that an agency may be facing declining revenues. Expansion may mean an agency is looking for more supply. Table 16 shows five-years' worth of total billed consumption for participating agencies. About half of the agencies experienced trends that were predominantly decreases in consumption. This could be due to a host of factors including conservation and economic recession.

Table 16: Trends in total billed consumption for participating agencies

Agency	2006	2007	2008	2009	2010	Trend
Clayton	8986	8361	8095	7777	7920	
Denver	71911	66315	66315	61235	67137	
Fort Collins	8616	8188	7739	6989	7435	
Peel	44569	46432	43380	42163	42909	
San Antonio	57610	49421	58720	55176	52477	
Scottsdale	17082	23136	22986	22923	21670	
Tacoma	18920	18521	18252	18494	17376	
Toho	11847	13849	13969	13464	13059	
Waterloo	7024	7037	6723	6139	5375	
Aurora	15468	15279	15279	13295	15020	
Austin	49515	41413	47167	48255	39455	
Cary	3666	4149	3780	4413	5090	
Chicago	206144	204627	199955	193614	190356	
Cobb	21443	20768	17523	17928	19513	
Colorado Springs	26408	25678	28000	22641	34167	
Edmonton	24589	24472	24533	25225	23662	
Henderson	28051	28558	27200	26983	26018	
Miami	71674	67302	65147	66086	64430	
Mountain View	3853	4071	4089	3803	3523	
Otay	12430	13542	13226	12647	10870	
Philadelphia	57820	54912	57210			
Portland	21100	21400	20900	20700	20400	
RWA	16767	15822	16032	14756	14359	
San Diego	69828	71675	67374	61934	56598	
Santa Barbara	4121	4615	4486	4189	3837	



WATER SUPPLY

Water supply drives many of the issues and challenges faced by water agencies. Supply water's availability and cost should and does influence use patterns and conservation attitudes, both at the agency level and the customer level. Table 17 gives the water sources for participating agencies. Most (24 out of 26) agencies rely on surface water for some or all of their supply. Ground water is the second most common source, with 62% agencies reporting it as a source, but reclaimed water (54% of agencies) came in a close third.

Table 17: Water sources for participating agencies

	Surface Water	Ground Water	Desalinated Water	Reclaimed Water	Non-potable Water	Harvested Rainwater
Aurora	Yes	Yes		Yes	Yes	
Austin	Yes		Yes			Yes
Cary	Yes				Yes	

	Surface Water	Ground Water	Desalinated Water	Reclaimed Water	Non-potable Water	Harvested Rainwater
Chicago	Yes					
Clayton	Yes	Yes		Yes		
Cobb	Yes					
Colorado Springs	Yes	Yes		Yes*	Yes	
Denver	Yes				Yes	
Edmonton	Yes			Yes		
Ft. Collins	Yes			Yes	Yes	
Henderson	Yes			Yes	Yes	
Miami		Yes				
Mountain View	Yes	Yes		Yes		
Otay	Yes			Yes		
Peel	Yes	Yes				
Philadelphia	Yes					
Portland	Yes	Yes				
RWA, CT	Yes	Yes				
San Antonio	Yes	Yes		Yes	Yes	
San Diego	Yes	Yes		Yes	Yes*	Yes
Santa Barbara	Yes	Yes	Yes	Yes		
Santa Fe	Yes	Yes		Yes		
Scottsdale	Yes	Yes		Yes*		
Tacoma	Yes	Yes				
Toho		Yes		Yes		
Waterloo	Yes	Yes				

**Notes: Colorado Springs' reclaimed water is non-potable.*
San Diego has an indirect potable reuse pilot project.
Scottsdale uses reclaimed water but only for non-residential.

WATER RATES

Utilities set water rates in order to generate revenues required to operate their systems, and they do so in a highly variable manner. There was a wide variety of water rate structures encountered in the 25 agencies that provided rate information in this study. There were a total of 19 agencies that used an increasing block rate structure, 4 that used uniform rates and 2 that used declining block rates.

Blocks and Breakpoints

The number of blocks used for the various block structures ranged from 2 to 5. Table 18 shows the number of blocks and the breakpoint between the lower and higher block for each of the agencies with increasing block rate structures. Averages and ranges of values are presented as well. On average the first block included use up to 6 kgal, but this ranged from as low as 2 kgal up to 20 kgal. The upper limit to block 2 consumption averaged 17 kgal, but this ranged from 6 to 44 kgal.

Table 18: Number of blocks and breakpoints between blocks

		Top of Block Volumes (kgal)			
Agency	No. Blocks	**1**	**2**	**3**	**4**
Aurora	**3**	20	40		
Austin	**5**	2	9	15	25
Cary	**4**	5	8	23	
Clayton	**4**	3	8	20	
Cobb	**5**	3	15	29	49
Colorado Springs	**3**	7.5	18.7		
Denver	**4**	11	30	40	
Edmonton	**2**	15.9			
Ft Collins	**3**	7	13		
Henderson	**4**	6.1	16.2	30.4	
Miami	**4**	3.7	6.7	12.7	
Mt View	**3**	2.2	18.7		
Otay	**4**	3.7	7.5	16.5	
San Antonio	**4**	6	12.7	17.2	
Santa Barbara	**3**	3	15		
Santa Fe	**2**	10			
Scottsdale	**3**	8.3	44		
Tacoma	**2**	3.7			
Toho	**4**	2	6	15	
Average		6	17	22	37
Max		20	44	40	49
Min		2	6	12.7	25

In addition to charges for water, there were a number of different systems for charging for wastewater services. Three agencies charged a flat fee for wastewater, 21 used commodity charges, and 1 did not include charges for wastewater service on the water bill. Of the agencies that charged for wastewater using a commodity fee structure some levied this charge only on the average winter consumption and some charged for wastewater on all water used by the customer.

In order to be consistent all of the water and wastewater rates were put into a spreadsheet model that calculated the total billed amount or cost for water and wastewater charges based on the fixed fees, commodity rates, and block structures used for each agency. The total cost could then be used to determine the average rate for water and wastewater ($/kgal) for consumption within the different levels of consumption. No charges were included for other miscellaneous fees that some utilities add to their bills, such as flood control. Only charges for water and wastewater were included in this analysis, since these two types of charges are directly related to water use. The spreadsheet allowed charges for water and wastewater (expressed as average price/kgal) to be compared across agencies in a consistent manner.

The research team wanted to express customers' costs for water and wastewater in terms of both average and marginal rates. This raised the question of how best to represent the average rates that customers with so many different block rate structures were paying. In order to do this in a simple manner the total cost for water and wastewater were determined for each agency based on three volumes of use: 5 kgal, which was intended to capture the average non-irrigation cost for water, and 25 kgal, which was intended to capture the average cost during the irrigation season, and for 50 kgal of use, which was calculated in order to capture the cost during the peak usage month. These charges, representing the average price of water at the various levels of consumption, are shown in Table 19.

Each of these costs was then divided by the total volume of consumption in order to determine the average cost for water and wastewater during the respective demand condition. The marginal rate for water was also determined, which was based on the top tier cost for water-only service. This was intended to show the marginal rate being paid for water by customers in peak times. Since these top rates do not normally include wastewater charges, which are usually based on non-irrigation use, this was the rationale for not including wastewater charges in the marginal rates.

In an attempt to bring some kind of order to the plethora of the rate structures shown in Table 20, and to have a consistent set of parameters, based on rates, for comparison and modeling, the following values were determined for each agency based on their individual rate structure:

- The total billed amount for variable and fixed water and sewer charges for a consumption of 5 kgal per month, which was meant to replicate billed consumption for typical winter or non-irrigation season conditions.
- The total billed amount for monthly consumption of 25 kgal, which was meant to replicate summer, or irrigation season conditions.
- The total billed amount for 50 kgal of consumption, which was meant to capture peak use conditions.
- The fixed charges included on the bill for water and wastewater
- The average price paid by the customer at the 5 kgal level of consumption
- The average price for paid by the customer at the 25 kgal level of consumption
- The average price paid by the customer at the 50 kgal level of consumption
- The marginal price charged (for water only) by the agency
- The dollar increment between the top rate and base (5 kgal) rate, where the top rate is the higher of the marginal rate and the rate at the 50 kgal consumption level.

Billed Amounts and Average Prices

The values for the last six parameters in the above bullet list are shown for each agency in Table 19. Several of the items shown in this table are worthy of further investigation. Figure 29 shows a graph of the total billed amount for water and wastewater for the 5 and 25 kgal volume of consumption. This figure shows that the total charges increase as the consumption level increases, which suggests that there is at least an intent to have a progressive element to the rate structures in that, as consumption increases so does the billed amount.

When the billing is expressed in terms of the average rates at the 5 and 25 kgal level of consumption it is noteworthy that most of the average prices *decrease* as one goes from the lower to the higher volume. In other words, the effective rates are actually decreasing as consumption goes up, even though the rates pegged into the various block may be increasing. The reason that the effective rates are decreasing is the fixed charges. As shown Table 19 almost all of the agencies include a fixed fee on their water and wastewater bills, which reached a maximum of $36/month in one case. Only 2 of the agencies did not include a fixed fee of some kind on the bill.

While the use of fixed charges may aid with revenue stability, and may be warranted by a cost of service analysis, their effect is to decrease the price signal on consumption. The higher the fixed charges the greater this effect. When the rates are plotted as shown in Figure 30, and compared to the fixed fees shown in Figure 31 the decrease in the effective rates can be seen clearly. Another way of showing this is to plot the difference in the average cost for the top tier and the base rate. As can be seen in Figure 32 only 5 of the 25 sites have a positive difference between the top rate and the base rate. Having a fixed fee simplifies the billing and may add to revenue stability, but from the perspective of rates they appear to act in a way that lowers the average price per kgal for water as consumption goes up, which is something to consider when considering rates as demand management tools.

Table 19: Total billed amounts for 5, 25 and 50 kgal of use per month

Agency	Fixed Charges for Water and Wastewater ($)	Total Bill for 5 kgal ($)	Avg. Price @ 5 kgal ($/kgal)	Total Bill for 25 kgal ($)	Avg. Price @25 kgal ($/kgal)	Total Bill for 50 kgal ($)	Avg. Price @ 50 kgal ($/kgal)	Top Marginal Rate (water only) ($/kgal)
Aurora	$15.03	$55.03	$11.01	$164.08	$6.56	$329.07	$6.58	$7.50
Austin	$16.46	$44.39	$8.88	$185.13	$7.41	$435.12	$8.70	$10.00
Cary	$6.14	$55.24	$11.05	$301.00	$12.04	$738.00	$14.76	$10.94
Chicago	$0.00	$18.69	$3.74	$93.47	$3.74	$186.93	$3.74	$2.01
Clayton	$17.50	$49.67	$9.93	$272.19	$10.89	$576.94	$11.54	$7.14
Cobb	$12.30	$55.51	$11.10	$253.81	$10.15	$534.56	$10.69	$7.78
Colorado Springs	$25.78	$54.91	$10.98	$176.97	$7.08	$383.17	$7.66	$8.25
Denver	$21.98	$42.27	$8.45	$114.01	$4.56	$282.80	$5.66	$8.44
Edmonton	$14.22	$69.71	$13.94	$195.35	$7.81	$355.23	$7.10	$6.40
Ft Collins	$26.78	$48.74	$9.75	$99.34	$3.97	$166.89	$3.34	$2.70
Henderson	$32.69	$41.54	$8.31	$90.19	$3.61	$179.03	$3.58	$3.46
Miami	$6.45	$26.45	$5.29	$242.28	$9.69	$526.88	$10.54	$5.16
Mt View	$29.74	$47.24	$9.45	$166.65	$6.67	$392.88	$7.86	$9.05
Otay	$35.92	$57.13	$11.43	$148.67	$5.95	$289.36	$5.79	$5.63
Peel	$0.00	$25.31	$5.06	$126.56	$5.06	$253.12	$5.06	$2.89

Agency	Fixed Charges for Water and Wastewater ($)	Total Bill for 5 kgal ($)	Avg. Price @ 5 kgal ($/kgal)	Total Bill for 25 kgal ($)	Avg. Price @25 kgal ($/kgal)	Total Bill for 50 kgal ($)	Avg. Price @ 50 kgal ($/kgal)	Top Marginal Rate (water only) ($/kgal)
Philadelphia	$10.15	$44.34	$8.87	$173.43	$6.94	$325.27	$6.51	$3.99
Portland	$9.46	$80.48	$16.10	$364.56	$14.58	$719.66	$14.39	$10.08
RWA_CT	$21.40	$42.65	$8.53	$127.64	$5.11	$233.87	$4.68	$4.25
San Antonio	$18.36	$42.95	$8.59	$150.34	$6.01	$357.42	$7.15	$4.45
Santa Barbara	$29.99	$68.10	$13.62	$205.65	$8.23	$373.10	$7.46	$6.70
Santa Fe	$20.39	$59.26	$11.85	$340.29	$13.61	$768.79	$15.38	$17.14
Scottsdale	$17.38	$37.86	$7.57	$146.62	$5.86	$312.77	$6.26	$7.14
Tacoma	$32.14	$60.02	$12.00	$101.84	$4.07	$154.11	$3.08	$2.09
Toho	$ 10.91	$ 38.11	$7.62	$ 163.63	$6.55	$ 366.63	$7.33	$3.80
Waterloo	$2.69	$58.44	$11.69	$281.44	$11.26	$560.19	$11.20	$5.38
Max	$35.92	$80.48	$16.10	$364.56	$14.58	$768.79	$15.38	$17.14
Min	$0.00	$18.69	$3.74	$90.19	$3.61	$154.11	$3.08	$2.01
Range	$35.92	$61.79	$12.36	$274.37	$10.97	$614.68	$12.29	$15.13

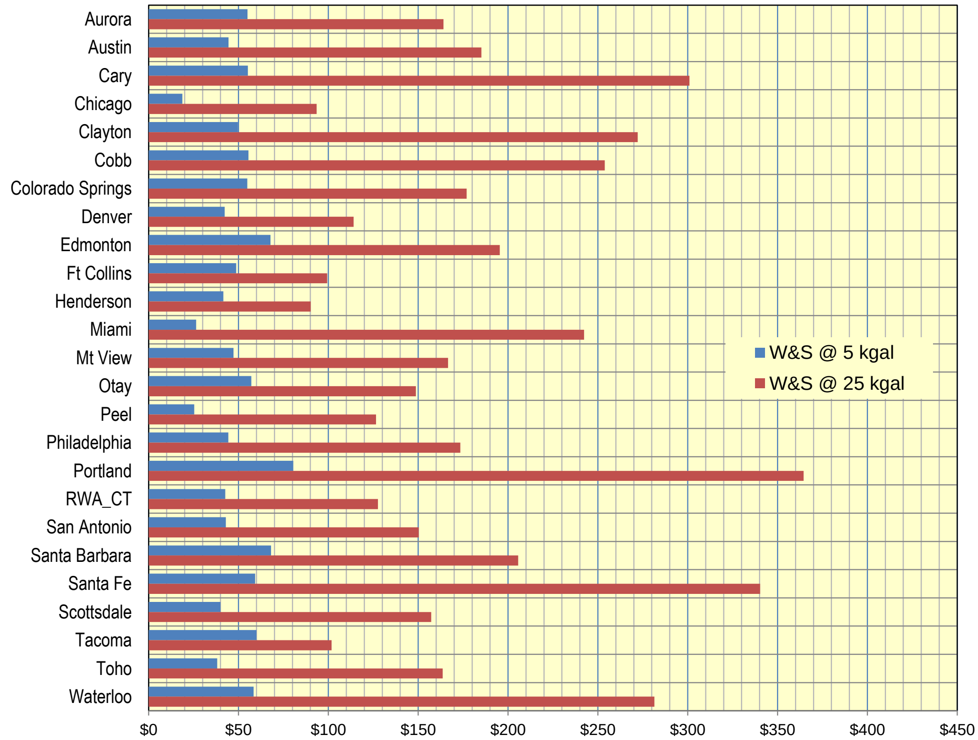


Figure 29: Total amount billed for water and wastewater at 5 kgal and 25 kgal of use

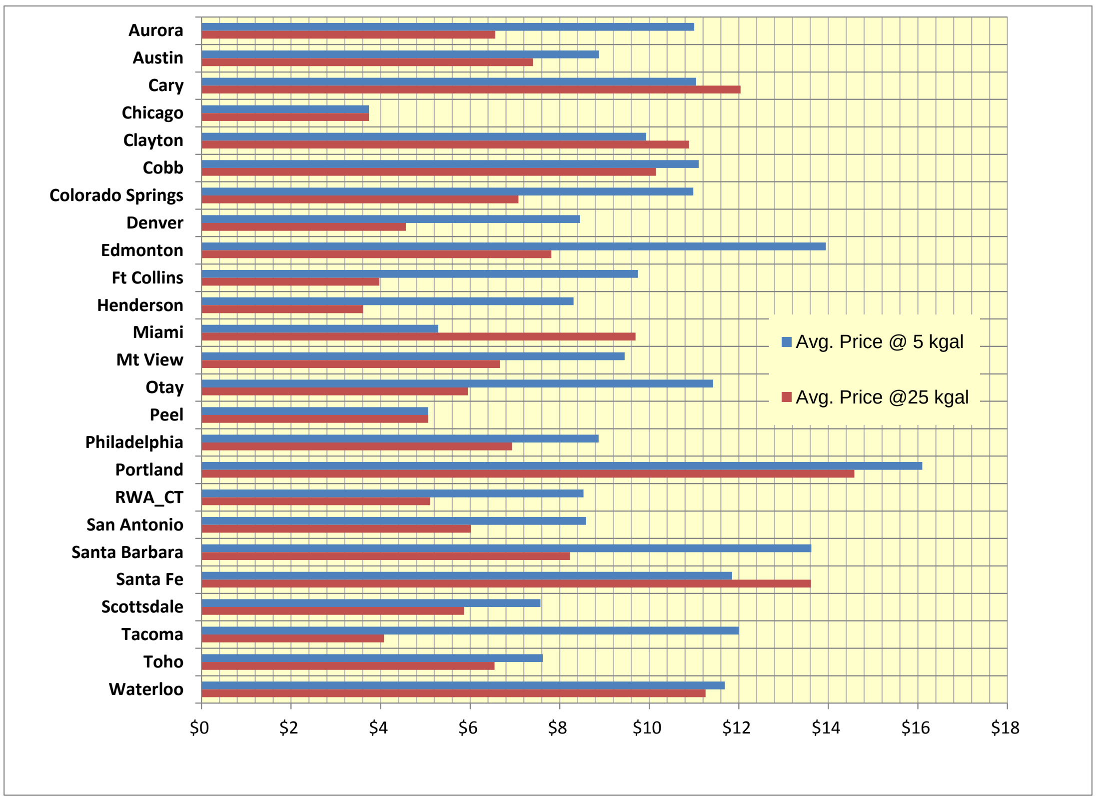


Figure 30: Average prices for water and wastewater at 5 and 25 kgal of use ($/kgal)

Table 20: Rate structure summary

Agency	Billing structure	Block 1		Block 2		Block 3		Block 4		Block 5		Max vol for sewer billed?	Sewer rate, $/kgal
		Price, $/kgal	Tier, kgal	Price, $/kgal	Tier, kgal	Price, $/kgal	Tier, kgal	Price, $/kgal	Tier, kgal	Price, $/kgal	Tier, kgal		
Aurora	Inclining block rate	$5.27	< 20.0	$6.00	< 40.0	$7.50	> 40.0					Yes	$2.73
Austin	Inclining block rate	$1.00	< 2.0	$2.62	< 9.0	$6.71	< 15.0	$9.00	< 25.0	$10.00	> 25.0	Yes, two tiers.	$3.43, $7.73
Cary	Inclining block rate	$3.28	< 5.0	$3.83	< 8.0	$5.44	< 23.0	$10.94	> 23.0			No	$6.54
Chicago	Uniform rate	$2.01										No	86% of water charges
Clayton	Inclining block rate	$2.00	< 3.0	$4.81	< 8.0	$5.95	< 20.0	$7.14	> 20.0			Yes	$2.15
Cobb	Inclining block rate	$2.83	< 3.0	$4.11	< 15.0	$5.12	< 29.0	$6.00	< 49.0	$7.78	> 49.0	No	$5.30
Colorado Springs	Inclining block rate	$2.99	< 7.5	$5.59	< 18.7	$8.25	> 18.7					Yes	$3.29
Denver	Inclining block rate	$2.11	< 11.0	$4.22	< 30.0	$6.33	< 40.0	$8.44	> 40.0			Yes	$1.95
Edmonton	Inclining block rate	$6.19	< 15.9	$6.40	> 15.9							Yes	$4.53
Ft Collins	Inclining block rate	$2.04	< 7.0	$2.35	< 13.0	$2.70	> 13.0					Yes	$2.64
Henderson	Inclining block rate	$1.46	< 6.1	$1.90	< 16.2	$2.47	< 30.4	$3.46	> 30.4			NA	Fixed fee
Miami	Inclining block rate	$0.50	< 3.7	$3.00	< 6.7	$3.90	< 12.7	$5.16	> 12.7			No, three tiers.	$1.85, $5.90, $6.22
Mt View	Inclining block rate	$2.21	< 2.2	$4.55	< 18.7	$9.05	> 18.7					NA	Fixed fee
Otay	Inclining block rate	$1.80	< 3.7*	$2.81	< 7.5	$3.65	< 16.5	$5.63	> 16.5			Yes	$2.23
Peel	Uniform rate	$2.89										No	$2.89
Philadelphia	Declining block rate	$3.99	< 15.0	$3.23	< 748	$2.96	< 14,960	$2.25	> 14,960			No	$2.85

Agency	Billing structure	Block 1		Block 2		Block 3		Block 4		Block 5		Max vol for sewer billed?	Sewer rate, $/kgal
		Price, $/kgal	Tier, kgal	Price, $/kgal	Tier, kgal	Price, $/kgal	Tier, kgal	Price, $/kgal	Tier, kgal	Price, $/kgal	Tier, kgal		
Portland	Uniform rate	$4.13										No	$ 10.08
Regional Water Authority, CT	Declining block rate,	$4.25	< 2494	$ 3.34	> 2494							NA	Not charged with water
San Antonio	Inclining block rate	$0.92	< 6.0	$1.44	< 12.7	$2.15	< 17.2	$4.45	> 17.2			Yes	$2.08
Santa Barbara	Inclining block rate	$3.80	< 3.0	$6.36	< 15.0	$6.70	> 15.0					Yes	$2.79
Santa Fe	Inclining block rate	$4.79	< 10.0	$17.14	> 10.0							Yes	$3.58
Scottsdale	Inclining block rate	$1.80	< 8.3	$3.35	< 44.0	$7.14	> 44.0					No	$2.23
Tacoma	Inclining block rate	$1.67	< 3.7	$2.09	> 3.7							Yes	$4.34
Toho	Inclining block rate	$0.73	< 2.0	$1.38	< 6.0	$1.66	< 15.0	$2.28	> 15.0			No	$4.32
Waterloo	Uniform rate	$5.38										No	$5.77

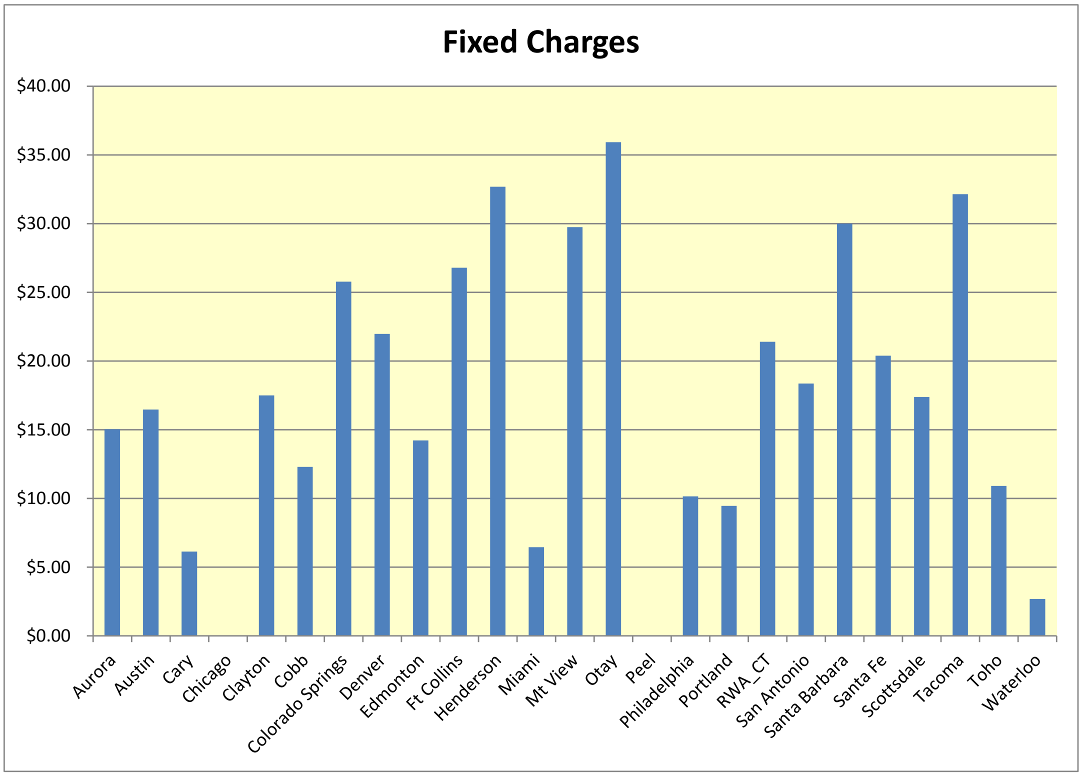


Figure 31: Fixed fees charged by agencies

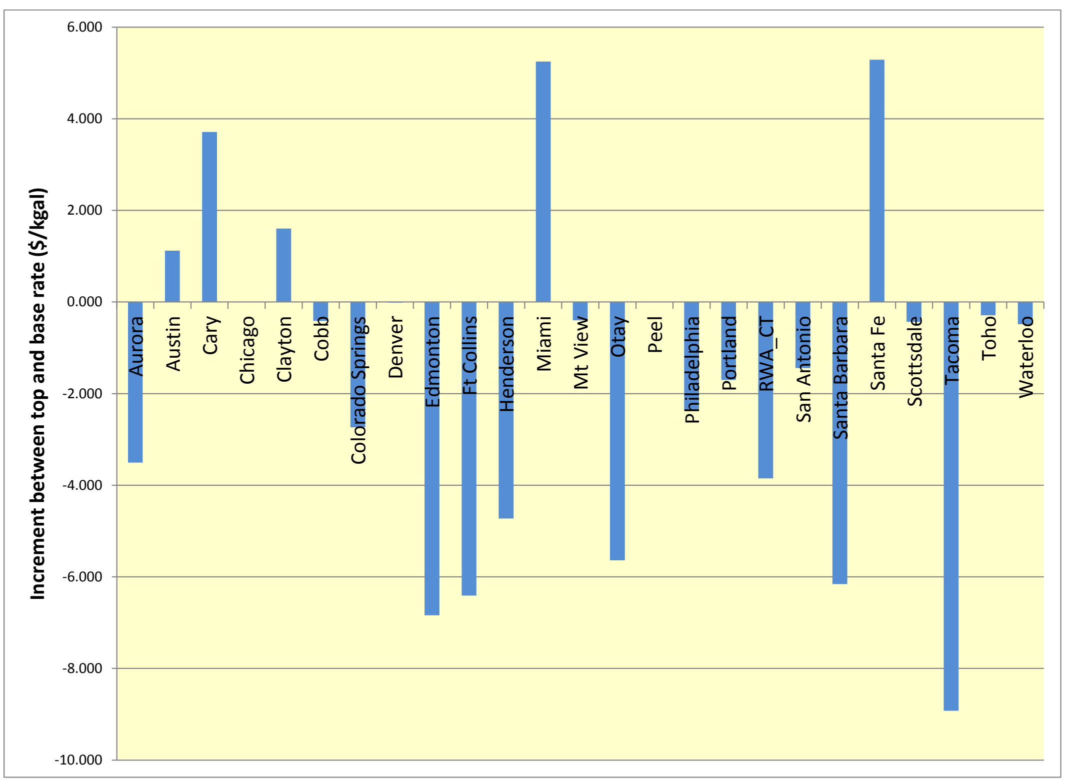


Figure 32: Increment in average prices between top and 5 kgal prices ($/kgal)

Marginal Prices

From an economics perspective the marginal price is the price that the customer pays for the next unit of consumption. As such it represents the amount of money that the customer stands to save if that consumption is foregone. Whenever the rates for water change with consumption, so will the marginal prices, but in all cases these prices are solely for the purchase of water, and do not include fixed fees or wastewater charges. Table 21 shows the marginal prices for water for each of the study sites at the three levels of consumption used for determining the billed amounts and the average prices for water and wastewater. During the winter period the relevant price would in most cases be the 5k price, since most winter consumption is in this range. During the summer the most relevant price to all but the largest user would be the 25 kgal price since this would capture the majority of the summer water use.

Table 21: Marginal prices for water

Agency	5k	25k	50k
Aurora	$ 5.27	$ 6.00	$ 7.25
Austin	$ 2.62	$ 10.00	$ 10.00
Cary	$ 3.83	$ 10.94	$ 10.94
Chicago	$ 2.01	$ 2.01	$ 2.01
Clayton	$ 4.81	$ 7.14	$ 7.14
Cobb	$ 4.11	$ 5.12	$ 7.78
Colorado Springs	$ 2.99	$ 8.25	$ 8.25
Denver	$ 2.11	$ 4.22	$ 8.44
Edmonton	$ 6.19	$ 6.40	$ 6.40
Ft Collins	$ 2.04	$ 2.70	$ 2.70
Henderson	$ 1.46	$ 2.47	$ 3.46
Miami	$ 3.00	$ 5.16	$ 5.16
Mt View	$ 4.55	$ 9.05	$ 9.05
Otay	$ 2.81	$ 5.63	$ 5.63
Peel	$ 2.89	$ 2.89	$ 2.89
Philadelphia	$ 3.99	$ 3.23	$ 3.23
Portland	$ 4.13	$ 4.13	$ 4.13
RWA_CT	$ 4.25	$ 4.25	$ 4.25
San Antonio	$ 0.92	$ 4.45	$ 4.45
Santa Barbara	$ 6.36	$ 6.69	$ 6.69
Santa Fe	$ 4.79	$ 17.14	$ 17.14
Scottsdale	$ 1.80	$ 3.35	$ 7.14
Tacoma	$ 2.09	$ 2.09	$ 2.09
Toho	$ 1.38	$ 2.28	$ 2.28
Waterloo	$ 5.38	$ 5.38	$ 5.38
Average	$ 3.43	$ 5.64	$ 6.16
Maximum	$ 6.36	$ 17.14	$ 17.14
Minimum	$ 0.92	$ 2.01	$ 2.01

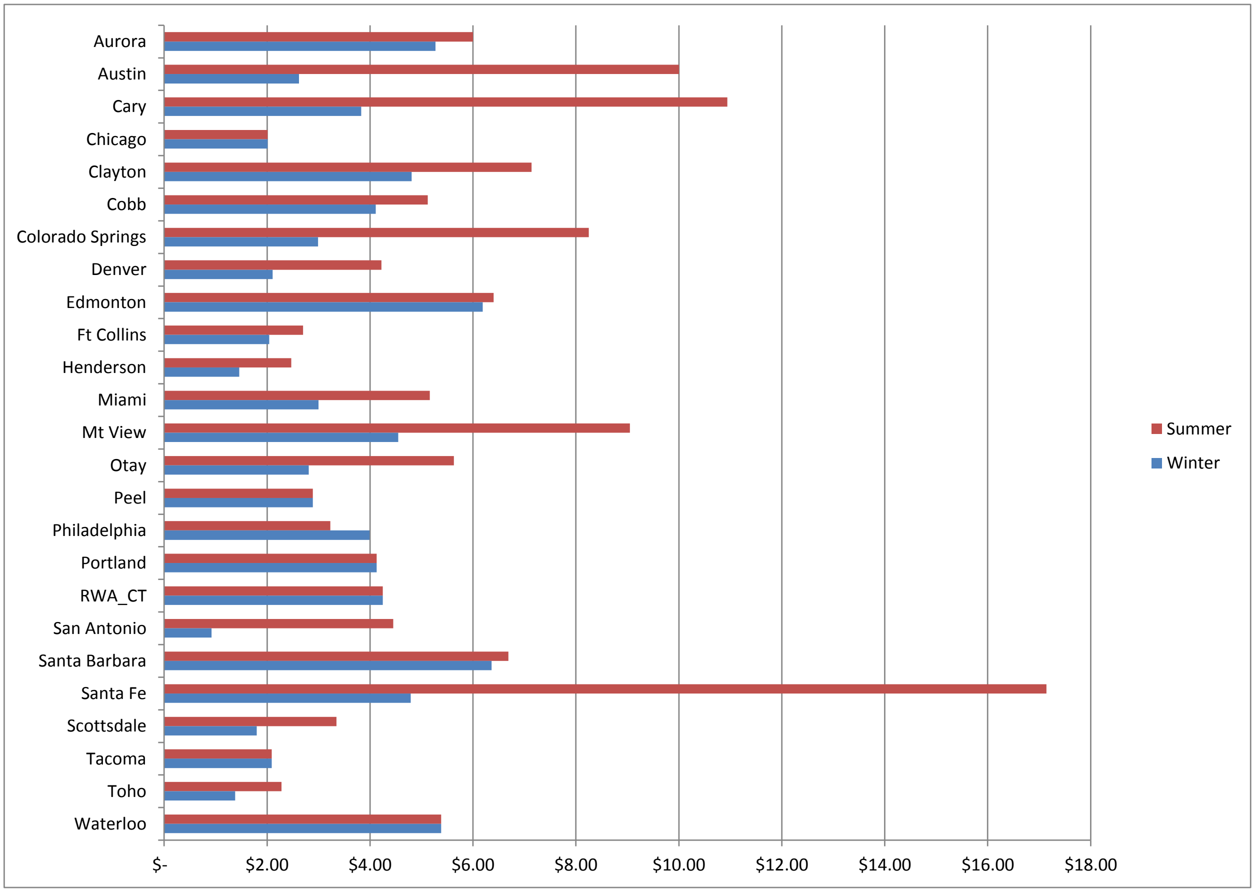


Figure 33: Summer and winter marginal prices for water ($/kgal)

The 25 water agencies in the study had a robust variety of rate structures including uniform, increasing and decreasing block rates. All but one of the agencies included a fixed fee for water and wastewater. The research team endeavored to organize this information by setting up a spreadsheet that determined the total amount billed by each agency for water and wastewater use. This was then used to determine the billed amount for consumptions of 5, 25 and 50 kgal per month. The billed amounts were then divided by the respective volumes in order to determine the average rates being paid by the customers at each range of use. The final piece of information noted for each agency was the top rate charged for water use only. The combination of these four parameters for average and peak use was then used as part of the modeling effort in order to determine how average and peak rates affect water use.

Which rates parameter is the most applicable for a given customers or group of customers depends on how those customers interpret and analyze their water bills. If they look at the total amount billed and compare this to their total consumption then the average prices would probably be the most applicable. If, however, the bill makes it clear, and they know the cost of their last increment of consumption then the marginal prices would be most applicable. Since we do not know how the customers interpreted their water bills it is important to investigate both parameters to see which gives the better results.

CONSERVATION PRACTICES

Staffing and Budget

Conservation staffing and budget is a clear measure of a program's vitality and conservation's overall importance in a utility. Resources dedicated to conservation also reflect an agency's current and future water supply and should be based on costs of augmenting supply. **Error! Reference source not found.** shows staff size and budget for each participating agency.

Table 22: Conservation staffing and budgets

Agency	FTE dedicated to water conservation	Annual Budget	Notes
Clayton County	0	$101,500	
Denver	20	$11,400,000	Adds 6.5 full time seasonal temporary employees for summer enforcement.
Fort Collins	3	$512,712	
Peel	4	$3,000,000	
San Antonio	21	$5,300,000	
Scottsdale	4	$832,946	
Tacoma	2	$578,000	
Toho	2-3	$287,800	
Waterloo	5	$1,300,000	
Aurora	10	$1,745,298	
Austin	21	$6,700,000	
Cary	2.5	$451,000	Please note there are 2 additional FTE who are no longer in the water conservation budget, but who do water conservation work.
Chicago	0.1	$0	
Cobb County	2.5	$400,000	

Agency	FTE dedicated to water conservation	Annual Budget	Notes
Colorado Springs	6	$1,115,929	
Edmonton	1	$175,000	Various staff to a total of 1 FTE. Operating budget does not include staff costs.
Henderson	10	$840,480	Staff varies by year; in 2010 it was 10 and in 2011 it was 2.5.
Miami	2	$1,300,000	
Mountain View	2	$313,000	$285,000 for personnel / $28,000 non-personnel. Rebate programs are funded through wholesale water rates and administered regionally.
Otay	3	$666,000	For FY 2012. Program budget is $316,000. If you include staffing, it would be approximately another $350,000
Philadelphia	1	$200,000	Staff is for water "accountability and loss control." Budget includes consulting services.
Portland	5	$704,994	
RWA, CT	<1	$2,000	Budget does not include industrial water audit, which was originally budgeted but not performed.
San Diego	17	$2,600,000	City of San Diego runs its own in-house programs as well as participating in regional programs.
Santa Barbara	2.5	$287,500	Budget does not include staff time.
Santa Fe	2	$220,000	
Average	6	3,039,000	

Indoor Conservation Measures

Toilet replacement programs have long been a mainstay of conservation programs. These programs can take many different forms. Table 23 summarizes indoor conservation programs for each participating agency. The level of utility effort can range from direct install programs, though uncommon (only two agencies report having direct install), through ordinances requiring replacement on resale. Most agencies in this study used rebates or vouchers to increase toilet replacement. Seven of the 26 participating agencies, including one of the Level 1 sites (San Antonio) report that they have no toilet replacement program. It is interesting to note that San

Antonio ranked fourth out of nine in the percentage of low volume flushes despite their lack of a toilet rebate program (see Table 51).

The REUWS1 found that average clothes washer demand was 39 gphd, ranking as the second highest indoor use after toilets. This finding highlighted the importance of improving conservation for clothes washing. Since the 1999 study, dramatic changes have occurred for this end use. The present study finds that average clothes washer use has dropped to 23 gphd. High efficiency (HE) clothes washers have become much more common; approximately two-thirds of households in the study report having EnergyStar clothes washers (as opposed to the REUWS1, which found only 2% of households had front-loading clothes washers). These changes may explain why only half (50%) of participating agencies report that they currently have a clothes washer replacement program. Concerns about free-ridership were specifically cited by Peel. Miami ended their program in 2009 and Tacoma ended their program in 2011.

Conservation education programs are in place in all but two participating agencies. Audits are another linchpin of many conservation programs, with almost two-thirds of agencies reportedly offering audits. These could range from in-home visits to do-it-your-self kits and brochures. In some cases, home audits were used as an opportunity for showerhead and faucet aerator distribution, which was the case in Santa Fe, San Antonio, and Aurora. However, faucet aerators and showerhead replacement programs were not limited to auditing programs. Replacement programs were active in all but four participating agencies.

Dishwasher replacement programs were relatively uncommon; Ft. Collins reported having a rebate or voucher program and Edmonton reported having an education measure that targeted dishwashers. Few agencies reported having any incentives for hot water recirculation systems. San Antonio and San Diego had distribution programs and Scottsdale and Santa Fe reported having rebate/voucher programs for hot water recirculation devices.

Table 23: Indoor conservation measures

Agency	Level	Toilet replacements	Showerhead replacement	Faucet aerators	Dishwashers	Clothes washers	Audits	Hot water recirculation	Information & education
Aurora	2	Rebate or voucher	Distribution	Distribution	None	Rebate or voucher	Yes	None	Education
Austin	2	Rebate or voucher	Distribution	Distribution	None	Rebate or voucher	Yes	None	Education
Cary	2	Rebate or voucher	Distribution	Distribution	None	None	Yes	None	Education
Chicago	2	None	Distribution	Distribution	None	None	None	None	Education
Clayton County	1	Rebate or voucher	Distribution	Distribution	None	None	Yes	None	Education
Cobb County	2	Rebate or voucher	Distribution	Distribution	None	None	Yes	None	Education
Colorado Springs	2	Rebate or voucher	None	None	None	Rebate or voucher	None	None	Education
Denver	1	Direct install, rebate or voucher	Direct install	Direct install	None	Rebate or voucher	Yes	None	Education
Edmonton	2	Education	Education	Education	Education	Education	None	None	Education
Ft. Collins	1	Direct install, rebate or voucher	Distribution	Distribution	Rebate or voucher	Rebate or voucher	Yes	None	Education
Henderson	2	None	Distribution	Distribution	None	None	None	None	Education
Miami	2	Distribution	Distribution	Distribution	None	None	None	None	Education
Mountain View	2	Rebate or voucher	Distribution	Distribution	None	Rebate or voucher	Yes	None	Education

Agency	Level	Toilet replacements	Showerhead replacement	Faucet aerators	Dishwashers	Clothes washers	Audits	Hot water recirculation	Information & education
Otay	2	Rebate or voucher	Distribution	Distribution	None	Rebate or voucher	None	None	Education
Peel	1	Rebate or voucher	None	None	None	None	Yes	None	Education
Philadelphia	2	None	None	None	None	None	None	None	None
Portland	2	Rebate or voucher	Distribution	Distribution	None	None	Yes	None	Education
RWA, CT	2	None	None	None	None	None	Yes	None	Education
San Antonio	1	None	Direct install, Distribution	Direct install, Distribution	None	None	Yes	Distribution	Education
San Diego	2	Rebate or voucher	Distribution	Distribution	None	Rebate or voucher	Yes	Distribution	Education
Santa Barbara	2	Rebate or voucher	Distribution	Distribution	None	Rebate or voucher	Yes	Education	Education
Santa Fe	2	Distribution, rebate or voucher	Distribution	Distribution	None	Rebate or voucher	Yes	Rebate or voucher	Education
Scottsdale	1	Rebate or voucher	Rebate or voucher	Distribution	None	None	Yes	Rebate or voucher	Education
Tacoma	1	None	Distribution	Distribution	None	Rebate or voucher	None	None	Education
Toho	1	Rebate or voucher	Distribution	Distribution	None	Rebate or voucher	None	None	Education
Waterloo	1	Rebate or voucher	Distribution	Distribution	None	None	None	None	Education

Irrigation Conservation

Just over half of the agencies have some sort of controller measure; whether that is a rebate/voucher, education or distribution measure in place (see Table 24). This is interesting given that the REUWS1 found that households using an automatic controller used 47% more water than households that did not have a controller. Hardware replacement programs promoting high efficiency toilets and clothes washers have proven quite successful for reducing indoor use, and many look to weather-based irrigation controllers (WBIC) as a similar solution for outdoor efficiency. However, only two agencies specifically report having a WBIC rebate program. Two additional agencies distribute rain sensors and Chicago distributes soil-moisture sensors. Aquacraft's 2009 study of WBICs found that the pre-existing irrigation practices, such as excess irrigation, are the most important factor in determining whether a WBIC will actually save water. Deficit irrigators may actually increase outdoor demand when a WBIC is installed. **Error! Reference source not found.** shows that for the logging sample, only a minority of households irrigate in excess.

Turf replacement programs are another outdoor conservation measure. Austin, Cary, Mountain View, and Otay all have incentives for replacing turf with low use or native plantings.

Rotating, or assigned, watering days are another well-known outdoor conservation measure. However, only 38% of participating agencies report having limits to which days of the week households may irrigate. Almost all agencies (24 out of 26) report having some level of outdoor conservation education program.

Table 24: Outdoor conservation measures

Agency	Smart Irrigation Controller	Rotating Water Days	Waterwise landscape program	Irrigation audits/ upgrades	Irrigation water budgets	Information and Education
Aurora	None	Yes	Rebate or voucher, Education	Rebate or voucher, Education	None	Yes
Austin	Rebate or voucher	None	Rebate or voucher	Rebate or voucher, Education	None	Yes
Cary	Education	None	Education	None	yes	None
Chicago	None	None	None	None	None	Yes
Clayton	None	None	None	None	None	Yes
Cobb	None	Yes	Education	Education	Education	Yes
Colorado Springs	Rebate or voucher	None	None	None	None	Yes
Denver	Rebate or voucher	Yes	None	Direct install	None	Yes
Edmonton	None	None	Education	None	None	Yes
Ft. Collins	Rebate or voucher	None	Education	Direct install, education	None	Yes
Henderson	Rebate or voucher, education	Yes	Rebate or voucher, Education	Education	Education	Yes
Miami	Distribute	Yes	Education	Rebate or voucher, education	None	Yes
Mountain View	Rebate or voucher	Yes	Rebate or voucher	Rebate or voucher	None	Yes
Otay	Rebate or voucher	None	Rebate or voucher	yes	some	Yes
Peel	None	None	Education	None	None	Yes
Philadelphia	None	None	None	None	None	None
Portland	None	None	None	Distribution, education	None	Yes
RWA, CT	None	None	None	None	None	Yes
San Antonio	None	None	Rebate or voucher	Education	None	Yes
San Diego	Rebate or voucher	Yes	Rebate or voucher	Rebate or voucher, education	Education	Yes

Agency	Smart Irrigation Controller	Rotating Water Days	Waterwise landscape program	Irrigation audits/ upgrades	Irrigation water budgets	Information and Education
Santa Barbara	Rebate or voucher	None	Rebate or voucher	Education	Education	Yes
Santa Fe	Rebate or voucher	Yes	Education	Rebate or voucher	None	Yes
Scottsdale	Rebate or voucher	None	Education	Education	Education	Yes
Tacoma	None	None	None	None	None	Yes
Toho	None	Yes	Education	Education	Education	Yes
Waterloo	None	Yes	Education	Periodically	None	Yes

Information for Households

Feedback on water use and information about weather are other conservation practices that empower water customers to better manage their water use. Table 25 summarizes some of the data that agencies make available to households. The majority (65%) of agencies allow customers to read their own meters for informational purposes. Responses from the surveying portion of this study indicate that the vast majority (84%) of households agree that they should be able to track their water use via the web or reading their own meter. Roughly the same percent (83%) of household survey respondents believe that households would conserve more if they had an easier way to monitor their water use, however, only two agencies offer in-home meter feedback devices, which provide the customers with real-time information on their meter reading and water use.

Table 25: Information for customers

Agency	Use or provide climate or ET data?	Allow customers to read their own water meter?	Offer in-home meter feedback devices?
Aurora	No	No	Yes
Austin	No	Yes	No
Cary	Yes	Yes	No
Chicago	No	Yes	Yes
Clayton County	No	No	No
Cobb County	Yes	Yes	No
Colorado Springs	Yes	Yes	No
Denver	Yes	No	No
Edmonton	No	Yes	No
Ft. Collins	Yes	Yes	No

Agency	Use or provide climate or ET data?	Allow customers to read their own water meter?	Offer in-home meter feedback devices?
Henderson	No	Yes	No
Miami	No	No	No
Mountain View	No	Yes	No
Otay	No	Yes	No
Peel	No	Yes	No
Philadelphia	No	No	No
Portland	Yes	Yes	No
RWA, CT	No	No	No
San Antonio	Yes	No	No
San Diego	Yes	Yes	No
Santa Barbara	Yes	Yes	No
Santa Fe	No	No	No
Scottsdale	Yes	Yes	No
Tacoma	No	Yes	No
Toho	No		No
Waterloo	No	Yes	No

Conservation Planning

Integrated Resource Planning (IRP) is a planning approach that looks at an agency's overall water supply as well as demand. Rather than focusing solely on increasing supply, IRP incorporates demand management as an equally important part of meeting future needs. In this context of demand monitoring, conservation performance evaluation is critical. Participating agencies were asked to report on how they evaluate their conservation program. Table 26 summarizes these responses.

Table 26: Conservation plan evaluation, selected agencies

Agency	How is conservation plan performance evaluated?
Aurora	Through program data and GIS analysis.
Austin	Performance is evaluated by the degree to which AW has met the 5 and 10-year water savings goals set out in the plan.

Agency	How is conservation plan performance evaluated?
Cary	Not formally evaluated; evaluation often happens with next plan done every 5 years.
Chicago	Varies by plan, but mainly replacement of water main and overall decrease in water pumpage.
Clayton	Annual review.
Cobb	District plan audited by state. Protection division, Cobb tracks per capita, non-revenue water, water purchased, usage per account, and attrition rate of programs.
Colorado Springs	CSU maintains a model for tracking all program performance. The model quantifies and tracks costs and savings for individual programs and compares projected and actual demand-side management (DSM) savings. The model enables CSU to routinely analyze water conservation programs and alternatives. CSU also utilizes standard methodologies to monitor per customer and per capita demand on an annual basis. To the extent possible, assumptions are based on industry accepted practices and standards.
Denver	Comparing pre- and post-consumption for participants provides an average consumption reduction for each activity. However, some objectives of the plan are not quantifiable.
Edmonton	
Ft. Collins	Annual reporting of major data, some tracking is being established currently.
Henderson	Decrease in gpcd.
Miami	Targets are set for both the number of incentives and the total monthly, quarterly and annual water savings achieved by the conservation program.
Mountain View	Mountain View reports the implementation of water conservation and water-use efficiency measures to meet the best management practices requirements for members of the California Urban Water Conservation Council.
Otay	We monitor our gpcd.
Peel	Measure and monitor savings by some program while water savings of other programs are estimated. An annual report to Regional council is made on the plan's progress and achieved water savings.
Philadelphia	Annual auditing process.
Portland	Update annually, report back to State every 5 years.
RWA, CT	Plan does not have measurable goals; performance is not evaluated.
San Antonio	San Antonio has internal gpcd targets by year as determined through the water resources plan.
San Diego	Evaluating goal achievement.
Santa Barbara	BMP tracking.
Santa Fe	Primarily by gpcd.
Scottsdale	Annual reporting on accomplishment, program analysis.

Agency	How is conservation plan performance evaluated?
Tacoma	Annual review, conservation goal tracking.
Toho	Compare annual average pre and post for all participants and report in conservation plan
Waterloo	Measured results.

Water Loss

Water loss control is a program of accounting for all water in a system and extends far beyond leak detection and repair. The American Water Works Association water loss methodology (detailed in the M36 manual) presents a method for comprehensively auditing authorized consumption and water losses in a given distribution system. Table 27 provides a visual breakdown of a water balance. A major target for water loss programs is reducing non-revenue water. Non-revenue water can be due to many factors including leaks and unmetered water. Leak detection (and repair) and meter testing are two activities recommended as part of a water loss control program.

Table 27: Water balance from the AWWA Water Loss evaluation method (AWWA M36)

<table>
<tr><td rowspan="9">Water from Own Sources (corrected for known errors)</td><td rowspan="11">System Input Volume</td><td>Water Exported</td><td rowspan="5">Authorized Consumption</td><td rowspan="3">Billed Authorized Consumption</td><td>Billed Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td rowspan="10">Water Supplied</td><td>Billed Metered Consumption</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-revenue water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td rowspan="2">Water Imported</td><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections Up to Point of Customer Metering</td></tr>
</table>

Note: All data in volume for the period of reference, typically one year.

Participating agencies were surveyed with regards to their water loss strategies. Almost all agencies reported having a leak detection program, but some of these programs were reactive rather than proactive. Most agencies (92%) have active meter testing programs. Table 28 shows the agencies' reported water loss measures.

Table 28: Water loss control activities

Agency	Have a water loss control program?	Do you use the AWWA M36 system audit method?	Do you have an active leak detection program?	Do you have an active meter-testing program?
Aurora	Yes	Yes	Yes	Yes
Austin	Yes	Modified	Yes	Yes
Cary	Yes	Yes	Yes	Yes
Chicago	Yes	No	Yes	yes
Clayton County	Yes	Yes	Yes	Yes
Cobb County	Yes	Yes	Yes	Yes
Colorado Springs	Yes	Yes	Yes	Yes
Denver	Yes		Yes	Yes
Edmonton	Yes	Yes	Yes	Yes
Ft. Collins	Yes	No	Yes	Yes
Henderson	Yes	No	Yes	Yes
Miami	Yes	Yes	Yes	Yes
Mountain View	No	Yes	No	No
Otay	Yes	Yes	Yes	Yes
Peel	Yes	Yes	Yes	Yes
Philadelphia	Yes	Yes	Yes	Yes
Portland	Yes	Not sure	Yes	Yes
RWA, CT	Yes	Yes	Yes	Yes
San Antonio	Yes	Yes	Yes	Yes
San Diego	Yes	Yes	Yes	Yes
Santa Barbara	Yes	Yes	Yes	Yes
Santa Fe	Yes	No	Yes	Yes
Scottsdale	Yes	Modified	Yes	Yes
Tacoma	Yes	Modified	Yes	Yes
Toho	Yes	Modified	Yes	Yes
Waterloo	Yes	Yes	Yes	NA

LOGGING GROUPS

The goal of the project was to obtain flow trace data from as close to 100 homes as possible, and to obtain data from10 meters installed on the hot water feed lines in each of the study sites except for Tacoma, where the goal was to obtain hot water data for 37 homes.

Table 29: Logging Samples

Study Site	Den	Fort Collins	Scotts	San Antonio	Clayton	Toho	Peel	Waterloo	Tacoma
Number Logged	100	100	100	100	100	100	79	83	100
Number Main	97	88	96	91	96	65	60	71	98
Number Hot	10	10	10	10	7	5	6	9	33
Days/trace	12.3	13.4	13.1	11.9	12.9	12.2	12.9	12.9	12.4
Logging Month	Feb-12	Mar-12	May-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Jan-13

SUMMARY OF SURVEY RESPONSES

The methodology used for selection of survey recipients was outlined in the Methodology Chapter. This section summarizes the responses to some key questions.

RESPONSE RATE

Response rates from all Level 1 and Level 2 sites averaged 33%. Table 30 shows the response rate from all of the Level 1 sites as well as the North American Survey. The lowest response rate was 17% from Toho, FL. The highest response rate was 48% from Fort Collins, CO. Over all, the response rates were lower than the original REUWS, which averaged 46%. Fourteen of the returned surveys had unreadable or missing keycode identifiers, and as such were excluded from further analysis.

Table 30: Response rates from Level 1 and the North American Survey

Sample	Survey time frame	Surveys Sent	Surveys Returned	Response Rate
Clayton County	Feb / Mar 2012	1009	369	37%
Denver	Nov / Dec 2011	917	356	39%
Fort Collins	Nov / Dec 2011	999	476	48%
Peel	Apr 2012	951	231	24%
San Antonio	Mar 2012	1013	280	28%
Scottsdale	Feb / Mar 2012	1012	349	34%
Tacoma	Mar / Apr 2012	993	347	35%
Toho	Feb 2012	855	147	17%
Waterloo	Apr 2012	1000	347	35%
North American	2011-2013	5000	1741	35%

Sample	Survey time frame	Surveys Sent	Surveys Returned	Response Rate
Survey				
Total		13,749	4643	34%

The study group comprises a wide variety of single-family homes from the U.S. and Canada. Survey responses came from a range of household sizes, occupancies, and incomes. The largest household had 13 people in the home while the smallest households had single occupants. Only 5.4% of Level 1 respondents were renters. Some homes had one bedroom, while 32 had six bedrooms or more. The average number of toilets in the homes was 2.5; the maximum number of toilets in any home was six. Landscapes varied from lush lawns to xeric to pasture, and many of these variations were found throughout the different climates included in the study.

While ranges are important, it is also helpful to have a sense of the average characteristics of survey respondents. For the Level 1 sites, the average household size was 2.6 people. Table 31 summarizes average characteristics for household size for Level 1 sites.

Table 31: Average characteristics for Level 1 sites

	Average	Standard Deviation	Number of responses
Persons per home	2.6	1.4	2,790
Adults	2.1	0.9	2790
Teens	0.2	0.5	482
Children	0.3	0.7	730
Infants/toddlers	0.1	0.3	173

COMPARISON OF SURVEY RESPONSES

This section looks at survey responses from and across the nine Level 1 sites as well as these responses combined with the North American Survey. These data are based on all survey responses, not just survey responses used in the data logging portion of the study. As a result, these data are almost certainly different from data for the logging sample.

It is believed that the survey responses are from a representative sample of homes. The sample was determined by drawing approximately 1000 homes at random (this was referred to as the Q1000 sample), and checking the average annual use of this pool of homes against the average annual use for all single family homes in an agency's billing database. Once a sample matched the agency's annual average, surveys were sent to all homes in the sample. This sample was identified as the Q1000 sample throughout the study. It is possible that respondents were self-selecting. That is to say, perhaps homes more inclined to value conservation participated at a higher rate.

Understanding the survey responses is important for using this study's results. From a utility perspective, it can be helpful to understand how this study's sample is similar to or different from a given service population. From a conservation leader's perspective, it might be helpful to understand water conservation attitudes and actions that are important to survey respondents.

Survey Questions

The survey consisted of a multi-page survey with a total of 47 questions, but since many questions contained multiple sub-questions the number of actual responses to the survey was

184. Each question, however, dealt with a single topic. For example, question 1a of the survey asks how many toilets are in the house.

The questions on the survey can be divided into six general categories and the breakdown of the survey is shown in Table 32.

Table 32: Summary of Survey Questions

Category	Number of Questions	Percent of Total	Description of Survey Question
Hardware	18	38	Presence of fixtures and appliances, pools, irrigation controllers, etc.
Demographic	9	19	Number and age of residents, income, employment, age etc.
Behavioral	13	28	Water use habits
Geographic	2	4	Lot and home size
Judgment	3	6	Opinions on drought, landscape, wait for water
Water Supply	2	4	Whether alternative water supplies (other than treated tap water are in use.

Hardware Survey Responses

Information on types of water-using appliances, fixtures, and household features is important for understanding end use analysis. In fact, the collection of water-using devices practically delineates the water-using profile for the home. A home built before the Energy Policy Act that has been upgraded with high efficiency toilets and a high efficiency clothes washer could be indistinguishable from a newer home built with the same fixtures (from a water-using perspective).

The first question of the survey asks about bathroom fixtures. Table 33 shows how the results for this and other questions are summarized.

Table 33: Format of questions and data summary for survey. These responses are for all survey sites, including the North American Survey sample.

	None	One	Two	Three	Four	Five	Six	Seven or more	Total
Toilet	0%	12%	44%	32%	10%	2%	1%	0%	100%
Bathtub with shower	5%	63%	28%	4%	0.4%	0.2%	0.0%	0.0%	100%
Standard bathtub only	66%	30%	4%	1%	0.1%	0.0%	0.0%	0.0%	100%
Large bathtub tub w/jets	73%	26%	1%	0%	0.0%	0.0%	0.0%	0.0%	100%
Shower stall only	27%	58%	13%	2%	0.4%	0.1%	0.0%	0.0%	100%

The average number of toilets per house for the all Level 1 respondents was 2.51, based on 2849 responses to this question. The average number of toilets ranged from 2.1 in San Antonio, TX to 2.97 in Peel, ON. Likewise, the average number of bathtub/shower combination fixtures was 1.31 per home, with a low of 1.17 in Waterloo, ON and a high of 1.52 in Peel, ON. A count of toilets and other bathroom fixtures can be used as a metric of household size in each study site. Based on a comparison of toilet count, the larger homes in the study would be Peel, Scottsdale, Fort Collins, and Waterloo. The smaller homes would be found in Denver, Clayton County, Toho, Tacoma, and finally San Antonio. Table 34 summarizes these data (see following page).

Table 34: Average numbers of bathroom fixtures, by survey site

Agency	Number of responses to number of toilets question	Average of number of toilets	Number of responses to bath w/shower	Average of bath w/shower	Number of responses to tub only question	Averages of tub only	Number of responses to shower stall only question	Average of shower stall only
Clayton	363	2.4	357	1.5	359	2.0	361	2.0
Denver	346	2.5	340	1.2	344	1.4	349	2.1
Fort Collins	465	2.7	459	1.3	464	1.5	467	2.2
Peel	230	3.0	222	1.5	224	2.0	226	2.1
San Antonio	275	2.1	263	1.3	266	1.6	270	1.9
Scottsdale	345	2.8	322	1.3	332	1.6	338	2.4
Tacoma	339	2.2	324	1.2	333	1.5	337	1.8
Toho	143	2.2	135	1.3	137	1.7	140	2.1
Waterloo	343	2.7	323	1.2	341	1.6	342	1.9
Level 1 Average	2849	2.5	2745	1.3	2800	1.6	2830	2.1

In the REUWS1, only 2% of homes reported having a high-efficiency clothes washer (referred to in the older report as front-loading clothes washers). The 1999 study also determined that over 20% of an average household's indoor use went to clothes washing. These findings highlighted an opportunity for conservation and efforts were directed at improving saturation of high efficiency of clothes washers. The current study asked homeowners about the presence of high-efficiency clothes washers in their homes. The study-wide (Level 1 plus North American Survey) average among survey respondents indicated that 67% of homes now have HE devices (Table 35). The lowest saturation rates were in San Antonio, TX (59%) with the highest being in Toho, FL (78%). In either case, this shows a major change in device efficiency for this end use category.

Dishwashers were a common household appliance, with 84% of homes reporting having one. The lowest saturation was in San Antonio, TX (67%) and the highest saturation found in Fort Collins, CO (94%). On-demand hot water systems were relatively uncommon, with a study-wide average showing only 13% of homes having on-demand hot water systems. Please see Table 35.

Table 35: Saturation of water appliances

	Dishwasher		Water & energy efficient (EnergyStar) clothes washer		On-demand hot water system (recirculating pump)	
Site	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
All surveys	83.7%	16.3%	67.3%	32.7%	13.4%	86.6%
N. American Sample	81.9%	18.1%	68.6%	31.4%	15.0%	85.0%
Clayton	78.7%	21.3%	63.4%	36.6%	11.2%	88.8%
Denver	87.5%	12.5%	62.8%	37.2%	11.3%	88.7%
Ft. Collins	94.5%	5.5%	60.7%	39.3%	6.8%	93.2%
Peel	80.6%	19.4%	74.8%	25.2%	13.1%	86.9%
San Antonio	67.3%	32.7%	58.6%	41.4%	8.4%	91.6%
Scottsdale	94.0%	6.0%	67.6%	32.4%	29.6%	70.4%
Tacoma	85.1%	14.9%	67.0%	33.0%	9.8%	90.2%
Toho	83.6%	16.4%	77.6%	22.4%	12.1%	87.9%
Waterloo	81.7%	18.3%	75.2%	24.8%	11.7%	88.3%

Swimming pools and hot tubs were also common – but only at some sites. Scottsdale led both of these categories with 57% of home reporting pools and 29% reporting hot tubs. Toho also had a significant number of pools, at 37%, but one of the lower rates of hot tubs at 3%. Figure 34 summarizes data for swimming pools and hot tubs.

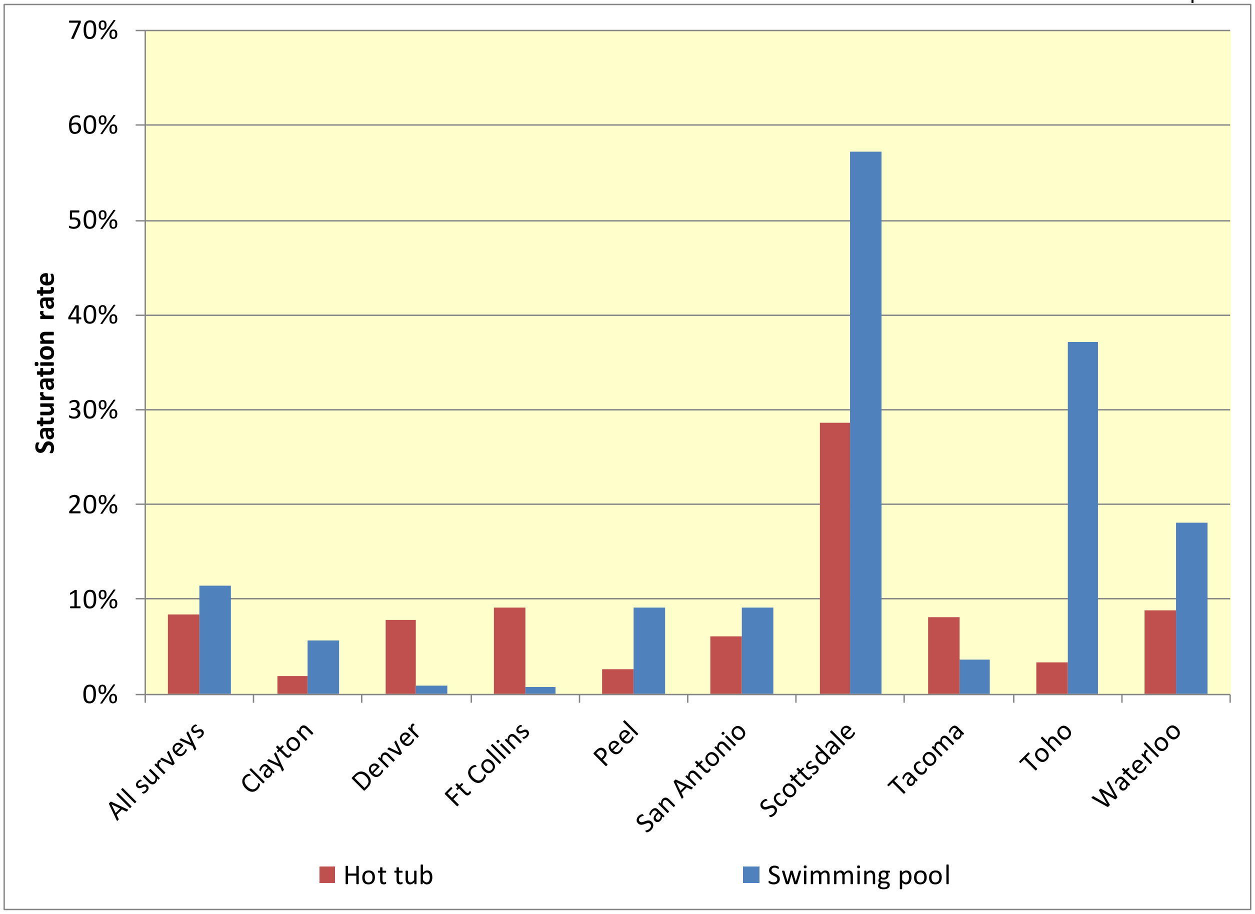


Figure 34: Sites reporting pools and hot tubs

Evaporative coolers were another water end use that is highly dependent on climate. Evaporative coolers (also known as swamp coolers) work best in dry climates and provide moderate cooling with potentially lower energy loads than air conditioning. For this reason they were found in the more arid sites in the study. Denver, CO and Scottsdale, AZ lead this category, with 23% and 12% saturation, respectively. Fort Collins, CO and Peel, ON also had some evaporative coolers. Toho, which has significant humidity, reported no evaporative coolers. These data are presented in Table 36. Humidifiers, usually attached to a home's furnace, proved house-wide humidification. These devices were also found in drier climates. Peel showed the highest saturation of these devices with 57% of respondents saying they have these devices. Water treatment was another end use explored by the survey. Looking at data from all study sites, treatment is not a typical feature in homes; only 13% of all respondents reported having it. Like pools and coolers, the presence of treatment is affected by the environment of the study sites, more specifically the hardness of the water supply for a given site. More than half (51%) of Waterloo, ON respondents reported having house-wide water treatment.

Table 36: House-wide water end uses, coolers, humidifiers, and water treatment

	Evaporative/swamp cooler		Whole house humidifier (usually attached to furnace)		Whole house water treatment system like a water softener or a reverse osmosis system	
Site	Yes	No	Yes	No	Yes	No
All surveys	6.2%	93.8%	18.5%	81.5%	13.1%	86.9%
N. American Sample	6.4%	93.6%	14.8%	85.2%	8.8%	91.2%
Clayton	2.6%	97.4%	4.1%	95.9%	1.4%	98.6%
Denver	23.1%	76.9%	20.5%	79.5%	3.3%	96.7%
Ft. Collins	6.1%	93.9%	44.2%	55.8%	0.9%	99.1%
Peel	2.8%	97.2%	56.9%	43.1%	4.6%	95.4%
San Antonio	0.4%	99.6%	2.4%	97.6%	20.9%	79.1%
Scottsdale	11.6%	88.4%	3.7%	96.3%	46.6%	53.4%
Tacoma	1.3%	98.7%	3.1%	96.9%	0.3%	99.7%
Toho	0.0%	100.0%	1.5%	98.5%	19.0%	81.0%
Waterloo	1.3%	98.7%	36.9%	63.1%	51.4%	48.6%

The present REUWS effort evaluates hot water demand and for this reason, several survey questions were included asking about hot water use in the home. One of the questions asked about the energy source for hot water heating. The vast majority of participants reported that their hot water was heated by gas (Figure 35). The survey also asked questions about how long respondents had to wait for water. The question stated: "Thinking of the room where it takes hot water the longest to reach, how long would you say you have to wait for hot water?" and asked respondents to select from four answers. About 60% of respondents reported only a short or no wait time for hot water. Some (4%) reported having a long wait (let the water run a minute or two). Table 37 details these findings.

Table 37: Wait for hot water

Wait for water	Percent of Respondents
Almost no time at all	15.4%
Not very long, we just have to let the water run for a few seconds	46.0%
Pretty long, we have to let the water run a minute or two before it gets hot	34.8%
Very long, we have to let the water run more than two minutes before it gets hot	3.8%

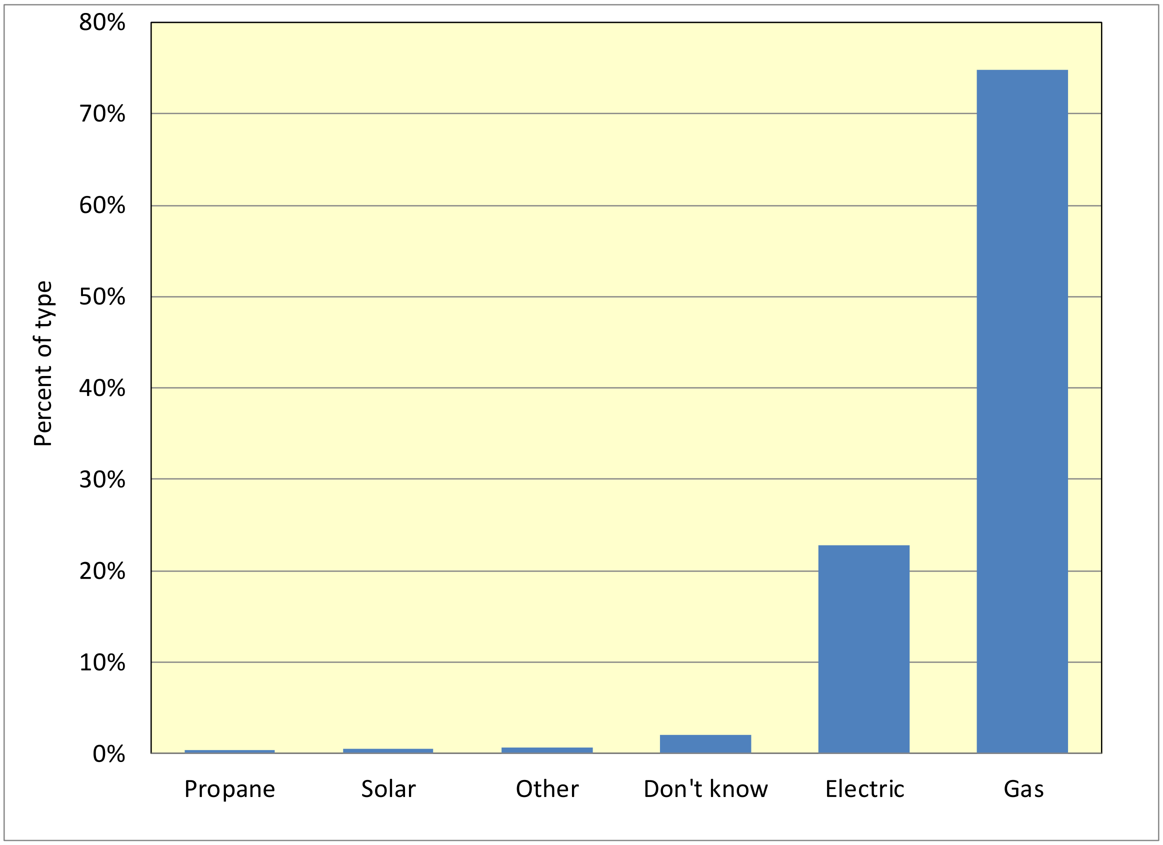


Figure 35: Energy sources for hot water heating, all Level 1 and North American Survey sites

Demographics

Demographics are a significant driver of water demand. One of the most fundamental water demand modeling variables is the number of people per home. The survey asked how many people lived full-time at the surveyed address. Respondents were asked to indicate the number of adults, teenagers, children, and infants or toddlers. Table 38 shows the breakdown of the responses for this question. The study-wide average was 2.59 people per household. This is a reduction from the 2.71 people per household found in the REUWS1. The Canadian sites, Peel and Waterloo, had the highest occupancies, at 3.43 and 3.08 people per household (respectively). Scottsdale, AZ had the lowest occupancy at 2.21 people per household.

Table 38: Household occupancy, by site

	Adults (age 18+)	Teens (age 13-17)	Children (age 3-12)	Infants / Toddlers (< age 3)	Total in Household
All surveys	2.12	0.17	0.25	0.06	2.59
REUWS1	2.08	0.2	.43[a]		2.71
N. American Sample	2.08	0.15	0.23	0.04	2.51
Clayton	1.99	0.23	0.31	0.07	2.59
Denver	2.00	0.13	0.23	0.09	2.45

	Adults (age 18+)	Teens (age 13-17)	Children (age 3-12)	Infants / Toddlers (< age 3)	Total in Household
Ft. Collins	2.06	0.17	0.25	0.05	2.53
Peel	2.72	0.19	0.41	0.11	3.43
San Antonio	2.12	0.13	0.24	0.07	2.56
Scottsdale	1.93	0.12	0.14	0.03	2.21
Tacoma	2.07	0.16	0.20	0.04	2.48
Toho	2.14	0.23	0.24	0.06	2.67
Waterloo	2.45	0.22	0.35	0.06	3.08

[a] included with children in REUWS1 (see table 4.10)

Survey respondents were also asked to provide information on their level of education. The survey question asked, "What is the highest level of education in the household?" and respondents could select from:

- 12th grade or less, no diploma
- High school diploma
- Some college, no degree
- Associate's degree (e.g. AA, AS)
- Bachelor's degree (e.g. BA, AB, BS)
- Graduate degree or professional degree

Looking at responses study wide, 84% reported having at least some college education. Nearly a third, 31%, reported having advanced degrees. Fort Collins, CO had the highest percentage of respondents with advanced degrees, at 47%. Combining all college degrees, 68% of households reported having a degree (associates, bachelors or graduate), with Fort Collins again reporting the highest level of college degrees at 83%. Figure 36 shows the distribution of education across study sites.

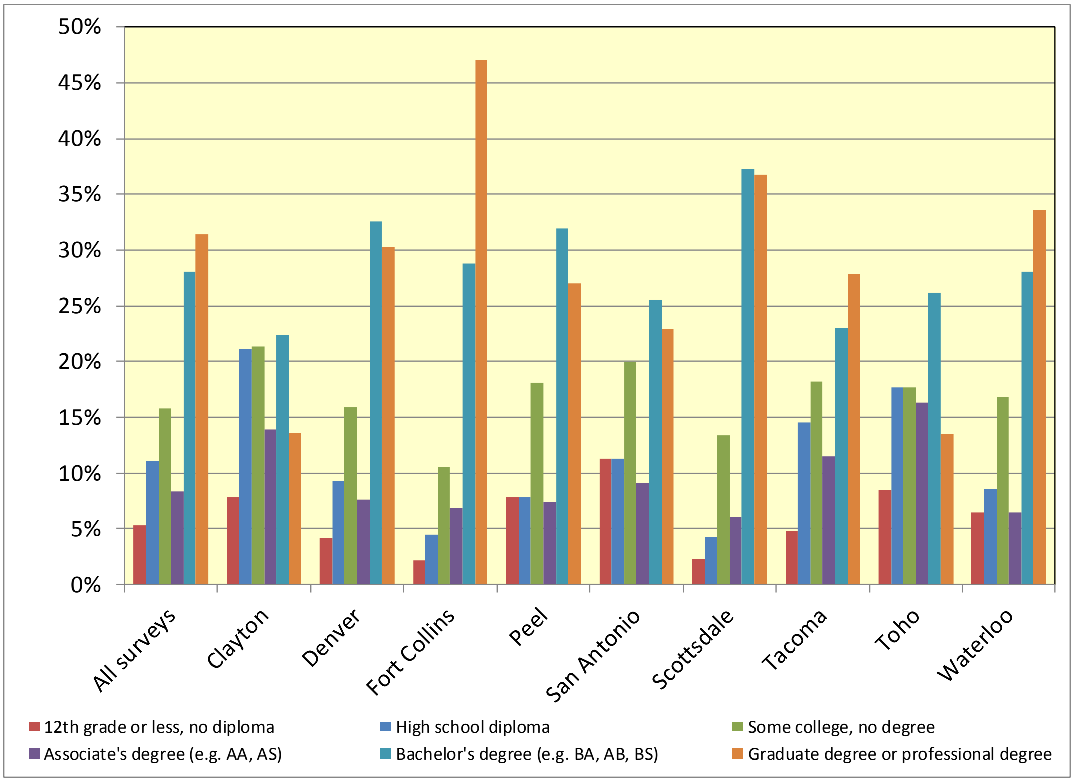


Figure 36: Education levels of households

Income level is another household demographic that can characterize households. Respondents were asked about their combined, before tax, household income and they could choose from seven brackets. Figure 37 shows the income distributions at each of the Level 1 study sites as well as the study-wide distribution. Scottsdale, AZ had the highest percentage of respondents in the highest income bracket (18%). Toho, FL and San Antonio, TX tied for highest number of respondents (22%) in the lowest income bracket, and Clayton County was also very close to this range (21%). Waterloo had a comparatively normal distribution of income ranges centered in the $75,000 to $100,000 range.

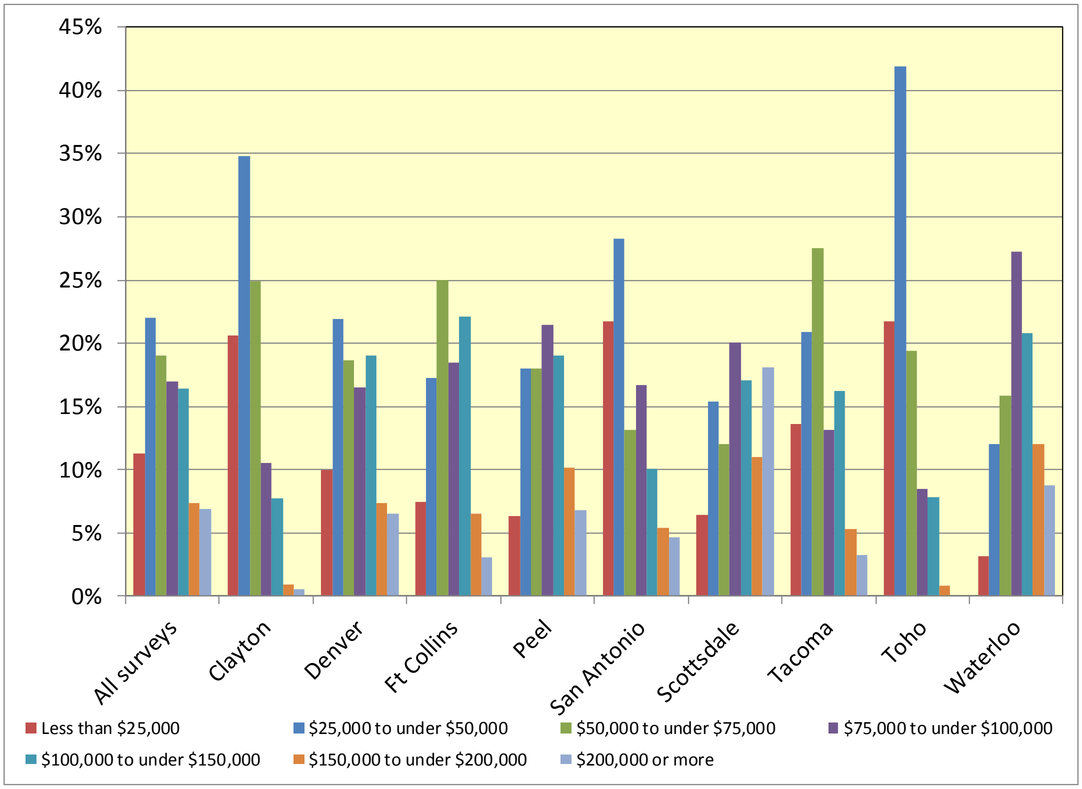


Figure 37: Income distributions, by site

Behavior

The survey asked several questions to elucidate information about residents' behavior patterns. These questions covered a range of water use habits. Perhaps some of the most interesting questions related to water conservation. One question asked if the household had taken any action to conserve water in the last few years. A clear majority (73%) said they had. These results are shown in Table 39. If survey respondents reported conserving, they were asked what actions they had taken. Table 40 details some of these responses. Study-wide, the most common (72%) action was to avoid irrigating during the heat of the day. Over half (52%) of people reported taking short showers.

Table 39: Percent of households reporting conservation activities

	ALL	N.A.S.	Clayton	Denver	Ft. Collins	Peel	San Antonio	Scottsdale	Tacoma	Toho	Waterloo
Yes	73%	74%	56%	79%	79%	66%	70%	73%	68%	66%	80%
No	27%	26%	44%	22%	21%	34%	30%	27%	32%	34%	20%

Table 40: Survey respondents' conservation actions

	ALL	N.A.S.	Clayton	Denver	Fort Collins	Peel	San Antonio	Scottsdale	Tacoma	Toho	Waterloo
Installed water-efficient clothes washer	44%	46%	31%	36%	42%	49%	37%	42%	48%	50%	53%
Take shorter showers	52%	55%	65%	55%	47%	53%	46%	41%	55%	56%	46%
Installed low-flow showerheads	46%	47%	33%	42%	51%	49%	41%	40%	59%	49%	49%
Installed new toilet(s)	44%	45%	37%	39%	40%	53%	49%	42%	36%	37%	55%
Use dishwasher less/use fuller loads	63%	61%	60%	60%	69%	65%	51%	70%	66%	71%	64%
Use clothes washer less/use fuller loads	60%	59%	67%	57%	58%	62%	60%	58%	61%	60%	62%
Repaired leaks in faucet/toilet	46%	45%	59%	51%	45%	45%	50%	51%	41%	43%	39%
Catch water in bucket to re-use while waiting for water to get hot	11%	14%	14%	11%	12%	5%	11%	6%	8%	7%	4%
Installed water-efficient dishwasher	29%	28%	18%	26%	30%	25%	20%	40%	31%	25%	38%
Wash car less often	30%	30%	43%	23%	22%	39%	26%	23%	33%	53%	33%
Water lawn and shrubs less often	49%	49%	39%	55%	48%	51%	59%	37%	48%	70%	57%
Avoid watering lawn and shrubs during the heat of the day	72%	71%	51%	85%	87%	73%	76%	58%	75%	71%	71%
Installed low-water-use landscaping/plants	24%	26%	9%	28%	29%	11%	19%	43%	16%	19%	21%
Reduced run-times on automatic sprinklers	25%	26%	4%	45%	41%	4%	17%	42%	17%	42%	5%
Repaired damaged or leaking irrigation system	22%	22%	3%	35%	33%	3%	20%	53%	9%	35%	4%
Monitor irrigation system for leaks, blown heads, etc.	25%	24%	3%	42%	41%	5%	19%	50%	13%	34%	5%
Use graywater/reuse household water	7%	10%	5%	8%	8%	4%	5%	5%	5%	5%	6%
Installed a rain barrel or cistern	10%	13%	3%	1%	4%	8%	6%	3%	4%	1%	35%
Did not check any	3%	4%	3%	3%	2%	3%	5%	3%	3%	3%	2%

Irrigation

Irrigation accounts for a significant portion of single family water use and for this reason irrigation was carefully scrutinized in this present study. This evaluation included a section in the survey exploring irrigation practices, behaviors, and attitudes. Figure 38 shows the percentages of respondents who irrigate. The combined responses show that 70% of households report irrigating. At all sites – except Clayton County, GA – the majority of homes were irrigating. Like pools, coolers and water treatment, irrigation is likely affected by the climate of the study site.

The survey also asked what types of landscape were present at the study homes. Respondents could of course select more than one type of plants since landscapes are typically comprised of various plantings. Figure 39 shows that turf and trees/shrubs are common landscape elements (about 80% of homes) while veggie gardens were only reported at about 30% of homes. The survey also asked residents about how much of their landscape was watered manually. Figure 40 shows this breakdown. The most common response (36%) was that less than half of the landscape was watered by hand. About 38% reported watering all or mostly by hand. REUWS 1999 found that homes using hand-held (manual) irrigation used 33% less water than other households.

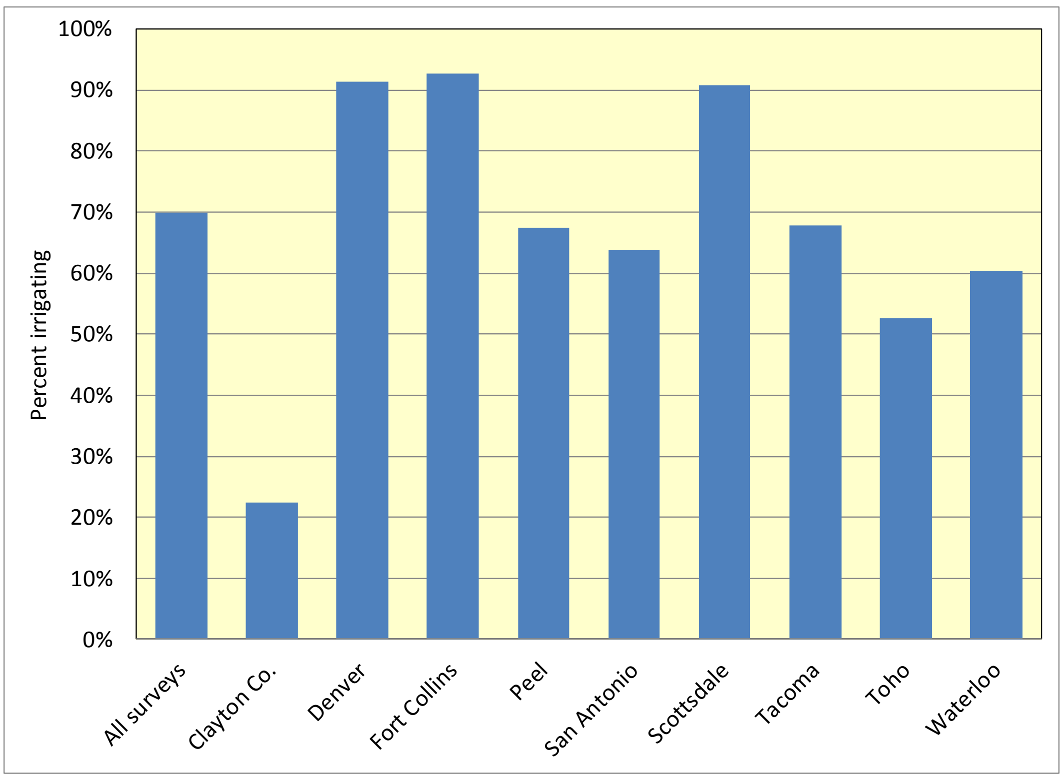


Figure 38: Survey respondents who irrigate at all Level 1 and North American Survey sites

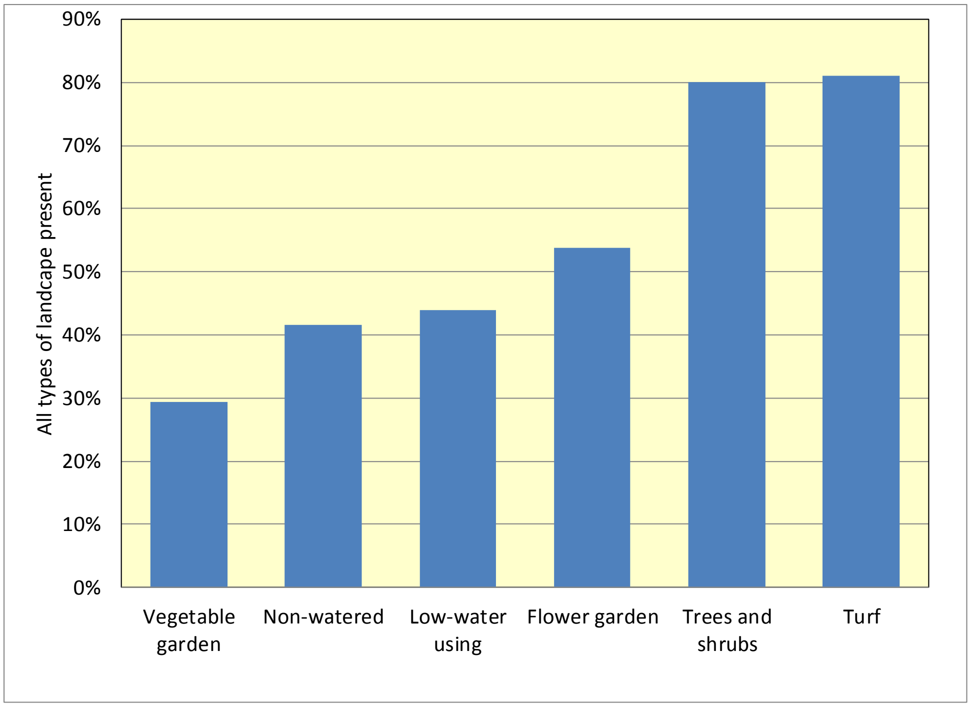


Figure 39: Types of landscape plantings reportedly present at all Level 1 and North American Survey sites

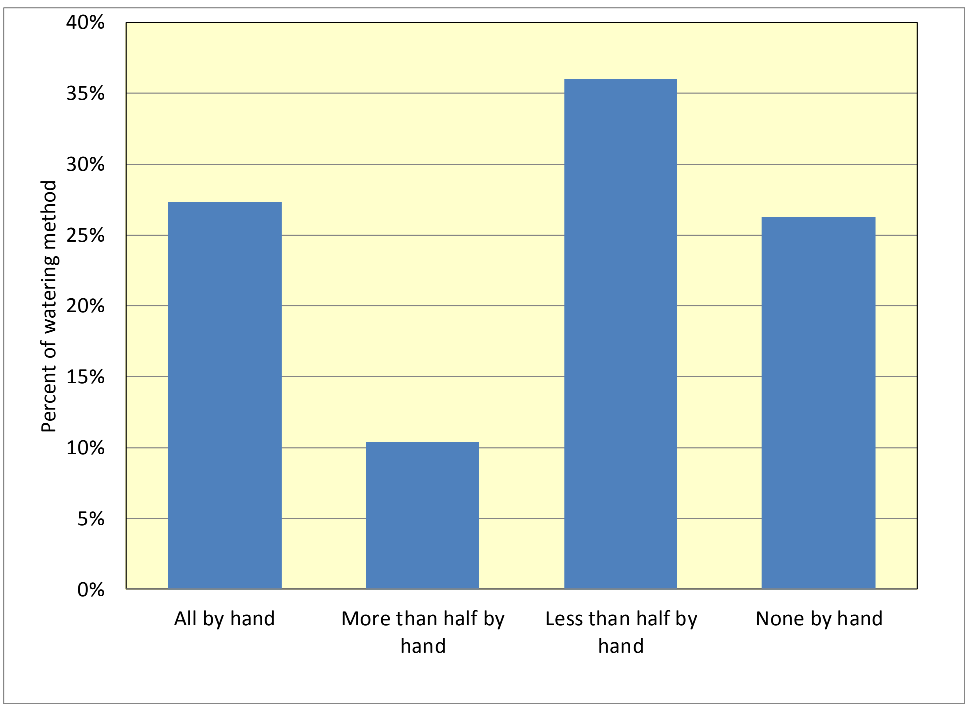


Figure 40: Irrigation methods reported from all Level 1 and North American Survey sites

In-ground irrigation systems were present in just over half (53%) of all survey respondents' (please see Table 41). The respondents were asked, if they had an in-ground system, about some of the features of those systems. Table 41 shows some of the responses. Most in-ground systems included an automatic timer / controller. Weather-based ("Smart") controllers were still relatively uncommon.

Table 41: In-ground irrigation systems and their features

	Do you have an in-ground irrigation/sprinkling system?		Respondents with in-ground systems were asked if their irrigation system had:	
	Yes	No	Automatic timer/controller	Weather-based "smart" controller
All	53.0%	47.0%	87.9%	16.40%
N. American Sample	52.4%	47.6%	85.2%	19.6%
Clayton	15.5%	84.5%	57.9%	26.3%
Denver	74.1%	25.9%	93.9%	8.5%
Ft. Collins	69.0%	31.0%	92.9%	8.4%
Peel	10.3%	89.7%	60.9%	26.1%
San Antonio	36.9%	63.1%	83.6%	34.2%
Scottsdale	88.8%	11.3%	91.6%	7.3%
Tacoma	33.3%	66.7%	80.7%	14.8%
Toho	76.9%	23.1%	87.5%	50.0%
Waterloo	13.1%	86.9%	76.7%	53.3%

Judgment

Judgment questions on the survey requested information on residents' opinions of water rates, conservation, and drought. When asked whether their community was experiencing drought, respondents could choose among five responses:

- No drought
- Mild drought
- Moderate drought
- Severe drought
- Don't know

Responses to this question were fairly evenly split at many sites and for all combined answers (Figure 41). However, a majority of Tacoma, WA respondents said their community was not experiencing drought. Peel, ON and Clayton County, GA respondents' most common answer was that there was no drought in their area. Tacoma's responses agree with the U.S. Drought Monitor (Figure 42). Other communities' perception of drought and their actual level of drought level, based on the North American and U. S. Drought Monitors, are shown in Table 42.

Table 42: Drought status in Level 1 sites, along with most common survey response

	Survey time frame	Drought status, North American Drought Monitor	Most common survey response
Clayton	February/March 2012	Moderate / severe	don't know (32%), no (31%)
Denver	November / December 2011	No drought	mild drought (35%)
Ft. Collins	November / December 2011	No drought	mild drought (31%)
Peel	Apr-12	Abnormally dry / moderate drought	no drought (35%)
San Antonio	Mar-12	Abnormally dry / moderate drought	moderate drought (32%)
Scottsdale	February/March 2012	Severe / extreme	moderate drought (38%)
Tacoma	March / April 2012	No drought	no drought (76%)
Toho	Feb-12	Moderate drought	moderate drought (30%)
Waterloo	Apr-12	Abnormally dry / moderate drought	moderate drought (41%)

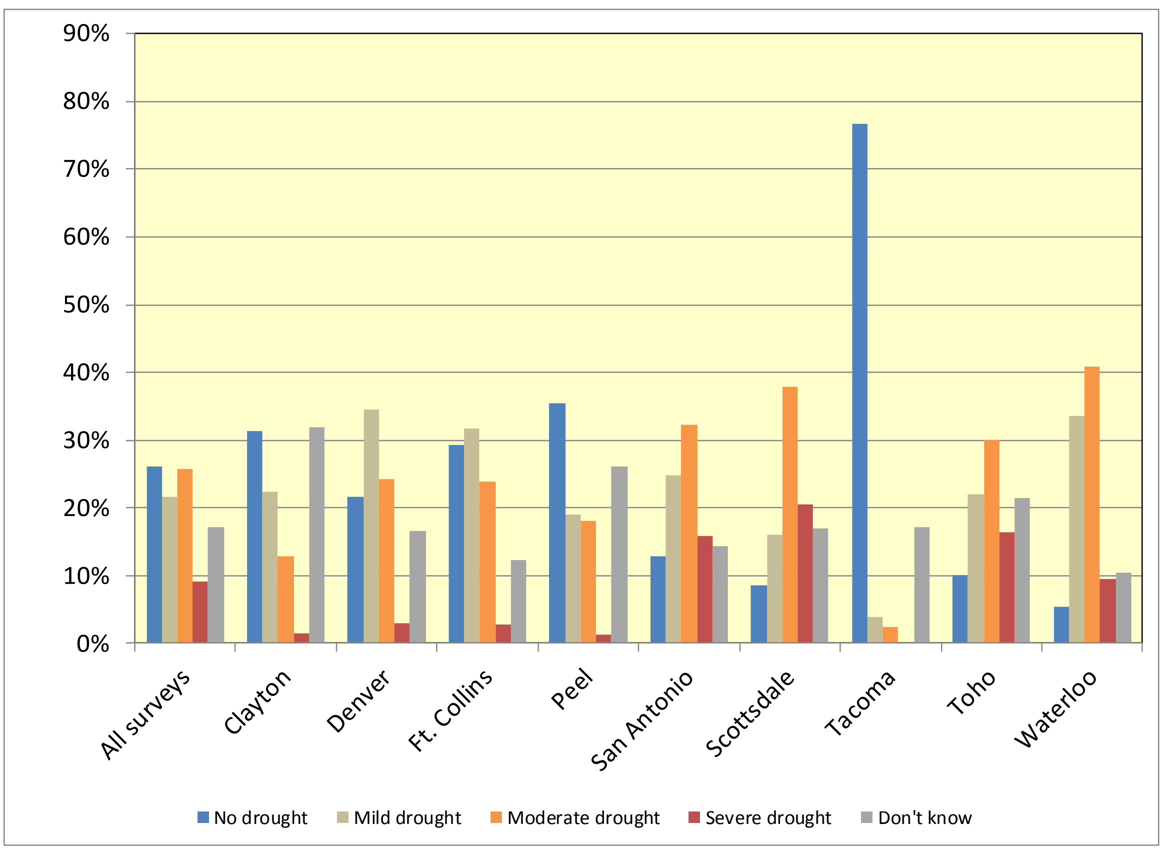


Figure 41: Respondents' opinions on whether their community was experiencing drought

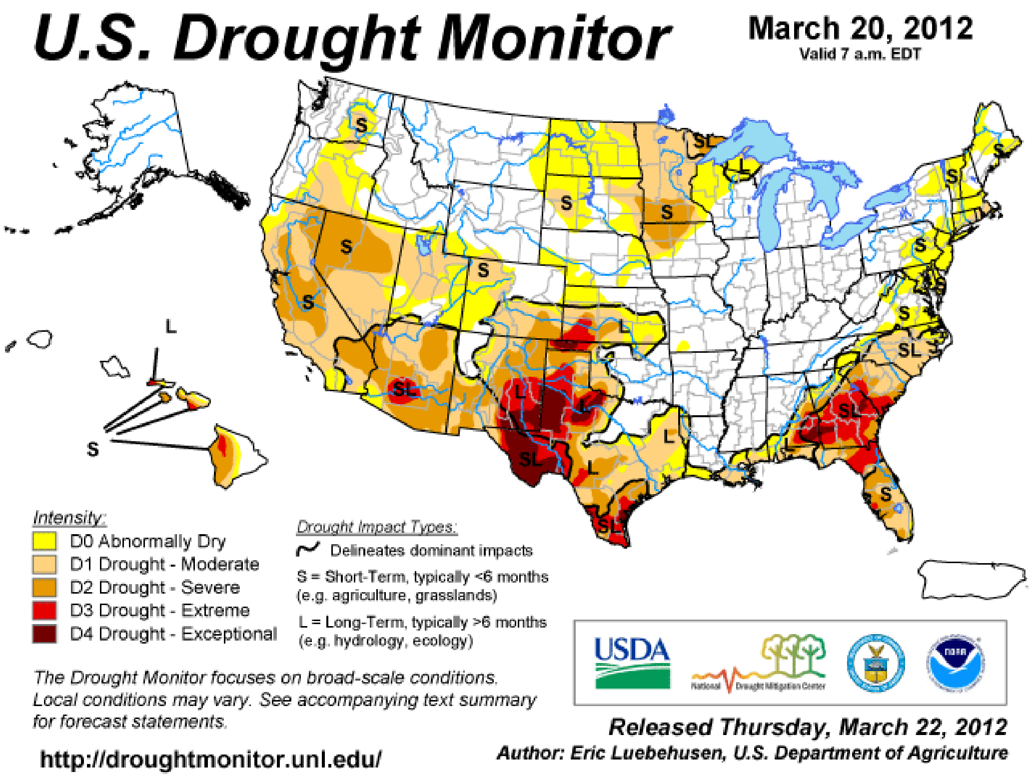


Figure 42: U.S. Drought Monitor map for March, 2012, during the middle of the survey process

In addition to drought awareness, the survey looked at attitudes about conservation. Based on the study-wide average, 92% of respondents agreed that conservation was critical for their community. A small majority (51%) also said that people who use more water should pay higher rates. Figure 43 shows the breakdown for all Level 1 sites.

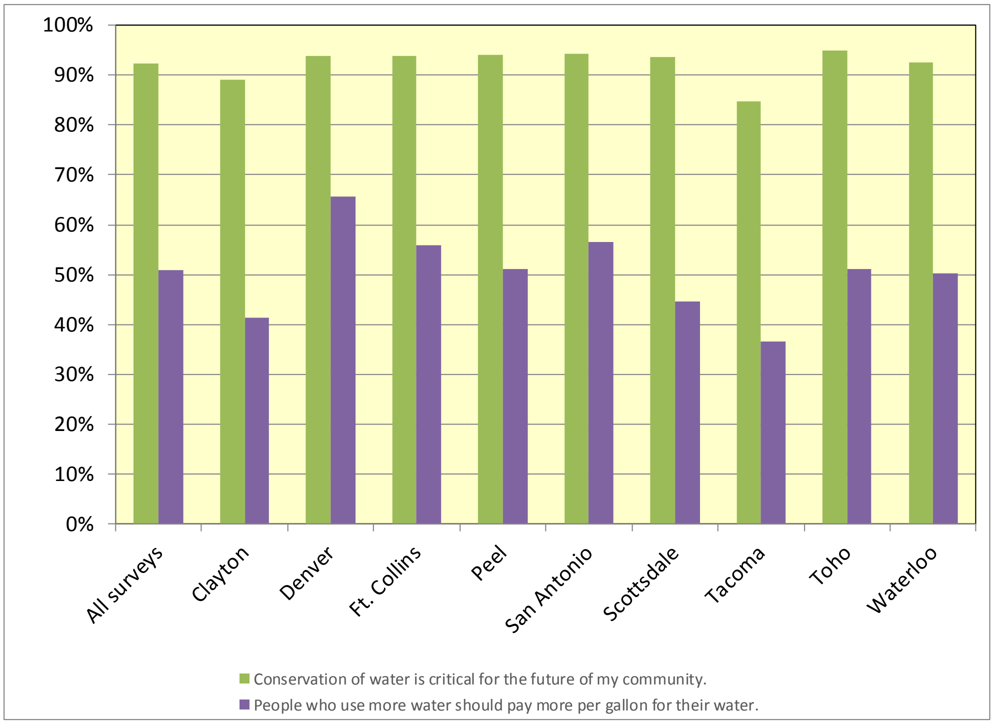


Figure 43: Conservation and water rates as conservation tool

The survey explored water customers' level of awareness of their own water use. Over half of respondents (57%) reported that they knew their average household water use. Most (4%) respondents also supported allowing customers to track their own water use. Figure 44 shows this data.

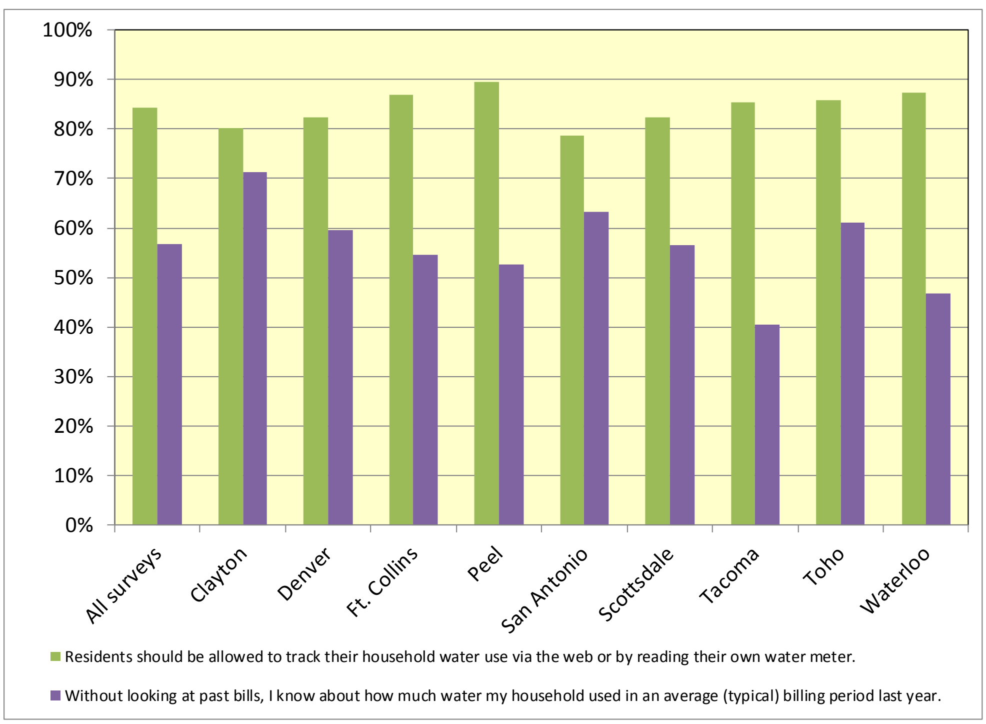


Figure 44: Responses to information about water use

PROJECT DATABASES

The data collected for this project came primarily from three sources: billing databases provided by the participating water agencies, survey information provided by the responding water customers and water agencies, and flow trace data obtained from the data logging effort. This is true for both the historical studies and the current REUWS2 study. The data has been compiled into five Xcel spreadsheets that can be used as the starting point for future analyses as required.

A great deal of effort was required to summarize the data from the various sources into useable tables. This was especially true of the survey information since each survey was slightly different from the others and as a result the compilation of the results required a significant amount of programming in order to reorder and re-code the responses. In addition, not all surveys contained the same questions, so it was necessary to create a summary response table for the historical survey data that consisted of a subset of the most commonly asked questions.

Table 43 shows a list of the studies included in the historical data set. Table 44 shows the names and descriptions of the 5 database files that make up the project database. List of the variables included in each files with descriptions are provided in Appendix ___.

Table 43: Table of historical studies included in database (Number of surveys =14,066)

STUDY NAME	NUMBER OF HOMES IN RECORD	START OF DATA COLLECTION
Albuquerque Bernalillo County (ABQ)	209	8/30/10
ABQ_Retrofit	29	8/10/11
Cal-Single Family	734	7/19/07
EPA Retrofit - Tampa + EBMUD	178	5/22/02
EPA Retrofit-Seattle	111	3/18/00
EPA-HE-New Homes	25	7/18/09
EPA-New Home Study	302	4/16/08
Louisville, KT	59	11/21/07
REUWS1	1187	1/18/97
REUWS2	762	8/2/12
Westminster, CO	61	12/4/10
TOTAL/AVERAGE	3657	--

Table 44: Description of database files

No.	File	Variables	Cases	Contents
1	Common Survey Questions.xlsx	57	16,901	Common 57 survey questions. The most frequently repeating survey questions from the surveys sent to major end-use studies. Includes responses for both historical and REUWS2 studies.

2	REUWS2 All Customer Surveys.xlsx	165	13,752	Xcel version of complete REUWS2 survey mailing table. Includes annual, seasonal and non-seasonal water use from Q_{1000} tables.
3	REUWS2_Combined indoor_all studies.xlsx	60	3658	Summary of daily indoor use data for historical and REUWS2 studies.
4	REUW2_Combined outdoor all studies.xlsx	39	1889	Summary of outdoor use data for historical and REUWS2 data
5	REUWS2 Level 1 Survey & Water Use	256	771	A large combined data set that includes most of the working data for the logged homes from the REUWS2 study. Includes the survey responses, indoor and outdoor water use data for the Level 1 sites. Used for much of the modeling work.
6	Daily Use Table.xlsx	Each fixture	6959	Table of daily water use by end use for main water traces for all homes in logging group.

SURVEY RESPONSE DATA

The survey information has been presented in the first two files. The first file, Common Survey Questions.xlsx, contains the responses to the 57 most frequently asked questions for all of the surveys, including both historical and for REUWS2. This file contains most of the useful questions that can be used for analyzing the various datasets. Each case is identified by its keycode and/or survey ID, so that it can be linked to the appropriate water use data.

The second data file, REUWS2 All Customer Surveys.xlsx, contains an extensive set of survey and billing data information for each of the surveys mailed out at part of the REUWS2 study. Where surveys have been returned the response fields have been filled-in, and where no survey was returned only the billing data appear. This provides a complete record of the survey and Q_{1000} data. All information identifying specific customers has been erased. Custom questions asked by specific utilities were not included since these do no extend to the entire study group.

FLOW TRACE DATA

The flow trace data consist of nearly 2 million individual water events that were derived from the analysis of the raw 10 second data files using the Trace Wizard program. These data were summarized for each home such that the key daily use and fixture use appear on one row, which is identified by its key code.

The indoor summaries are shown in REUWS2_Combined indoor_all studies.xlsx and the outdoor summaries are shown in REUW2_Combined outdoor all studies.xlsx. These files contain only data from homes which had been successfully data-logged, which is why they contain fewer records than do the survey files.

COMBINED DATA

The NEXT l data set, REUWS2 Level 1 Survey & Water Use includes survey and water use data for the REUWS2 Level 1 study homes. This is the data set that was used for much of the models presented in the modeling chapter. Even though there are many variables for each home since the data are all on a single row it makes them easy to analyze.

DAILY USE DATA

The final data set is an excel file that contains the daily use by fixture for all of the houses in the study group. The file name for this is Daily Values by Fixture.xlsx. It contains approximately 7000 rows, and each row includes the daily water use for each fixture for each house of the study group. The name of the site, the keycode of the house, the number of persons in the home, the first and last day of the logging period are also included in each row.

DESCRIPTIVE STATISTICS

This portion of the report provides information on water use data obtained from the billing records and from the end use analyses. Each of the Level 1 and Level 2 sites provided the research team with one year of billing data (mainly from 2010) for a random sample of 1000 single family homes from their populations. These data were used to generate water use data for annual, seasonal and non-seasonal water use. For consistency and ease of analysis all water use was converted from whatever billing unit was used by the agency to units of thousands of gallons (kgal).

Annual water use was simply the total water use for the customer for the year. Non-seasonal use was estimated as the water use during the winter period pro-rated to the entire year. For this purpose the winter period was taken as the consumption during the minimum month or minimum 2 month period, where this was the billing period used by the agency. This value was then multiplied by the appropriate factor in order to pro-rate it to the entire year. Seasonal use was taken as the annual use minus the non-seasonal use.

Statistics for the indoor and outdoor end uses were taken from the end use data tables created from the flow traces as described the Data Analysis chapter.

ANNUAL AND SEASONAL USE

The most readily available water use information for water agencies comes from the billing database. This data source always contains information about annual water use, and will have various degrees of additional data depending on the frequency with which the meter are read. Monthly billing predominates, followed by bi-monthly or quarterly readings. The billing databases were used to establish the average annual use for the single family customers in each of the study sites, and from this to select representative samples of customer to receive the survey. Table 45 provides a summary of the annual, seasonal and non-seasonal water use for all of the study sites.

Table 45: Annual and seasonal water use for single family accounts in Q_{1000} samples

Agency	Level	Number of SF Accounts 2010	Annual Use in 2010 (kgal)	Seasonal Use (kgal)	Non-Seasonal use (kgal)	% Seasonal
Clayton	1	70,421	58	6	52	9%
Denver	1	195,487	118	63	56	46%
Ft Collins	1	27,867	105	52	53	44%
Peel	1	273,989	82	11	72	12%
San Antonio	1	331,853	106	43	63	37%
Scottsdale	1	146,138	175	46	129	23%
Tacoma	1	85,288	69	17	52	20%
Toho	1	68,021	88	31	57	26%
Waterloo	1	55,733	55	19	47	27%
Aurora	2	70,608	98	39	59	35%
Austin	2	189,038	93	51	42	50%
Cary	2	45,120	70	18	52	18%
Chicago	2	269,698	91	12	78	12%
Edmonton	2	220,090	54	5	49	9%
Henderson	2	80,352	141	83	59	54%
Miami	2	377,846	83	7	76	8%
Mtn View	2	11,802	83	37	46	40%
Otay	2	40,994	127	68	59	51%
Philadelphia	2	392,639	57	4	53	6%
Portland	2	153,500	53	10	43	16%
RWA-CT.	2	107,141	67	10	58	11%
Santa Barbara	2	16,919	96	51	44	52%
Santa Fe	2	26,871	44	10	34	21%
Average		141,627	88	30	58	27%
Maximum		392,639	175	83	129	1
Minimum		11,802	44	4	34	0

Agency	Level	Number of SF Accounts 2010	Annual Use in 2010 (kgal)	Seasonal Use (kgal)	Non-Seasonal use (kgal)	% Seasonal
Std. Dev.			32	23	19	16%

The split between seasonal and non-seasonal use is shown graphically in Figure 45. One would expect seasonal use to vary more widely than non-seasonal given the fact that non-seasonal use is composed primarily of indoor water use. As can be seen in Table 45, there is in fact a much larger variance in seasonal use than non-seasonal use, but there is more variance in non-seasonal use than one would expect from exclusively indoor water use. This suggests that the non-seasonal use includes a mixture of indoor and outdoor uses.

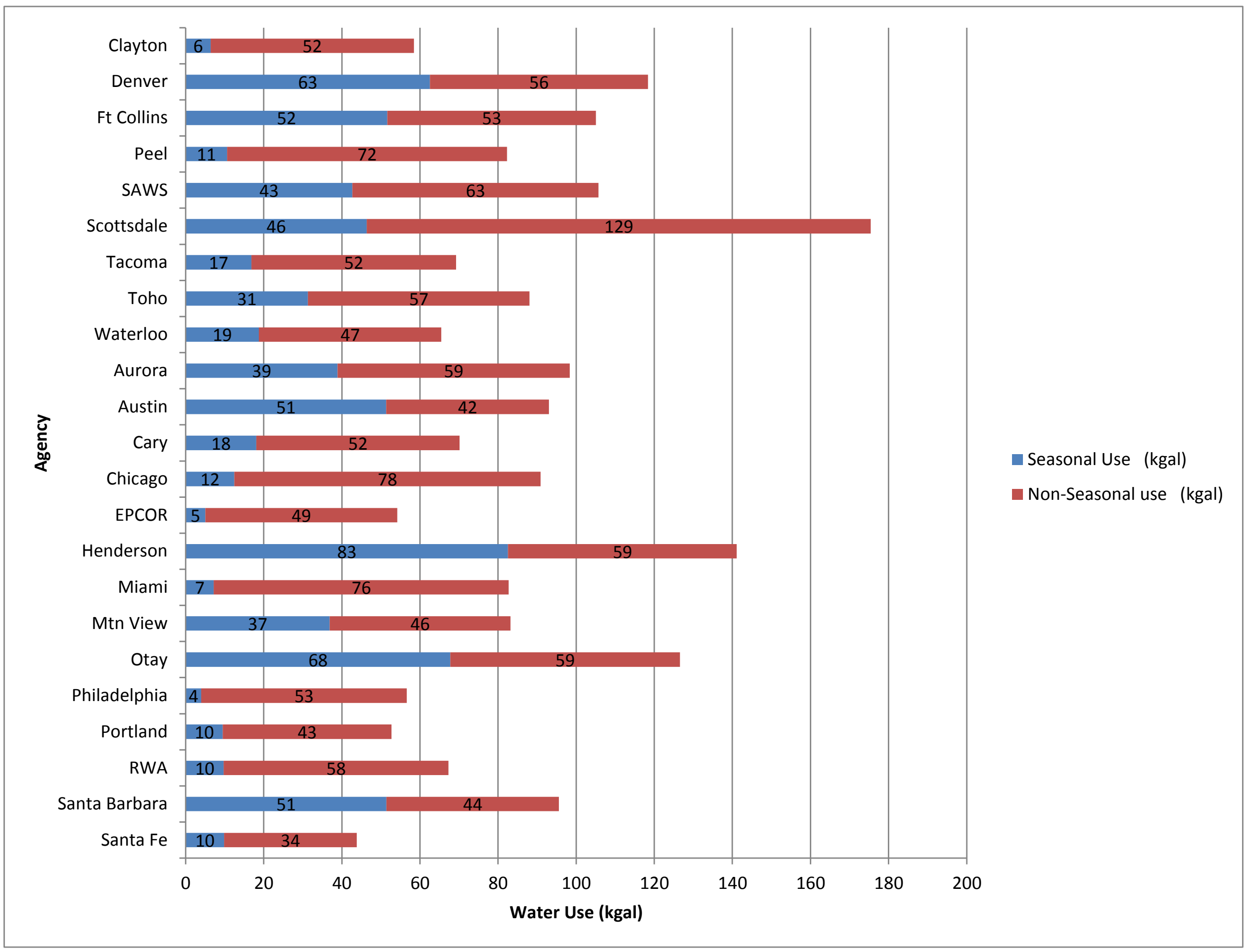


Figure 45: Seasonal/Non-Seasonal water use by agencies (kgal)

Per Capita Use

Per capita use is a convenient and common way of normalizing water use in a community. It can be expressed for the system as a whole by dividing total produced or purchased water, minus exports, by the service area population. It can also be calculated for just individual customer categories. Table 46 shows the annual and non-seasonal per capita water use for the entire study group. These data are shown graphically in Figure 46 and Figure 47. The average non-seasonal per capita water use for the group was 63 gpcd, and the average for just the level 1 sites was 70.3 gpcd. Clearly, Scottsdale, AZ, at 164 gpcd, is an outlier in this data set. This is due to the fact that so many of the residents in Scottsdale leave the city during the summer, which depresses the summertime use from which seasonal water demands are determined. The remaining sites are all between 40 and 80 gpcd of non-seasonal use.

Table 46: Annual and non-seasonal per capita water use

Agency	Annual GPCD	Non-seasonal GPCD
Clayton	62	56
Denver	132	64
Ft Collins	114	59
Peel	66	59
San Antonio	113	69
Scottsdale	217	164
Tacoma	77	59
Toho	90	60
Waterloo	58	43
Aurora	110	68
Austin	99	45
Cary	68	52
Chicago	81	71
Edmonton	58	54
Henderson	179	76
Miami	86	80
Mtn View	87	50
Otay	124	59
Philadelphia	68	65
Portland	58	49
RWA	69	60
Santa Barbara	112	53
Santa Fe	62	49
Average (all)	95	63
Average (Level 1)	103	70
Maximum	217	164
Minimum	58	43

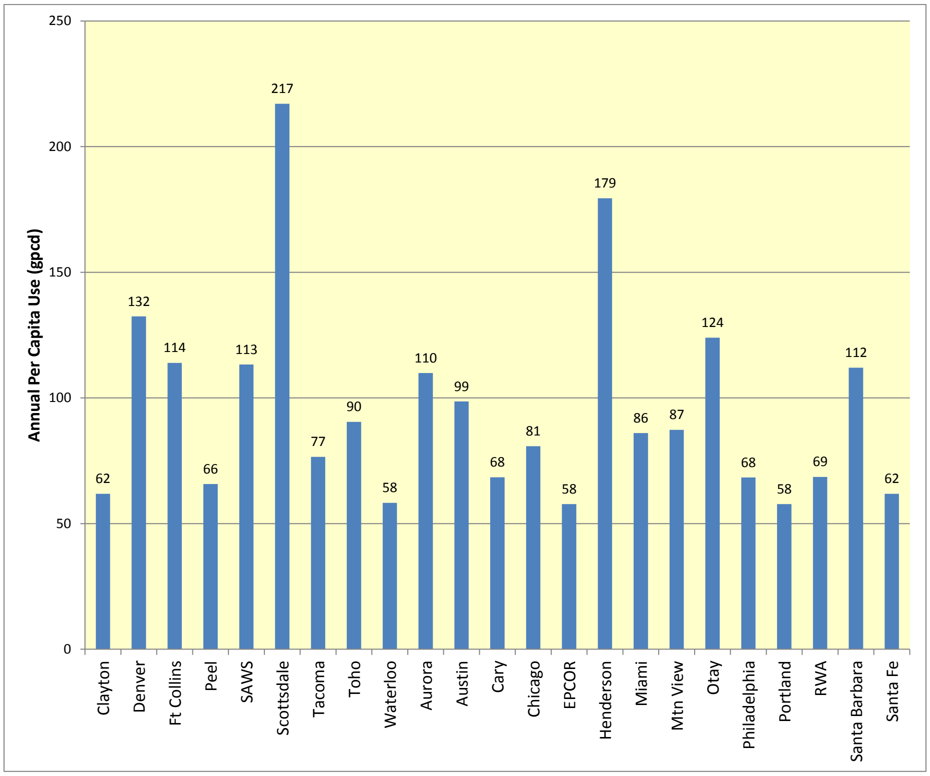


Figure 46: Annual per capita water use

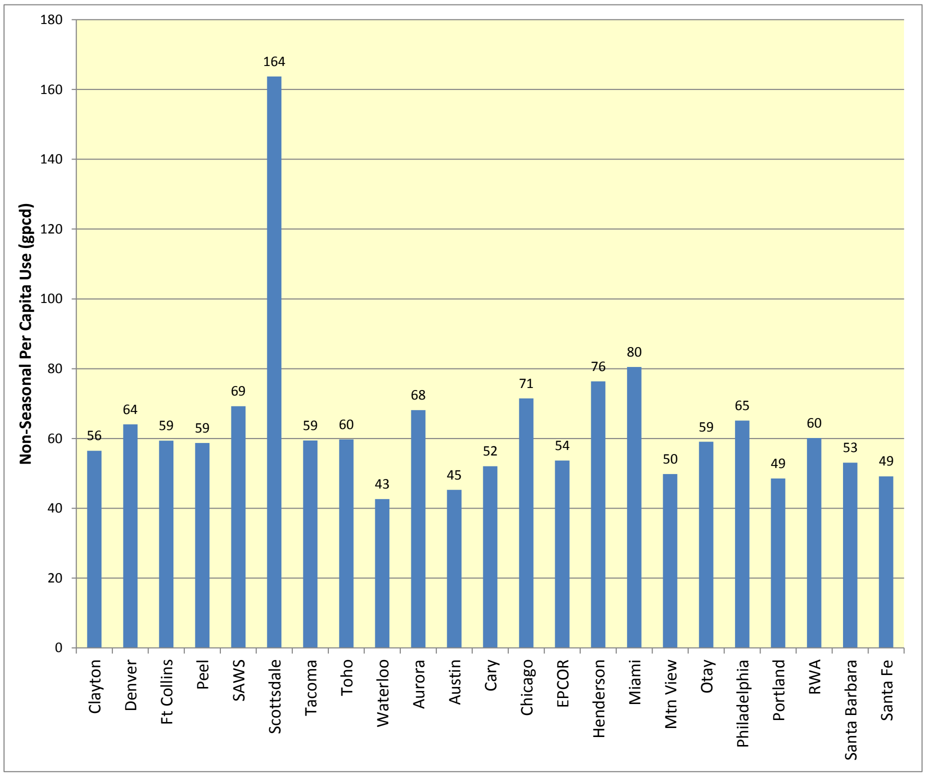


Figure 47: Non seasonal per capita water use

INDOOR END USES OF WATER

During the disaggregation process each water use event that was identified through the trace analysis process was assigned a category of use and this was linked to the study home through the keycode. The result of this was a water event database that contains 2.98 million individual records. These records were summarized in order to generate the statistical tables shown in this section of the report. A key element of the analysis is that large irrigation events were excluded from the indoor analysis. One caveat to this is to realize that all leakage and faucet are classed as indoor use, but some of these uses may occur outside.

Total Indoor Household Water Use

Total indoor water use for each home was the sum of the end uses for all of the identified indoor categories. Leaks were included as indoor events, even though it is known that some leaks are associated with outdoor uses such as irrigation systems and pools. The average indoor water use measured in REUWS2 was 138 gpd, (521 lpd). Indoor has dropped significantly from the REUWS1 levels of 177 gpd (670 LPD). Table 47 shows a comparison of the indoor water use measured in the REUWS2 and the REUWS1. Figure 48 gives a visual comparison of the mean and range of indoor use.

Table 47: Total indoor use statistics for REUWS2 and REUWS1

	Total Indoor Use REUWS2		Total Indoor Use REUWS1	
	GPD	LPD	GPD	LPD
Number	762	762	1188	1188
Mean	138	521	177	670
Median	125	472	160	606
StDev	80	302	97	367
95th CI	6	21	6	21
Lower CB	132	499	171	649
Upper CB	143	542	183	691

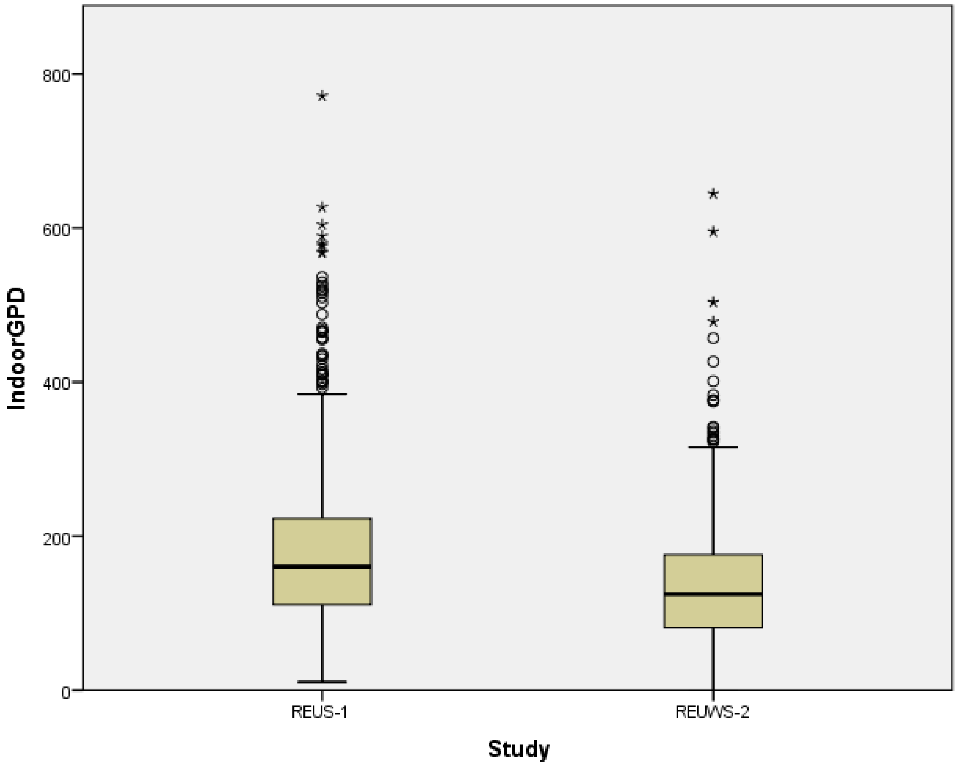
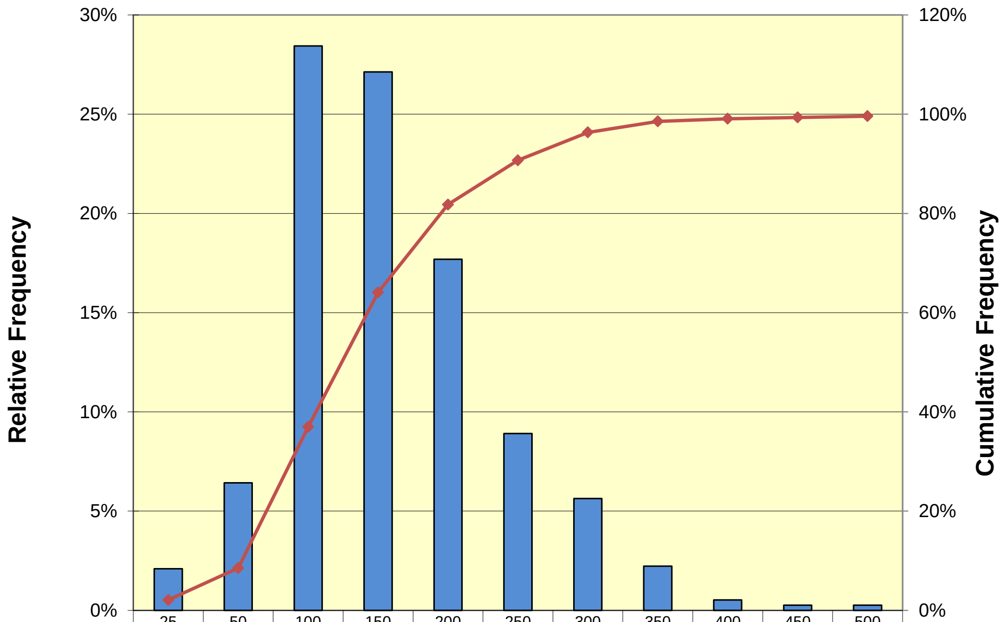


Figure 48: Box diagram comparison of REUWS2 to REUWS1 indoor use

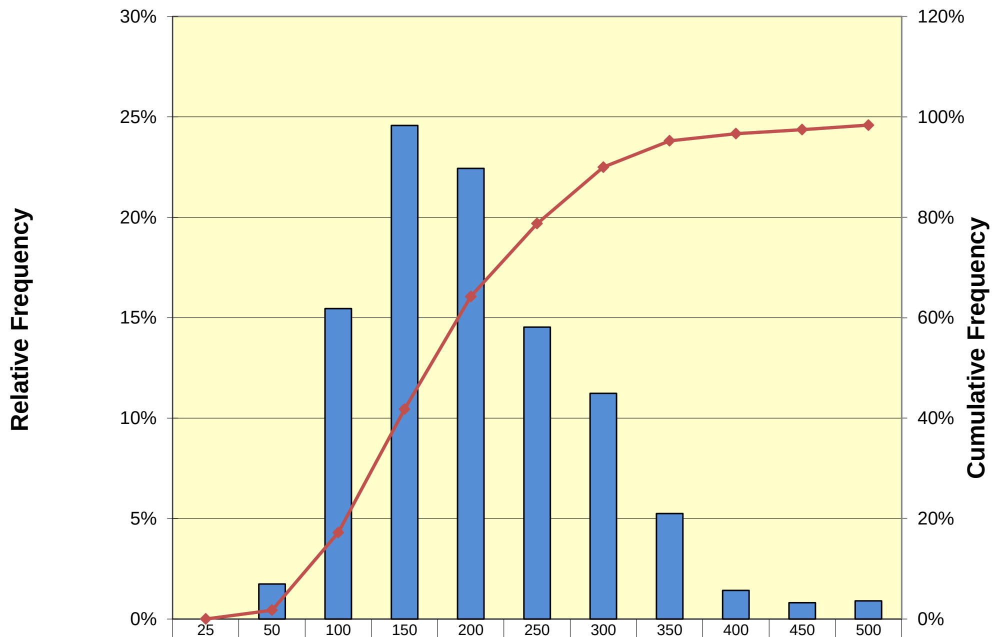
Figure 49 and Figure 50 show the distributions of indoor water use among the logged homes in the REUWS2 study group. The first figure shows the percentage of homes that fall into the individual use bins: <25. 25-50. 51-100 etc. This figure shows a skewed distribution pattern with a few users at the high end of the distribution raising the average above the median use. Such log-normal distributions are common when looking at water demand patters for a sample of single-family homes. The effects of the users at the upper end are shown in Figure 50, which shows the percent of total indoor water use accounted for by each bin of users. In this view the percent of total indoor use accounted for by the members of the larger bins is larger than their percentage of the number of homes. This impact gets more pronounced as the bins get larger. For example, only 18% of all homes were found to be using more than 200 gpd of water for indoor purposes (Figure 49), but these homes accounted for 36% of all of the indoor use (Figure 50).

Table 48 shows the indoor water use for each study site, the average number of residents per home obtained from the survey respondents and the overall average per capita use for each site.



	25	50	100	150	200	250	300	350	400	450	500
% of homes	2%	6%	28%	27%	18%	9%	6%	2%	1%	0%	0%
Cum %	2%	9%	37%	64%	82%	91%	96%	99%	99%	99%	100%

Figure 49: Distribution of indoor water use by percent of homes.



	25	50	100	150	200	250	300	350	400	450	500
% of Total Vol.	0%	2%	15%	25%	22%	15%	11%	5%	1%	1%	1%
Cum % of Indoor Vol	0%	2%	17%	42%	64%	79%	90%	95%	97%	97%	98%

Figure 50: Distribution of indoor water use as percent of total indoor use volume

Table 48: Occupancy and Indoor Per Capita Use

Site	Adults	Teens	Children	Infants	Total Residents	Indoor Use	GPCD
Clayton	2.0	0.2	0.3	0.1	2.6	126.9	48.99
Denver	2.0	0.1	0.2	0.1	2.5	131.7	53.76
Ft. Collins	2.1	0.2	0.3	0.1	2.5	133.9	52.98
Peel	2.7	0.2	0.4	0.1	3.4	158.2	46.10
San Antonio	2.1	0.1	0.2	0.1	2.6	139.3	54.51
Scottsdale	1.9	0.1	0.1	0.0	2.2	146.6	66.23
Tacoma	2.1	0.2	0.2	0.0	2.5	127.4	51.40
Toho	2.1	0.3	0.2	0.1	2.7	139.0	52.14
Waterloo	2.4	0.2	0.3	0.1	3.1	146.8	47.65
Overall	2.1	0.2	0.3	0.1	2.6	137.7	51.64

Comparison of Non-seasonal and Indoor Water Use

It has been suggested that non-seasonal water use is not a precise measure of indoor use since it includes winter irrigation in warm climate sites. Recall that non-seasonal use was estimated as the water use during the winter period pro-rated to the entire year. For this purpose the winter period was taken as the consumption during the minimum month or minimum 2 month period, where this was the billing period used by the agency. Differences between indoor use taken from logging data and non-seasonal use as calculated from billing data are demonstrated in Table 49. This shows that the measured indoor water use was 27% lower than the non-seasonal water use. In all but the case of Waterloo, the measured indoor use was lower than the non-seasonal use. This may be due to year-round irrigation use, which is almost certainly the case in Scottsdale. These data show why it is important to use non-seasonal water use as a measure of indoor use with caution, especially in regions with mild, dry winters.

Table 49: Comparison of non-seasonal and indoor water use

Site	Non-Seasonal Per Capita Use (gpcd)	Measured Indoor Use (gpcd)
Clayton	56	49
Denver	64	54
Fort Collins	59	53
Peel	59	46
San Antonio	69	55
Scottsdale	164	66
Tacoma	59	51
Toho	60	52
Waterloo	43	48
Average	70.3	51.6

The distribution of indoor use on a per capita basis is shown in Figure 51. In previous studies the per capita water use was seen to vary with the number of residents in the home. However, it is important to note that an increase in number of residents does not result in a linear increase in indoor demand. Figure 52 shows number of residents in homes and their corresponding indoor use. A power curve has been fitted to the data and though there is considerable scatter, it gives some sense about how water use increases. Note that large-occupancy homes – which are a much smaller subset of the sample – have a significant effect on the fit of the curve. Figure 53 shows the average indoor per capita use grouped by the number of residents in the homes for all 761 logged homes.

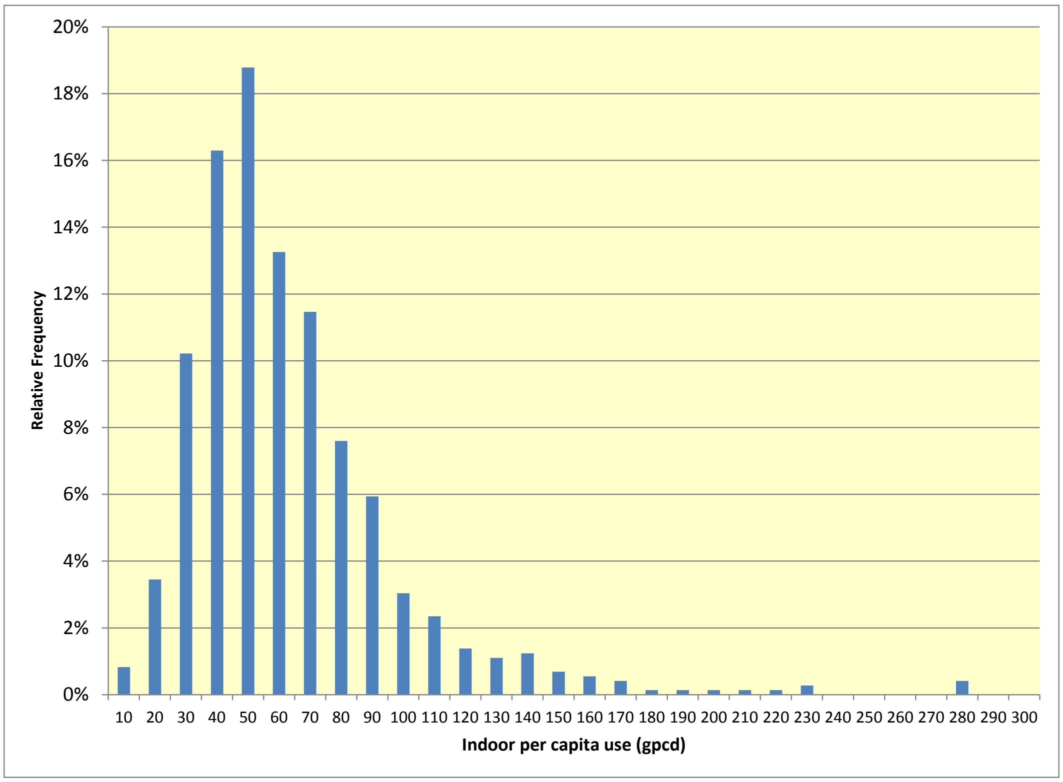


Figure 51: Distribution of indoor per capita use

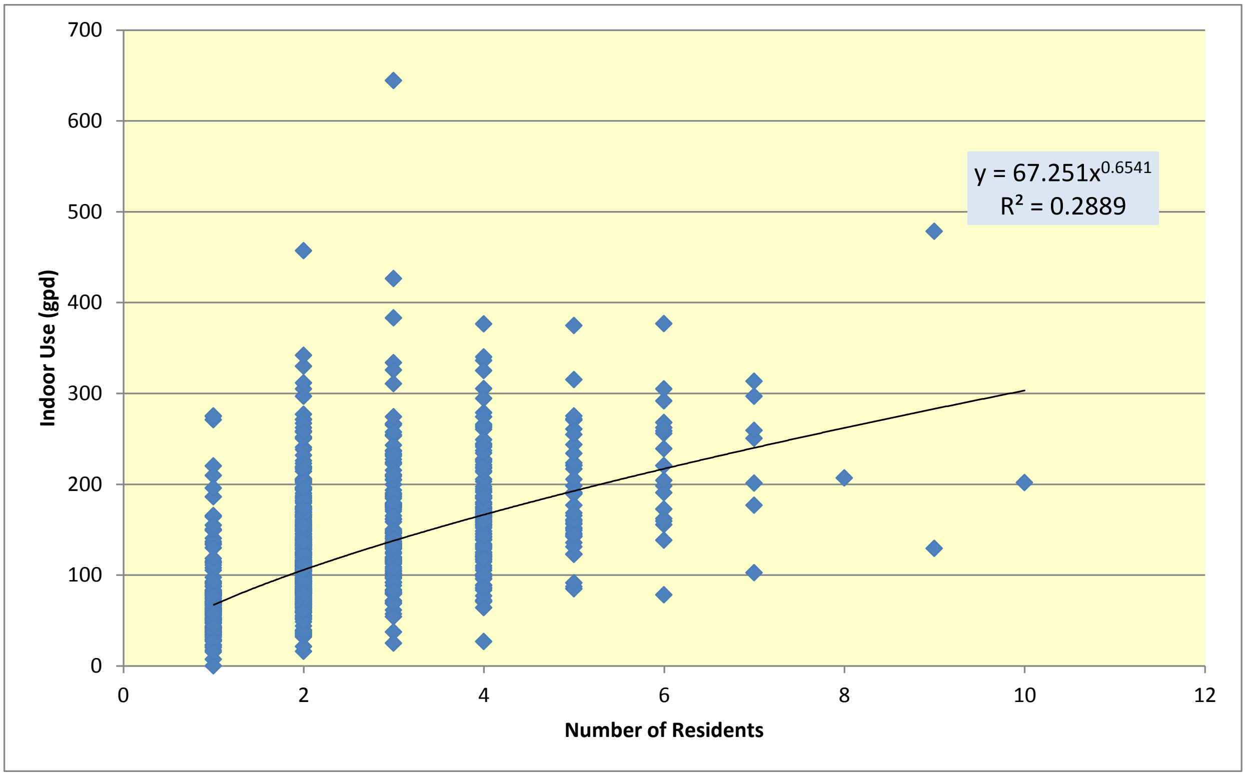


Figure 52: Indoor household use versus number of residents

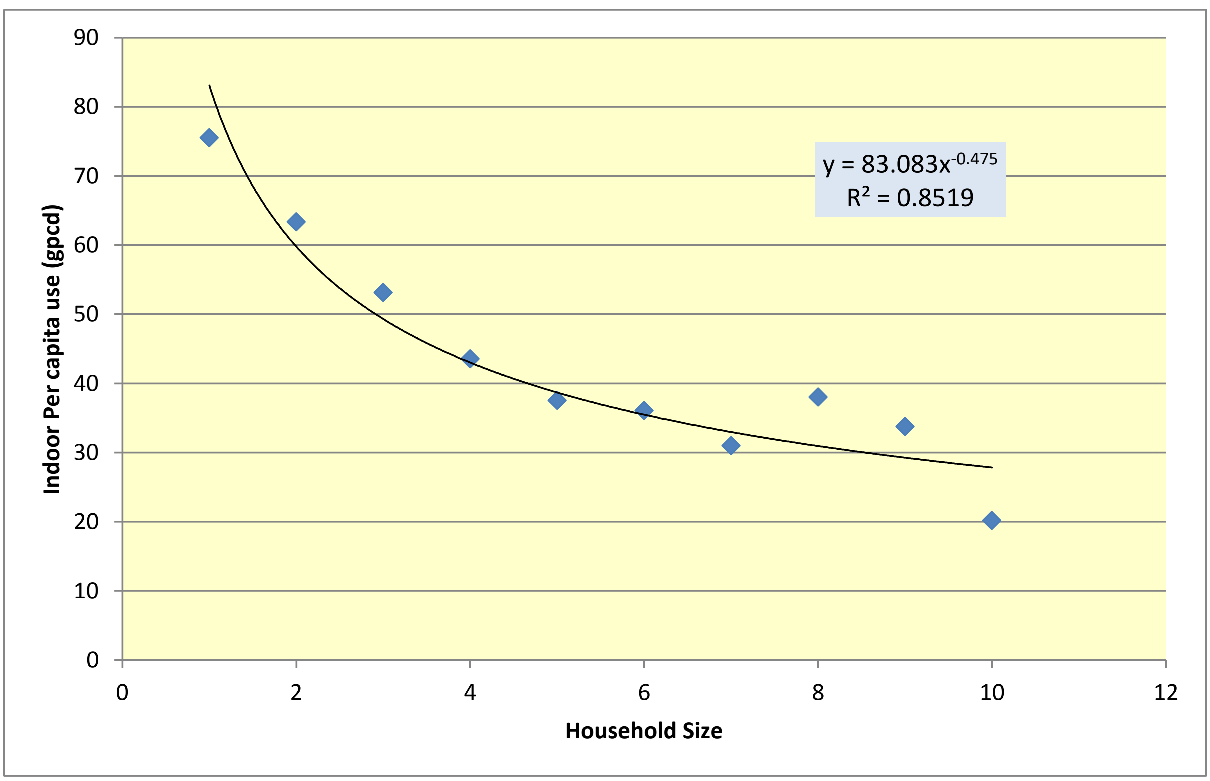


Figure 53: Per capita indoor use versus number of residents

Indoor End Use Analysis

Information on each indoor end use has been extracted from the data and presented here.

Summary of Uses

As shown in Figure 54 five categories of indoor use predominate in the study group:

- Toilets (24% of volume)
- Showers (20.4%)
- Faucet use (19.1%)
- Clothes washers (16.5%), and
- Leaks (12.4%)

These are the same use categories that have been found to dominate indoor use in all of the historical studies. Figure 55 shows the average household water use for each category for the REUWS1 and REUWS2 studies. The data show that usage for toilets and clothes washers has dropped significantly. The data show decreases in the other categories, but the decreases are not statistically significant at the 95% confidence level. Similarly, Figure 56 compares REUWS 1 to REUWS 2 based on per capita end uses.

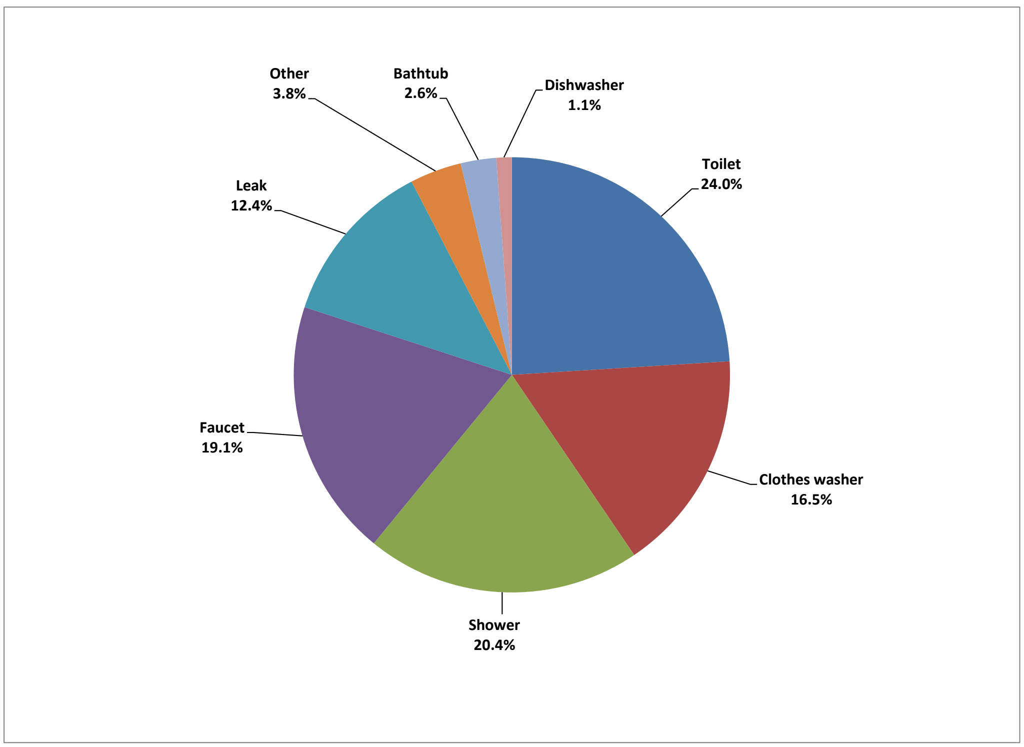


Figure 54: Pie chart of end uses from REUWS2.

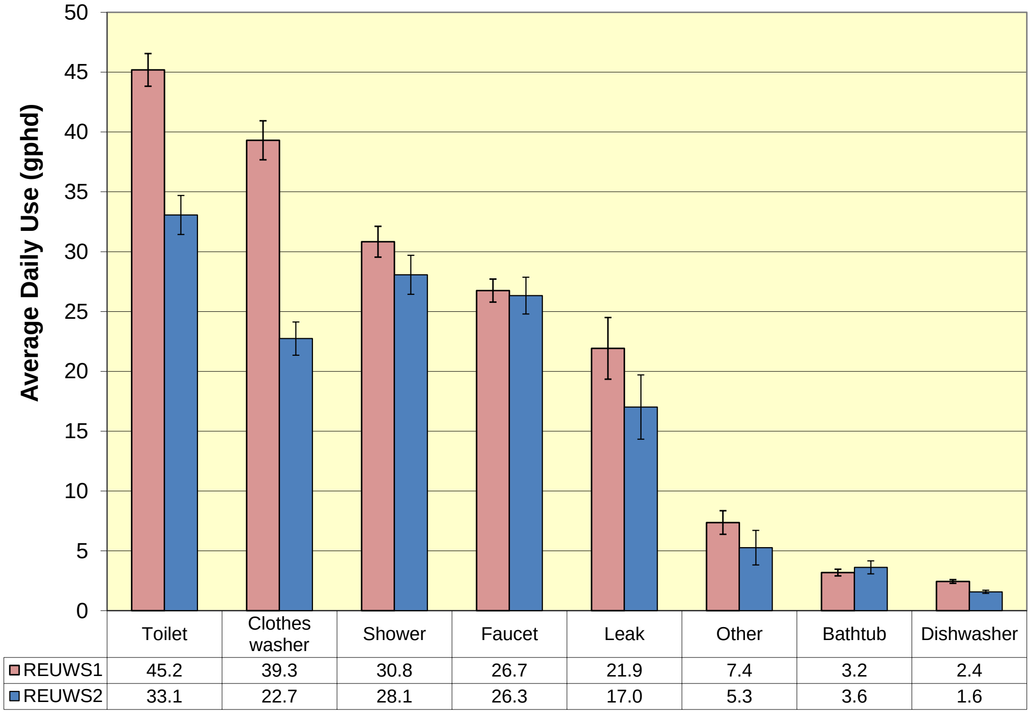


Figure 55: Comparison of indoor end uses for REUWS2 and REUWS1

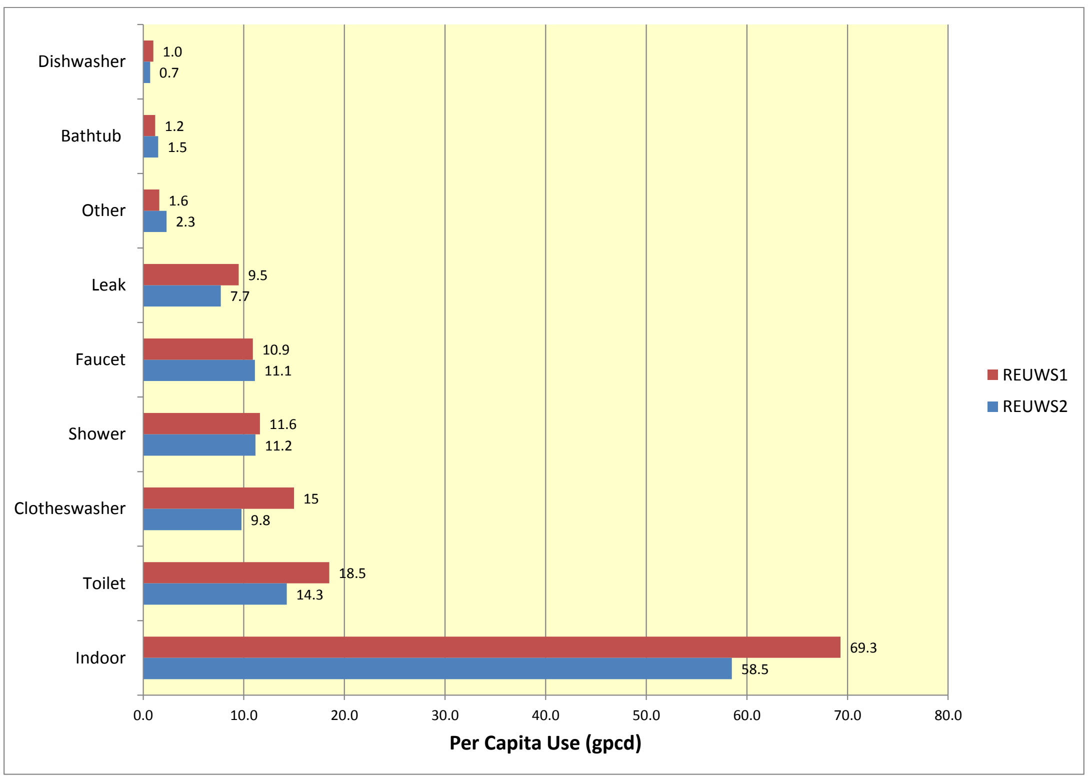


Figure 56: Per Capita end uses comparison between REUWS1 and REUWS2

Toilets

Water for toilet flushing was the number one end use of indoor water for the study group. A total of nearly 125,000 flush events were recorded by the data loggers during the logging periods. This averages 13 flushes per day for 762 study homes that were logged for an average of 13 days. A summary of the other statistics for toilet flushes from the study group is provided in Table 50.

Table 50: Summary statistics for Toilet Use

	REUWS2	REUWS1
Number of houses logged	762	1187
Total number of flushes recorded	124,611flushes	348,345 flushes
Total number of days logged	9659 days	28013
Average number of residents per home	2.6	2.7
Total volume of water devoted to toilet flushes during the logging study	318,049 gal	1,266,655 gal
Average flushes/household per day	13 flushes/household/day	12.4 flushes/household/day
Average flushes per person per day	5.0	4.6
Average flush volume	2.6 ± .01 gal	3.65 ± .06 gal
Average daily use for toilet flushing	33.1 ± 2 gpd	45.2 gpd
Median daily use for toilet flushing	29 gpd	43 gpd
% of Flushes < 2.2 gal	51%	16%

The average household flush volume shown in Table 50 hides much of the detail among the study houses. Some of this detail can be seen in Figure 57 which shows the average flush volume calculated for each of the 762 study homes. This average was determined by taking the total volume of water in the toilet category divided by the number of flushes recorded by the loggers. The average household flush volume represents the functional efficiency of each home. It shows the average volumes used for flushing toilets in the homes based on the way the occupants live in the home and use these fixtures. A home may have only one high efficiency toilet, but if that is the one that is used most often then the home will likely show up in the high efficiency range. The converse is also true.

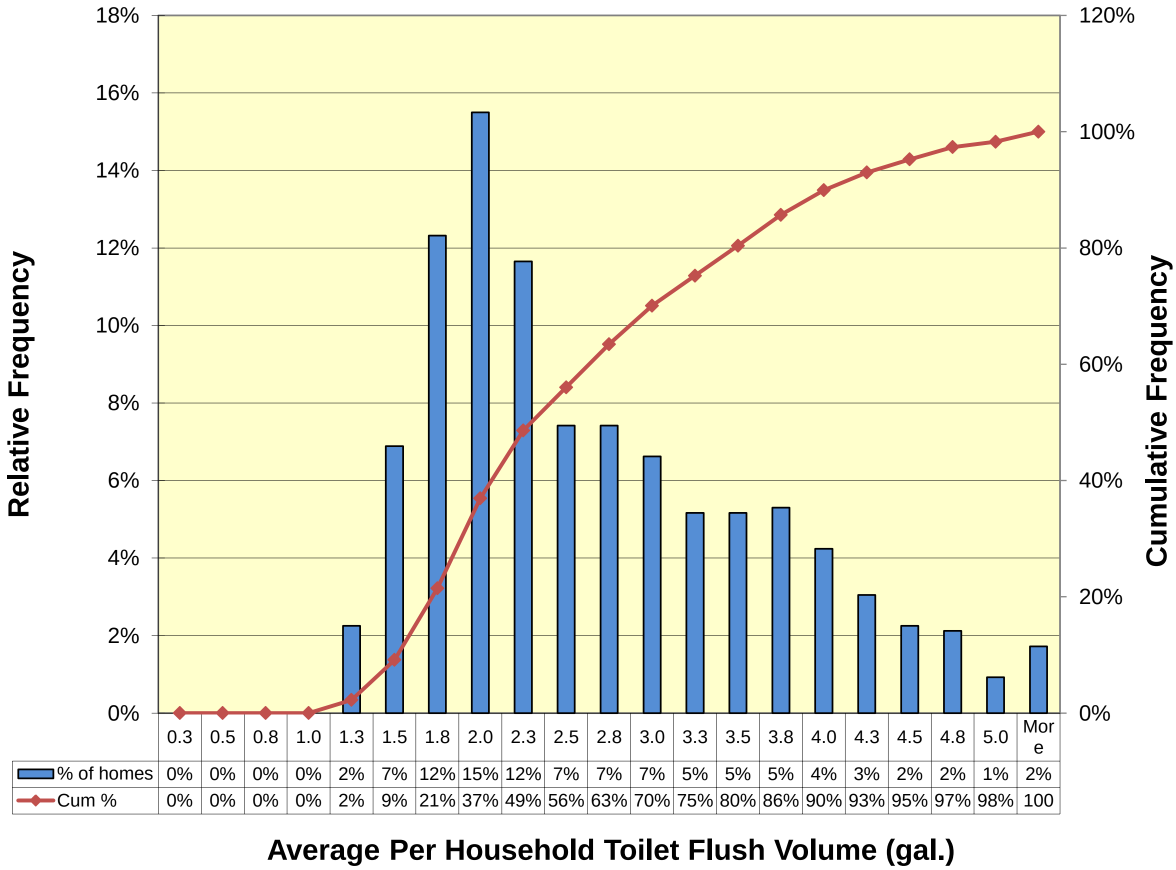


Figure 57: Histogram of average toilet flush volumes

There is no absolute line of demarcation between efficient and less efficient homes with respect to average toilet flush volumes. For purposes of classifying homes with respect to the efficiency levels of their toilets, there must be some criteria or standard. The standard that was established by the 1992 National Energy Policy Act (NEPAct) of 1.6 gpf was used. Some volume was added as an allowance for the fact that these toilets often flush above the 1.6 gpf target, and also sometimes the data logging may capture some faucet flow in the flush. Consequently, the use of 2.0 gpf for the average household flush volume for efficient toilets seems to be a good dividing line between homes that are equipped exclusively with efficient toilets and homes that contain a mixture of efficient and older models. Homes with newer design toilets, flushing at 1.28 or 1.1 gpf will also be classified as efficient using this criterion, but will show up in the lower bins.

Table 51: Comparison of percent of low volume flushes among Level 1 sites

Level 1 Site	Average of % of Flushes < 2.2
Fort Collins	38.46%
Clayton County	42.60%
Toho	46.17%
Denver	46.69%
Scottsdale	47.28%

Level 1 Site	Average of % of Flushes < 2.2
San Antonio	50.21%
Tacoma	52.30%
Waterloo	55.62%
Peel	61.13%
Average	48.35%

As seen in Figure 57, there is a clear decline at the 2.3 gpf bin. Nearly 50% of the homes in the study group had average flush volumes of 2.3 gpf or less, and 37% of the homes had average flush volumes of 2.0 gpf or less. All of these homes have efficient toilets, which are used the majority of the times. The homes in the 2.3 gpf bin either have 1.6 gpf toilets that are out of adjustment or have a mixture of toilets that are used in such a way as to yield the observed average flush volumes. Homes in the larger bins are those that have yet to replace their toilets, or if they have replaced one or more of them, they still continue to use the older toilets enough to raise their average.

The changes in toilet flush volumes can be clearly seen when the average flush distributions are compared between the REUWS 1 and REUWS 2. This comparison is shown in Figure 58, which shows a dramatic shift to lower average flush volumes.

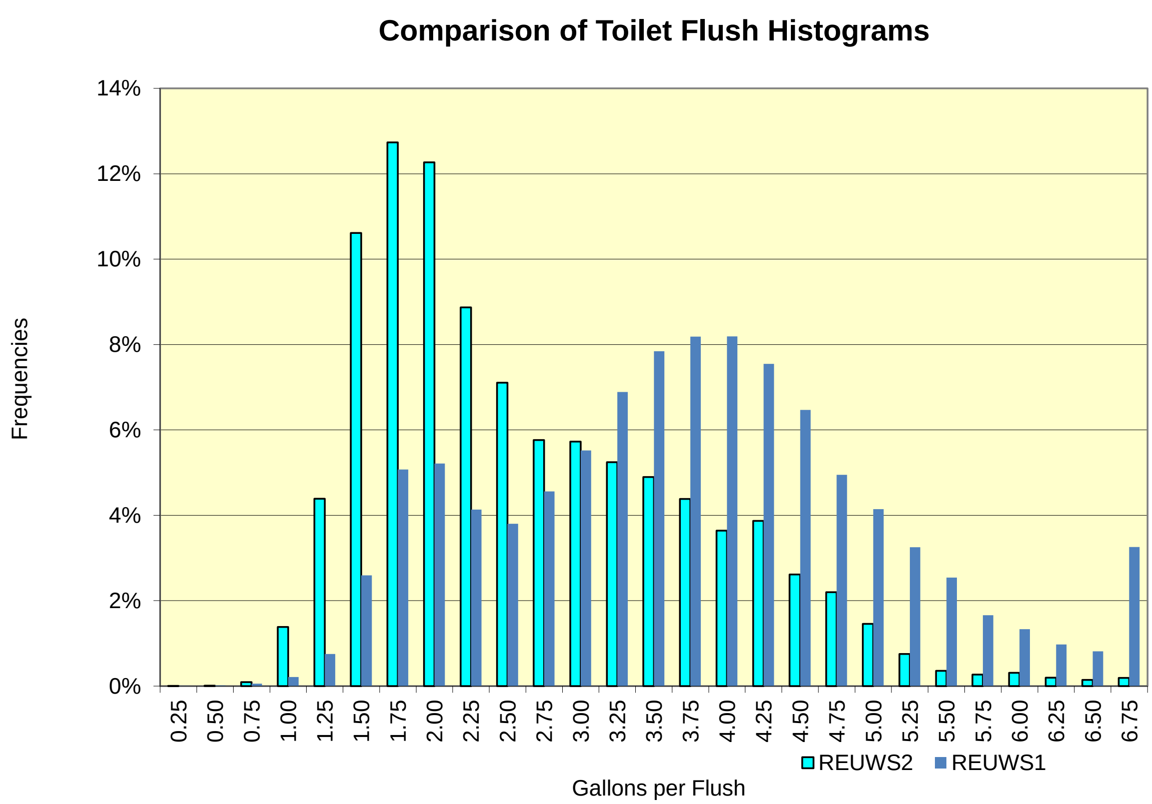
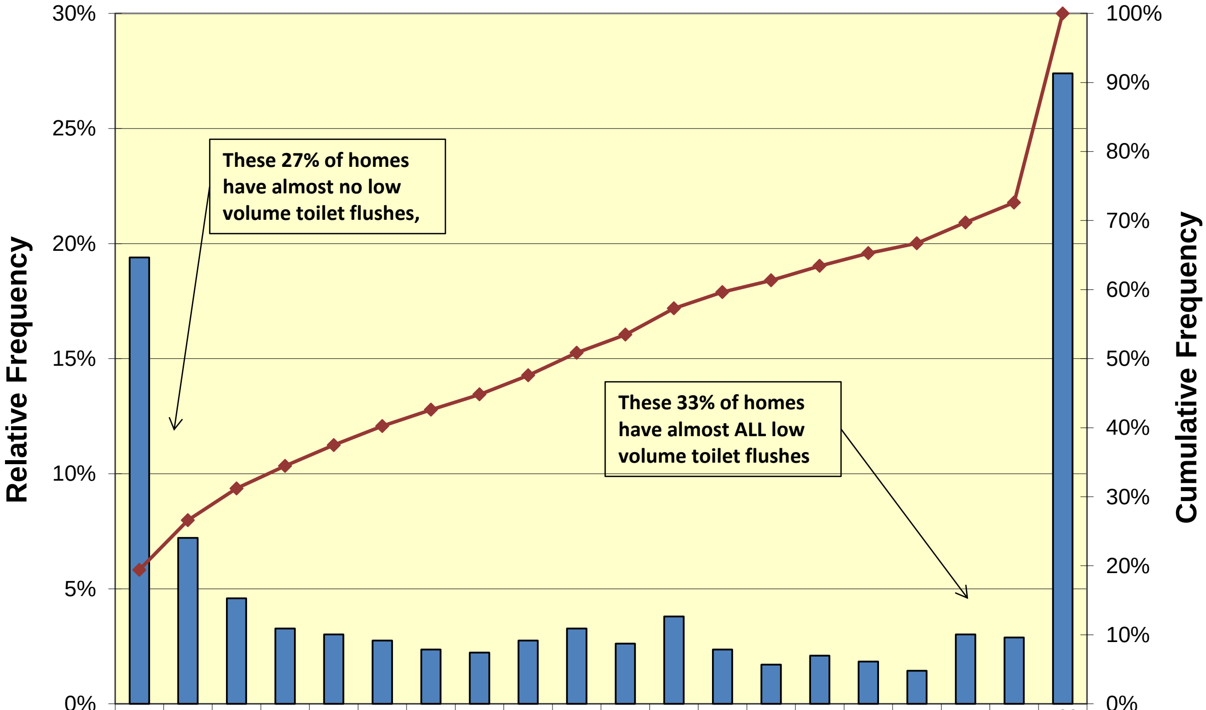


Figure 58: Comparison of toilet flush distributions between REUWS2 and REUWS1

Additional insights into the question of the mixtures of toilets found in the study homes can be obtained by considering what the research team refers to as the toilet heterogeneity diagram, shown in Figure 59. This diagram shows two different percentages on the x-axis. The primary value on the axis is the percentage of flushes in the homes that were less than 2.2 gallons. (Since these data are for individual toilet flushes a bit more leeway was allowed in the flush volumes so as not to exclude toilets from the high efficiency category because of adjustment problems). The data that are plotted on the graph represent the percent of homes in the study group for which the percentage of flushes less than 2.2 gallons matched the corresponding bin. In this way the diagram captures the mixture of toilet flush volumes in the homes by tracking the ratio of small flushes to total flushes for each home.



	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100 %
% of Homes	19%	7%	5%	3%	3%	3%	2%	2%	3%	3%	3%	4%	2%	2%	2%	2%	1%	3%	3%	27%
Cum %	19%	27%	31%	34%	37%	40%	43%	45%	48%	51%	53%	57%	60%	61%	63%	65%	67%	70%	73%	100%

Percent of Homes with Toilet Flushes < 2.2 gal

Figure 59: Toilet heterogeneity diagram

The best way to understand the toilet heterogeneity diagram is to look first at the two extremes. On the left end of the distribution are homes with few or no flushes at less than 2.2 gpf. In the case of this study group there were 27% of the home in which fewer than 10% of the flushes were less than 2.2 gpf. These homes probably are not equipped with any efficient toilets. At the other end of the diagram are homes in which the large majority of flushes were at 2.2 gpf or less. In this study group 33% of the homes have 90% or more of their flushes at 2.2 gpf. These homes are probably fully equipped with high efficiency toilets. The diagram shows an interesting grouping of the homes with approximately one third with few or no efficient toilets, one third with a preponderance of efficient toilets and ne third somewhere in the middle.

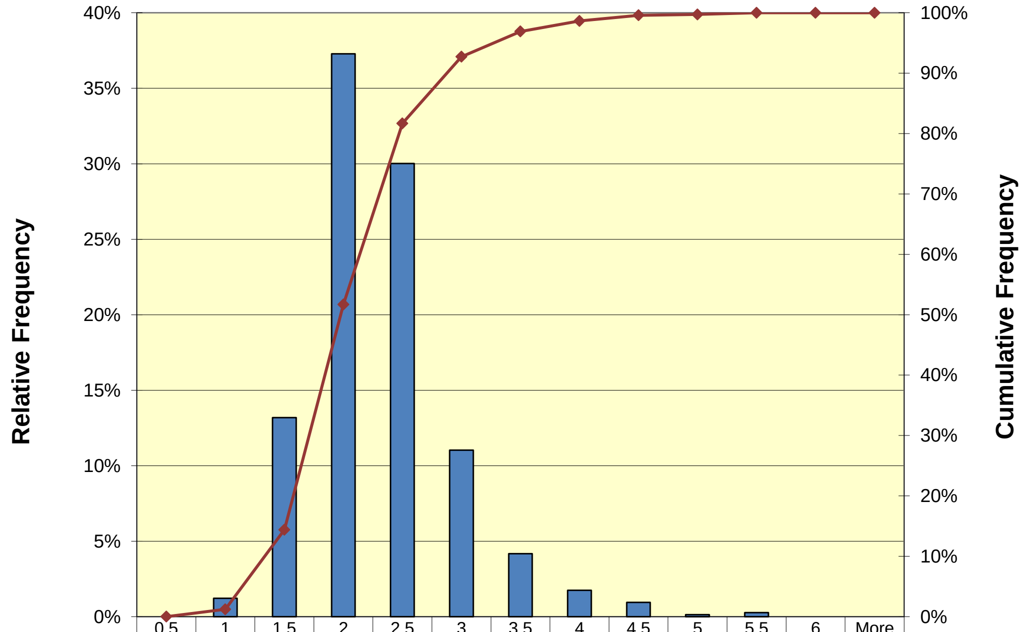
Showers

The second largest category of water use inside the study homes was for showering. On average there were roughly two showers per day taken in the homes that had an average duration of 8 minutes and used 16 gallons of water per shower. Exact statistics are given in Table 52. These statistics show a fairly durable pattern of use for showering over the years. People generally take a shower around every other day with a duration of 7.8 minutes that uses between 15 and 18 gallons of water. The data do suggest a small but perceptible decrease in the daily use and per shower use between the two REUWS studies, but it is barely significant.

Table 52: Summary statistics for showers

	REUWS2	REUWS1
Number of houses logged	762	1187
Total number of showers recorded	17,066 showers	50,286 showers
Total number of days logged	9,659 days	28,013
Average number of residents per home	2.6	2.7
Total volume of water devoted to showering during the logging study	271,067 gal	864,858 gal
Average showers/household per day	1.8 showers/household/day	1.8 showers/household/day
Average showers per person per day	0.69 showers/person/day	0.66 showers/person/day
Average shower volume	15.8 ± .5 gal	16.7 ± .3 gal
Average shower duration	7.8 ± .02 minutes	7.8 ± .14 minutes
Average daily use for showering	28 ± 2 gpd	31 ± 1 gpd
Median daily use for showering	22 gpd	26 gpd
Average flow rate for showers (gpm)	2.1 ± .04 gpm	2.2 ± .04 gpm

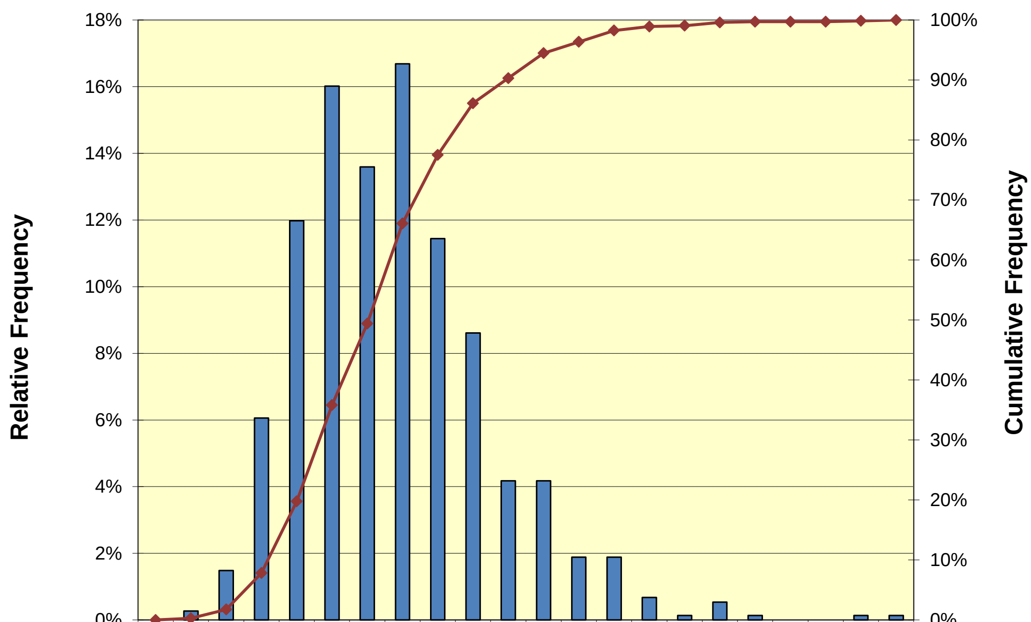
The distribution of shower flow rates, volumes and durations are provided in Figure 60 through Figure 62. The largest flow rate bin was between 1.5 and 2.0 gpm, which contained 37% of all of the showers. As a whole, over 82% of the showers recorded were flowing at 2.5 gpm or and 90% of the showers had volumes of 25 gallons or less. Figure 62 shows that 97% of all showers were 14 minutes or less in length. Even though there were relatively few showers at the high volume and duration bins these larger events accounted for a disproportionate share of the total shower volumes.



	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	More
% of homes	0%	1%	13%	37%	30%	11%	4%	2%	1%	0%	0%	0%	0%
Cum %	0%	1%	14%	52%	82%	93%	97%	99%	100%	100%	100%	100%	100%

Shower Flow Rate (gpm)

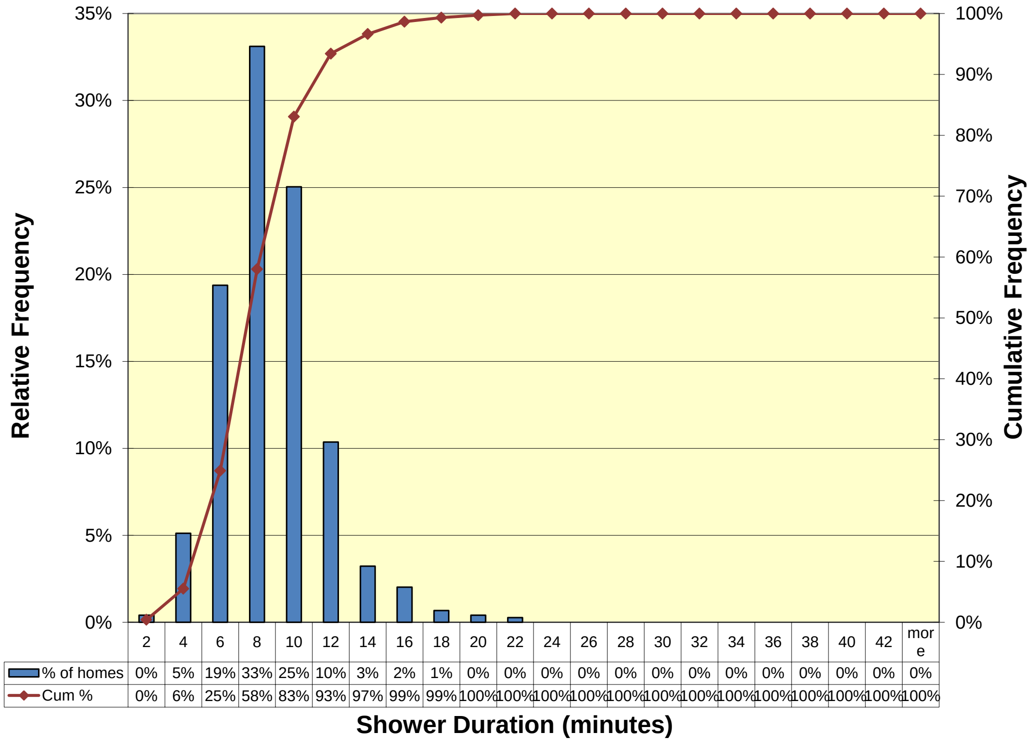
Figure 60: Histogram of shower flow rates



	0	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	42.5	45	47.5	50	More
% of homes	0%	0%	1%	6%	12%	16%	14%	17%	11%	9%	4%	4%	2%	2%	1%	0%	1%	0%	0%	0%	0%	0%
Cum %	0%	0%	2%	8%	20%	36%	49%	66%	78%	86%	90%	94%	96%	98%	99%	99%	100	100	100	100	100	100

Average Shower Volume (gal.)

Figure 61: Histogram of shower volumes



	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	more
% of homes	0%	5%	19%	33%	25%	10%	3%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cum %	0%	6%	25%	58%	83%	93%	97%	99%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 62: Histogram of shower durations

Miscellaneous Faucet Uses

Faucet use was the third largest indoor water use category in the study. Faucet use comprises a wide variety of water use events, which basically do not fall into any other recognizable category. If an event does not have the right pattern or volume to be identified as one of the signature events such as a toilets, clothes washer, shower, dishwasher, leak irrigation or bath tubs then it will normally be classified as a faucet. These include kitchen, bathroom, hose bib, and utility sink faucets. Faucets use is the most discretionary of the categories, so we expect to see high numbers of these events and a high degree of variability in the statistics. Table 53 shows faucet statistics. The average and median day faucet demand for the two groups has remained amazingly similar over the roughly 15-year period between studies, with both values within 1 gpd of each other.

Table 53: Summary statistics for faucet use.

	REUWS2	REUWS1
Number of houses logged	762	1187
Total number of faucet events recorded	495,958 faucet events	1,150,872 faucet events
Total number of days logged	9,659 days	28,013
Average number of residents per home	2.6	2.7
Total volume of water devoted to faucet use during the logging study	254,357 gallons	748,305 gal

	REUWS2	REUWS1
Average faucet uses/household per day	51 faucet uses/household/day	41 faucet uses/household/day
Average faucet uses per person per day	20 faucet uses/person/day	15 faucet uses /person/day
Average faucet use volume	0.5 gallons per use	0.65 gallons per use
Average faucet duration	30 seconds	30 seconds
Average daily use for faucets	26.3 ± 1.5 gpd	27 ± 1 gpd
Median daily faucet use	22.5 gpd	23 gpd

The distribution of faucet use is more skewed to the right than any of the other uses, which makes sense since it is the most affected by behavior. The average daily use for the REUWS 2 set was 26.3gpd while the median value was only 22.2 gpd (Table 53). The homes with the larger daily use accounted for a disproportionate share of total faucet use, which indicates that if ways could be found to reduce faucet use in the heavy users the average for the group could be reduced. To understand the potential for faucet use modification further modeling of this end use is necessary (see Conservation and Benchmarking section).

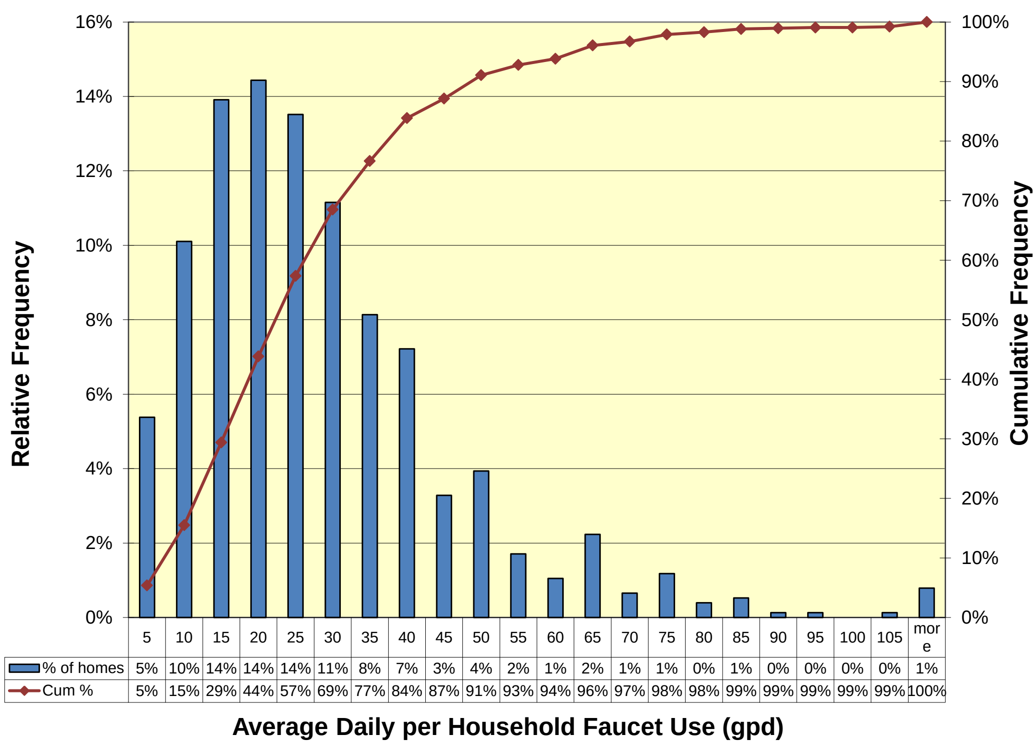


Figure 63: Histogram of average daily faucet use

The majority of water use events in the homes were classified under the miscellaneous faucet category. Most of these events were short, small volume events. There were a total of 495931 events in the faucet category, and the breakdowns of these events by their duration is shown in Table 54. This table shows that 50% of the faucet events are less than 20 seconds in duration and have an average draw volume of 0.2 gallons or less; 90% of the faucet events have an average duration of 70 seconds or less and use an average volume of 0.8 gallons. The situation is even more skewed when the distribution of faucet events is shown according to the volume of the draw. Table 55 shows that 99.9% of all of the faucet events have an average volume of 0.5 gallons or less and an average duration of 38 seconds or less.

Table 54: Distribution of faucet events by duration

Duration (sec)	Frequency	Average Duration (sec)	Avg. Volume (gal)	Rel. Freq.	Cum. Freq.
10	467	5.0	0.1	0.09%	0.09%
20	127448	10.0	0.1	25.70%	25.79%
30	124681	20.0	0.2	25.14%	50.93%
40	75677	30.0	0.4	15.26%	66.19%
50	45048	40.0	0.5	9.08%	75.28%
60	31749	50.0	0.6	6.40%	81.68%
70	23298	60.0	0.7	4.70%	86.38%
80	17770	70.0	0.8	3.58%	89.96%
90	10787	80.0	1.2	2.18%	92.13%
100	7168	90.0	1.4	1.45%	93.58%
110	5518	100.0	1.7	1.11%	94.69%
120	4165	110.0	1.9	0.84%	95.53%
130	3246	120.0	2.1	0.65%	96.19%
140	2686	130.0	2.3	0.54%	96.73%
150	2167	140.0	2.5	0.44%	97.17%
160	1748	150.0	2.6	0.35%	97.52%
170	1469	160.0	2.8	0.30%	97.81%
180	1323	170.0	3.0	0.27%	98.08%
190	1086	180.0	2.9	0.22%	98.30%
200	909	190.0	2.9	0.18%	98.48%
210	837	200.0	3.2	0.17%	98.65%
220	761	210.0	3.1	0.15%	98.81%
230	588	220.0	3.4	0.12%	98.92%
240	535	230.0	3.4	0.11%	99.03%
250	450	240.0	3.5	0.09%	99.12%
260	396	250.0	3.5	0.08%	99.20%
270	374	260.0	3.6	0.08%	99.28%
280	322	270.0	3.9	0.06%	99.34%
290	290	280.0	4.0	0.06%	99.40%
300	2968	458.4	5.8	0.60%	100.00%
Total	495931				

Table 55: Distribution of faucet events by volume

Volume (gal)	Frequency	Avg. Duration (sec)	Avg. Volume (gal)	Relative Frequency
10	495438	38.0	0.5	99.9%
20	415	529.7	12.9	0.08%
30	58	982.4	23.8	0.01%
40	11	1409.1	33.3	0.00%
50	4	1675.0	47.6	0.00%
60	2	1380.0	54.4	0.00%
90	1	2430.0	82.4	0.00%
100	1	3970.0	98.6	0.00%
190	1	5620.0	188.6	0.00%
Total	495931			

Table 56 gives the flow rate distribution for faucets. While it is tempting to conjecture that the lower-flow rate faucet events are bathroom, we cannot be certain how many of these lower flows are truly from lower flow taps. For example, a kitchen faucet valve could be opened only partially, resulting in a lower flow rate. That having been clarified, it is worth noting that most (98.9%) of flows are less than 3 gpm, which implies that faucet aerators are widely installed and intact.

Table 56: Distribution of faucet events by flow rate (gpm)

Flow Rate Bin (gpm)	Frequency	Average Flow (gpm)	Rel. Freq.	Cumulative F.
1	310,500	0.48	62.6%	62.6%
2	158,227	1.39	31.9%	94.5%
3	21,930	2.31	4.4%	98.9%
4	3,654	3.38	0.7%	99.7%
5	1,044	4.40	0.2%	99.9%
6	359	5.41	0.1%	100.0%
7	140	6.40	0.0%	100.0%
8	41	7.50	0.0%	100.0%
9	26	8.39	0.0%	100.0%
10	5	9.66	0.0%	100.0%
11	3	10.69	0.0%	100.0%
13	1	12.40	0.0%	100.0%
14	1	13.42	0.0%	100.0%
	495,931			

Clothes Washers

Clothes washers are a type of use, like toilets and unlike faucets, that has been dramatically affected by technological improvements in appliances. Please see Table 57. In the REUWS1 study clothes washers were the second largest water end use, at 39.3 gpd. In this present study they have dropped down to number four at 22.7 gpd. This represents a 42%

decrease in water use for clothes washing in the interval between the two studies. Note that the average number of loads washed per day and per person per day has remained almost the same between the two studies. The decrease in daily volume demand seems to be due to increased efficiency. Recall from the survey section that 2% of REUWS 1 survey respondents reported having a high efficiency clothes washer, while 67% of REUWS 2 respondents report having high efficiency clothes washers.

Table 57: Summary statistics for clothes washers

	REUWS2	REUWS1
Number of houses logged	761	1187
Total number of clothes washer loads recorded	7,509	26,982 clothes washer loads
Total number of days logged	9,659 days	28,013
Average number of residents per home	2.6	2.7
Total volume of water devoted to clothes washing use during the logging study	218,231 gallons	1,104,179 gallons
Average loads per household per day	0.78 loads/household/day	0.81 loads/household/day
Average loads uses per person per day	0.3 loads/person/day	0.3 loads/person/day
Average gallons per load	31 gallons per load	41 gallons per load
Median gallons per load	31 gallons per load	40 gallons per load
Average daily use for clothes washing	22.7 ± 1.4 gpd	39.3 ± 1.6 gpd
Median daily use for clothes washing	17.8 gpd	32.8 gpd

Dishwashers

Dishwashers were found in the 84% of homes (based on all survey responses) and 68% of the homes used a dishwasher at least once during the logging period. Table 58 shows the use statistics for dishwashers.

Table 58: Summary of Dishwasher Statistics

	REUWS2	REUWS1
Number of houses logged	761	1187
Total number of dishwasher events recorded	2498	6810
Total number of days logged	9,659 days	28,013
Average number of residents per home	2.6	2.7
Total volume of water	15,353 gal	67,902 gal

	REUWS2	REUWS1
devoted to dishwasher use during the logging study		
Average dishwasher uses/household per day	0.26 uses/day	0.24 uses per day
Average dishwasher uses per person per day	0.10 uses/person/day	0.09 uses/person/day
Average dishwasher use volume	6.1 gallons per use	10.0 gallons per use
Average daily use for dishwasher	1.58 ± 0.13 gpd	2.40 ± 0.2 gpd
Median daily dishwasher use	0.99 gpd	2.0 gpd

One question that occurs around dishwashers is whether their use tends to decrease faucet use in the homes due to the fact that they wash dishes more efficiently than hand washing in a sink. Table 59 shows that the 520 households that used dishwashers had an average faucet use of 26.34 gpd and the 241 homes that did not use dishwashers used an average of 26.43 gpd for faucets. These two values are not statistically different, which suggests that in this group the use of dishwashers was not associated with less faucet use.

Table 59: comparison of faucet use in homes with and without dishwashers

Dishwasher Present	Number of homes	Average of Faucet gpd
No	241	26.43
Yes	520	26.34
Grand Total	761	26.37

Bathtubs

Table 60 shows the statistics for bathtub use. While the number of uses (per day and also by per person per day) has gone up since the REUWS 1, the average daily use is not statistically different between the two studies.

Table 60: Bathtub usage statistics

	REUWS2	REUWS1
Number of houses logged	761	1187
Total number of bathtub events recorded	1,742	4,105
Total number of days logged	9,659 days	28,013
Average number of residents per home	2.6	2.7
Total volume of water devoted to bathtub use during the logging study	35,222 gal	89,735 gal

	REUWS2	REUWS1
Average bathtub uses/household per day	0.18 uses/day	0.15 uses per day
Average bathtub uses per person per day	0.07 uses/person/day	0.05 uses/person/day
Average daily use for bathtub	3.6 ± 0.5 gpd	3.2 ± 0.3 gpd
Median daily use for bathtub	0.0 gpd	1.0 gpd

Leakage

Out of the 762 homes in the study group 662 registered some leakage events. The average leakage rate for all homes was 17 gallons per day, while the median was just 4.3 gpd, which shows a heavy skew to the right in the data, and that a few homes with large leakage rates are affecting the mean. The total daily leakage of the entire group was 12,970 gpd. The minimum leakage rate observed in the group was 0 gpd and the maximum rate was 553 gpd. The rate of leakage was far from normal. As shown in Figure 64 the distribution of homes falling into leakage bins ranging up to 600 gpd is highly skewed to the right. The majority of homes were leaking at less than 5 gpd, and around 80% of the homes registered less than 20 gpd of leakage.

While the number of homes in the larger leakage rates was low, these homes contributed disproportionately to the total leakage volume. The distribution of the percent of the total volume of leakage that each leakage bin contributes is shown in Figure 65. This figure shows that the higher ranges of leakage contribute a significant proportion of the total volumes of leaks occurring in the group. The 80% of homes at rates of 20 gpd or less contribute on 17% of the total leakage volume, while the 3% of homes at rates of 100 gpd or more contributed 31% of the total leakage.

The number of leaks events recorded in the home does not necessarily correlate to larger leak volumes. Figure 66 shows the total number of leak events in each of the study homes, sorted from the fewest to largest number of leaks. It also shows the corresponding volume of leaks in the homes. In this figure the blue (upper) line shows the number of leak events and the red line (lower) shows the total volume of leakage. The figure shows the some homes with a small number of leaks had much larger leak volumes that homes with a very high number of leaks. This makes sense since the duration and flow rate of the leaks are more important in determining the volume of leakage than the number of events.

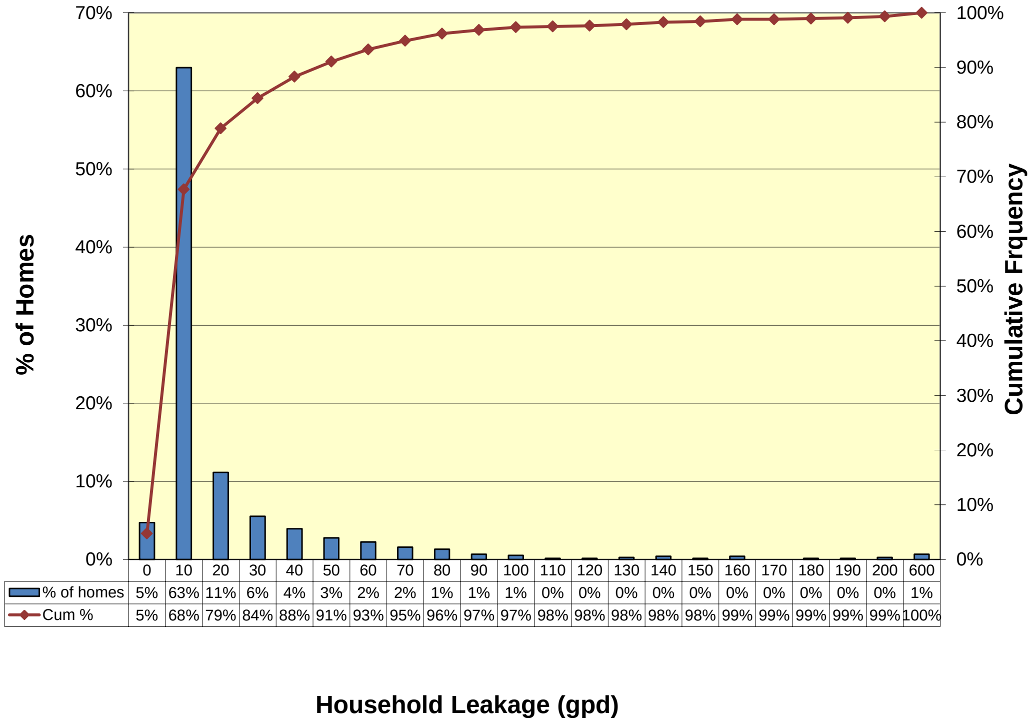


Figure 64: Distribution of homes falling into leakage rate bins

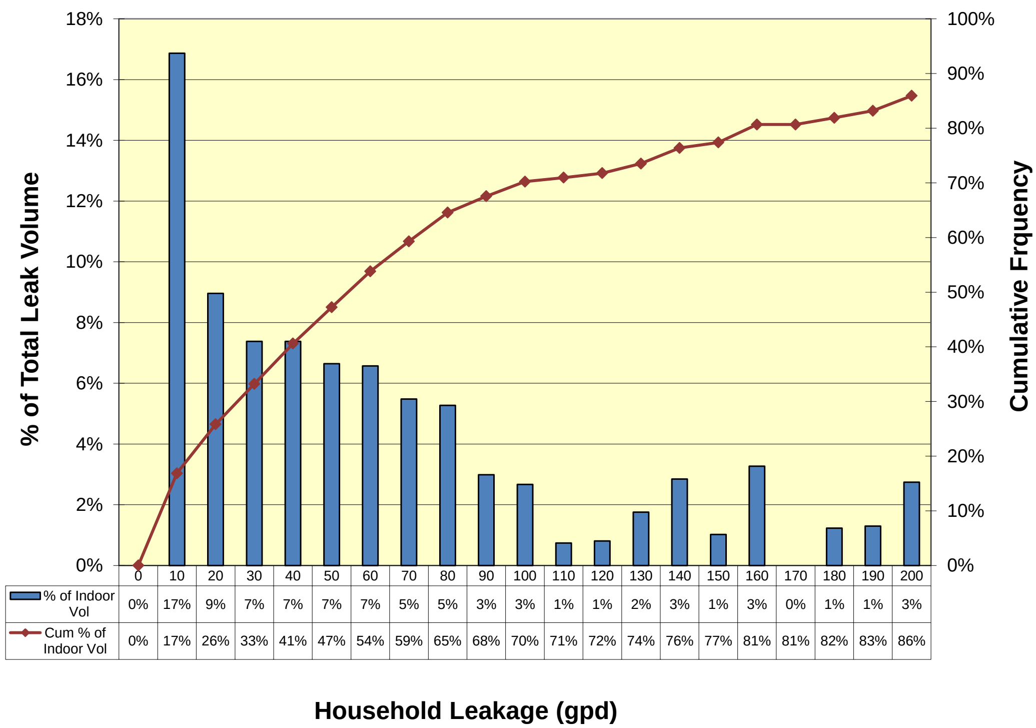


Figure 65: Distribution of leakage rates as a percent of the total leakage volume

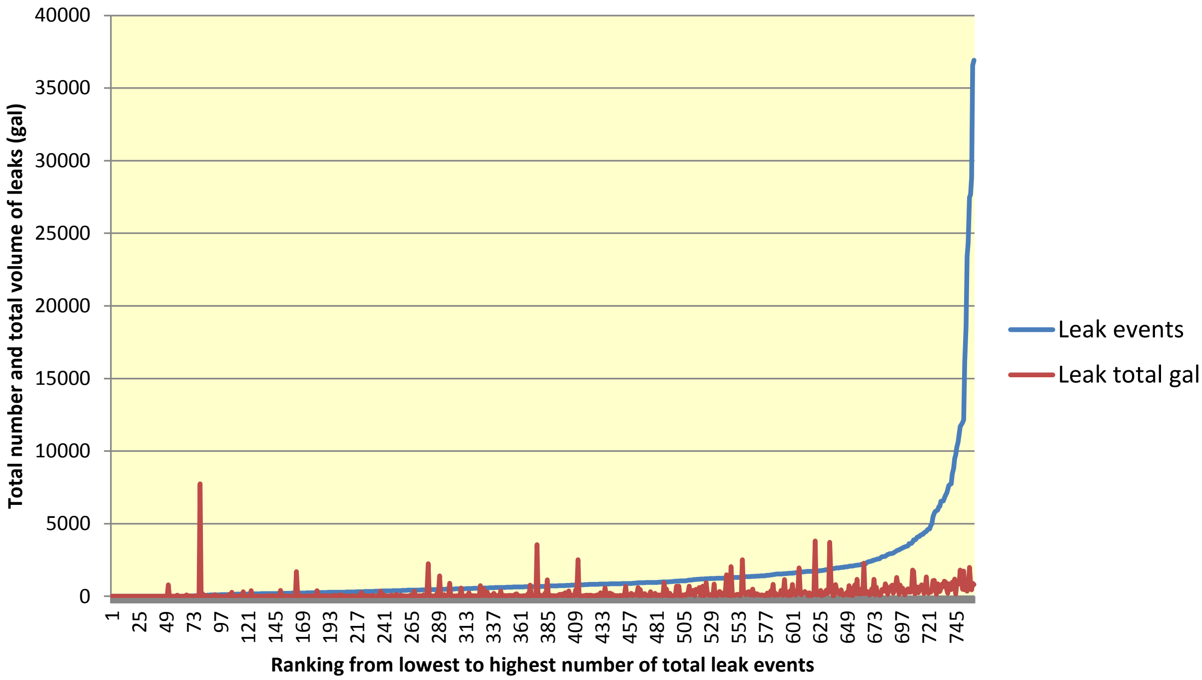


Figure 66: Total leak volume verses number of leaks events recorded

The importance of a small number of homes that registered high rates of leakage can be seen from the data shown in Table 61. This table shows the number of homes in each of four leakage ranges, the percent of homes they represent, the average rate and total volume of leakage for the group, and the percent of the total daily leakage accounted for by the group. As seen in the second row of the table, there were a total of 21 homes (3% of the group) that were leaking in the range of from 100 to 500 gpd, and the average for which equaled 189 gpd. This group accounted for 31% of the total leakage volume.

Table 61: Distribution of leakage rates

Leakage Range	Number of Homes	Percent of Homes	Avg. Leakage GPD	Total Leakage GPD	Percent of Leakage Volume
All Homes	762	100%	17	12970	100%
100-550	21	3%	189	3968	31%
50-99	48	6%	67	3227	25%
0-49	693	91%	8	5774	45%

It is understood that flow trace analysis makes inferences about leakage events based on their timing, flow rates, durations, and patterns of repetition. There is always a possibility that water use events may appear to be leaks when in fact they are due to other legitimate uses of water such as water treatment, irrigation, or swimming pool filling. In order to examine the likelihood that the 21 top leaking homes in the study group were influenced by these other uses the research team examined these homes in more detail. The first area of examination was the occurrence in these homes of water uses that are likely to be associated with leakage by the Trace Wizard program. The comparison of the frequencies of occurrence of the end uses in the group of 21 high leak homes and all of the survey respondents is shown in Table 62.

Table 62: Comparison of frequencies between high leak group and all survey respondents

End Use	Percent in Group of 21 high leak homes	Percent in all survey respondents	Ratio
water feature	14%	2%	7.14
auto fill system on pool	29%	5%	5.71
pool	48%	13%	3.75
leaky pool	5%	1%	3.66
other leak	10%	3%	3.53
leaky irrigation	10%	3%	3.17
hot tub	29%	9%	3.14
treatment	29%	15%	1.90
Other fixture or appliance not listed in survey?	14%	9%	1.59
drip Irrigation	24%	15%	1.59
Ice Maker	86%	59%	1.45
leaky toilet	10%	8%	1.27
in-ground irrigation	67%	53%	1.25
dripping faucet	10%	8%	1.15
evaporative cooler	5%	6%	0.79
humidifier	10%	20%	0.48

Table 62 shows the percent of homes in the group of 21 and all survey respondents who reported having one of the end uses or conditions listed in column 1 of the table. The final column shows the ratio of homes having a positive response in the group of 21 to the entire group. This number is a reflection of the likelihood of the condition occurring in the group of 21 to the population of survey respondents. The items have been listed from the highest to lowest ratios. This means that the items at the top of the list are more likely to be found in the high leaking homes than those on the bottom.

Examination of the results shown in Table 62 shows that the top three items that are associated with high leakage homes are the presence of a water feature, an auto fill system on the swimming pool, and the presence of a swimming pool on the lot. Nearly half of the high leakage homes had a swimming pool, while only 13% of the survey respondents had one. The chance of a pool in a high leak home was 3.75 times the chance of having a pool in the population. It makes perfect sense for water features and pools to be associated with leakage. The question these data pose is the extent to which the increase in leakage events is due to normal uses posing as leak and actual leakage occurring in the pool or water feature. Both things are occurring: pools and water features may use water in a way that appears to be a leak on the flow trace, and they may actually be leaking water.

The next three items on the list are instructive on whether the extra water used in these homes is due to legitimate use or leakage. Homes in which the occupants are aware of, and willing to admit to, leaks in their pools, irrigation systems or other leaks are between 3.2 and 3.7

times as likely to by high leakers. This does not count the homes in which leaks are present in these devices, but of which the owner is unaware.

The second way in which the leakage results were examined was by going back and re-examining the flow trace files for the top 21 high leak homes. The purpose of this was to make certain that there were no obvious explanations of the high leak volumes that pointed away from actual leakage to some other explanation for these water use events. Since there are so few homes in the high leak group, and their results have such a large impact on the overall results it is feasible to examine them individually.

The following sections show samples of the traces from five homes that were among the top 10 leakage homes in the study group. Their average daily leakage rate ranged from 553 gpd to 173 gallons per day. Taken together the homes accounted for 891 gallons per day of leakage, or 6.9% of the total leakage for the group as a whole.

One thing that all of the traces in the top group have in common is that their traces show very long or continuous leak events. In examining the traces none of the continuous events could be attributed to any normal water using fixture or device, and all of them appeared to be due to mal-functioning or leaking devices in the homes.

Home 12S356

This home recorded the highest volume of leakage in the entire study group, having an average leak rate of 553 gallons per day, which is equal to about 4% of the total leakage observed in the group. According to the survey results the fixtures present in the homes from the list in Table 62 were an ice maker, a humidifier and an in-ground irrigation system that had no drip zones present. The logged volume and the register volume agreed so we know that the trace data was not affected by noise and that the volumes are accurate. The trace showed a continuous event that was classified as a leak by the analyst. This event ran for the entire duration of the trace at an average rate of 0.4 gpm.

The data were collected in mid-May when the furnace would not be expected to be running, and irrigation demands would be low. A sample of the flow trace for the home is shown in Figure 67. This figure, which is a screen shot from Trace Wizard, shows the leak event as a continuous baseline flow at the bottom of the trace. The trace also shows that there were 7 distinct irrigation events in the trace that accounted for just under 3600 gallons of use. If the continuous event was due to the irrigation system it was certainly not part of its normal operations. No irrigation system operates 24 hours a day for 14 days intentionally. It is possible that the event could be a stuck irrigation valve that the owners were not aware of, but this this type of malfunction would properly be classified as a leak.

The same is true of ice machines or home humidifiers. Ice machines only operate as short and low volume faucet-like events; they never operate continuously. If the event was due to a malfunctioning ice machine it is likely that the kitchen would have been flooded. It is also possible that the event was due to a toilet that was stuck in an open position. Given the information about the home from the survey and the trace there appears to be no reasonable explanation for this continuous event other than an actual leak.

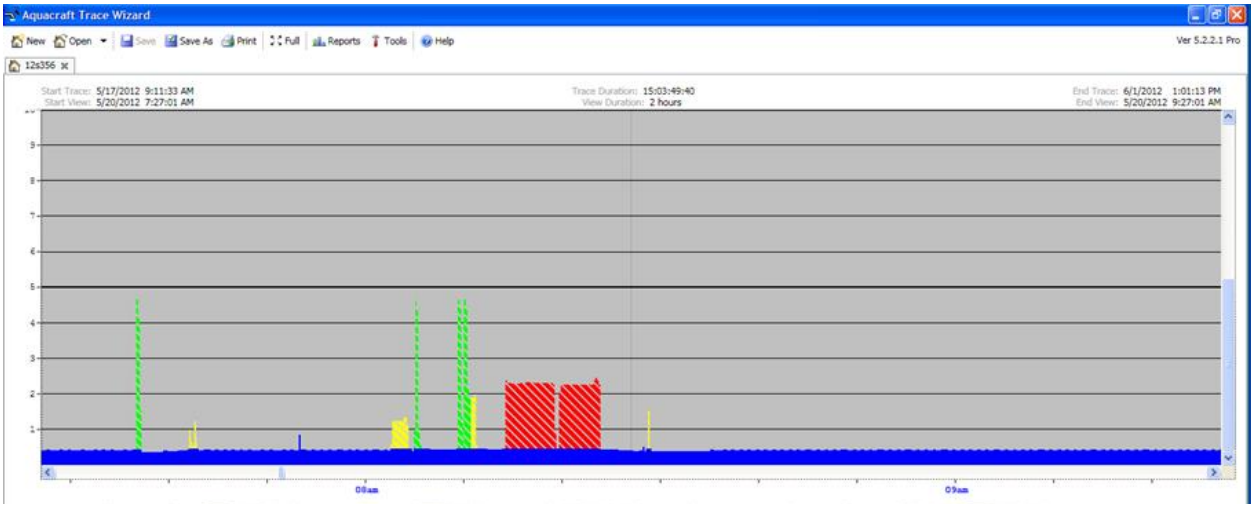


Figure 67: Two-hour view of 12S356. Leaks are blue, faucets are yellow, toilets are green, and showers are red.

Home 12S862

Like 12S356, this home is a case of a 0.2 gpm run-on leak that ran for the 12.4 days of the trace for a total of 3851 gallons of leak, or 312 gpd. This volume of leak accounts for just over 2% of the leak volume in the entire logging sample. Much like 12S356, process of elimination rules out miss-identification of this leak as something else: this home does not have a pool, evaporative cool, or treatment. It does have an icemaker. But it is hard to imagine a typical household needing 29,000 pounds of ice in a two-week period. The icemaker could be malfunctioning, but the resulting flood would reasonable be described as a leak. Such a large volume of water would be noticeable except perhaps a leaking toilet or from an in-ground irrigation system.

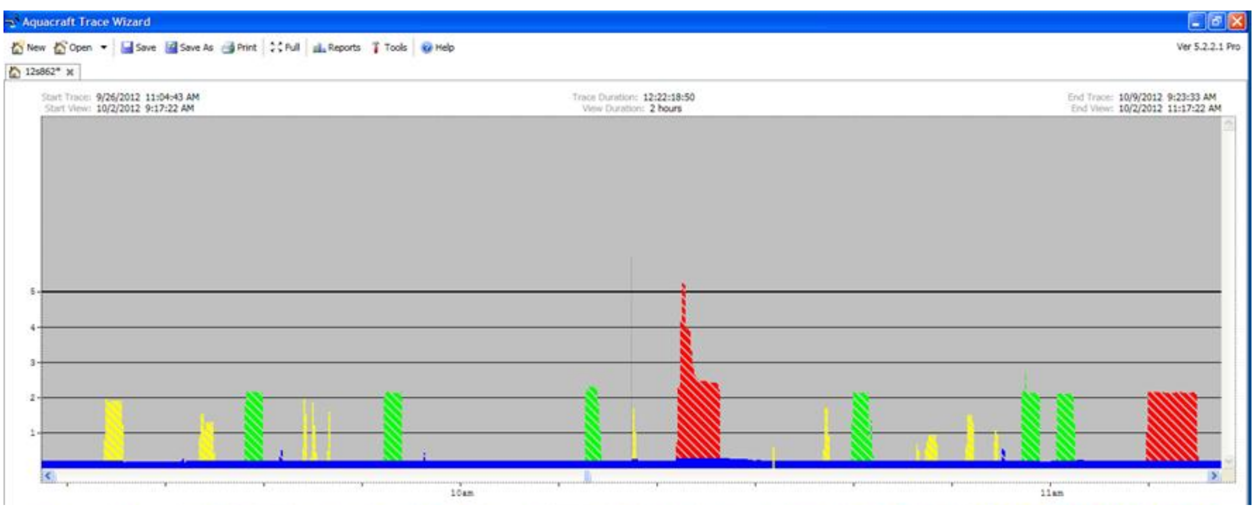


Figure 68: Two-hour view of 12S862. Leaks are blue, faucets are yellow, toilets are green, and showers are red.

Home 12S756

This home, having the fourth-highest leakage, showed a similar continuous leak pattern as did home 12S356. The total daily leakage for the home was 254 gpd, which accounts for just under 2% of the total leakage in the entire logging sample. The flow trace showed a continuous flow of ~0.2 gpm lasting for the duration of the trace. A total of 3725 gallons of water were involved with this event, and it accounted for over 82% of the total water use recorded during the logging period. The logged volume and the register volume for the trace agreed, so we know that there is no error in the flow trace volumes.

The residents reported having an ice machine, water treatment and another unspecified water fixture or device. No pool, water feature, hot tub or in-ground irrigation system were present in the home. They did report knowing that they had a leaky toilet and faucet.

The only water use that could be associated with continuous flows would be a reverse osmosis system, which is being used to treat a very large percentage of the indoor water use. Most RO systems treat only drinking water at the kitchen sink, and it is highly unlikely that this home had such an unusual treatment system. The more likely explanation for the continuous flow in the home is the leaky toilet and faucets.

Figure 69: Two-hour view of 12S756. Leaks are blue, faucets are yellow, toilets are green, and showers are red.

Home 12S465

Home 12S46 is the fifth highest in average daily leakage. The trace showed a continuous flow event of 229 gallons per day that accounted for over 2800 gallons of water, or 29% of the total indoor use during the logging period. The logging and register volume agreed, which indicates that there were no volume errors in the trace file. The residents of the home reported on the survey that they had known leaks in their pool, at least one of their toilets and their irrigation system. The pool has an automatic filling device, which could be a source of the leaks.

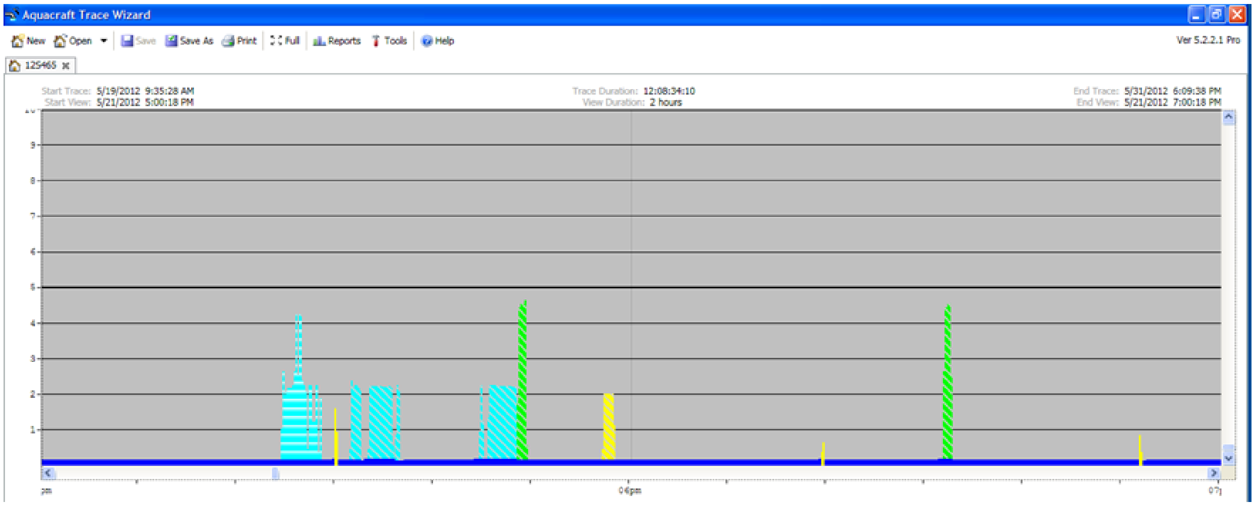


Figure 70: Two-hour view of 12S465. Leaks are blue, faucets are yellow, toilets are green, and clothes washers are teal.

Home 13S127

Home 13S127 has a toilet with a faulty flapper that sticks open occasionally, and remains open until it is flushed again or the chain is manually re-adjusted. While this leak does stop, it also starts again periodically. This phenomena occurs over two dozen times in the 14-day trace. This leaky device accounted for 173 gallons per day, which was over 44% of the total indoor water use in the home. This trace shows how a single defective part in one toilet can boost a home into the top ten in a group of 762 homes. One can say that this single defective toilet accounted for 1.3% of the total leak volume recorded in the study group.

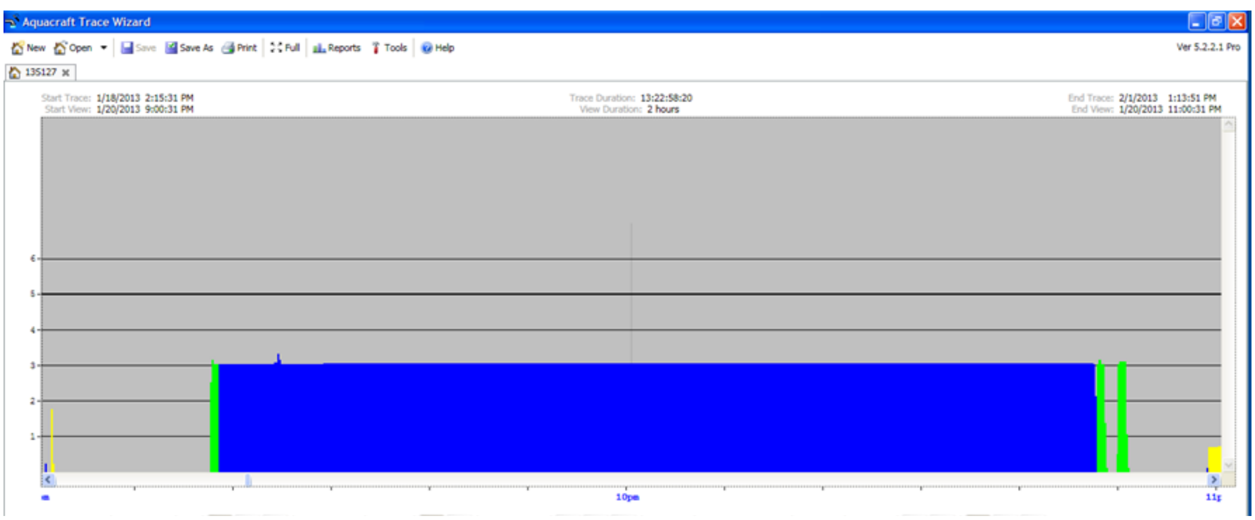


Figure 71: Example of a home with a jammed flapper in a two-hour view. Leaks are blue, and toilets are green.

Home 13S118 – median leakage

While it is good to scrutinize these high-leakage homes, it is important t to remember that these are on the far end of the distribution shown in Figure 64. Figure 72 presents a different picture, and one that is more common. This image comes from the median leakage house (ranked by total gallons of leakage). It should also be noted that there is some ambiguity in what is being called leak. These could be very small faucet draws. But even if all of this is leak, it is a relatively small component of indoor use. This home had 4.179 gpd of leakage, or just under 4%

of the household's indoor demand (and at 113 gphd, this was a highly efficient home. It would have been 3% of total demand based on the study-wide average for indoor use). This 4gphd is not trivial; it extrapolates to 1.5 kgal of leakage per year.

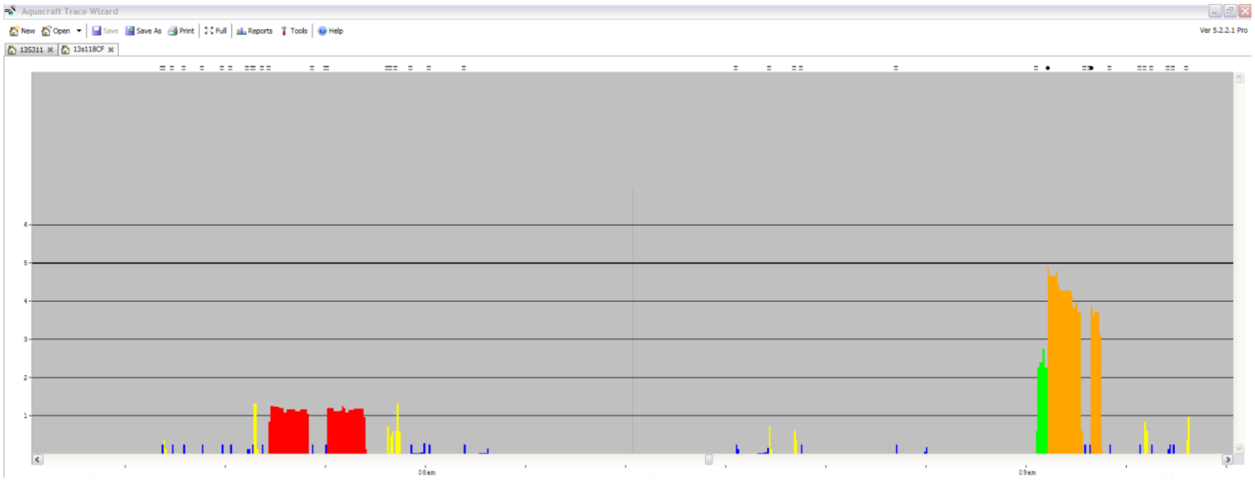


Figure 72: Two-hour view of leakage from an average leak home

Penetration Rates for High Efficiency Devices

Using the end-use data it was possible to obtain estimates of the percentage of homes in the study group that met specific efficiency criteria for the three main indoor water using devices: clothes washers, showers and toilets. The criteria used to qualify a home are shown in Table 63. The percentages of homes that met these criteria are shown in Figure 73.

Table 63: Criteria for qualification as high efficiency device

Device	Criteria for qualification as high efficiency
Clothes washer	Average gallons/load < 30 gal
Shower	Average mode flow < 2.5 gpm
Toilet	Average flush volume < 2 gpf

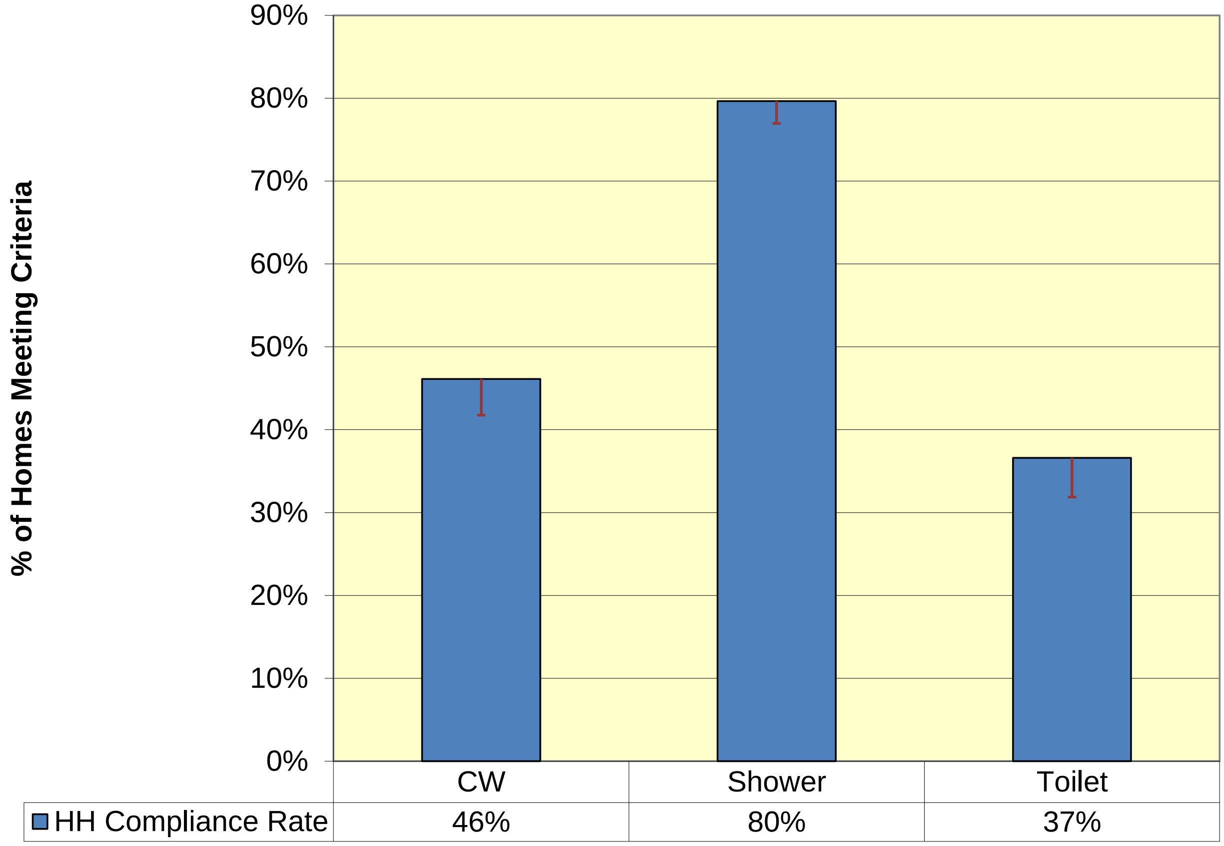


Figure 73: Percent of homes meeting efficiency criteria for clothes washers, showers and toilets

HOT WATER USE

A total of 110 homes were equipped with meters on the inflow lines to their water heaters. During the logging period data were obtained simultaneously from both the main and the hot water meters. This allowed comparisons to be made between total use and hot water use for each category. Time of day and seasonal comparisons were made as well. Energy use for hot water was estimated for home based on measured hot water use and temperature increments through the water heater.

Daily Hot Water Use

The average daily hot water use for each study site, the average for the group as a whole, and the percent of total use made up of hot water is shown in Table 64. These group averages are also shown graphically in Figure 74. Overall, hot water use in these homes equaled 33% of the total indoor use recorded during the logging period. The largest hot water use in the homes was for showers, at 18 gpd, and this was followed by faucet use, at 15 gpd. These two end uses accounted for nearly 80% of the total hot water use in the homes. Clothes washers accounted for only 4 gpd of hot water use and only 20% of the total water used for clothes washers was hot.

Table 64: Average daily hot water use

Study Site	Total (gpd)	Bath (gpd)	Clothes Washer (gpd)	Dishwasher (gpd)	Faucet (gpd)	Leaks (gpd)	Other (gpd)	Shower (gpd)
Clayton	40.4	2.5	5.5	1.3	15.4	2.2	0.1	13.4
Denver	52.8	3.1	5.1	2.7	18.0	3.3	1.4	18.9
Fort Collins	42.1	1.9	2.2	2.2	11.3	3.4	6.3	14.7
Peel	36.0	1.4	2.7	2.4	16.8	1.2	0.0	10.4
San Antonio	35.9	1.1	3.9	1.4	10.8	1.4	0.0	17.2
Scottsdale	35.9	1.6	3.1	2.3	15.8	2.8	0.0	10.3
Tacoma	49.3	2.9	5.7	2.5	15.9	1.5	0.0	20.7
Toho	38.7	0.1	1.7	0.5	13.7	1.6	0.1	21.0
Waterloo	54.2	7.3	5.0	2.7	17.5	1.0	0.0	20.6
Average (hot water meter)	45.5	2.6	4.4	2.2	15.4	2.1	0.9	17.8
Average (main meter)	137	4.4	22.0	2.3	27.0	17.8	4.0	26.9
Percent Hot	33%	59%	20%	100%	57%	12%	22%	66%

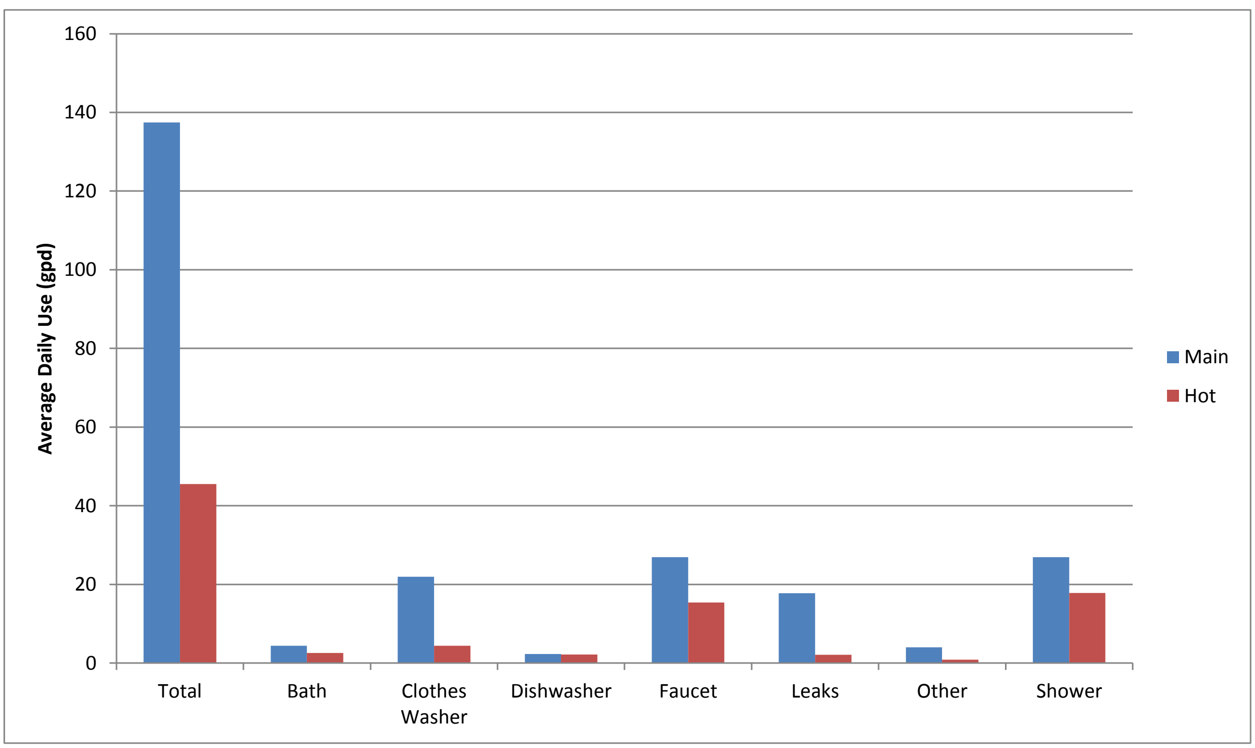


Figure 74: Comparison of main meter and hot water meter use by end use

Energy Use for Water Heating

By knowing the average daily hot water use and the number of degrees the water was heated it is possible to obtain estimates of the net energy used for water heating. These ignore flue and tank losses. On average the homes used 765,567 BTU/month to heat and average of 1426 gallons of water by 62 ^{o}F . These values are affected only by the volume of water heated and the increment of temperature. The largest increment was in Tacoma, which heated water by an average of 84 ^{o}F. Since most people maintain a steady setting on their water heaters the increment is inversely related to the inflow temperature of the water: the lower the inflow temperature the greater the increment of heating. Since we know that the volumes of hot water are greater in the winter months it stands to reason that the total energy required for water heating is greater in the winter than the summer.

Table 65: Monthly calculated energy use for water heating

Study Site	Month of Logging Start	Average of Indoor Hot Water Use (gpd)	Average of Delta T (^{o}F)	Average of BTU/Month
Clayton	8	40	43	458,531
Denver	2	60	66	1,015,808
Fort Collins	3	42	69	722,897
Peel	10	36	70	653,414
San Antonio	7	36	36	349,006
Scottsdale	5	36	35	321,739
Tacoma	1	49	84	1,058,726
Toho	7	39	35	326,376
Waterloo	11	54	59	827,188
Grand Total		**46**	**62**	**752,928**

Seasonal Use of Hot Water

As one would expect, the month of the year impacts the average daily volume of hot water used in the homes. Figure 75 shows the average gallons per day of hot water for all homes logged in the same months. There were no homes in which the logging start occurred in December, so this moth is missing from the chart. The data from the 11 months in which logging did commence shows a clear tendency for higher daily use during the fall and winter months and lower daily use during the spring and summer.

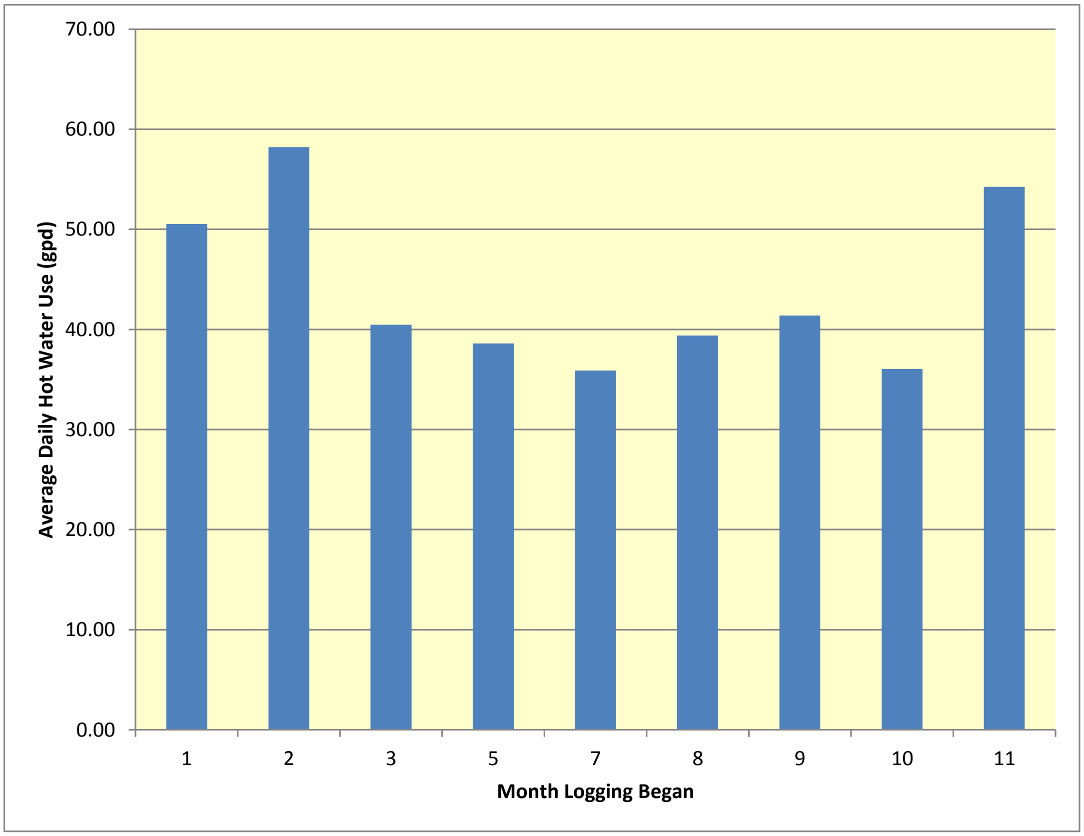


Figure 75: Average daily hot water use versus logging month

Hot Water Use for End Uses

It is often useful for designers of hot water systems to know the characteristics of the hot water uses for the various end uses. Figure 76 shows the average number of hot water uses per day in the study homes. The vast majority of hot water uses (or draws) are for faucets at nearly 40 draws. Next come showers, at around 2 draws per day. Dishwashers, clothes washers and baths followed at less than one per day.

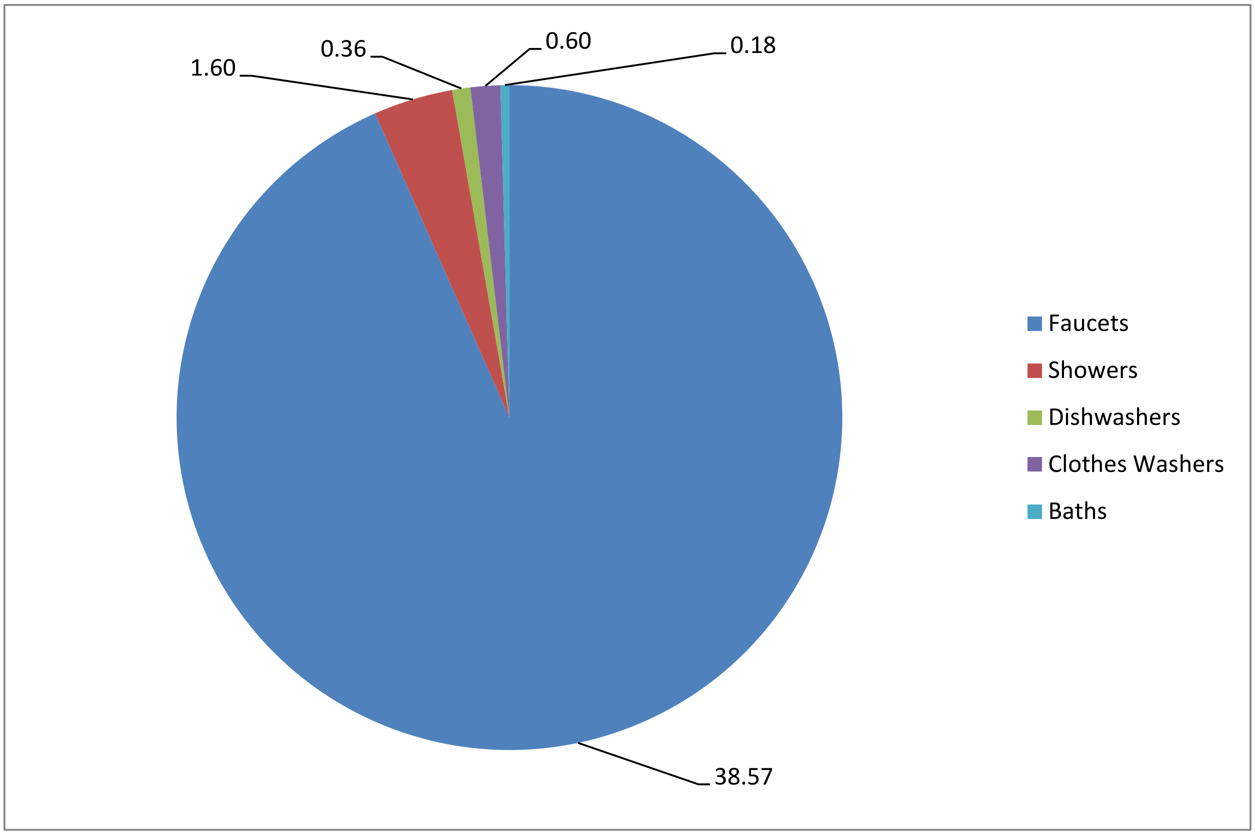


Figure 76: Average number of hot water uses per day by fixtures

Faucets

Faucet uses occurred, on average, 39 times per day. These uses accounted for an average of 15.4 gallons of hot water use per day for an average use per draw of 0.39 gallons and an average duration of 45 seconds per draw. As shown in Table 54, there were ~496,000 total faucet events in the database, and ~59,000 of these (13%) were hot water draws. As was the case for all faucet uses the vast majority of the hot water draws were short duration and small volume. As shown in Table 66, 50% of the hot water faucet uses were 20 seconds or less and had average volumes of less than 0.2 gallons. Ninety percent of the hot water draws lasted for 90 seconds or less and used a volume of 1 gallon or less. The distribution of hot water use by volumes showed that 99.96% of the hot water faucet uses were 0.4 gallons or less. There were only 22 hot water faucet events that used more than 10 gallons of water.

Table 66: Distribution of hot water faucet events by duration

Durations (sec)	Frequency	Avg Duration	Avg Volume	Rel. Freq.	Cum. Freq.
20	15635	10	0.085	26%	26%
30	**13618**	**20**	**0.171**	**23.0%**	**49.3%**
40	8057	30	0.308	13.6%	62.9%
50	5089	40	0.441	8.6%	71.5%
60	3701	50	0.514	6.2%	77.8%

Durations (sec)	Frequency	Avg Duration	Avg Volume	Rel. Freq.	Cum. Freq.
70	2716	60	0.622	4.6%	82.3%
80	2142	70	0.684	3.6%	86.0%
90	1559	80	0.812	2.6%	88.6%
100	**1075**	**90**	**1.011**	**1.8%**	**90.4%**
110	807	100	1.082	1.4%	91.8%
120	652	110	1.284	1.1%	92.9%
130	579	120	1.371	1.0%	93.8%
140	472	130	1.298	0.8%	94.6%
150	382	140	1.440	0.6%	95.3%
160	292	150	1.510	0.5%	95.8%
170	270	160	1.471	0.5%	96.2%
180	234	170	1.662	0.4%	96.6%
190	214	180	1.557	0.4%	97.0%
200	176	190	1.355	0.3%	97.3%
210	178	200	1.563	0.3%	97.6%
220	163	210	1.916	0.3%	97.9%
230	126	220	1.646	0.2%	98.1%
240	108	230	1.975	0.2%	98.3%
250	80	240	1.516	0.1%	98.4%
260	87	250	1.885	0.1%	98.5%
270	88	260	1.803	0.1%	98.7%
280	52	270	1.740	0.1%	98.8%
290	43	280	1.650	0.1%	98.8%
300	686	498	2.347	1.2%	100.0%
Total	59281				

Showers

On average there were 1.6 showers per day per home in the data set. Each shower used and average of 11 gallons of hot water over a duration of 8 minutes and a flow rate of 1.4 gpm. There were a total of 2428 hot water draws for showers. As one would expect these were larger volumes than were the faucet events. The fiftieth percentile of events had durations of 430 seconds (7 minutes) or less and used volumes of 9.6 gallons or less. The ninety percentile event had durations of 942 seconds (15 minutes) and used 15.5 gallons of hot water or less.

Table 67: Distribution of hot water shower events by durations

Durations (sec)	Frequency	Avg. Duration (sec)	Avg. Volume (gal)	**Rel. Freq.**	**Cum. Freq.**
30	1	10.0	0.8	0.0%	0.0%
60	5	44.0	1.4	0.2%	0.2%
90	9	72.2	1.8	0.4%	0.6%

Durations (sec)	Frequency	Avg. Duration (sec)	Avg. Volume (gal)	**Rel. Freq.**	**Cum. Freq.**
120	23	102.6	2.6	0.9%	1.6%
150	54	130.4	3.4	2.2%	3.8%
180	81	161.6	3.8	3.3%	7.1%
210	124	191.2	4.5	5.1%	12.2%
240	102	222.2	5.0	4.2%	16.4%
270	141	250.2	5.4	5.8%	22.2%
300	148	280.9	6.3	6.1%	28.3%
330	123	309.8	7.6	5.1%	33.4%
360	108	339.6	8.2	4.4%	37.9%
390	125	369.9	8.3	5.1%	43.0%
420	115	399.7	9.4	4.7%	47.7%
450	**117**	**430.4**	**9.6**	**4.8%**	**52.6%**
480	95	459.3	11.5	3.9%	56.5%
510	98	488.2	10.6	4.0%	60.5%
540	81	520.4	12.4	3.3%	63.8%
570	73	549.7	13.1	3.0%	66.8%
600	65	580.0	13.1	2.7%	69.5%
630	66	610.3	14.4	2.7%	72.2%
660	72	640.6	14.4	3.0%	75.2%
690	63	670.0	14.2	2.6%	77.8%
720	49	701.4	16.3	2.0%	79.8%
750	54	728.0	15.7	2.2%	82.0%
780	38	758.4	16.0	1.6%	83.6%
810	27	789.3	17.1	1.1%	84.7%
840	50	817.6	17.6	2.1%	86.8%
870	20	853.5	19.3	0.8%	87.6%
900	25	881.6	16.5	1.0%	88.6%
930	22	912.3	17.2	0.9%	89.5%
960	**13**	**942.3**	**15.5**	**0.5%**	**90.1%**
990	19	974.2	20.7	0.8%	90.9%
1020	22	996.8	16.5	0.9%	91.8%
1050	17	1030.0	17.4	0.7%	92.5%
1080	24	1057.5	17.9	1.0%	93.5%
1110	10	1094.0	19.9	0.4%	93.9%
1140	20	1116.0	21.8	0.8%	94.7%
1170	21	1151.0	21.9	0.9%	95.6%
1200	10	1176.0	21.4	0.4%	96.0%
1230	13	1209.2	23.1	0.5%	96.5%
1260	7	1237.1	28.4	0.3%	96.8%
1290	7	1268.6	31.7	0.3%	97.1%
1320	7	1300.0	21.1	0.3%	97.4%

Durations (sec)	Frequency	Avg. Duration (sec)	Avg. Volume (gal)	Rel. Freq.	Cum. Freq.
1350	5	1328.0	37.0	0.2%	97.6%
1380	5	1364.0	36.6	0.2%	97.8%
1410	4	1392.5	31.6	0.2%	97.9%
1440	9	1418.9	28.5	0.4%	98.3%
1470	5	1450.0	30.7	0.2%	98.5%
1500	36	1792.8	33.0	1.5%	100.0%
	2428				

OUTDOOR USE ANALYSIS

The analysis of outdoor use for this study was based on an annual time period. The annual outdoor water use was estimated for each study home using a combination of billing data obtained from the water agencies and the best estimate that could be obtained for the annual indoor water use in each home. The difference between annual use and the best estimate of indoor was used as the estimate of outdoor use. In this context outdoor use included all water use for non-indoor purposes including automatic irrigation and large uses such as pool filling or manual irrigation. The one exception to this was the Toho water agency (Orlando Florida area) where separate metering was available for outdoor water use, which eliminated the need to make estimates. In all other cases the research had to rely on this estimation technique since only a single meter was available, and the data loggers were in place for only a short period. (It should be noted that if the loggers were left in place permanently it would be possible to determine outdoor use directly from the logger data over the entire year). In addition to water use, irrigation analysis parameters include type and amount of plantings in a given landscape as well as local ET data. These three parameters (water, plantings, and weather) combine to allow an analysis that focuses on the relationship between theoretical irrigation requirements and actual use.

The techniques used to analyze outdoor water use were described in the Research Methods chapter. This section of the report is devoted to providing summaries of the results for each of the important parameters used for the outdoor analysis.

Lot Size and Landscape Area

Lot size is one of the easiest to obtain and most accurate parameters for analysis of outdoor water use since it is based on surveyed plat maps, which can be obtained from publically available GIS databases. Lots sizes for the study group, shown in Table 68, averaged 9,554 sf and ranged from the smallest in Peel (5396 sf) to the largest in Scottsdale (16,797 sf). A histogram of the distribution of lot sizes in the study group is shown in Figure 77, and the average lot and landscape areas are shown graphically in Figure 78,.

There are some complications in attempting to determine the portion of the lot that is irrigated, which is why the table refers to landscape are as opposed to irrigated areas. A parcel of land does not necessarily need to be irrigated in order to be included as part of the landscape. Areas that appear to be part of a formal landscape, but are do not appear to be irrigated are included as part of the landscape area, but totally wild areas that are allowed to remain on the lot are not included as landscape areas, which is why there are some large lots with little or no landscape area.

In arid areas this problem is simplified by the fact that areas that are covered by green vegetation are only kept green by virtue of irrigation. In more temperate areas, however, the distinction between areas that are and are not irrigated was not so clear. In eastern portions of the country perfectly healthy turf, trees and shrubs can be maintained with little or no supplemental irrigation. Even in western areas there are areas of native vegetation that may extend onto residential lots and may be incorporated into the landscapes. Finally, it was not uncommon for residential landscapes to extend out from the actual platted lot area into the rights of way. These area were obviously cared for by the homeowners, and were included as part of their landscapes. An extreme case of this was found in Clayton County were the average landscape area for the study group was actually higher than the average lot size. Because of the impossibility of determining the exact areas that were irrigated on each lot the research team focused on estimating the landscape area of each lot, and considered this the maximum areas that could be irrigated by the homeowners either as part of an automatic irrigation system or by means of hoses and sprinklers. The exception to this was that areas that were clearly native vegetation that were never part of an actual residential landscape, but had been borrowed by the homeowner, were counted as non-irrigated vegetation and were not assigned an irrigation requirement. Pools and water features, on the other hand, were included as part of the landscape and were assumed to have an irrigation demand based on the evaporation from an open water surface.

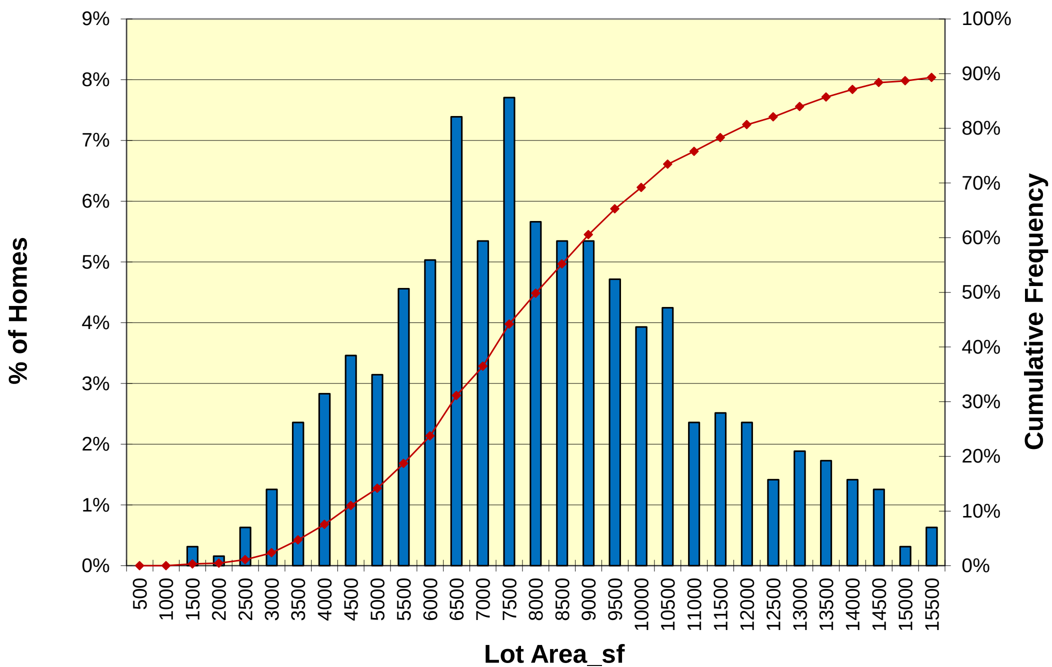


Figure 77: Distribution of lot sizes in the study group

Table 68: Lot and landscape areas for study groups

Agency	Average Lot Area_ (sf)	Average Landscape Area (sf)
Clayton	10,574	11,195
Denver	7,952	5,089
Fort Collins	9,883	7,603
Peel	5,396	2,494
San Antonio	9,950	7,238
Scottsdale	16,797	3,821
Tacoma	8,655	5,211
Toho	8,717	3,980
Waterloo	7,753	4,660
Average	9,831	5,826

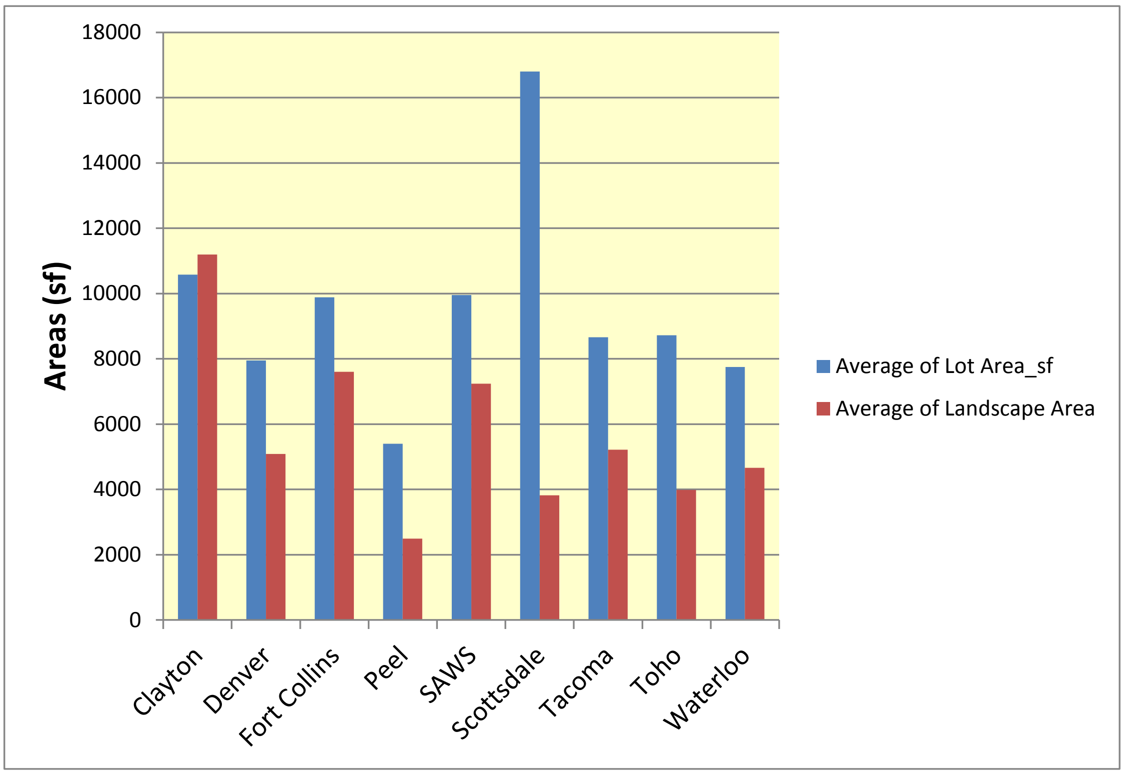


Figure 78: Lot and landscape areas

There is a significant amount of scatter in the area data, as shown in Figure 79. There appears to be a fairly strong relationship running from the origin through the point at 53,000 sf landscape area, but the lots with little landscape on large lots throw this relationship off. Figure 80 shows that the relationship is improved significantly if the 20 worst outliers are removed. In the opinion of the researchers this relationship is more typical.

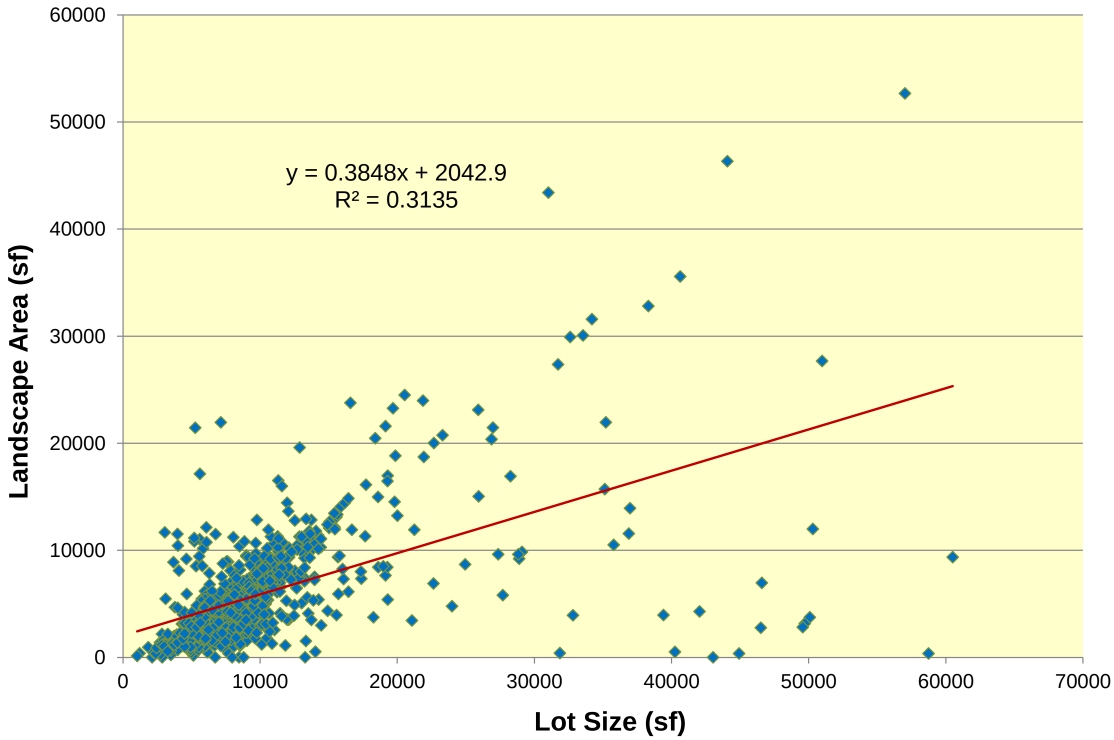


Figure 79: Landscape area versus lot size for entire study group (N=838)

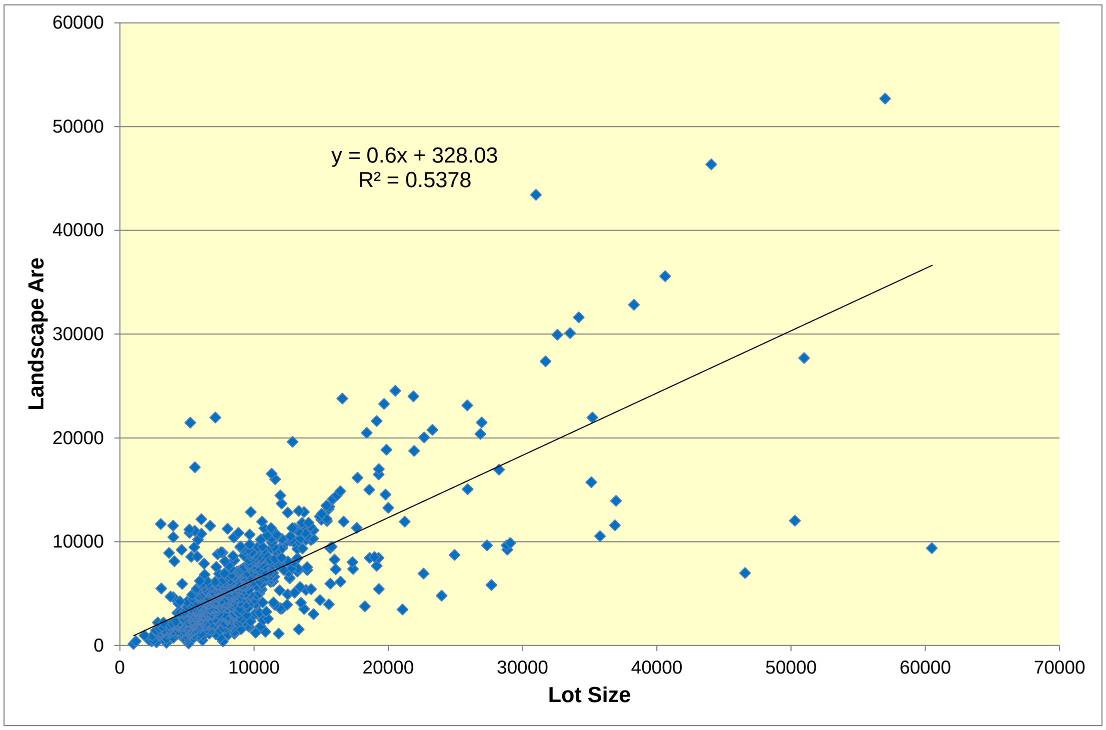


Figure 80: Landscape area versus lot size with outliers removed (N=818)

Outdoor Water Use

Table 69 shows the average annual water use for study groups, the estimated outdoor use for each and the percent of the annual water use used for outdoor purposes. The outdoor use shown in this table is the average of the outdoor use used for the landscape analysis, which was based on the difference between annual water use and the estimated annual indoor water use. On average the group used 51 kgal of water for outdoor purposes, which was 53% of their total annual use (in 2010). These values varied considerably among the groups, however. The Region of Waterloo had the lowest annual outdoor use, at 13 kgal per year, followed by Clayton County, at 19 kgal and Peel at 24 kgal. The highest outdoor use was found in Scottsdale followed by Denver and San Antonio.

Table 69: Annual and outdoor water use (2010)

Site	Average of Annual_kgal	Average of Outdoor_kgal	% Outdoor
Clayton	57.5	19.2	33%
Denver	119.4	77.0	65%
Fort Collins	98.3	55.9	57%
Peel	76.6	24.1	31%
San Antonio	103.9	62.0	60%
Scottsdale	175.1	120.4	69%
Tacoma	68.6	27.0	39%
Toho	83.2	33.1	40%
Waterloo	55.5	13.0	23%
Grand Total	95.5	50.5	53%

Irrigation Application Rates

The irrigation application rate is determined as the ratio of the total outdoor use to the landscape area. It is expressed in both inches and gallons per square foot in Table 70. The values in this table should be interpreted as the depth of water applied to the landscape if the total estimated outdoor use were applied evenly to the total estimated landscape area on the lot. It is recognized that this is an average application and that in reality some portions of the landscape will be more or less heavily irrigated, but that is not important for our purpose here, which is to estimate the overall application rate for the landscape during the study year.

Table 70: Irrigation application rates

Agency	Application (In)	Application (gpsf)
Clayton County	3.7	2.3
Denver	27.2	16.9
Fort Collins	12.9	8.0
Peel	20.3	12.7

Agency	Application (In)	Application (gpsf)
San Antonio	14.7	9.2
Scottsdale	77.1	48.1
Tacoma	10.3	6.4
Toho	19.1	11.9
Waterloo	5.0	3.1
Total	24.9	15.5

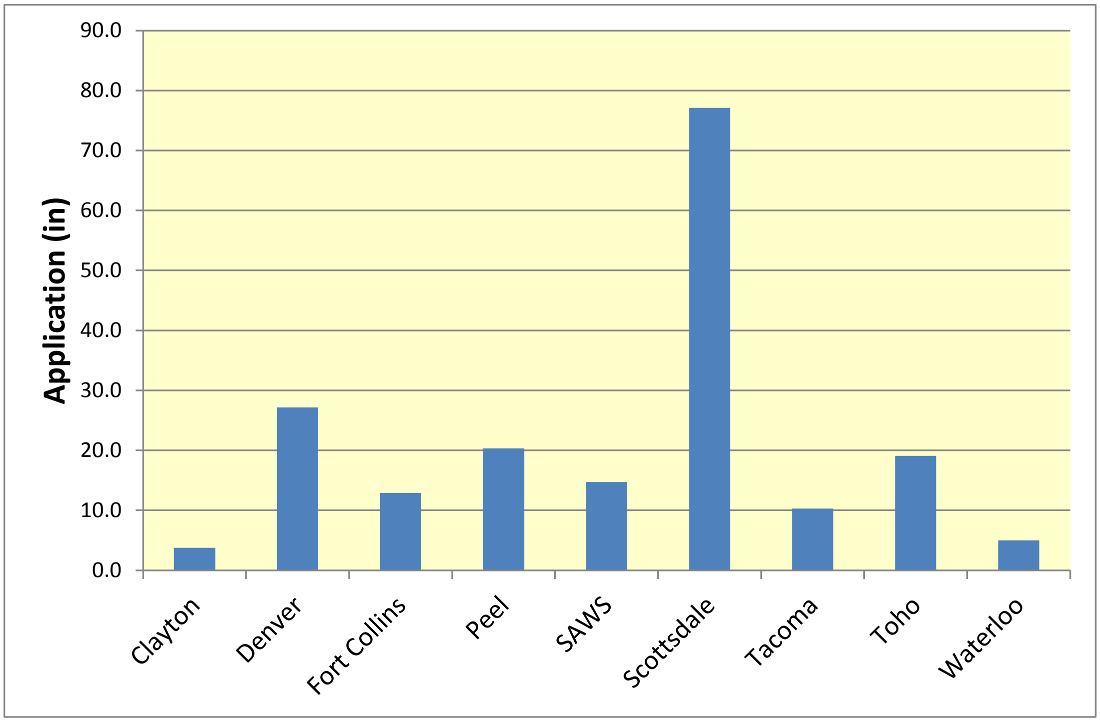


Figure 81: Average application rates for study sites

Theoretical Irrigation Requirements

The theoretical irrigation requirement is a measure of the volume of water that each lot would be expected to use in order to maintain a healthy landscape given the landscape area, the water requirements of the plants in the landscape, and the net evapotranspiration rate. An allowance for well-designed and maintained irrigation system efficiencies is also given. Table 71 shows site-wide averages of three parameters concerning the irrigation requirements: the reference demands, theoretical irrigation requirements (TIR) and the ratios of the TIR to the reference demands, which is referred to as the landscape ratio.

The reference demands are the demands that would occur with a landscape composed exclusively of cool season turf with no allowance for irrigation efficiencies. This provides a measure of the ETo based irrigation requirements for the property. This is especially useful in locations that regulate irrigation budgets on the basis of ET requirements. These values range from a low of 35 kgal in Peel to a high of 237 kgal in San Antonio and averaged 124 kgal per lot for the study group.

Table 71: Irrigation demands and landscape ratios

Site	Average Reference Demand (kgal)	Average TIR (kgal)	Average Landscape Ratio
Clayton	164.2	138.7	0.84
Denver	95.8	99.5	1.04
Fort Collins	174.0	175.8	1.01
Peel	35.0	38.0	1.12
San Antonio	237.4	147.3	0.65
Scottsdale	138.3	123.0	0.94
Tacoma	60.0	61.1	1.02
Toho	106.6	120.4	1.13
Waterloo	64.8	67.7	1.05
Grand Total	123.6	110.7	0.97

The theoretical irrigation requirements reflect the actual water requirements of the landscapes based on their actual size and make up, with allowances for system efficiencies. These ranged from a low of 38 kgal in Peel to a high of 123 kgal in Scottsdale.

If one takes the ratio of the theoretical irrigation requirements to the reference requirements this will provide a measure of the water use intensity of the landscapes in relation to a reference (cool season turf) demand. The lower the landscape ratio the less intense the water demands of the landscape in comparison to turf. In the study group the least intense water using landscapes were found in San Antonio, which had an average landscape ratio of 65% of ETo, while the most intense water using landscapes were found in Toho, at 113% of ET, due to the preponderance of turf in these cool Eastern areas. It is interesting to note that on average the landscape ratios are very close to 1.0.

Irrigation Application Ratios

The reference and theoretical demands represent calculated water requirements based on engineering and horticultural parameters. The actual outdoor use reflects actual water use by the customers based on their technology, individual preferences and habits. These vary quite a bit from the theoretical numbers, as shown in Figure 82 and Table 72.

Figure 82 shows that the predicted actual application for a given lot equals 0.36 x theoretical requirement plus 10.3 kgal. Note that the coefficient of the regression model is less than the average application ration, which is 58%. The reason for this is that the regression coefficient is closer to the median value, which in this case is 34% of the TIR because the best fit approach tends to place the regession line in the middle of the data. If there was no scatter in the data, or if the data were perfectly symmetrical around the average then the slope of the linear regression model would be the same as the average.

Table 72 shows that on average the actual water use by the residents in the study was 58% of their TIR, and that this ratio went as low as 19% in Clayton County to a high of 131% in

Scottsdale, which was the only site in which the average actual outdoor use was greater than the calculated TIR. The key information shown in the table is the most of the homes in the study group are applying significantly less than their theoretical requirements.

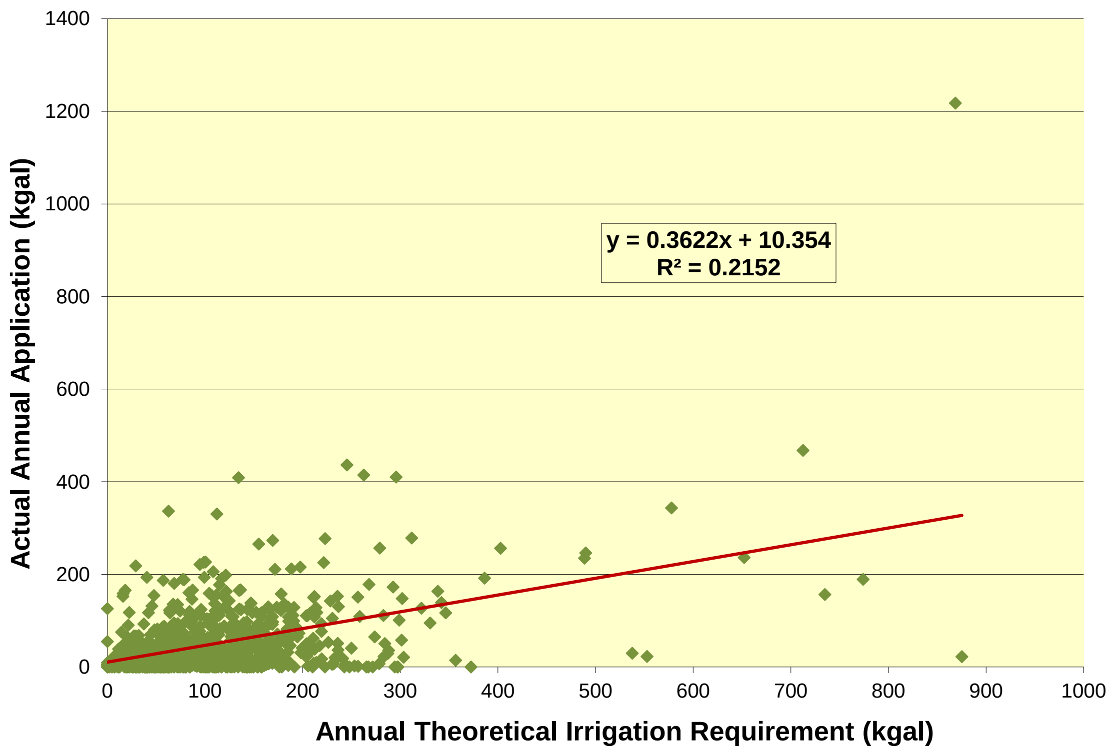


Figure 82: Actual versus theoretical irrigation applications

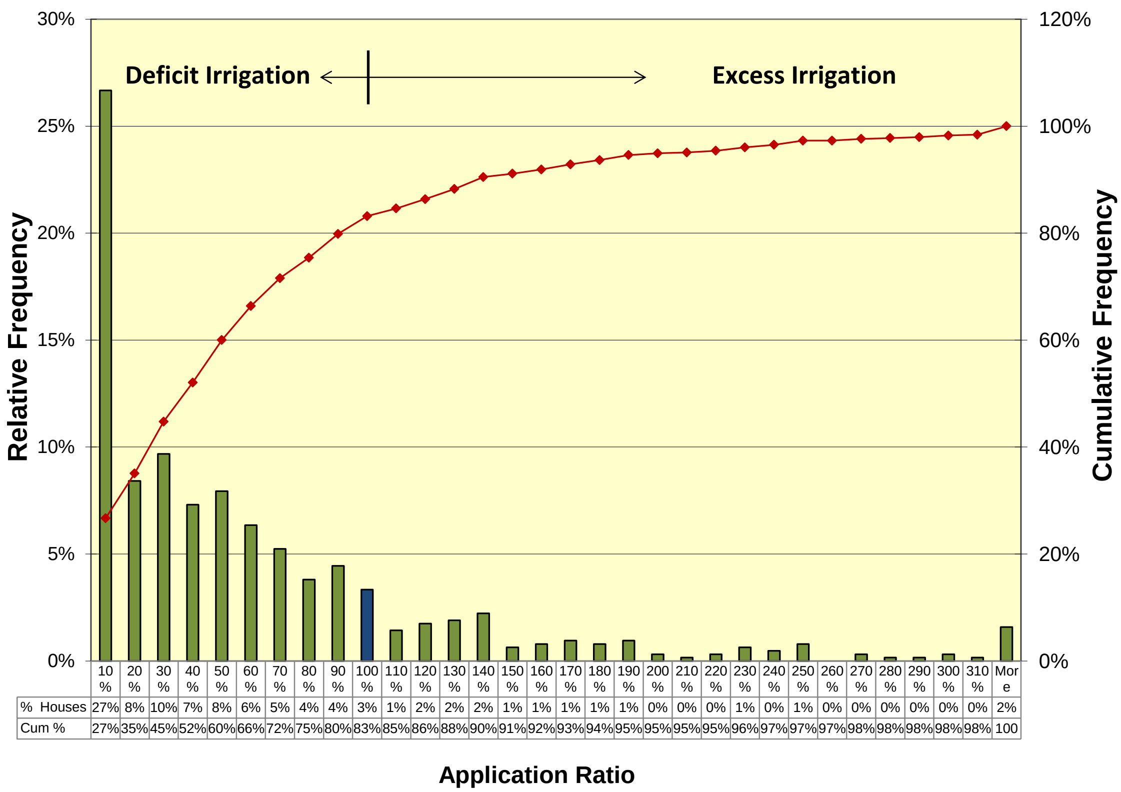
Table 72: Average of individual values for TIR, actual use and application ratios

Site	Average of TIR_kgal	Average of Outdoor_kgal	Average of Application Ratio
Clayton	138.729962	19.18546236	19%
Denver	99.50837656	77.02031817	87%
Fort Collins	175.777407	55.85554198	34%
Peel	38.02613871	24.11994328	82%
SAWS	147.2770347	61.96399118	46%
Scottsdale	122.9860801	120.3685423	131%
Tacoma	61.13252615	27.01119164	55%
Toho	120.3976806	33.09473684	39%
Waterloo	67.69112894	13.03067939	21%
Overall means	110.7064711	50.53574708	58%

Table 73 shows the percent of homes in each study site that were found to be applying more than their theoretical requirement. Overall, this ratio came out to 20% of the homes and ranged from a low of 0% in Fort Collins to a high of 41% in Scottsdale. In Figure 83 the distribution of application ratios for the entire study group is presented. When presented in this way we can see that not only are 80% of the households applying less than the theoretical irrigation applications, but 27% are applying only 10% of the expected application. This finding has important implications for irrigation conservation planning.

Table 73: Percent of homes excess irrigating

Agency	% of homes in excess
Clayton County	3%
Denver	27%
Fort Collins	0%
Peel	30%
San Antonio	8%
Scottsdale	41%
Tacoma	16%
Toho	17%
Waterloo	7%
Total	20%



	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %	110 %	120 %	130 %	140 %	150 %	160 %
% Houses	27%	8%	10%	7%	8%	6%	5%	4%	4%	3%	1%	2%	2%	2%	1%	1%
Cum %	27%	35%	45%	52%	60%	66%	72%	75%	80%	83%	85%	86%	88%	90%	91%	92%

	170 %	180 %	190 %	200 %	210 %	220 %	230 %	240 %	250 %	260 %	270 %	280 %	290 %	300 %	310 %	More
% Houses	1%	1%	1%	0%	0%	0%	1%	0%	1%	0%	0%	0%	0%	0%	0%	2%
Cum %	93%	94%	95%	95%	95%	95%	96%	97%	97%	97%	98%	98%	98%	98%	98%	100

Figure 83: Distribution of application ratios for all study homes

Excess and Net Irrigation Volumes

In order to analyze the actual volumes of excess irrigation the data were examined in two ways. First the excess use on each lot was determined, where excess use was defined as the greater of the actual application minus the TIR and zero. Secondly the net application for each lot was determined, which was the simple difference, where the deficit irrigators were assigned a negative application. There were a total of 142 lots out of 838 that were excess irrigating. The total volume of excess use was 6884 kgal.

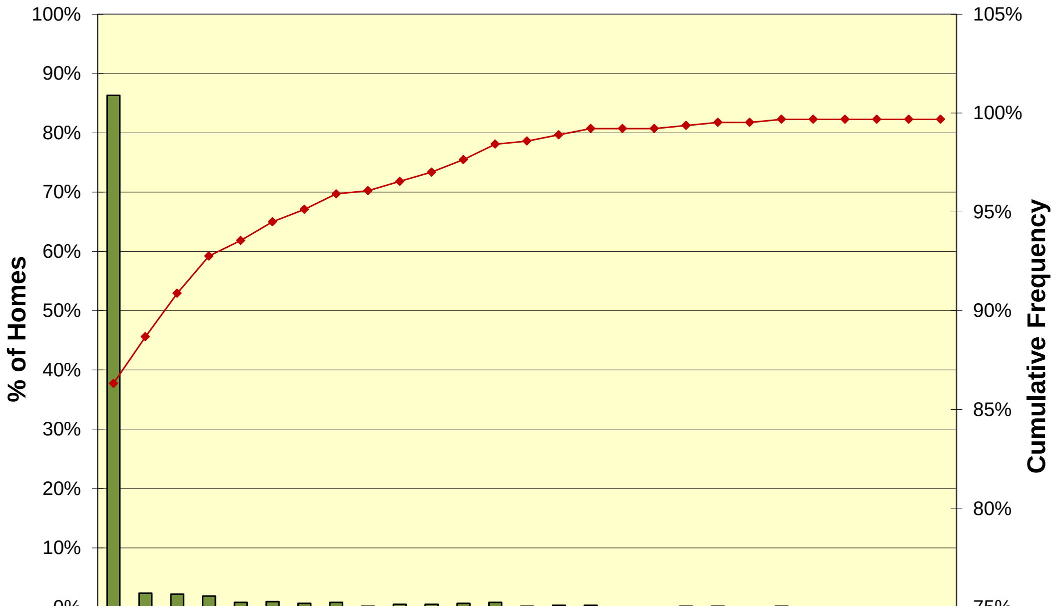
The excess use approach resulted in lots that were deficit irrigating being assigned a value of zero excess use. Since the total estimated volume of annual excess irrigation use in the group was 6884 kgal the overall average excess use was 8.21 kgal per home, as shown in Table 74. This is the amount that could be saved per home (for the entire group; not just the excess irrigators) if excess use could be eliminated on those lots on which it is occurring, while leaving the other homes to continue their pattern of deficit irrigation.

The excess use on the 142 homes that were over-irrigating averaged 48.5 kgal (6884/142=48.5). This means that if it were somehow possible to eliminate the excess irrigation on these 142 homes an average of 48.5 kgal per home would be saved on them, and the average use for the entire 838 home study group would be reduced by 8.2 kgal. The distribution of excess irrigation has been shown in Figure 84. This shows that 86% of the homes were applying between 0 and 10 kgal of excess water to their landscape. An additional 2% were applying from 10 to 20 kgal of excess water and so on.

In the net irrigation approach, if all of the lots were brought to 100% of their TIR the effect would be to increase water use by an average of 60 kgal per lot. The algebraic sum of the net irrigation was -50,440 kgal, so the overall average net application was -50,440/838 = -60.19 kgal. The consequence of this is that if an automated system were installed on all of the landscapes that applied precisely the "correct" amount of irrigation water to each lot the average water use for the group would increase by over 60 kgal per year.

Table 74: Excess and net irrigation use in study group (N=838)

	Data	
Site	**Average of Excess Irrigation (kgal)**	**Average of Net application (kgal)**
Clayton	0.18	-119.54
Denver	12.92	-22.49
Fort Collins	0.00	-119.92
Peel	6.42	-13.91
San Antonio	3.80	-85.31
Scottsdale	34.38	-2.62
Tacoma	5.24	-33.62
Toho	3.21	-87.30
Waterloo	1.95	-54.66
Overall Average	8.21	-60.19
Total Volume	6880	-50,440

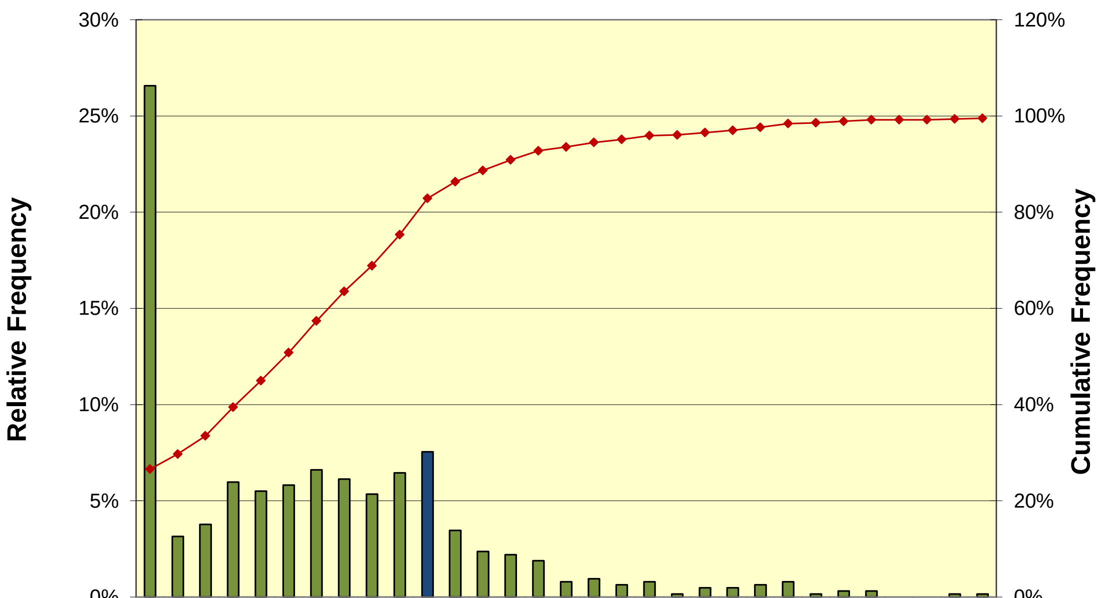


	10	20	30	40	50	60	70	80	90	100	110	120	130	140
% Houses	86%	2%	2%	2%	1%	1%	1%	1%	0%	0%	0%	1%	1%	0%
Cum %	86%	89%	91%	93%	94%	94%	95%	96%	96%	97%	97%	98%	98%	99%

	150	160	170	180	190	200	210	220	230	240	250	260	270
% Houses	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cum %	99%	99%	99%	99%	99%	100%	100%	100%	100%	100%	100%	100%	100%

Annual Excess Irrigation Application (kgal)

Figure 84: Distribution of excess irrigation



	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40
% of Houses	27%	3%	4%	6%	6%	6%	7%	6%	5%	6%	8%	3%	2%	2%	2%
Cum %	27%	30%	33%	39%	45%	51%	57%	64%	69%	75%	83%	86%	89%	91%	93%

	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
% of Houses	1%	1%	1%	1%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
Cum %	94%	94%	95%	96%	96%	97%	97%	98%	98%	99%	99%	99%	99%	99%	99%	100

Annual Deficit and Excess Irrigation Application (kgal)

Figure 85: Distribution of net irrigation applications

It should be kept in mind that these results are for a particular set of water customers in a single year, which was impacted by drought in several of the sites and still affected by the recession of 2008. Consequently, it is not advisable to generalize too broadly from the specific numbers in these results, or to do so with caution. On the other hand, the pattern of excess and net irrigation observed in this study group is similar to every other similar study that the researchers have conducted, so while the precise numbers may vary, the pattern does not.

DIURNAL USE

Because logging data is date and time-stamped, diurnal uses have been tracked. Table 75 shows a percentage breakdown of the total hourly use occurring during each hour, and Figure 86 gives a visual of this data. Table 76 and Figure 87 show the percent of each end use that takes place during each hour.

These profiles show a preponderance of use in the morning. This tracks with data from other studies that look at distribution system data. One interesting aspect of looking and diurnal end use data is seeing which end uses drive the daily peaks. Showering is the largest driver of the morning peak. This has several interesting implications. First, improvements in showerhead efficiency and standards may lower this peak. A second implication has to do with energy use. Showers account for 665 of household water use, on average.

Table 75: Percent of total indoor use accounted for by end uses

Hour (start)	Bathtub	Clotheswasher	Dishwasher	Faucet	Humidifier	Leak	Other	Shower	Toilet	Hourly Use as % of Total
0	0.05%	0.18%	0.04%	0.29%	0.00%	1.12%	0.10%	0.33%	0.56%	2.67%
1	0.01%	0.07%	0.02%	0.18%	0.00%	0.29%	0.35%	0.15%	0.41%	1.47%
2	0.02%	0.06%	0.01%	0.11%	0.00%	0.32%	0.41%	0.09%	0.35%	1.36%
3	0.01%	0.04%	0.00%	0.11%	0.00%	0.26%	0.31%	0.16%	0.36%	1.26%
4	0.03%	0.03%	0.01%	0.17%	0.00%	0.31%	0.10%	0.28%	0.43%	1.36%
5	0.04%	0.10%	0.01%	0.40%	0.00%	0.36%	0.12%	0.99%	0.76%	2.80%
6	0.09%	0.33%	0.02%	0.80%	0.01%	0.44%	0.10%	1.72%	1.24%	4.75%
7	0.14%	0.63%	0.04%	1.11%	0.01%	0.57%	0.11%	2.18%	1.60%	6.38%
8	0.16%	0.96%	0.05%	1.21%	0.01%	0.59%	0.11%	1.57%	1.40%	6.05%
9	0.14%	1.22%	0.06%	1.14%	0.01%	0.57%	0.11%	1.38%	1.26%	5.89%
10	0.10%	1.29%	0.05%	1.03%	0.00%	0.54%	0.14%	1.19%	1.12%	5.45%
11	0.08%	1.23%	0.04%	0.94%	0.00%	0.57%	0.15%	0.97%	1.05%	5.04%
12	0.10%	1.16%	0.05%	0.97%	0.00%	0.54%	0.13%	0.76%	1.00%	4.72%
13	0.07%	1.08%	0.04%	0.92%	0.00%	0.54%	0.11%	0.69%	0.96%	4.42%
14	0.07%	0.97%	0.04%	0.83%	0.00%	0.54%	0.11%	0.66%	0.99%	4.22%
15	0.12%	0.92%	0.04%	0.84%	0.00%	0.56%	0.13%	0.68%	1.04%	4.32%
16	0.12%	0.83%	0.03%	0.99%	0.00%	0.55%	0.13%	0.74%	1.14%	4.55%
17	0.11%	0.83%	0.05%	1.19%	0.01%	0.70%	0.15%	0.77%	1.23%	5.05%
18	0.19%	0.94%	0.07%	1.37%	0.01%	0.52%	0.11%	0.77%	1.22%	5.20%
19	0.27%	0.91%	0.11%	1.28%	0.01%	0.53%	0.14%	1.05%	1.20%	5.48%
20	0.28%	0.90%	0.10%	1.14%	0.00%	0.55%	0.10%	1.05%	1.23%	5.35%

21	0.23%	0.78%	0.10%	1.01%	0.00%	0.55%	0.09%	1.06%	1.30%	5.13%
22	0.16%	0.57%	0.09%	0.79%	0.00%	0.45%	0.08%	0.82%	1.19%	4.16%
23	0.12%	0.34%	0.08%	0.50%	0.00%	0.37%	0.08%	0.57%	0.85%	2.92%
Total	2.71%	16.37%	1.18%	19.33%	0.11%	12.31%	3.47%	20.63%	23.88%	100.00%

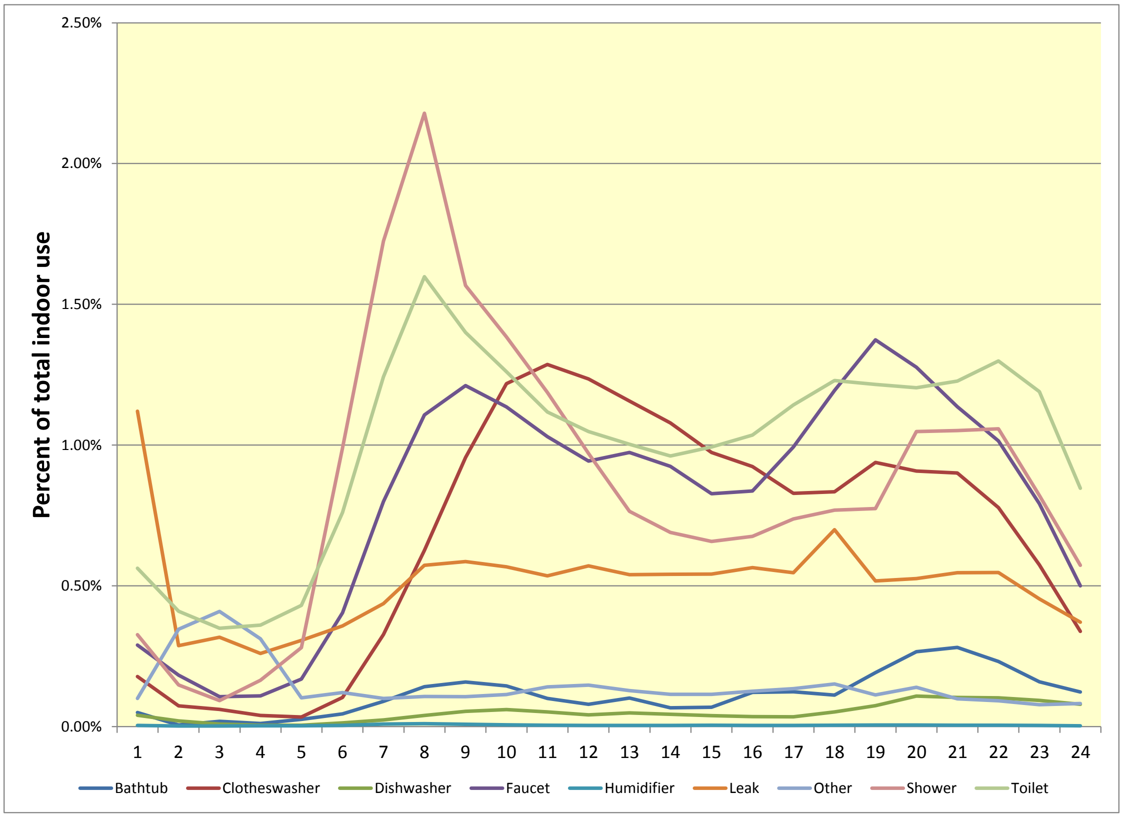


Figure 86: Hourly percent of total indoor use represented by end uses

Table 76: Percent of end use occurring during each hour of the day

Hour (start)	Bathtub	Clotheswasher	Dishwasher	Faucet	Humidifier	Leak	Other	Shower	Toilet	Total
0	2%	7%	1%	11%	0%	42%	4%	12%	21%	100%
1	0%	5%	1%	12%	0%	19%	23%	10%	28%	100%
2	1%	4%	1%	8%	0%	23%	30%	7%	26%	100%
3	1%	3%	0%	9%	0%	21%	25%	13%	29%	100%
4	2%	3%	0%	12%	0%	23%	8%	21%	32%	100%
5	2%	4%	0%	14%	0%	13%	4%	35%	27%	100%
6	2%	7%	0%	17%	0%	9%	2%	36%	26%	100%
7	2%	10%	1%	17%	0%	9%	2%	34%	25%	100%
8	3%	16%	1%	20%	0%	10%	2%	26%	23%	100%
9	2%	21%	1%	19%	0%	10%	2%	23%	21%	100%
10	2%	24%	1%	19%	0%	10%	3%	22%	20%	100%
11	2%	25%	1%	19%	0%	11%	3%	19%	21%	100%
12	2%	25%	1%	21%	0%	11%	3%	16%	21%	100%

13	2%	24%	1%	21%	0%	12%	3%	16%	22%	100%
14	2%	23%	1%	20%	0%	13%	3%	16%	24%	100%
15	3%	21%	1%	19%	0%	13%	3%	16%	24%	100%
16	3%	18%	1%	22%	0%	12%	3%	16%	25%	100%
17	2%	17%	1%	24%	0%	14%	3%	15%	24%	100%
18	4%	18%	1%	26%	0%	10%	2%	15%	23%	100%
19	5%	17%	2%	23%	0%	10%	3%	19%	22%	100%
20	5%	17%	2%	21%	0%	10%	2%	20%	23%	100%
21	5%	15%	2%	20%	0%	11%	2%	21%	25%	100%
22	4%	14%	2%	19%	0%	11%	2%	20%	29%	100%
23	4%	12%	3%	17%	0%	13%	3%	20%	29%	100%

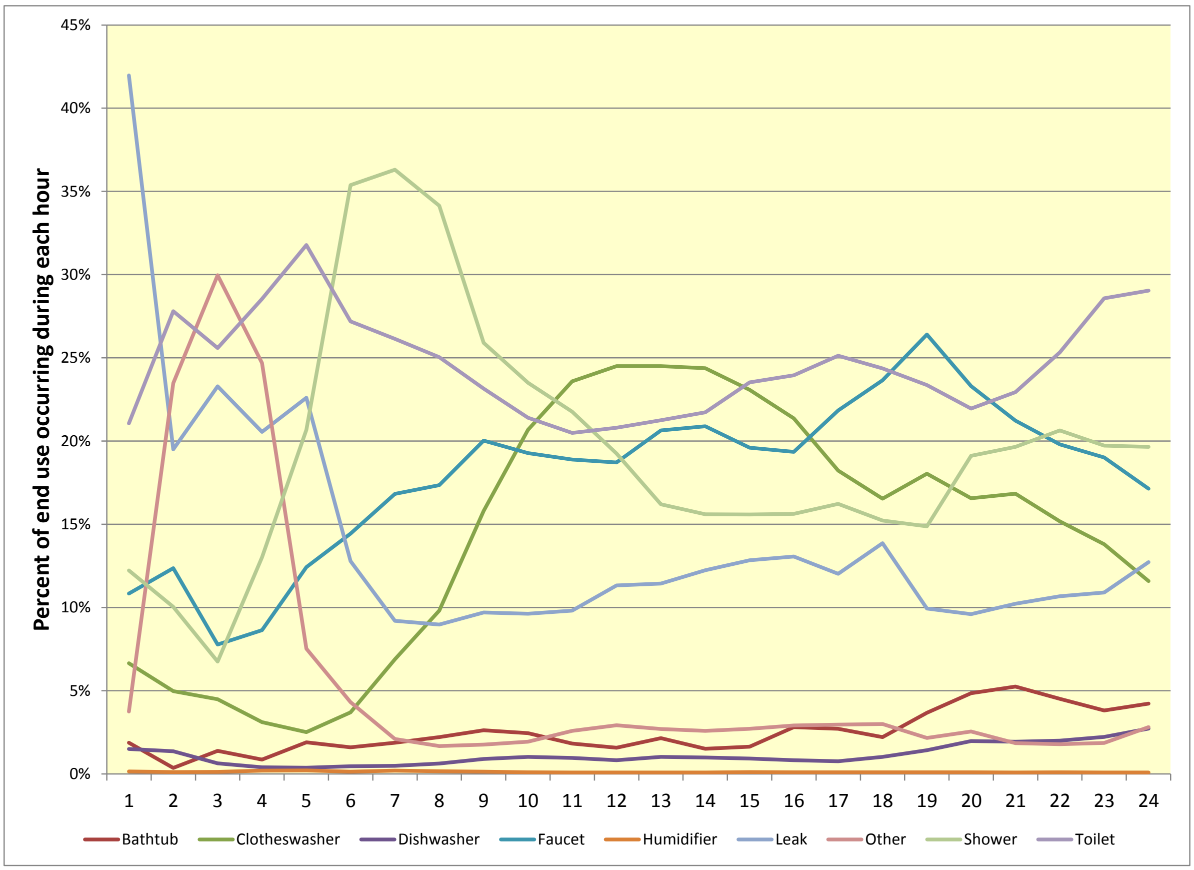


Figure 87: Percent of end use occurring during each hour of day

MODELS OF WATER USE

This section presents the results of correlating measurements of water use from homes that were data-logged with survey and other supplementary information. The fundamental objective of this analysis is to understand and infer—by means of statistical modeling—how various factors influence indoor and seasonal water usage patterns.

The fundamental modeling approach used in this analysis is multiple regression, which relies on the fact that the value of one variable often relies on the value of another. The system is useful when the value of the desired variable, or dependent variable, can be estimated using information on one or more known other variables, or independent variables. In our case, the dependent variable is average daily indoor or outdoor water use, which are the two values which are being explored and the independent variables are a series of known parameters gathered from surveys and data logging. The goal of the modeling is to create a series of equations that can be used to predict how changing of the independent variables is likely to affect the value of the dependent variable.

This is not simply an academic exercise because the results of modeling can be used to show which factors are most important in affecting water use, and therefore can provide guidance to water planners in design of demand management and water conservation programs.

The simplest regression model is one in which the value of the dependent variable is directly related to the value of the independent variable (or group of variables) in a linear fashion. For example, as shown in Equation 1 the value of the indoor water use (IWU) is equal to a constant (or intercept term) plus the number of residents (Res) in the home times a constant coefficient (C).

$$IWU = a + C * Res \qquad \text{Equation 1}$$

In many cases, however, linear models are not the best way to represent the data, especially where they are not normally distributed around a mean. Residential water use is often skewed by a relatively small number of high use customers, which typically give the distribution a right side tail. In cases like this it is often necessary to scale the values from linear to logarithmic. This is called a transformation, so when the term "logarithmic transformation of the data" is used this is what is meant. Also, in the transformation process certain other mechanistic adjustments are often employed to help eliminate certain problems that arise due to logarithmic transformation. For example when values of a variable equal 0 the natural log (ln) is undefined. So a rule that has been used in this analysis is to add a 1 to the arithmetic value before changing it to the natural log in cases where true 0's are present in the data. In a logarithmic analysis the value of the dependent variable is associated with the value of the independent variable, or series of variables, each raised to a power γ. As shown in Equation 2 the indoor water use now is related in a multiplicative way to a constant and the number of residents raised to some power γ, which can technically assume any value and be negative or positive (although in the example γ would be expected to be positive).

$$IWU = a * Res^{\gamma} \qquad \text{Equation 2}$$

In order to eliminate the exponent the equation is converted to its log form by taking the natural log of both sides, which converts it to the form as shown in Equation 3. This is the form that most of the mathematical analysis has been done in the modeling effort.

$$\ln\ IWU \ = a' + \gamma * \ln(Res) \qquad \text{Equation 3}$$

It is very common to describe the changes in water use in response to changes in the value of one or more independent variables in terms of the elasticity of the relationship. Equation 4 represents the elasticity of water to the number of residents in the home. It says that the ratio of the indoor water use for case x to the mean for the group is proportional to the ratio of the number residents in the home x to the average number for the study group raised to the power γ. The equation can be expanded to include multiple independent variables, as shown in Equation 5, where other factors can be added. In this case factors for areas and the price of water (P) have been added.

$$\frac{IWU_x}{IWU_{Ave}} = \left(\frac{Res_x}{Res_{Ave}}\right)^{\gamma} \qquad \text{Equation 4}$$

$$\frac{IWU_x}{IWU_{Ave}} = \left(\frac{Res_x}{Res_{Ave}}\right)^{\gamma_1} \cdot \left(\frac{Area_x}{Area_{Ave}}\right)^{\gamma_2} \cdot \left(\frac{P_x}{P_{Ave}}\right)^{\gamma_3} \qquad \text{Equation 5}$$

Equation 5 can be rearranged to show the projected water use at home x as a function of the average for the group and the series of elasticity relationships shown in the equation, which has been done in Equation 6, and it can be expressed in logarithmic form as in Equation 7. In this form it can be seen that the predicted water use equal a constant plus a series of terms each equaling a coefficient times the ln of a value for one of the independent variables.

$$IWU_x = IWU_{Ave} \cdot \left(\frac{Res_x}{Res_{Ave}}\right)^{\gamma_1} \cdot \left(\frac{Area_x}{Area_{Ave}}\right)^{\gamma_2} \cdot \left(\frac{P_x}{P_{Ave}}\right)^{\gamma_3} \qquad \text{Equation 6}$$

$$\begin{aligned} \ln IWU_x = \ln IWU_{Ave} \ + \ \gamma_1 \ \ln Res_x - \ln Res_{Ave} \\ + \ \gamma_2 \ \ln Area_x - ln\ Area_{Ave} \\ + \gamma_3 \ \ln P_x - \ln P_{Ave} \end{aligned} \qquad \text{Equation 7}$$

If one examines Equation 7 it can be seen that four of the seven terms on the right hand side are constants based on the average values for the study group. This allows the equation to be rearranged and consolidated to give an equation for indoor water use based on the coefficients and values for the variables, with all of the constants aggregated into a single intercept.

$$\begin{aligned} \ln IWU_x = \ln Intercept + \ \gamma_1 \ \ln Res_x \ \ + \ \gamma_2 \ \ln Area_x \\ + \gamma_3 \ \ln P_x \end{aligned} \qquad \text{Equation 8}$$

And the water use for a modified group *x* would be estimated using Equation 9, where n = the number of variables in the system of equations, I = the intercept value, γ_i is the estimate coefficient for each variable and Var_i = the value for the i_{th} variable in the system.

Equation 9

$$IWU_x = \mathrm{C} \cdot \exp \sum_{i=1}^{n} \ln \gamma_i \cdot \ln Var_i$$

The following sections describe how the data were used to generate the lists of relevant variables for describing the water use, and coefficients for regression analysis. The results are used to set up a predictive tool for estimating water use based on the values of the individual parameters.

DESCRIPTION OF MODELING DATABASE

Data associated with a maximum of 759 single-family households were made available for statistical modeling. These data correspond to homes that had data-logging devices installed and for each home include:

- Estimates of daily average consumption by end use
- Estimates of daily average "indoor" consumption
- Estimates of annual average seasonal or "outdoor" use
- Responses to the mail survey
- Water and sewer prices
- Climatic observations and averages

These data were compiled into a single file served as the basis for further analysis, including creation of additional variables, data screening, and estimation of regression models. Each row of the database consists of information associated with a specific home that was data-logged.

DEFINITION OF DEPENDENT VARIABLES

The measurements of the dependent (or left-hand-side) variables of the regression models described in this section were constructed primarily as a means of interpreting and translating flow traces over the respective data-logging periods of 759 homes. End use events and corresponding flows were translated into estimates of daily average water use by end use, as evaluated over the data-logging period, which, depending on any given home, ranged from a period of 6 to 14 days and where the mean (median and mode) logging period was 13 days.

Estimates of daily average "indoor" consumption were derived as a sum of average daily water use estimates for toilet flushing, showering and bathing, clothes-washing machines, dish-washing machines, faucet fixtures, leaks, and "other" end use categories. It is important to note that logged use for faucet fixtures and events designated as leaks can include uses of water that technically can occur outside the homes. Furthermore, it is possible that some uses of water that occur inside the home can be influenced by weather conditions, although the relatively short logging periods and varying calendar dates of logging periods across geographic areas generally preclude the meaningful ability to infer the weather-sensitivity of indoor use.

Estimates of "outdoor" use were derived by jointly assessing logged "indoor" use (as just described) and the monthly water utility billing records provided for each household. Seasonal use, which is traditionally taken as an estimate of outdoor use, was estimated for each household by subtracting an average of water use occurring during the base or low water use period associated with each household from average total use using water-billing records. These estimates of seasonal use were then compared with estimates of "outdoor" use derived as the difference between annual total use from billing records and the estimates of annual total "indoor" inferred from the logging data. Judgments were then made for assigning estimates of outdoor use, but in general a preference was maintained toward those made on the basis of logging data. In cases where estimated annual indoor use exceeded or matched observed total annual use outdoor use was assigned a value of zero.

MODEL ESTIMATION AND SPECIFICATION PROCESSES

Aside from the definitional imprecisions associated with "indoor" and "outdoor" use, there were several things to consider in formulating the general approach to modeling "indoor" and "outdoor" consumption. More specifically:

The modeling database contains only a single measurement of any given water use metric for any given household, meaning that variability in water use across modeling observation is completely cross-sectional.

Observations for climatic and pricing variables are associated with groups of households (cross-sections) for a given geographic area (i.e., study site) and the values of other demographic and socioeconomic variables may also have a tendency to cluster geographically.

Logged consumption for any given "indoor" end use or group of "indoor" end uses occurs over a maximum of two weeks, which can be subject to unique circumstances experienced by sampled households such as vacations or visitors.

These circumstances may not align with general demographic and socioeconomic characteristics measured by the survey, which may be assumed to vary systematically with water use in general, but not over short periods of time for a given household.

With these factors in mind, there was a strong a priori case for employing robust estimation methods, which, as a group of techniques, focus on reducing the undue influence of specific observations on estimation results, with the objective of obtaining "stable" estimates that hold up even in the face of problematic observations. Potentially problematic observations include outliers that represent observations whose values lie at the extremes and leverage points, which may not necessarily be considered extreme, but can influence the overall fit and estimated parameters of a model. In regression analysis with several independent (or right-hand-side explanatory) variables, outliers and leverage points occur in a multidimensional setting that make them difficult to identify without automated iterative procedures afforded by modern statistical software packages.

All models presented in this section were estimated using the MM estimation technique introduced by Yohai (1987). Among robust regression techniques, MM estimation is well suited for cases where there are outliers on both the left- and right-hand sides of the equation. MM estimation employs an iteratively reweighted least squares (IRLS) algorithm, which samples and re-samples modeling observations and applies lower weight in the estimation process to observations that are considered outliers and leverage points.[7] Once the estimated coefficients converge, then the iterative process concludes and estimates of model coefficients are obtained.

In all models the dependent variable was first expressed in terms of average gallons per day and transformed into a natural logarithmic form. In most cases aside from binary (0/1) variables, independent variables are also transformed into natural logs to aid in interpretation of

[7] It should be noted that a particular observation for a right-hand-side can be designated as a leverage point, but not a "bad" leverage point. In other words, an extreme value that generally fits (or falls along the plane of) most observations is weighted more highly than one that does not.

results. Where possible, survey data were used to verify the presence of a particular end use in order to differentiate among cases where there were no events logged due to absence of a particular end use versus having no logged indoor use due to particular circumstances occurring during the logging period. Except for “outdoor” use, observations with no end use consumption were omitted from the regression analyses.

Finally, the model selection process can be characterized as an iterative search for statistically significant relationships governed by some guiding principles and constraints:

- Test and include variables that directly measure or serve as proxies for willingness and ability to pay
- Test and include variables that directly measure or serve as proxies for water requirements
- Increase sample sizes by relying on variables with fewer missing values
- Test and include variables (where possible) to distinguish the effects of efficient water-using technologies
- Seek model parsimony by explaining water use variability with an efficiently small set variables
- Assess parameter estimates by the sign and magnitude of estimated coefficients, as well as statistical significance.

The following sections describe water use models estimated for combined “indoor” use, a subset of key indoor end uses, and “outdoor” use.

Models of indoor uses

Table 77 presents a model for total “indoor” use, which represents a sum of logged use classified into toilets, showers, baths, faucets, clothes washers, dishwashers, leaks, and other end use categories. As expected, the number of permanent residents at the home has a significant impact on indoor water use. The elasticity of “indoor” use with respect to persons per household is less than 1.0, which suggests that per capita indoor use decreases as households become larger. A one percent increase in the number of people in the home is estimated to lead to about a 0.75 percent increase in water use. The elasticity of “indoor” use with respect to persons per household depends on the age of people residing in the home. The implied elasticity for adding children 12 or younger is 0.562 (or 0.748 – 0.186). Of course, people are not added to a household on such a fine scale—for example, adding an additional person to a one-person household is a 100 percent change.

Table 77 Estimated Model of “Indoor” Water Use

Dependent Variable: ln (logged "indoor" use)						
Iteratively Re-Weighted Least Squares Parameter Estimates						
Parameter	**Estimate**	**Standard Error**	**95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	3.281	0.309	2.6	3.8	112.	<.00

Dependent Variable: ln (logged "indoor" use)						
Iteratively Re-Weighted Least Squares Parameter Estimates						
Parameter	**Estimate**	**Standard Error**	**95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
			75	88	55	01
ln (persons residing at the home)	0.748	0.043	0.664	0.832	304.55	<.0001
ln (number of persons 12 years of age and under + 1)	-0.186	0.054	-0.291	-0.080	11.92	0.0006
ln (size of parcel in sq. ft.)	0.122	0.033	0.057	0.188	13.39	0.0003
Indicator for swimming pool (0/1)	0.082	0.043	-0.002	0.165	3.67	0.0554
ln (sewer rate, $/kgal)	-0.112	0.051	-0.211	-0.013	4.87	0.0274
Indicator for presence of efficient toilets/flushes (0/1)	-0.174	0.036	-0.245	-0.103	22.94	<.0001
Indicator for presence of efficient clothes washers/washloads (0/1)	-0.073	0.035	-0.142	-0.005	4.39	0.0362
Indicator for home water treatment system (0/1)	0.155	0.055	0.047	0.262	7.94	0.0048
Indicator for hot water on demand system (0/1)	-0.109	0.054	-0.216	-0.003	4.06	0.0440
Number of Observations	723					
Outliers detected	14					
Leverage points detected	188					
Robust R-Square	0.3041					

Figure 88 illustrates the estimated cumulative and incremental impacts on “indoor” use of adding additional people to an existing household (holding all other factors in the model constant). By additional people is meant in relation to a house with one occupant. So, 1 additional person is a home with 2 person, 2 incremental person is for a home with 3 occupants and so on. The increments shown in Figure 89 matches the increments derived from the power curve shown in Figure 52

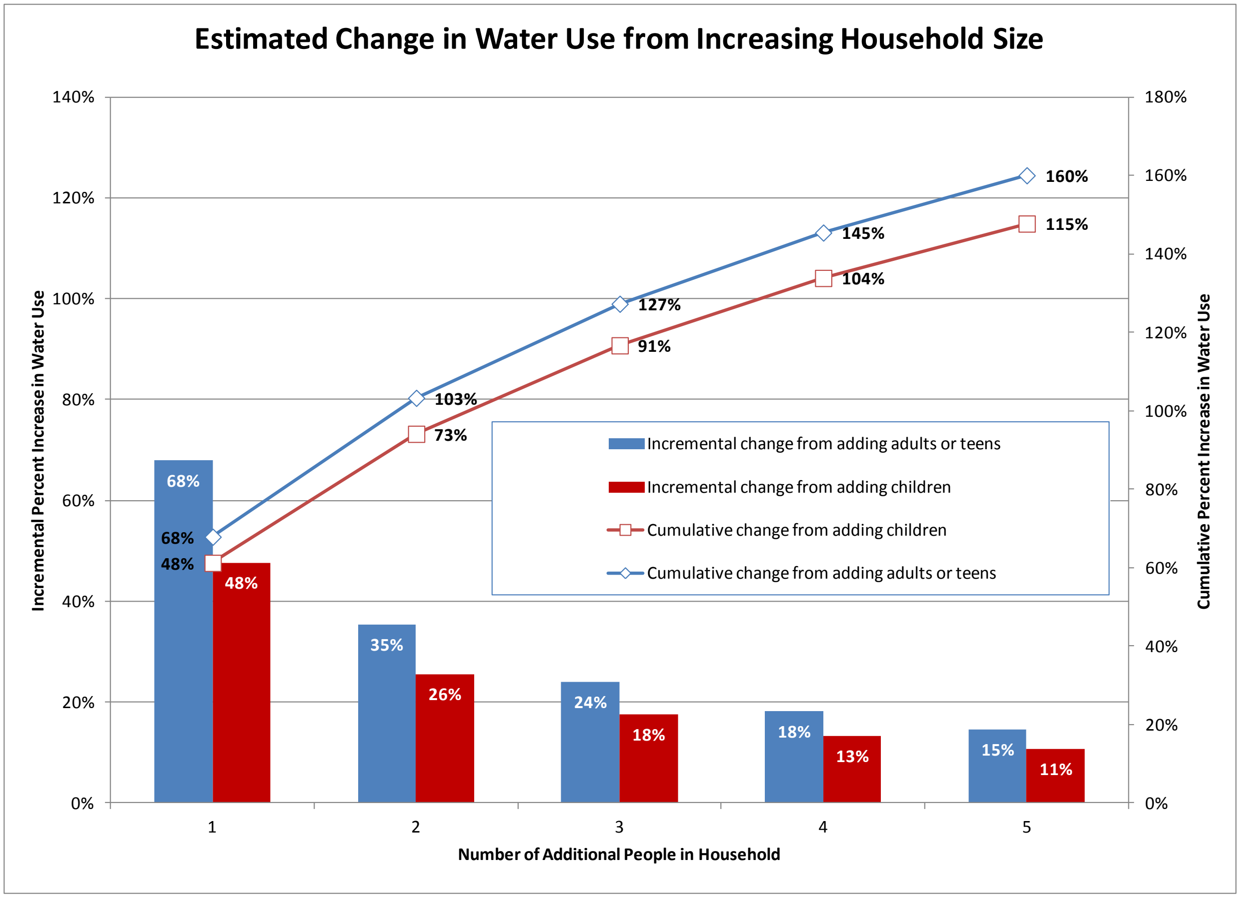


Figure 88: Relationship between increment in water use versus increment in number of residents

Parcel size is used as a rough proxy for income, mostly because of practical deficiencies with income as reported in the mail survey. Parcel size had fewer missing values and is measured on a continuous scale (instead of by discrete categories) and consistently showed superior statistical power. Nevertheless, as a proxy the coefficient estimate suggests that higher income and/or wealth leads to higher “indoor” water use.

The price of sewer outperformed available measures for the price of water in the “indoor” model. The estimated coefficient for the price of sewer retains a high degree of statistical significance and has the expected (negative) sign and a rational magnitude. A one percent increase in the price of sewer is estimated to lead to a 0.1 percent decrease in “indoor use.”

As expected, the efficiency of toilets and clothes washers has an important impact on "indoor" use. The binary (0/1) variable for efficient toilets assumes a value of 1 for households where average flush volumes were below 2.0 gallons per flush (gpf) and a value of 0 otherwise. The coefficient estimate suggests that homes that are fully equipped with high efficiency toilets use about 16 percent less water for "indoor" purposes,[8] accounting for the effects of the other model variables. The binary (0/1) variable for efficient clothes washers assumes a value of 1 for households where average wash load volumes were under 30 gallons per load and a value of 0 otherwise. The coefficient estimate for the efficient clothes washer variable implies that "indoor" use is about 7.1 percent less for homes with efficient clothes washers, given the effects of the other model variables.

It is possible that the measurements of "indoor" use can be influenced by specific technologies or end uses that could not be readily identified in the flow traces. As shown in Table 77, the presence of home water treatment systems has a statistically significant impact on water use. On average, the presence of these systems is estimated to result in a 16.5 percent increase in "indoor" use. On the other hand, hot water on demand systems, which reduce waiting times for hot water are estimated on average to reduce "indoor" use by about 10.5 percent.

Finally, and as noted earlier in this section, "indoor" use is inclusive of faucets that may serving outdoor uses, as well as leaks that could also be occurring outside of the home. Among various outdoor uses that were tested for association with "indoor" use, only the presence of swimming pools was found to be consistently statistically significant. On average, the presence of a swimming pool was found to increase estimates of "indoor" use by about 8.4 percent. As will be shown below, the connection of swimming pools to "indoor" use is verified to be occurring by means of faucets and leaks.

MODELS OF SELECTED "INDOOR" END USES

The process of developing the "indoor" model described above begged several questions about how the estimated relationships relate to specific "indoor" end uses. For example, does price and ability to pay affect specific "indoor" uses more than others? Does household size and composition matter more for certain end uses? Are there specific pathways through which the presence of pools influence "indoor" water use as it is currently defined? The sections below briefly describe additional water use models that were estimated for selected water end uses that are contained within the "indoor" water use measurements. Relatively less attention is paid to statistical significance of the parameters estimates and deservedly more focus is given to contrasting parameter estimates with those of the "indoor" model and finding influence of factors that may not have contributed significantly to (or "washed out" of) explaining "indoor" use as a whole.

Toilet Flushing

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[8] The estimate of the relative percent change in use is calculated as $100 \times \ e^{\beta-0.5\sigma_\beta^2} - 1$, where β is the coefficient estimate for the binary (0/1) variable and σ is the standard error of the coefficient estimate. Accounting for the other model variables, a home with all toilets operating at flush volumes less than 2 gpf would be estimated to use $100 \times \ e^{-0.174-0.5(0.036)^2} - 1$ = -15.96 percent less water for "indoor" purposes. Similar calculations are performed in the interpretation of all binary variables discussed in this section.

Table 78 presents a model of water used for toilets. As one should expect, the number of people in the home is a strong predictor and more people—especially those who are normally at home during the day—lead to more flushing. Other inferential items of note include:

- Teens and children tend to use less water for flushing than adults.
- There is a practically small but statistically significant influence of the income proxy, parcel size.
- There is a small and statistically insignificant effect of sewer price.
- Renters use less water for toilet flushing (perhaps because they tend not to be home as often during the day; further, this could be reflective of incentives for landlords to install more efficient toilets).

The impact of having efficient toilets is relatively large. Given the effects of the other variables in the model, home with average flushes volumes less than 2.0 gpf used about 45 percent less water for flushing ($100 \times \; e^{-0.598-0.5\ 0.039\ ^{2}} - 1 \; = -45.0$).

Table 78: Estimated Model of Toilet Use

Dependent Variable: ln (logged toilet use, gpd)						
Iteratively Re-weighted Least Square Parameter Estimates						
Parameter	**Estimate**	**Std. Error**	**95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	2.441	0.313	1.827	3.056	60.67	<.0001
ln (persons residing at the home)	0.656	0.054	0.551	0.761	150.40	<.0001
ln (number of persons 13-17 years of age + 1)	-0.144	0.073	-0.287	-0.001	3.88	0.0489
ln (number of persons 12 years of age and under + 1)	-0.184	0.060	-0.302	-0.066	9.37	0.0022
ln (number of persons home during the day + 1)	0.244	0.046	0.154	0.334	28.41	<.0001
ln (size of parcel in sq. ft.)	0.060	0.034	-0.006	0.126	3.20	0.0735
ln (sewer rate, $/kgal)	-0.054	0.054	-0.159	0.052	1.00	0.3170
Indicator for presence of efficient toilets/flushes (0/1)	-0.598	0.039	-0.674	-0.521	236.16	<.0001
Indicator for renter (0/1)	-0.144	0.084	-0.309	0.020	2.96	0.0856

Dependent Variable: ln (logged toilet use, gpd)						
Iteratively Re-weighted Least Square Parameter Estimates						
Parameter	**Estimate**	**Std. Error**	**95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Number of Observations	705					
Outliers detected	14					
Leverage points detected	237					
Robust R-Square	0.3464					

Showers and Baths

Table 79 presents a model for water used for showering and bathtub use combined. More people in the household leads to more showering/bathing, and the model estimates suggest that teenagers use more water for showering than other age cohorts. Other notable findings include:

- The greater the number of people employed outside the home, the more water that is used for showering/bathing.
- There is a statistically significan.t influence of the income proxy, parcel size
- There is a statistically significant effect of sewer price (1 percent increase in price is estimated to lead to a -0.2 percent decrease in water used for showering/bathing).
- The presence of a hot water on demand system reduces the amount of water used for showering/bathing. The coefficient estimate for this variable suggests that homes with these systems used about 14 percent less water on average than those homes without these systems (given the effects of other variables specified in the model).

Table 79: Estimated Model of Shower and Bath Use

Dependent Variable: ln (logged shower and bath use, gpd)						
Iteratively Re-weighted Least Square Parameter Estimates						
Parameter	**Estimate**	**Std. Error**	**95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	1.328	0.426	0.493	2.164	9.710	0.0018
ln (persons residing at the home)	0.739	0.073	0.596	0.882	102.830	<.0001
ln (number of persons 13-17 years of age + 1)	0.282	0.092	0.101	0.462	9.350	0.0022

Dependent Variable: ln (logged shower and bath use, gpd)						
Iteratively Re-weighted Least Square Parameter Estimates						
Parameter	**Estimate**	**Std. Error**	**95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
ln (number of persons 12 years of age and under + 1)	-0.114	0.077	-0.264	0.036	2.230	0.1356
ln (size of parcel in sq. ft.)	0.124	0.045	0.035	0.212	7.420	0.0064
ln (number of adults employed outside of the home + 1)	0.508	0.064	0.384	0.633	64.070	<.0001
ln (sewer rate, $/kgal)	-0.201	0.070	-0.339	-0.064	8.240	0.0041
Indicator for hot water on demand system (0/1)	-0.152	0.077	-0.304	-0.001	3.900	0.0484
Number of Observations	704					
Outliers detected	7					
Leverage points detected	188					
Robust R-Square	0.3298					

Clothes Washers

Table 80 presents a model of water used for clothes washing by clothes washing machines. As expected, more people in the home leads to more water use for clothes washing, but unlike some of the other basic indoor end uses, the analysis did not find any significant differentiation of use according to the age composition of the home. In addition:

- The greater the number of people employed outside the home, the more water that is used for clothes washing (although the effect has relatively low statistical significance).
- There is a statistically significant influence of the income proxy, parcel size.
- There is a statistically significant effect of sewer price and it is comparable in magnitude to the price elasticity found for showering/bathing (1 percent increase in price is estimated to lead to a -0.16 percent decrease in water used for clothes washing).

The indicator variable for the presence of efficient clothes washers is highly significant statistically and in magnitude. Given the estimated effects of the other model variables, homes where the average wash-load volume was less than 30 gallons on average used about 47 percent less water than other homes ($100 \times \; e^{-0.628-0.5\;0.052^{\;2}} - 1 \;=\; -46.7$).

Table 80: Estimated Model of Clothes Washer Use

Dependent Variable: ln (logged clothes washer use, gpd)						
Iteratively Re-weighted Least Squares Parameter Estimates						
Parameter	**Estimate**	**Std. Error**	**95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	1.954	0.440	1.091	2.816	19.71	<.0001
ln (persons residing at the home)	0.574	0.057	0.462	0.685	101.87	<.0001
ln (size of parcel in sq. ft.)	0.100	0.047	0.009	0.191	4.59	0.0322
ln (number of persons employed full-time outside the home + 1)	0.076	0.066	-0.054	0.206	1.30	0.2534
ln (sewer rate, $/kgal)	-0.162	0.073	-0.306	-0.019	4.90	0.0268
Indicator for presence of efficient clothes washers/washloads (0/1)	-0.628	0.052	-0.730	-0.526	146.40	<.0001
Number of Observations	689					
Outliers detected	6					
Leverage points detected	42					
Robust R-Square	0.2331					

Faucets

Several variables were found to influence or to be associated with the amount of water used for faucets. Unlike some other end uses, faucet fixtures can serve multiple purposes, such as cleaning, washing, rinsing, and cooking. In cases where the volume of use is small faucets may also include water used for outdoor water uses such as irrigation, pool re-filling, and recreation. Although large faucet uses for these purposes were normally labeled as irrigation (landscape) uses during flow trace analysis. Table 81 presents a model of the logged water used for faucets. Similar to the models for toilets and showers, the age composition of people residing in the home influences the amount of water used for faucets. The proxy for income (parcel size) retains the expected positive sign, but is low in magnitude and statistical significance. The price variable is marginally significant, but retains an unexpected (positive) sign. This general outcome was the same using other available definitions of price as well. There is no supportable explanation for this irrational result according to economic theory. However, the 95 percent confidence interval for the parameter estimate suggests that there is a chance that the estimated relationship with price could in fact be negative.

Other inferences from the model of logged faucet use include:

- Teens and children tend to use less water for faucet use than adults
- Homes with hot water on demand systems used about 12 percent less water for faucets than those with such systems
- There is a small negative but statistically insignificant correlation with the indicator for irrigating households, which suggests negligible influence of irrigation on faucet estimates in the sample
- The presence of pools have almost no effect on the estimates, except for those with automatic refill systems as one would expect

The indicator variable for automatic pool refill systems is highly significant and its coefficient estimate is relatively large in magnitude. Homes that had pool auto-refill systems on average had 66 percent higher logged faucet use than those homes that did not ($100 \times e^{0.511-0.5\ 0.123\ ^{2}} - 1 = 65.5$). This is also an expected result since small water uses for pool refilling would normally be labeled as faucet use during analysis.

Table 81: Estimated Model of Faucet Use

Dependent Variable: ln (logged faucet use, gpd)						
Iteratively Re-weighted Least Squares Parameter Estimates						
Parameter	**Estimate**	**Std. Error**	**95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	1.834	0.427	0.998	2.670	18.49	<.0001
ln (persons residing at the home)	0.700	0.071	0.561	0.839	97.87	<.0001
ln (number of persons 13-17 years of age + 1)	-0.199	0.097	-0.388	-0.010	4.24	0.0394
ln (number of persons 12 years of age and under + 1)	-0.169	0.079	-0.322	-0.015	4.61	0.0318
ln (number of persons home during the day + 1)	0.155	0.060	0.038	0.272	6.76	0.0093
ln (size of parcel in sq. ft.)	0.059	0.046	-0.032	0.150	1.61	0.204
ln (sewer rate, $/kgal)	0.131	0.071	-0.007	0.270	3.46	0.063
Indicator for hot water on demand system (0/1)	-0.122	0.077	-0.272	0.029	2.50	0.1139
Indicator for swimming pool (0/1)	-0.027	0.062	-0.148	0.095	0.19	0.6641
Indicator for swimming pool with an automatic refill system (0/1)	0.511	0.123	0.271	0.751	17.42	<.0001

Dependent Variable: ln (logged faucet use, gpd)						
Iteratively Re-weighted Least Squares Parameter Estimates						
Parameter	**Estimate**	**Std. Error**	**95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Indicator for irrigator (0/1)	-0.078	0.056	-0.188	0.032	1.95	0.163
Number of Observations	693					
Outliers detected	11					
Leverage points detected	192					
Robust R-Square	0.1953					

Leaks

Leakage should be considered a unique "end use," since conceptually it combines wasteful losses of water associated with potentially several types of specific fixtures or purposes. Table 82 presents a model of water use identified as being associated with leaks. Some findings of note include the following:

- Larger household sizes are associated with more leakage; there is also a tendency for more leaks to be associated with the number of people employed outside the home, although the effect has low statistical significance
- The amount of use identified as leaks is positively related to parcel size
- The price variables retains the expected sign, but is low in statistical significance
- The presence of efficient toilets is negatively related to leaks, which may suggest some leaks are remedied with the installation of newer toilets; furthermore, this may also suggest that efficient water using behaviors spill over to reducing wasteful water losses

Finally, the presence of swimming pools has a statistically significant estimated effect on water use identified as leaks. The presence of a pool alone on average increases the estimated amount of leaks by about 60 percent. The coefficient estimates also suggest that homes with pool auto-refill systems have more than double the amount of use assigned to leaks (+259 percent) than other homes, given the effects of other variables in the model. This can be the result of small pool refills being identified as leakage and the fact that pools are often sources of actual leaks which are assigned to this category during analysis.

Table 82: Estimated Model of Leaks

Dependent Variable: ln (logged leak use, gpd)
Iteratively Re-weighted Least Squares Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept	-0.168	1.083	-2.290	1.954	0.02	0.8767
ln (persons residing at the home)	0.385	0.143	0.104	0.665	7.21	0.0072
ln (number of adults employed outside of the home + 1)	0.160	0.164	-0.161	0.480	0.95	0.3290
ln (size of parcel in sq. ft.)	0.168	0.116	-0.059	0.394	2.10	0.1470
Indicator for swimming pool (0/1)	0.485	0.158	0.175	0.795	9.38	0.0022
Indicator for swimming pool with an automatic refill system (0/1)	1.332	0.332	0.682	1.983	16.12	<.0001
ln (sewer rate, $/kgal)	-0.157	0.187	-0.523	0.210	0.70	0.4023
Indicator for presence of efficient toilets/flushes (0/1)	-0.301	0.134	-0.563	-0.039	5.08	0.0242
Number of Observations	684					
Outliers detected	11					
Leverage points detected	194					
Robust R-Square	0.0750					

Summary Comparison of Estimated "Indoor" Elasticities

Table 83 presents a brief comparison of the estimated influence of the three key socioeconomic variables that were specified among the models of "indoor" end uses described above. The natural logarithmic transformation of the dependent variable in the models and the independent variables for the number of people residing in the home, parcel size, and price of sewer permits a convenient interpretation of the estimated coefficients in terms of elasticity, and thus a ready means of evaluating differences in the estimated responsiveness of water use across the end uses.

Table 83: Comparison of Estimated "Indoor" Elasticities

End Use	Estimated Elasticities		
	Persons per Household	Parcel Size	Price of Sewer
"Indoor" Total	0.748	0.122	-0.112

End Use	Estimated Elasticities		
	Persons per Household	Parcel Size	Price of Sewer
Toilets	0.656	0.060	-0.054
Shower/Bath	0.739	0.124	-0.201
Clothes Washer	0.574	0.100	-0.162
Faucet	0.700	0.059	0.131
Leak	0.385	0.168	-0.157
Note: Red type indicates estimated elasticity is not significant at 95% confidence level of Chi-square test			

The number of people in the home is by far the most important indicator of "indoor" use and was statistically significant across all "indoor" models that were estimated. The responsiveness of combined "indoor" use to household size is most consistent with the elasticities estimated for shower/bath and faucet use. However, it is important to recall that the age composition of households also had a varying influence in addition to just the number of people in the home.

Parcel size was used consistently across models as a proxy measure of income in order to avoid assigning a limited number of discrete values for income as well as to increase sample size. Although imperfect as a proxy for ability to pay, the parcel size variable retained the expected positive sign across all models. Parcel size was statistically significant in the combined "indoor" model, and it appears this significance can be attributed to the influence of the variable on shower/bath and clothes washer use. The magnitude of the estimated elasticity for parcel size is largest for the leak model, where it is possible the variable could be picking up leakage occurring outside the home.

Finally, the price of sewer consistently out-performed other measures of price, including volumetric and average prices for water, in terms of correlating with "indoor" end uses. It is fair to judge the estimated influence of the price of sewer as a reasonable measure of price elasticity. Because water use for domestic purposes, such as most of those included in "indoor" use, represent household necessities, one should expect price elasticity to be relatively low. The estimated values in Table 83 reflect a generally low responsiveness of "indoor" use to price. Aside from the irrational positive elasticity for faucet use, all price elasticity estimates retain the expected negative sign. Price is a statistically significant regressor in the combined "indoor" model. The findings imply that the overall significance to "indoor" use stems from the significance of price to the shower/bath and clothes washer end uses.

Example Application of Results

Table 84 shows how the indoor use model can be applied to estimate the indoor water used for a group of homes with parameters specified by the user. In this case the input parameters have been set to the average study values determined from the study data. The natural logs are calculated for each parameter and multiplied by the respective coefficient values to derive predictions of the natural log of "indoor" water use. The sum of these terms is then used as the exponent to the base *e*, which provides the estimate of the average indoor water use for the group in the desired raw scale. In this case, the intercept coefficient was slightly modified to calibrate the model to the average indoor water use of 138 gphd, which is the average for the study group from Table 47.

Table 84: Example of use of "indoor" use models

Variable	Study Average	Input	Independent parameter	LN of Input Value= Ln(Col 3)	Coefficient	ln term = Col 5 x Col 6	Indoor gpd
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Intercept	1	3.33	3.365	
Persons residing at the home	2.60	2.60	ln (persons residing at the home)	0.96	0.748	0.715	
number of persons 12 years of age and under	0.40	0.40	ln (number of persons 12 years of age and under + 1)	0.34	-0.186	-0.063	
size of parcel in sq ft	9,554	9,554	ln (size of parcel in sq. ft.)	9.16	0.122	1.118	
swimming pool	1%	0.01	Indicator for swimming pool (0/1)	0.01	0.082	0.001	
sewer rate, $/kgal		3	ln (sewer rate, $/kgal)	0.92	-0.112	-0.103	
efficient toilets	37%	0.37	Indicator for presence of efficient toilets/flushes (0/1)	0.33	-0.174	-0.064	
efficient clothes washer	46%	0.46	Indicator for presence of efficient clothes washers/washloads (0/1)	0.46	-0.073	-0.034	
water treatment	3%	0.03	Indicator for home water treatment system (0/1)	0.03	0.155	0.005	
hot water on demand	11%	0.11	Indicator for hot water on demand system (0/1)	0.11	-0.109	-0.012	
Total Household Use						4.928	138.1
Average Per Capita Use							53.12

If the three variables that were found to decrease indoor water use: high efficiency toilets, clothes washers and hot water systems were all set to 100% saturation the model predicts that the household use for the group would decrease from 138 gpd to 108 gpd, or from 53 gpcd to 41.5 gpcd—a 21% reduction in indoor use.

MODEL OF LANDSCAPE USE

As indicated at the outset of this section, "outdoor" use for each home in the sample is generally defined as the difference on an annual average basis between total billed consumption and best estimate of "indoor" use as estimated from data logging and billing data. For the "outdoor" model, 1 gallon per day is added to the estimated "outdoor" use to permit the inclusion of zero-use observations within the logarithmic transformation. This approach was taken because of the relatively strong correlation between the proportion of observations that were zero for a given utility service area and both the price of water and general climate. Table 85 displays information on the proportion of outdoor water use estimates that assumed a value of 0 by utility along with price and climate metrics. Table 86 presents a simple linear regression of the fraction of observations assigned a value of 0, with independent variables shown in Table 85. Although the sample size is limited, the regression estimates suggest a fairly strong association of price and climate with the proportion of observations assigned a value of 0 for outdoor use; places with higher temperatures, lesser precipitation, and higher prices tend to have more observations assigned a 0 for "outdoor" consumption. Thus, conceptually, this analysis permits the estimated absence of "outdoor" use to be affected by the climate of any given region and choices involving the cost of water to the consumer.

Table 85: Summary of Landscape Water Use Observations and Related Price and Climate Data

Utility	Number of Observations		% Assigned Zero	Volumetric Price for 10 kgal	High Temp Index	Precip Index
	Total	Assigned Value of 0				
Clayton	94	32	34%	5.95	1.35	5.30
Denver	94	2	2%	2.11	1.21	1.60
Fort Collins	85	7	8%	2.35	1.20	1.72
San Antonio	91	10	11%	1.44	1.51	3.44
Scottsdale	96	9	9%	3.35	1.64	1.00
Tacoma	97	20	21%	2.09	1.15	4.16
Toho	66	9	14%	1.66	1.56	5.40
Peel	59	14	24%	2.89	1.04	3.30
Waterloo	61	36	59%	5.38	1.00	3.81
Total	743	139	19%			

Note: *High Temp Index* calculated as Annual Average High Temperature/53.2
Note: *Precip Index* calculated as Annual Total Precipitation/9.37

Table 86: Regression Model Demonstrating Correlation of "Outdoor" Water Use Estimates Assigned a Value of 0 with Price and Climate

Dependent Variable: Fraction of outdoor water use estimates with 0 value				
Variable	Estimate	Standard Error	t Value	Pr > |t|
Intercept	0.213	0.233	0.91	0.4028
High Temp Index	-0.254	0.153	-1.66	0.1584
Precip Index	0.036	0.022	1.61	0.1679
Volumetric Price 10 kgal	0.066	0.023	2.92	0.0329
F Value	7.07			
Pr > F	0.030			
Adjusted R-Square	0.695			
Number of Observations	9			

Table 87 presents a model estimated for "outdoor" use. As in the modeling of "indoor" end uses, the specification and selection of variables was the result of an iterative process of testing the contributions and significance of a wide range of variables. The impact of climate is accounted for by using the values of the temperature and precipitation indices shown in Table 87. As expected, "outdoor" use estimates tend to be higher in warmer and drier places, everything else remaining the same. Average maximum daily temperature and precipitation occurring during the month of the data logging period are also incorporated into the model in order to attempt to account for the practical difficulties in estimating values for outdoor use by means of subtracting "indoor" use or low-season water use values from total use. The signs of the coefficient estimates suggest that weather observed during the logging period has an impact on the estimates of outdoor use via estimation of the "indoor" water use component. The coefficient estimates suggest that there is a tendency for "outdoor" use estimates to be lower with higher values of temperatures during the logging period and higher with greater amounts of precipitation during the logging period. This is indicative of the possible under-estimation of "outdoor" use due to differences in (a) the timing of logging periods, (b) climates among sampled homes, including those that support year-round outdoor uses, and (c) the fact that "indoor" uses such as faucets and leaks may apply to water uses occurring outdoors. After accounting for these effects and general differences in climate, the following inferential items are of note:

Only a single measure related to household size or composition was significant in the landscape model. The greater the number of children age 12 and under, the lower is outdoor use. Once possible explanation for this is that households with small children may tend to address priorities that do not include lawn irrigation.

Table 87: Estimated Model of "Outdoor" Use

Dependent Variable: ln (Estimated Average Annual Landscape Use in gallons per day + 1)						
Iteratively Re-weighted Least Squares Parameter Estimates						
Parameter	**Estimate**	**Std. Error**	**95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	4.267	4.326	-4.211	12.746	0.970	0.3239
ln (number of persons 12 years of age and under + 1)	-0.316	0.142	-0.595	-0.038	4.940	0.0262
ln (size of parcel in sq. ft.)	0.611	0.118	0.381	0.842	27.070	<.0001
ln (percent of parcel that is irrigable + 1)	0.361	0.095	0.175	0.546	14.510	0.0001
Indicator for post 2006 construction (0/1)	0.906	0.370	0.181	1.630	6.000	0.0143
ln (volumetric price for water at 10 kgal, $/kgal)	-0.904	0.146	-1.190	-0.618	38.390	<.0001
ln (annual average maximum temperature index)	1.285	1.201	-1.068	3.638	1.150	0.2844
ln (annual total precipitation index)	-1.775	0.247	-2.258	-1.292	51.870	<.0001
ln (average maximum temperature during logging period)	-0.875	0.674	-2.196	0.446	1.690	0.1942
ln (total precipitation during logging period + 1)	0.772	0.175	0.428	1.116	19.360	<.0001
Indicator for presence of swimming pool (0/1)	0.326	0.156	0.021	0.631	4.380	0.0364
Indicator for presence of drip irrigation system (0/1)	-0.215	0.197	-0.601	0.170	1.200	0.2732
Indicator for presence of in-ground irrigation system with automatic timer (0/1)	1.134	0.163	0.815	1.454	48.390	<.0001
Indicator for no turf irrigated (0/1)	-0.436	0.143	-0.717	-0.155	9.270	0.0023
Indicator for use of rain barrel(s) (0/1)	-0.855	0.268	-1.381	-0.329	10.160	0.0014
Number of Observations	718					
Outliers detected	2					
Leverage points detected	237					
Robust R-Square	0.3188					

The variables for parcel size and the percentage of the parcel that is irrigable are highly significant and together capture the impact of income and potential scale of lawn irrigation. A one percent increase in parcel size is estimated to increase “outdoor” use by about 0.6 percent.

A small proportion of the sample represented homes built after 2006. Accounting for the effects of all other model variables, this segment of the modeling sample had much higher outdoor use. Although it is not possible to determine from the survey data, the higher water use estimates may be associated with establishing newly planted turf and other lawn material.

The estimated price elasticity of “outdoor” water use is relatively high and statistically significant. The coefficient estimate suggests that a 1 percent increase in the volumetric water rate applicable at 10,000 gallons per month decreases “outdoor” water use by about 0.9 percent. If one were to assume that 60 percent of annual use is “indoor” and 40 percent is “indoor” and given the estimated price elasticity of “indoor” use estimated above, an overall combined estimate of single-family price elasticity would be about -0.43.

On average, and accounting for the other model factors, the “outdoor” water use of households that reportedly do not irrigate turf is about 36 percent lower than those that do.

The “outdoor” water use of households with swimming pools is about 37 percent higher than the “outdoor” water use of households without swimming pools (everything else remaining the same)

Several irrigation-related technology variables were tested in the process of finalizing the “outdoor” water use model. Indicator variables for technologies associated with “ET-based” or “smart” controllers, soil moisture sensors, and rain sensors were found consistently to be statistically insignificant. Households using low-water-using drip irrigation systems had lower “outdoor” use (about 21 percent lower use on average relative to other households), but as shown in Table 87 retains generally low statistical significance. A small proportion of the “outdoor” modeling sample (about 5 percent) reportedly employ the use of rain barrels or rain harvesting methods as an alternative supply source for outdoor water needs. The coefficient of the rain barrel indicator suggests that “outdoor” use in this segment of the sample is about 59 percent lower on average than other households after accounting for the other variables in the model $(100 \times \ e^{-0.855-0.5\ 0.268\ ^{2}} - 1 \ = \ 59.0)$.

Finally, and perhaps statistically the strongest variable in the “outdoor” model other than climate, the presence of an in-ground irrigation system with a timer is confirmed to be a technology that is associated with higher irrigation demands. About 35 percent of the “outdoor” modeling sample report having such systems. Accounting for the estimated influence of other model factors, the coefficient estimate for this variable suggests that on average homes that use these systems use a little more than twice the amount water outdoors than households that do not $(100 \times \ e^{1.134-0.5\ 0.163\ ^{2}} - 1 \ = \ 206.7)$.

ASSESSMENT OF CONSERVATION POTENTIAL AND BENCHMARKING

ANALYSIS OF BILLING DATA SUMMARIES BY CUSTOMER SECTORS

Annual billing data summaries for total sales and major customer sectors were provided by nine Level 1 and sixteen Level 2 study participants. The data covered the 5-year period from 2006 to 2010. The sales data were analyzed to determine the structure of total water demand at each site and calculate metrics of aggregate and sectorial water use. The procedure for calculating the aggregate and sectorial metrics followed the approach used in Water Conservation Metrics Guidance Report (AWWA 2010).

Information on the number of customer accounts, total water sales, and percentage proportions of volumetric water sales by major customer sector are summarized in Table 88. The 25 study sites include both small and large utilities with the number of customer accounts ranging from 17,400 in Mountain View, CA to 472,200 in Philadelphia. PA. Similarly, total water sales range from 9.7 mgd in Mountain View, CA to 176.5 mgd in Miami-Dade, FL.

The breakdown of total sales by major customer sector shows that residential sectors (single-family and multifamily) generally account for 55% to 75% of total sales (on average 62%, see Figures 1 and 2, below); shares lower than 50% can be attributed to high proportion of sales through irrigation meters (e.g., Toho) and/or the presence of one or more very large quantity industrial customers (e.g., Tacoma). Water sales to nonresidential customers generally account for about 30% of the total and range from 20% to 40%. An important emerging sector includes urban irrigation meters. It accounts for significant proportion of total water use in some cities (Toho, Mountain View, Otay, Henderson and San Diego). Because irrigation meters generally do not distinguish between residential and nonresidential customers, the estimated shares of water use by these traditional sectors do not account for some irrigation use.

The metric of total annual sales per customer account was calculated and is included in the fourth column of Table 88. It shows a wide range of values from 224.4 gallons per account per day (gpad) in Waterloo, Ontario to 3,024 gpad in Chicago, Illinois. This implies that the structure of residential and nonresidential sectors in terms of average water use per account vary greatly among the 25 sites and is unique to each service area. Because of this, as well as other site-specific factors that influence water demand, *no dependable benchmarks of water use can be developed from aggregate annual consumption and number of customer accounts data*.

However, somewhat crude water use benchmarks can be developed using the average annual use metric (AUM) from sales to a relatively uniform single-family residential sector. Accordingly, the AUM metric was calculated for single-family sector for each study site as average usage rate per single-family account during the 2006-2010 period. The results are shown in Table 89. The average annual usage rate across the 25 study sites is 254 gallons per SF account per day (gpad), ranging from 152 gpad in Cary, NC to 476 gpad in Henderson, NV. Given the average occupancy rate of 2.7 persons per day the average per capita daily use was 93 gpcd.

Table 88: Aggregate Water Use Metrics and Structure of Sectorial Water Demand by Study Site

Study Site	No. of Customer Accounts in 2010	Total 2010 Sales, MGD	Average 2006-10 Sales per Account, gpad	Percent of Annual Use by Sector/Subsector (2006-10 Data)				
				Total Resid	SF Resid	MF Resid	Non-Residential	Irriga-tion
LEVEL 1								
1. San Antonio WS, TX	363,430	143.8	395.6	70.1	55.7	14.4	22.0	7.9
2. City of Scottsdale, AZ	174,520	59.4	340.2	78.1	62.9	15.2	21.7	0.2
3. Clayton County WA, GA	76,000	21.7	285.5	72.1	48.6	23.5	26.6	1.3
4. Region of Waterloo, Ontario	65,615	14.7	224.4	66.6	49.0	17.6	33.4	0.0
5. Region of Peel, Ontario	293,520	117.6	400.5	67.6	51.0	16.6	32.3	0.1
6. Toho Water Authority, FL [a]	108,410	35.8	330.0	28.9	28.9	0.0	32.9	38.2
7. Tacoma Water, WA [b]	97,136	47.6	490.1	45.4	34.6	10.8	52.1	2.5
8. Denver Water, CO	305,600	183.9	601.9	69.4	63.8	5.6	30.0	0.6
9. Austin Water Utility, TX	210,900	108.1	512.6	58.6	38.6	20.0	41.4	0.0
LEVEL 2								
1. City of San Diego, CA	273,950	155.1	566.0	55.9	36.8	19.1	30.7	13.4
2. Aurora Water, CO	76,730	41.2	536.3	70.4	45.8	24.5	19.9	9.8
3. Otay Water District, CA	48,530	29.8	613.7	61.6	52.3	9.3	14.7	23.7
4. EPCOR, Edmonton, Alberta	241,200	64.8	268.8	66.6	48.8	17.8	33.4	0.0
5. City of Santa Barbara, CA	26,513	10.5	396.5	69.7	46.6	23.1	24.7	5.6
6. Cobb County WS, GA	166,740	53.5	320.6	57.3	57.3		38.8	3.9
7. Regional Water Authority, CT	118,100	39.3	333.1	64.3	64.3	0.0	35.7	0.0
8. Portland Water Bureau, OR	184,300	55.9	303.3	57.9	41.1	16.8	42.1	0.0
9. Town of Cary, NC	57,190	13.9	243.8	70.0	53.2	16.8	27.5	2.5
10. City of Fort Collins, CO	33,760	20.4	603.4	52.1	37.0	15.1	47.9	0.0
11. Miami-Dade W & S, FL	420,367	176.5	419.9	69.4	47.0	22.4	26.0	4.6
12. Philadelphia Water Dept., PA	472,170	137.7	291.6	57.6	43.6	14.0	42.4	0.0
13. Colorado Springs Utilities, CO	134,150	93.6	697.8	56.4	56.4	0.0	43.6	0.0
14. City of Henderson, NV	134,147	71.3	531.4	59.9	50.0	10.0	17.4	22.6
15. City of Mountain View, CA	17,433	9.7	553.7	55.8	26.3	29.5	20.2	24.0
16. City of Chicago DWM, IL [c]	172,485	521.5	3,023.6	58.2	7.6	50.6	41.8	0.0
Total/Average	4,272,896	2,227.2	521.2	61.9	45.6	16.3	31.8	6.4

Notes: [a] Lower than average share of residential sales in Toho WA is affected by substantial deliveries (nearly 40% of total water sales) to irrigation accounts (meters).

[b] Lower than average shares of residential use in Tacoma are affected by a single large quantity use industrial customer that accounts for about 30% of total sales. If this customer is excluded from the data, residential sector would account for 65% of total sales (49.5% for SF and 15.5% MF residential).

[c] Data for Chicago include only metered accounts and the associated metered consumption. Additional 325,450 accounts are not metered. Also wholesale deliveries to Chicago suburbs are excluded.

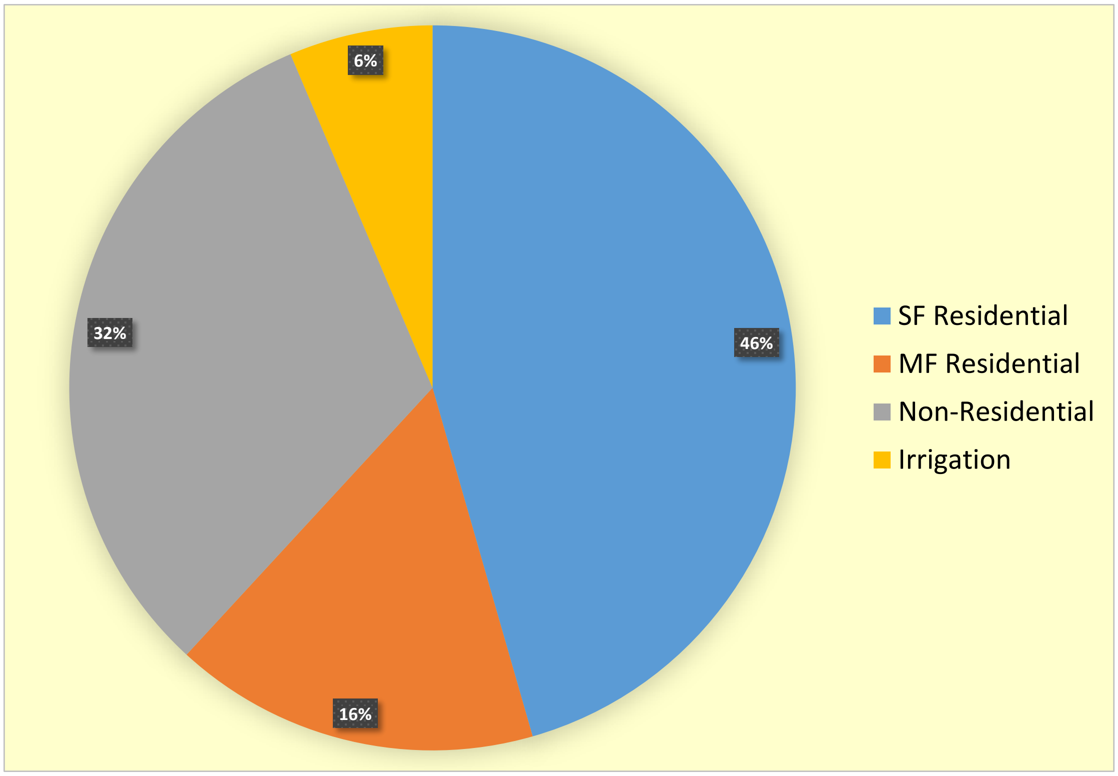

Figure 90: Average Percentage of Annual Water Sales by Major Sectors across 25 Study Sites

Figure 91: Distribution of Waters Sales across Customer Sectors (Level 1 Sites)

Table 89: Ratios of Sectorial Demands as Equivalent Single-Family Residential Accounts

Study Site	2006-10 Average SF Sales, gpad	Equivalent Accounts Ratio by Major Sector						Total SF-Equivalent Accounts Ratio
		MF Resi-dential	Irriga-tion	CII	Public	Other	Combined Non-residential	
LEVEL 1								
1. San Antonio, TX	259.4	24.1	5.8	6.5	0.0	0.0	6.5	1.64
2. City of Scottsdale, AZ	273.1	2.2	10.6	4.4	4.2	5.2	4.4	1.34
3. Clayton County WA, GA	154.6	78.2	4.3	7.0	16.4	41.6	8.2	1.91
4. Region of Waterloo, Ontario	152.9	3.3	0.0	10.6	4.7	5.1	10.3	1.73
5. Region of Peel, Ontario	230.4	16.6	0.3	12.7	16.0	1.8	11.9	1.82
6. Toho Water Authority, FL	175.3	--	3.1	6.1	0.0	0.0	6.1	2.15
7. Tacoma Water, WA	205.1	5.3	8.7	24.7	0.0	8.6	21.3	2.54
8. Denver Water, CO	333.9	4.7	10.2	7.2	21.7	1.8	1.8	1.82
9. Austin Water Utility, TX	259.5	16.6	0.0	10.2	52.3	482.8	12.6	2.36
LEVEL 2								
1. City of San Diego, CA	300.2	4.0	10.9	8.7	20.7	98.3	10.6	2.19
2. Aurora Water, CO	270.1	15.8	18.5	10.5	0.0	0.0	10.5	2.01
3. Otay Water District, CA	436.4	2.5	10.4	3.7	18.4	3.5	5.2	1.64
4. EPCOR, Edmonton, Alberta	154.1	23.1	0.0	8.5	0.0	0.0	8.5	1.87
5. City of Santa Barbara, CA	321.9	1.4	2.8	2.8	0.0	25.8	3.5	1.39
6. Cobb County WS, GA	198.3	--	3.9	12.5	20.4	0.0	15.6	1.65
7. Regional Water Authority, CT	264.3	--	--	6.0	14.1	2.3	5.4	1.41
8. Portland Water Bureau, OR	155.1	5.9	0.0	7.8	0.0	0.0	6.7	2.03
9. Town of Cary, NC	152.4	1.9	5.5	7.4	0.0	0.0	7.4	1.51
10. City of Fort Collins, CO	283.8	3.3	0.0	14.4		1,590.8	15.1	2.24
11. Miami-Dade W & S, FL	229.7	15.2	6.5	8.4	0.0	0.0	8.4	1.91
12. Philadelphia Water Dept., PA	167.4	3.2	0.0	7.9	60.8	0.0	9.2	1.90
13. Colorado Springs Utilities, CO	340.8	--	0.0	9.0	0.0	106.8	12.1	1.67
14. City of Henderson, NV	476.4	39.9	38.3	7.3	27.3	20.1	10.2	1.90
15. City of Mountain View, CA	241.8	5.2	11.4	4.2	0.0	0.3	4.1	2.56
16. City of Chicago DWM, IL	261.1	5.07	0.0	8.6	34.6	15.8	8.4	4.62
Average	251.7	13.2	6.3	8.7	13.0	96.4	9.0	1.99

The average annual rates of water use in the single-family sector were compared to per account use in other major sectors in order to calculate the ratios of average use in multifamily, CII, public and other sectors to the average rate in single-family sector. The resultant ratios are shown in the remaining columns of Table 89. For example, the equivalent accounts ratio for multifamily sector ranges from 1.4 in Santa Barbara to 78.2 in Clayton County. It indicates that average annual use per multifamily account is equivalent to 1.4 single-family accounts in Santa Barbara and 78.2 single-family accounts in Clayton County. On average, across the 25 study sites, water use by one multifamily account is equivalent to 13.2 single-family accounts. Similarly, per account water use in the CII (commercial, industrial, institutional) sector is on average 8.7 times higher than in single-family sector and ranges from 2.8 to 24.7 times the single-family rate.

The equivalent accounts ratios in Table 2 illustrate the great variability in the types and sizes of customers in multifamily and nonresidential sectors across the study sites. The last column of Table 2 captures these differences across the study sites by showing the equivalency of combined multifamily and nonresidential accounts ranging from 1.36 in Scottsdale to 4.62 in Chicago. It indicates that comparison of average per account usage rates across different utilities is not meaningful for user sectors other than single-family.

Comparisons of Annual Usage Rates in Single-Family Sector

The large differences in annual water use (AUM metric) of single-family sectors stem largely from the fundamental differences in climate across geographical regions in which the study sites are located. Figure 92 shows a plot of average annual single-family use vs. average annual precipitation at each location.

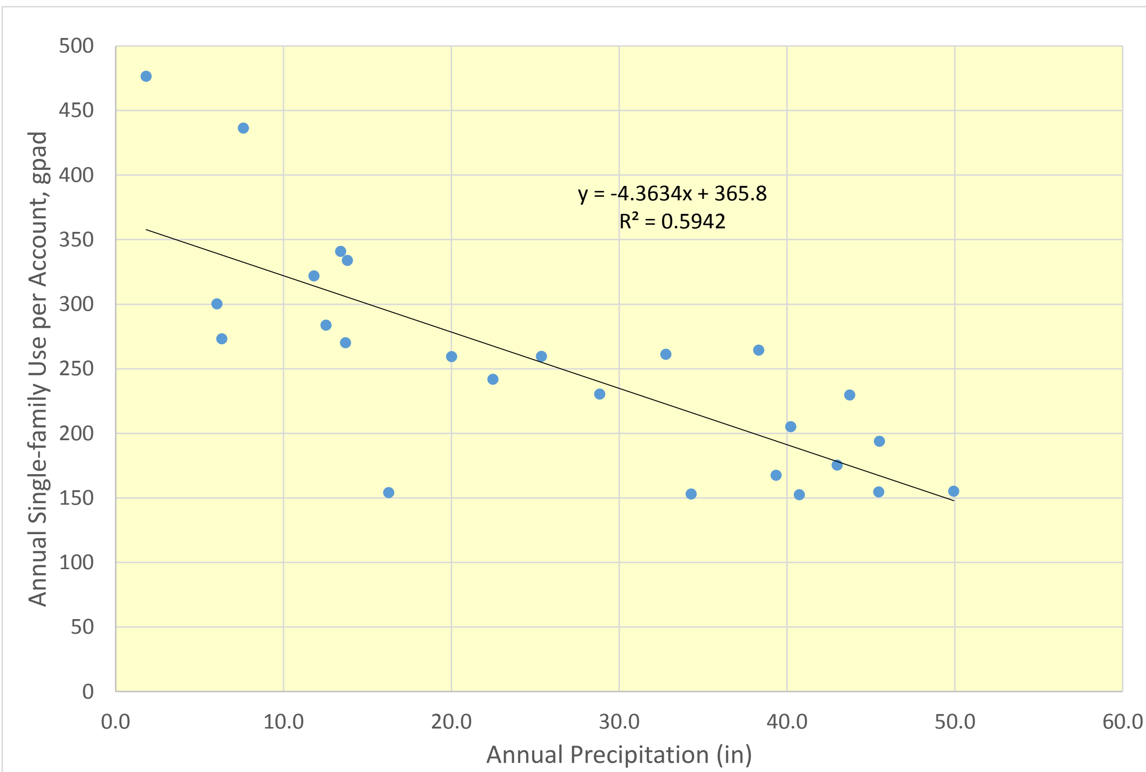

Figure 92: Effect of Annual Precipitation on Single Family Water Use per Account in 25 Study Sites

The graph shows that average annual precipitation alone explains 59% of the variability (i.e., total variance) in the single-family rates of water use across the 25 sites. In addition to average rainfall, water usage rate also depend on the physical demand for water as measured by evapotranspiration (ET_o). Figure 93 shows a plot of water use vs. the deficit of a natural supply of water (Penman's ET_o minus total annual precipitation) at each location. The goodness of fit is essentially the same as with precipitation alone; however, other factors also contribute to the differences in water use rates. Some of these factors are considered below.

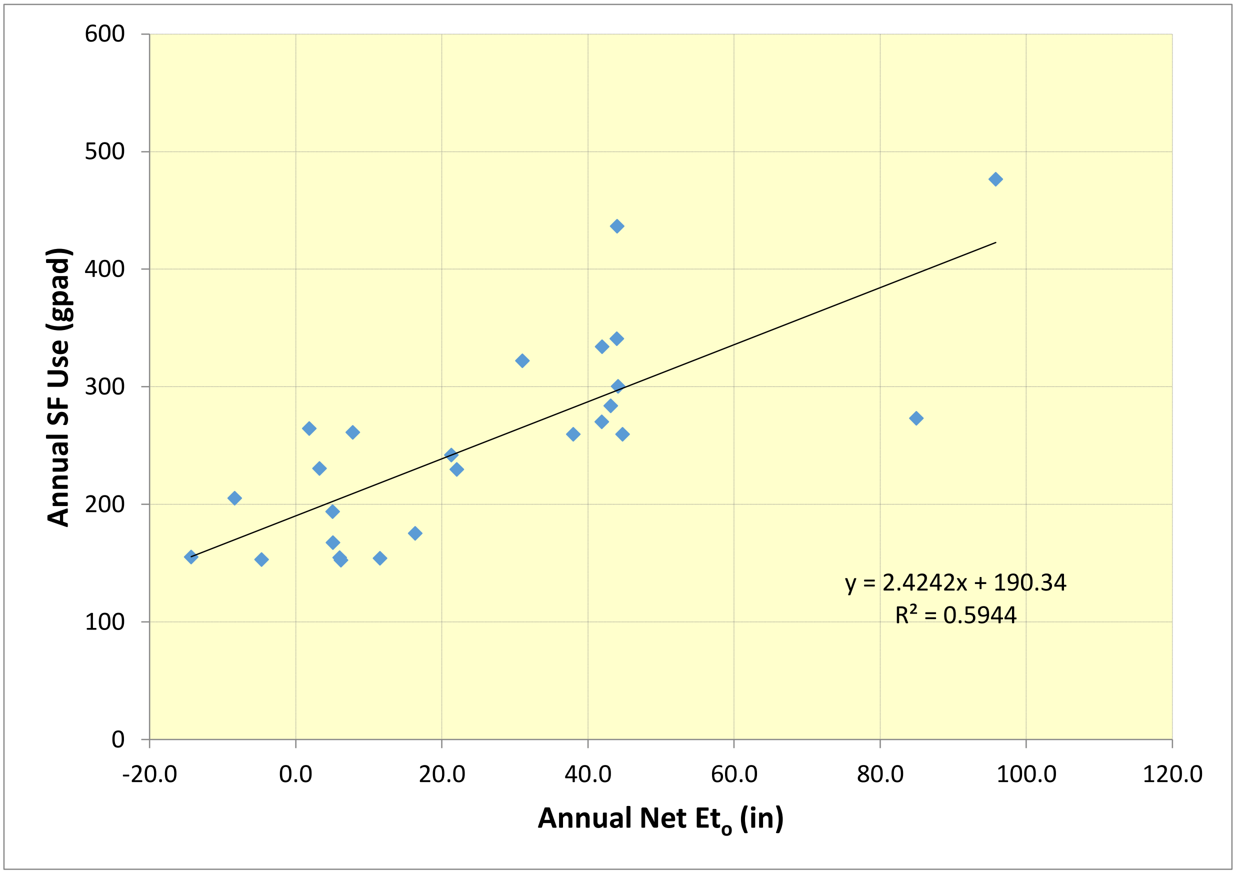

Figure 93: Effects of Climate (ET_o – Precipitation) on Annual Single-family Water Use per Account in 25 Study Sites

Single-Family Seasonal and Non-seasonal Usage Rates

It is only logical to assume that the average volume of single-family seasonal use should depend on local climatic conditions. Figure 94 shows a plot of seasonal single-family use as a function of the local annual need for irrigation water (annual ET_o vs. annual precipitation). This single measure of climate explains 61 percent of variability in seasonal use rates across the 22 study sites. This percentage is only slightly higher than the percentage of annual water use explained by net ET. This is somewhat surprising since one would expect seasonal water use to be more strongly correlated to climate than annual use.

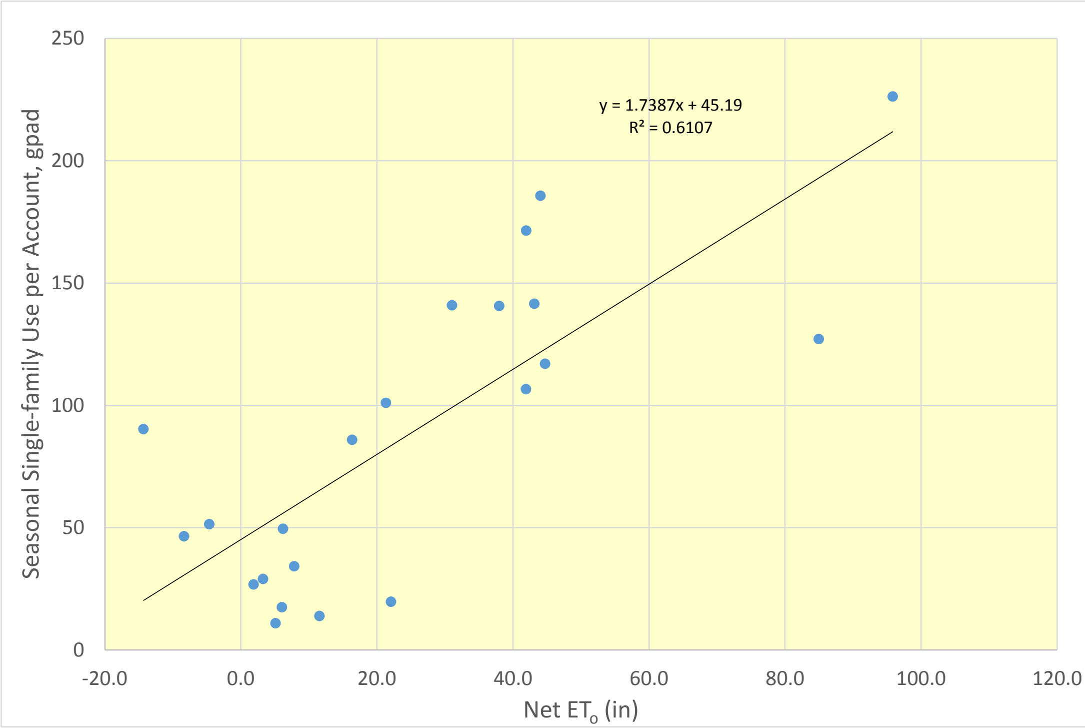

Figure 94: Effects of Climate (ET_o – Precipitation) on Average Seasonal Single-family Water Use per Account in 22 Study Sites

As one would expect non-seasonal use shows significantly less variability across the 22 sites than seasonal use. Given the fact that non-seasonal use is mainly for indoor uses the greater degree of uniformity from site to site make sense. Figure 45, in the Descriptive Statistics chapter, shows a bar chart of the estimated average non-seasonal use per single-family account. Not surprisingly, two sites with high non-seasonal use (Scottsdale and Miami-Dade) are likely affected by the overestimation of indoor use due to year-round irrigation and other outdoor uses.

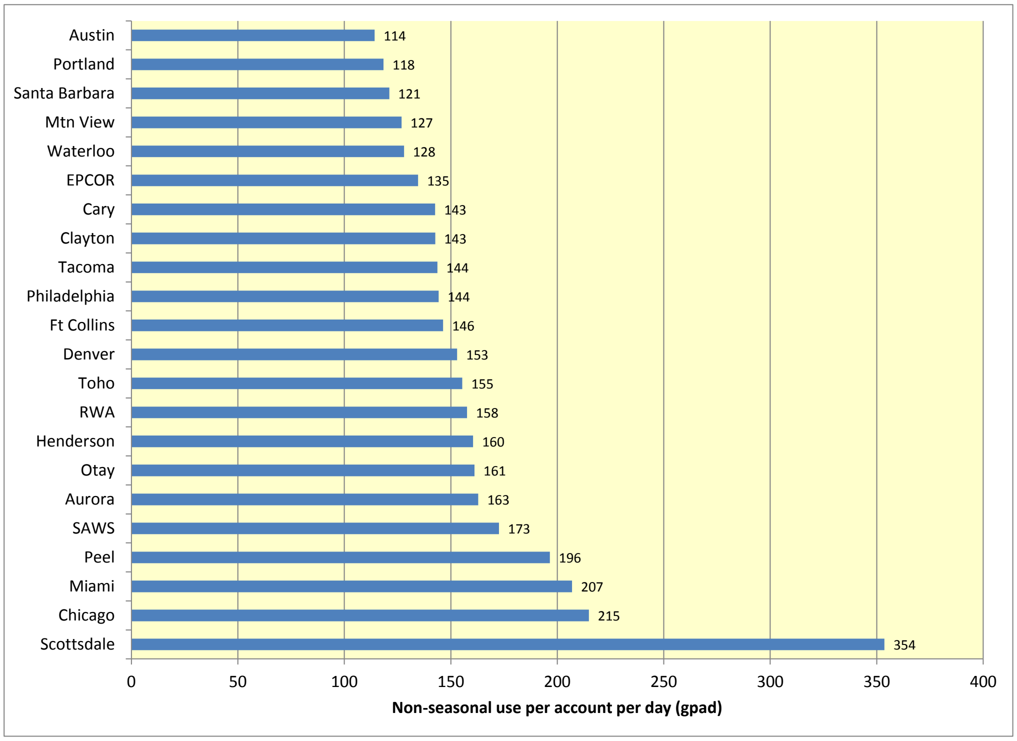

Figure 95: Estimated Non-seasonal Single-Family Water Use for Level 1 & 2 Study Sites

As with the aggregate billing data, the samples of billed water use by individual customers provide an imprecise measure of indoor use with the likely presence of upward bias of the estimates primarily due to the inclusion of "winter" irrigation as part of non-seasonal use. Table 49 compared the non-seasonal to indoor use on a per capita basis. Table 90 compares these on a per account basis. The tables show that with the exception of Waterloo, samples of customer billing data overestimate indoor usage rates obtained from logging data. The very high estimate of non-seasonal use in Scottsdale points to the fact that many homes in Scottsdale are vacant during the summer, and can be discounted. The percent overestimation in the remaining eight sites (not counting Waterloo) range from +9.3% in Ft. Collins to +47.5 in Aurora. The average overestimation after excluding Scottsdale is +15.6 percent.

Table 90: Differences between the Estimates of Non-seasonal and Indoor Use

Study Site	Nonseasonal Use (Billing Data)		Indoor Use (Logging Data)		Percent Difference From Logging Data.
	N	GPAD	N	GPAD	
San Antonio	1,014	172.6	91	139.3	23.9%
Scottsdale	1,012	353.6	90	146.6	141.1%
Clayton County	1,009	142.7	96	126.9	12.4%
Waterloo	447	128.0	71	146.8	-12.8%
Peel	951	196.5	59	158.2	24.2%
Toho	855	155.4	66	139.0	11.8%

Study Site	Nonseasonal Use (Billing Data)		Indoor Use (Logging Data)		Percent Difference From Logging Data.
	N	GPAD	N	GPAD	
Tacoma	994	144.4	99	126.3	14.3%
Denver	917	153.0	97	131.7	16.2%
Ft. Collins	999	146.4	88	133.9	9.3%
Total/ Average	9,143	175.5	796	135.9	29.2%
Total/Ave. w/o Scottsdale	8,131	155.7	706	134.7	15.6%

In summary, the metrics of seasonal and non-seasonal use that can be derived from samples of customer billing data offer limited opportunity for establishing efficiency benchmarks. It is possible develop efficiency benchmarks by use of the end use logging data to decompose total metered water use into specific end uses and also capture many important parameters about technical efficiency of water-using fixtures and appliances as well as water-using behavior of consumers. The latter approach is described in the following section.

INDOOR USE BENCHMARKS FROM END USE LOGGING DATA

The updated end use study collected two weeks' worth of high resolution meter flow data (80-100 pulses per gallon) in 10-second intervals for a sample of 763 single-family homes in 9 Level 1 study sites. Additional samples of end use studies were made available for analysis and interpretation for this update study from previous end use studies. Table 91 summarizes the end use measurement data that are now available for a number of sites in North America. In total, the research team assembled data for 3,411 single-family homes including the original end use study (REUWS #1) conducted during the mid-1990s.

In Table 91 the end use data in columns 2, 3 and 4 come from the combined dataset, the REUWS1 and the REUWS2 studies, which are all intuitively clear. The data from column 6, labeled "retrofits" needs some explanation. These data come from a group of homes that were known to be equipped with high efficiency fixtures and appliances, which generally met or exceeded the WaterSense specifications. These homes represent a known efficiency level that has been used as one of the benchmarks for the study. These homes included both existing homes that were retrofit with high efficiency devices, or new homes that were built with them.

Table 91: Benchmarking Parameters in End Use Studies

End Use Parameter	All Studies	REUWS #1	REUWS #2	Percent Diff. #1 - #2, %	Retrofits	Percent Diff. #2 – Retro., %
Number of homes	N=3,411	N=1187	N=763		N=247	
Average persons per household	2.60	2.77	2.64	-6.0%	2.58	-2.3%
Bathtub events/day	0.162	0.147	0.180	23.1%	0.284	57.3%
Clothes washer events/day	0.903	0.963	0.777	-19.3%	0.912	17.4%
Dishwasher events/day	0.245	0.243	0.259	6.4%	0.289	11.9%
Faucet events/day	45.87	41.08	51.35	25.0%	44.48	-13.4%
Leak events/day	62.4	n/a	117.20	--	112.79	-3.8%
Other events/day	3.77	5.32	4.50	-15.3%	0.25	-94.6%
Shower events/day	1.80	1.80	1.77	-1.6%	1.84	3.9%
Toilet events/day	12.72	12.44	12.90	3.7%	13.45	4.2%
Bathtub, gpd	4.07	5.22	3.62	-30.6%	6.62	82.9%
Clothes washer, gpd	31.84	40.26	22.76	-43.5%	21.20	-6.8%
Dishwasher, gpd	2.10	3.21	1.58	-50.8%	2.25	42.5%
Faucet, gpd	27.20	26.77	26.35	-1.6%	21.45	-18.6%
Leaks, gpd	23.06	21.99	17.04	-22.5%	11.64	-31.7%
Other, gpd	5.32	8.41	5.18	-38.4%	1.48	-71.4%
Shower, gpd	30.57	31.09	28.08	-9.7%	26.27	-6.4%
Toilet, gpd	38.07	45.23	33.08	-26.9%	21.08	-36.3%
Average clothes washer load, gal	36.18	40.88	30.98	-24.2%	23.28	-24.9%
Clothes washer loads per day	0.91	0.98	0.78	-20.4%	0.92	17.2%
Average shower length, seconds	482	468	464	-0.9%	478	3.0%
Average shower volume, gallons	16.74	16.73	15.78	-5.7%	14.1	-10.7%
Average shower mode flow, gpm	2.13	2.2	2.07	-5.9%	1.76	-14.9%
Shower minutes per day	15.18	14.48	14.38	-0.7%	15.15	5.3%
Average toilet flush volume, gpf	3.01	3.69	2.58	-30.1%	1.61	-37.6%
Toilet flush volume standard dev., gpf	0.71	0.98	0.51	-47.5%	0.44	-14.8%
Total flush events	753,319	348,345	124,611	--	42,045	--
Total toilet flushes > 2.2 gallons	505,759	288,010	61,154	--	3,140	--
Total toilet flushes < 2.2 gallons	247,836	60,335	63,457	--	38,905	--
Percent of flushes >2.2 gallons	67.1%	82.7%	49.1%	-33.6%	7.5%	-41.6%
Percent of flushes <2.2	32.9%	17.3%	50.9%	+33.6%	92.5%	+41.6%
Indoor GPD	**161.0**	**177.6**	**137.5**	-22.6%	**112.0**	-18.6%
Indoor use Standard Dev.	98.3	96.9	79.7	-17.7%	59.6	-25.2%
Outdoor GPD	**200.5**	**239.3**	**94.0**	-60.7%	**165.7**	76.4%
Indoor use Standard Dev.	391.5	459.8	296.5	-35.5%	284.5	-4.0%

In addition to sample size, Table 91 summarizes 35 different measurements that can be used in deriving efficiency benchmarks of indoor water use that are available from the disaggregated data obtained from the flow trace analysis. Most of these parameters are not available from billing data alone.

Comparison of REUWS #1 and #2 Studies – Water Savings

An overall expectation in comparing the results of the two REUWS studies (REUWS #2 vs. REUWS #1) is that the efficiency of indoor water use should have improved over the period of more than 15 years that separated the two studies. Indeed, the bottom rows of Table 91 show that average indoor water use is 22.6% lower in REUWS #2 sample (137.5 gpad) than in REUWS #1 sample (177.6 gpad). An important question is whether the 39.1 gpad decline in average indoor use is the result of improvement in efficiency or could be attributed to the differences between the two samples of homes being compared. Ideally, the two samples of 1,187 and 763 homes with end use logging data should be identical in terms of their occupancy and habits of use.

In terms of the parameters in Table 91, the samples could be considered "identical" if the following parameters had the same value or the differences (REUWS#1 vs. REUWS #2) were negligible (or not statistically different):

(a) Persons per household (2.81 vs. 2.62)
(b) Bathtubs events per day (0.147 vs. 0.180)
(c) Clothes washer events per day (0.963 vs. 0.777)
(d) Dishwasher events per day (0.243 vs. 0.259)
(e) Faucet events per day (41.08 vs. 51.35)
(f) Leak events per day (n/a vs. 117.2)
(g) Other events per day (5.32 vs. 4.50)
(h) Shower events per day (1.80 vs. 1.77)
(i) Toilet events per day (12.44 vs. 12.90)

In comparison to the first study, REUWS #2 average indoor use could be lower because the sample of 763 homes has lower number of persons per household (-6.0%), fewer clothes washer loads per day (-20%), and fewer other events per day (-15.3%). At the same time, indoor water use could be higher because of the higher number of bathtub events per day (+23.1), dishwasher events per day (+6.4%), faucet events per day (+25.0%) and toilet events per day (+3.7%). Because the percent difference in the frequency of fixture/appliance use have different weights (i.e., apply to different volumes of end use), the sum of positive and negative percent differences does not indicate that they balance out and have little effect on the estimated indoor use.

A straightforward check on the effects of differences in "frequency of use" on the estimated indoor use in the REUWS #2 study, is to recalculate the volume of end uses assuming the same frequencies of fixture/appliance use as were observed in the REUWS #1 study. Table 92 shows the recalculated indoor use for the update study where frequencies of usage events are changed to those in the REUWS1 study (without changing the average daily volume of leaks).

Table 92: Effects of Differences in Fixture/Appliance Frequency Use on the Estimated Indoor Water Use in REUWS #2 Study

End Use	Gallons per Day	Events/ day in REUWS2	Gallons/ Event	Events/ day in REUWS1	Adjusted Gallons per Day	Difference in gallons
Bathtub	3.62	0.180	20.111	0.147	2.96	-0.66
Clothes washer	22.76	0.777	29.292	0.963	28.21	5.45
Dishwasher	1.58	0.259	6.100	0.243	1.48	-0.10
Faucet	26.35	51.35	0.513	41.08	21.08	-5.27
Leaks	17.04	117.2			17.04	0.00
Other	5.18	4.50	1.151	5.32	6.12	0.94
Shower	28.08	1.77	15.864	1.80	28.56	0.48
Toilet	33.08	12.90	2.564	12.44	31.90	-1.18
Total indoor, gpad	137.69		--	--	137.35	-0.34

The last column of Table 92 shows that the effects of the differences in the frequency of use almost balance out (the largest effect on clothes washer use is compensated by the effect on faucet use) and the overall effect on indoor use is negligible. The “frequency” adjusted average use is only 0.35 gpd (0.25%) lower than the original estimate (137.35 gpad vs. 137.69 gpad). Therefore, the estimated savings of 40.1 gallons per day (a reduction of 22.5%) which represent the difference between average indoor use between REUWS #1 and REUWS #2 samples of single-family homes should be considered valid.

Conservation Benchmarks and Water Savings Potential

Additional water savings in single-family residential indoor water use are likely to occur over time because not all homes have installed efficient fixtures and appliances. Table 5 shows that only one half (50.9%) of toilet flushes in REUWS2 homes used less than 2.2 gallons per flush. Additional conservation potential is possible in average volumes of water used for clothes washing, showering and leaks. The next to last column of Table 5 show end use parameters and end use volumes for a sample of 247 homes that were retrofitted with efficient fixtures and appliances or already had the efficient fixtures installed. Average indoor water use in these efficient homes was 112.0 gallons per day, implying additional conservation potential of 25.5 gpad or 18.6 percent.

However, before deciding on whether the 112.0 gpad is an appropriate conservation benchmark for indoor residential use, it is important to check if the sample of 247 retrofitted homes is not biased. The following 12 end use parameters should be comparable between the samples in REUWS #2 and Retrofit homes:

(a) Persons per household (2.62 vs. 2.58)
(b) Bathtubs events per day (0.180 vs. 0.284)
(c) Clothes washer events per day (0.777 vs. 0.912)
(d) Dishwasher events per day (0.259 vs. 0.289)
(e) Faucet events per day (51.35 vs. 44.48)
(f) Leak events per day (117.2 vs. 112.8)
(g) Other events per day (4.50 vs. 0.25)

(h) Shower events per day (1.77 vs. 1.84)
(i) Toilet events per day (12. 90 vs. 13.45)

A check on the effects of differences in “frequency of use” parameters on the estimated indoor use in the sample of Retrofit homes was performed to recalculate the volume of end uses assuming the same frequencies of fixture/appliance use as were observed in the REUWS #2 study. Table 93 shows the recalculated indoor use for the Retrofit homes where frequencies of usage events are changed to those in the REUWS #2 study (without changing the average daily volume of “other” unidentified end uses).

Table 93: Effects of Differences in Fixture/Appliance Frequency Use on Estimated Indoor Water Use in the Sample of Retrofit Homes for High Efficiency benchmarks

End Use	Observed in Retrofit (gpd)	Events/ day in Retrofit	Gallons/ Event in Retrofit	Events/ day in REUWS2	High Efficiency Benchmark (gpd)	Difference in gallons
Bathtub	6.62	0.284	23.31	0.180	4.20	-2.42
Clothes washer	21.2	0.912	23.25	0.777	18.06	-3.14
Dishwasher	2.25	0.289	7.79	0.259	2.02	-0.23
Faucet	21.45	44.48	0.48	51.350	24.76	3.31
Leaks	11.64	112.79	0.10	117.200	12.10	0.46
Other	1.48	0.25	5.92	0.250	1.48	0.00
Shower	26.27	1.84	14.28	1.770	25.27	-1.00
Toilet	21.08	13.45	1.57	12.900	20.22	-0.86
Total indoor, gpad	112.0		--	--	108.1	-3.89

The results in Table 93 show that the effects on average indoor use of the differences in the frequency of fixture/appliance usage are relatively small. The “frequency” adjusted average use in the Retrofit sample is 3.89 gpd (3.5%) lower than the original estimate of 112.0 gpad. Interestingly, when fixture/appliance use frequencies from all end use studies are applied to the retrofit sample in Table 93 (while leaving the volume of leaks and “other” events unchanged, not shown on Table 92), the resultant indoor use is 107.6 gpad, practically the same as 108.1 gpad obtained with REUWS2 frequencies.

Therefore, the average indoor use in the Retrofit sample can be used as a benchmark value for estimating the additional water conservation potential. These savings can be achieved in the near to medium term (possibly over a 5 to 15 year time horizons) since it appears that more than half of the existing homes already have efficient toilets and other fixtures. In the REUWS2 sample 42% of homes used less water than the 112 gpad benchmark). For comparison, in the Retrofit sample of 267 homes, 92.5% of toilet flushes used less than 2.2 gallons and 58% of homes used less than 112 gpad).

Conservation Benchmarks for Ultra-Efficient Fixtures and Appliances

The recent EPA WaterSense specifications of 1.28 gallons per flush (gpf) for highly efficient toilets (HET), the maximum flow rate of 1.5 gpm for bathroom faucets (at 60 psi, and no less than 0.8 gpm at 20 psi), and the new standard for residential clothes washers with water factor F $\leq$ 8.0 gal/cycle/ft^3 (with proposed specifications of WF $\leq$ 7.5, and subsequently WF $\leq$

6.0 gal/cycle/ft^3) should be expected to reduce residential indoor use below the estimated current benchmark in the range of 108 to 112 gpad. However, these addition savings will not likely be realized in the near-term in existing homes. Considering the remaining average life expectancies of the currently installed fixtures and appliances, it may take 15 to 25 years or longer for their natural replacement with ultra-efficient models at least in existing homes. The situation is different for new homes, where many new homes are likely to adopt WaterSense standards.

For toilets the ultra-efficiency benchmark would be the goal of achieving the average flush volume of 1.28 gallons (set at the EPA standard) as compared to the currently observed average of 1.77 gpf in the sample of 247 retrofitted homes. The 1.28 gpf value is based on a maximum <u>effective flush volume</u> of 1.28 gallons per flush for single-flush fixtures, with no more than 0.40 gallon increase (to 1.68 gpf) with tank trim adjusted to maximum water use settings. For dual flush fixtures the 1.28 gpf standard allows the maximum of 1.40 gpf in reduced flush mode and 2.00 gpf in full flush mode.

According to EPA, a full-sized EnergyStar certified clothes washer (WF $\leq$ 8.0 gal/cycle/ft^3) should use on average 15 gallons of water per load, compared to at least two times that volume used by a standard machine. The end use logging data shows that about one fourth of homes in the REUWS2 and Retrofit samples used less than 20 gallons per load with the average volume of 15 gallons per load. Therefore, the average volume per load of 15 gallons can be used in establishing the ultra-efficiency benchmark for clothes washers.

For showerheads, the standard for maximum flow rate continues to be 2.5 gallons per minute (gpm) as set by the Energy Policy Act of 1992. However, manufacturers now offer ultra-efficiency showerheads with maximum flow rate below 2.0 gpm. Examples include Niagara's Sava Spa showerhead with flow rate of 1.75 gpm at high pressure and 1.45 gpm at low pressure, or the new Tri-Max showerhead with three pressure compensated flow rate (by non-removable pressure compensator) with options of 0.5, 1.0 and 1.5 gpm. For the purpose of benchmarking end use for ultra-efficient showerheads, the end use logging data were examined to determine average values for the recorded modal flow rate during showering. The data show that 50% of REUSE2 homes and 75% of retrofitted homes had modal flows less than 2.0 gpm and the average flow for these homes was 1.6 gpm. Therefore, the 1.6 gpm was selected as benchmark for ultra-efficient showerheads.

Finally, the end use data suggest that little additional water savings will result from the new standard of 1.5 gpm for bathroom faucets. As shown in Table 56 approximately 95% of all faucet events have an average flow rate of 1.39 gpm or less. Consequently, the 1.5 gpm standard will have little or no effect on these events. The larger faucet events are in all likelihood driven by the required volume of the end use, so having a lower flow rate will probably simply increase their duration.

Table 94 shows the calculations and assumptions for benchmarking the eight end uses and total indoor use for ultra-efficient fixtures and appliances.

Table 94: Assumptions and Calculations for Ultra-Efficiency Benchmarks for Single-Family Indoor Water Use Based on End Use Logging Data

Indoor End Use	Gallons per Day in Retrofit (adj.)	Events/ Day in REUWS2 Sample	Gallons/ Event in Retrofit Sample	Ultra-Efficiency Benchmark Gallons per Day	Difference in gallons per Day	Difference in Percent
Bathtub	4.20	0.180	23.31	4.20	0.00	0
Clothes washer	18.06	0.777	15.00	11.66	-6.41	-35.5
Dishwasher	2.02	0.259	7.79	2.02	0.00	0
Faucet	24.76	51.35	0.48	24.76	0.00	0
Leaks	12.10	117.2	0.10	12.10	0.00	0
Other	1.48	0.25	5.92	1.48	0.00	0
Shower	25.27	1.77	13.17	23.31	-1.96	-7.8
Toilet	20.22	12.9	1.28	16.51	-3.71	-18.3
Total indoor, gpad	108.1		--	96.0	-12.1	-11.2

The results in Table 94 show that the benchmark for ultra-efficient average indoor water use in the future would equal 96.0 gpad (assuming the frequencies of water-using events in REUWS2 obtain). This benchmark value implies additional water savings potential of 12.1 gpad (or 11.2%) relative to the benchmark derived from the observed data of 108 gpad from the efficient homes. The 12.1 gpad of additional savings would come primarily from the consumer adoption of ultra-efficient clothes washing machines (53% of new savings), HET toilets (31%) and WaterSense showerheads (16%).

In terms of water use per person, at the average value of 2.6 persons per residence (from all studies), the ultra-efficient residential indoor water use would be equivalent to about 37 gallons/person/day.

Figure 96 below compares total indoor use and eight individual end uses with two levels of benchmark values based on the analyses of savings presented here.

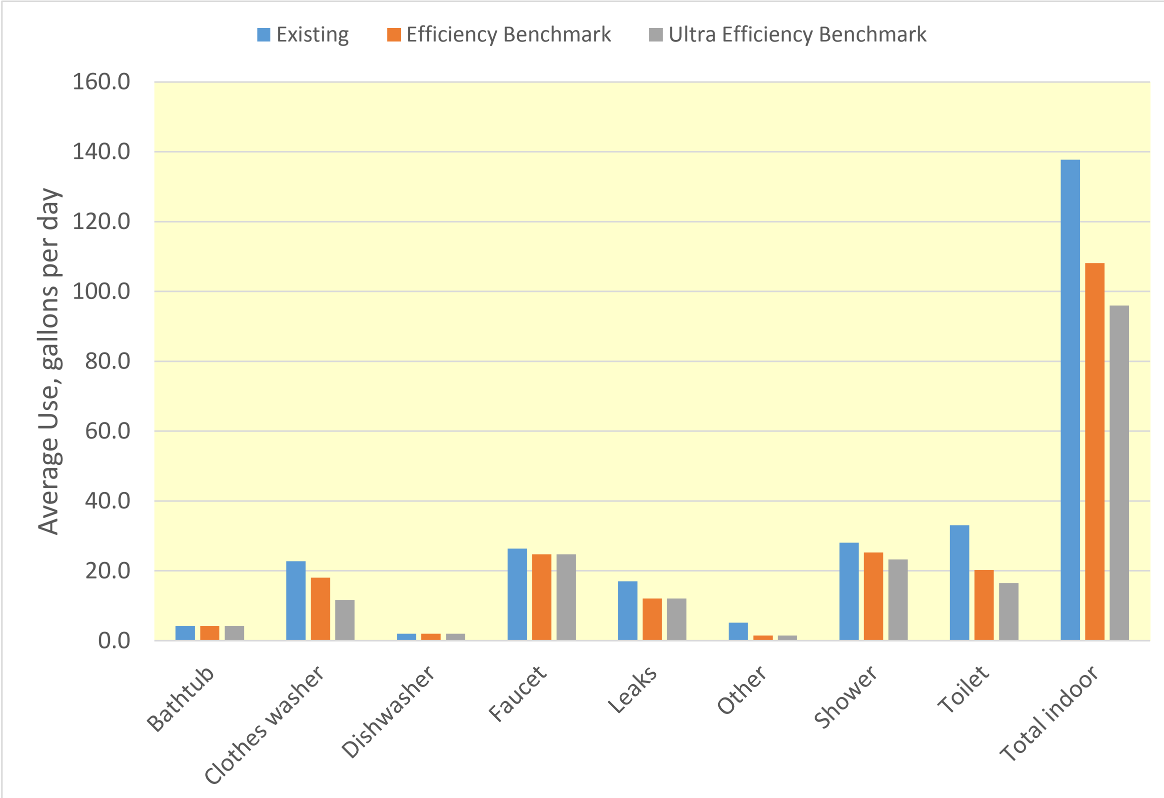

Figure 96: Exiting and Benchmark Quantities of Water End Uses and Total Indoor Use.

Indoor Conservation Index for Individual Study Sites

The two levels of conservation potential developed in the previous sections represent average (aggregate) effects derived from the combined samples of logged single-family homes from nine Level 1 study sites, and therefore, are not strictly applicable to a specific service area of a water utility. As shown in Table 90, the average indoor use obtained from the logging data ranged from 126.3 gpad in Tacoma, WA to 158.2 in Peel, Ontario. Because it is highly unlikely that the differences in average indoor use are caused only by an "inefficiency" factor (other factors such as average household size and family composition may contribute as well), each water service area can established its own value of efficiency benchmark.

Using the site-specific logging data, a ratio benchmark similar to Infrastructure Leakage Index (ILI) can be defined for each utility be estimating an efficient level of water use to be achieved. The Indoor Conservation Index (ICI) benchmark can be defined for single-family sector in each study area as:

$$ICI_i = \frac{IUM_i}{IUM_{Gi}}$$

Where: ICI_i = indoor conservation index as a ratio-type benchmark, IUM_i = estimated indoor use per account per day metric, IUM_{Gi} = efficiency goal (G) for residential single-family use per account per day. For the entire sample of 763 homes in REUWS2 study, the ICI can be calculated as:

$$ICI = \frac{137.7}{108.1} = 1.27$$

And the percentage conservation potential can be calculated as:

$$CP = 1 - \frac{1}{ICI} \cdot 100\% = \ 21.5\%$$

Table 95 summarizes the gallons per event for each of the end uses for the efficient homes (derived from the retrofit homes) and the ultra efficient homes based on the impacts of switching to WaterSense standard fixtures and appliances. These values are used to derive estimates of household water use for the individual study sites.

Table 95: Benchmark values for gallons per event

End Use	Efficient Benchmark Gal/Event	Ultra-Efficient Benchmark Gal/Event
Bathtub	23.35	23.31
Clothes washer	23.24	15.00
Dishwasher	7.77	7.79
Faucets	0.48	0.48
Leaks	0.10	0.10
Other	6.03	5.92
Shower	14.31	13.17
Toilets	1.57	1.28

Table 96 shows the calculation of site-specific conservation benchmarks for Level 1 study sites. Two benchmarks are shown in the table. Benchmark 1 (Efficiency Benchmark) is calculated by applying average quantities of water used per end use event obtained from the Retrofit sample (considered here as reference for efficiency benchmarking) to the frequency of use (i.e., average number of end use events per day) that were observed in the logging sample for each of the study sites. For example, for San Antonio, the resultant value of efficient indoor use is 102.2 gpad (or 41.9 gpcd) and the corresponding ICI-1 index is 1.36.

Benchmark 2 (Ultra-Efficient Benchmark) assumes ultra-efficient toilets, clothes washers and showerheads and is calculated using reduced average volumes per event of these end uses while keeping the frequencies of events obtained for each study site. For example, the resultant level of ultra-efficient indoor use for San Antonio is 88.9 gpad (or 35.1 gpcd) and when calculated against this benchmark the ICI-2 is 1.57. The two estimated values of ICI imply the potential conservation savings (below the current indoor use of 139.3 gpad) in single-family sector in San Antonio of 26.6% and 36.2%, respectively.

The calculations were repeated for other Level 1 study sites and the results in Table 96 are compared graphically on which shows the current indoor use with the two levels of benchmarks for each study site.

Table 96: Calculated Conservation Efficiency Benchmarks for Level 1 Study Sites

Study Site, Sample Size, Average Household Size	Local Gallons/ Day	Local Events/ Day	Efficient Bench-mark 1 Gallons/ Event	Efficient Bench-mark1 Gallons /Day	Ultra-Efficient Bench-mark 2 Gallons/ Event	Ultra-Efficient Bench-mark2 Gallons /Day
San Antonio n=91 PPH=2.53						
Bathtub	2.76	0.142	23.35	3.30	23.31	3.30
Clothes washer	28.97	0.881	23.24	20.46	15.00	13.21
Dishwasher	0.89	0.134	7.77	1.04	7.79	1.04
Faucet	23.37	39.552	0.48	19.08	0.48	19.08
Leak	19.76	125.516	0.10	12.95	0.10	12.95
Other	1.63	0.722	6.03	1.63	5.92	1.63
Shower	28.79	1.647	14.31	23.56	13.17	21.69
Toilet	33.14	12.868	1.57	20.17	1.28	16.47
Indoor use, gpad	**139.3**			**102.2**		**88.9**
Gallons/person/day	55.1			40.4		35.1
DENVER n=97 PPH=2.37						
Bathtub	2.82	0.133	23.35	3.10	23.31	3.09
Clothes washer	24.48	0.874	23.24	20.31	15.00	13.11
Dishwasher	2.07	0.334	7.77	2.60	7.79	2.61
Faucet	21.11	49.790	0.48	24.01	0.48	23.90
Leak	12.88	96.788	0.10	9.99	0.10	9.68
Other	8.03	16.388	6.03	8.03	5.92	8.03
Shower	28.04	1.687	14.31	24.14	13.17	22.22
Toilet	32.24	12.059	1.57	18.91	1.28	15.44
Indoor use, gpad	**131.66**			**111.08**		**98.08**
Gallons/person/day	55.55			46.87		41.38
FT COLLINS n=88 PPH=2.38						
Bathtub	4.42	0.205	23.35	4.79	23.31	4.78
Clothes washer	19.91	0.698	23.24	16.23	15.00	10.47
Dishwasher	2.20	0.345	7.77	2.68	7.79	2.69
Faucet	22.77	51.392	0.48	24.78	0.48	24.67
Leak	23.88	126.281	0.10	13.03	0.10	12.63
Other	1.56	4.515	6.03	1.56	5.92	1.56
Shower	26.31	1.558	14.31	22.28	13.17	20.51
Toilet	32.81	11.875	1.57	18.62	1.28	15.20
	133.86			**103.97**		**92.52**
	56.24			43.69		38.87
SCOTTSDALE n=96 PPH=2.25						

Study Site, Sample Size, Average Household Size	Local Gallons/ Day	Local Events/ Day	Efficient Bench-mark 1 Gallons/ Event	Efficient Bench-mark1 Gallons /Day	Ultra-Efficient Bench-mark 2 Gallons/ Event	Ultra-Efficient Bench-mark2 Gallons /Day
Bathtub	2.04	0.092	23.35	2.14	23.31	2.13
Clothes washer	18.64	0.704	23.24	16.35	15.00	10.56
Dishwasher	1.57	0.257	7.77	2.00	7.79	2.00
Faucet	26.70	51.076	0.48	24.63	0.48	24.52
Leak	25.00	130.350	0.10	13.45	0.10	13.03
Other	12.62	0.477	6.03	12.62	5.92	12.62
Shower	27.08	1.736	14.31	24.84	13.17	22.87
Toilet	33.00	12.085	1.57	18.95	1.28	15.47
Indoor use, gpad	**146.64**			**114.98**		**103.21**
Gallons/person/day	65.17			51.10		45.87
TACOMA n=96 PPH=2.44						
Bathtub	2.94	0.152	23.35	3.54	23.31	3.54
Clothes washer	23.09	0.838	23.24	19.48	15.00	12.57
Dishwasher	2.02	0.322	7.77	2.50	7.79	2.51
Faucet	25.42	52.412	0.48	25.28	0.48	25.16
Leak	13.67	221.868	0.10	22.89	0.10	22.19
Other	0.35	0.015	6.03	0.35	5.92	0.35
Shower	25.95	1.657	14.31	23.71	13.17	21.82
Toilet	34.69	13.834	1.57	21.69	1.28	17.71
Indoor use, gpad	**128.13**			**119.44**		**105.84**
Gallons/person/day	56.95			53.08		47.04
WATERLOO n=71 PPH=3.15						
Bathtub	5.43	0.295	23.35	6.89	23.31	6.88
Clothes washer	18.92	0.729	23.24	16.93	15.00	10.93
Dishwasher	2.33	0.390	7.77	3.03	7.79	3.04
Faucet	30.64	66.072	0.48	31.86	0.48	31.71
Leak	12.40	84.703	0.10	8.74	0.10	8.47
Other	13.47	5.541	6.03	13.47	5.92	13.47
Shower	27.54	1.732	14.31	24.78	13.17	22.81
Toilet	36.03	15.010	1.57	23.53	1.28	19.21
Indoor use, gpad	**146.76**			**129.24**		**116.53**
Gallons/person/day	46.59			41.03		36.99
TOHO-KISS. n=66 PPH=2.77						
Bathtub	1.66	0.093	23.35	2.18	23.31	2.17
Clothes washer	24.84	0.720	23.24	16.73	15.00	10.80
Dishwasher	0.74	0.126	7.77	0.98	7.79	0.98
Faucet	32.71	60.597	0.48	29.22	0.48	29.09
Leak	17.65	90.281	0.10	9.32	0.10	9.03
Other	2.35	0.326	6.03	2.35	5.92	2.35

Study Site, Sample Size, Average Household Size	Local Gallons/ Day	Local Events/ Day	Efficient Bench-mark 1 Gallons/ Event	Efficient Bench-mark1 Gallons /Day	Ultra-Efficient Bench-mark 2 Gallons/ Event	Ultra-Efficient Bench-mark2 Gallons /Day
Shower	30.61	2.098	14.31	30.02	13.17	27.63
Toilet	30.61	12.215	1.57	19.15	1.28	15.64
Indoor use, gpad	**141.18**			**109.95**		**97.69**
Gallons/person/day	50.97			39.69		35.27
PEEL-BRAMPTON n=59 PPH=3.52						
Bathtub	4.28	0.225	23.35	5.26	23.31	5.25
Clothes washer	21.12	0.829	23.24	19.26	15.00	12.43
Dishwasher	1.59	0.278	7.77	2.16	7.79	2.17
Faucet	38.62	67.142	0.48	32.38	0.48	32.23
Leak	16.79	99.783	0.10	10.30	0.10	9.98
Other	8.33	15.029	6.03	8.33	5.92	8.33
Shower	33.50	2.345	14.31	33.55	13.17	30.89
Toilet	33.98	15.730	1.57	24.66	1.28	20.13
	158.22			**135.90**		**121.40**
	44.95			38.61		34.49
CLAYTON CO. n=96 PPH=2.84						
Bathtub	6.21	0.293	23.35	6.85	23.31	6.84
Clothes washer	24.39	0.738	23.24	17.15	15.00	11.07
Dishwasher	0.75	0.133	7.77	1.03	7.79	1.04
Faucet	23.81	36.709	0.48	17.70	0.48	17.62
Leak	11.44	61.994	0.10	6.40	0.10	6.20
Other	0.33	0.413	6.03	0.33	5.92	0.33
Shower	28.10	1.770	14.31	25.32	13.17	23.30
Toilet	31.77	11.898	1.57	18.66	1.28	15.23
Indoor use, gpad	**126.79**			**93.44**		**81.63**
Gallons/person/day	44.65			32.90		28.74

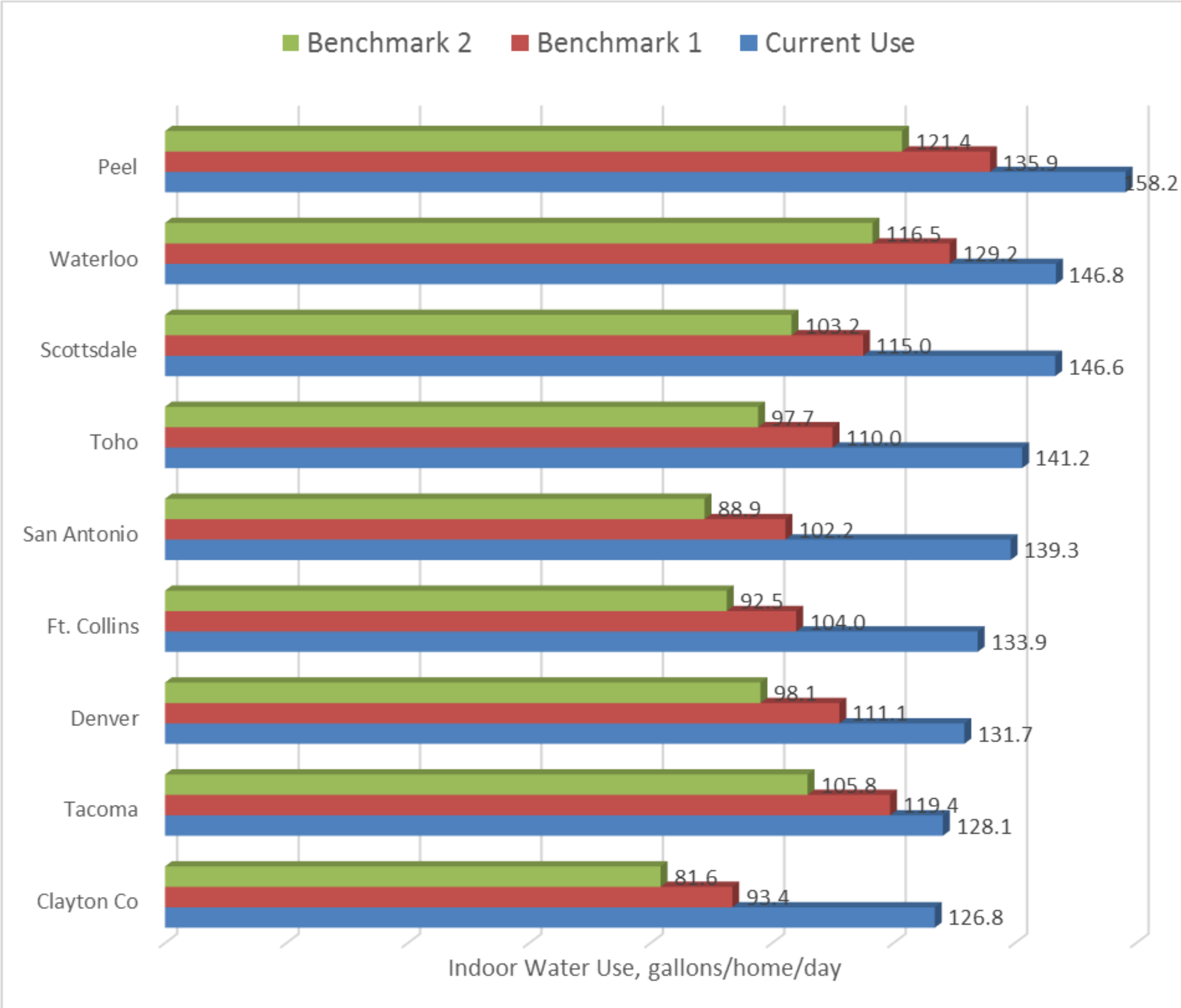

Figure 97: Comparison of Currents Use and Conservation Benchmarks for 9 Study Sites

The projected household savings at the efficient and ultra efficient levels are shown in Table 97 and Figure 98. These show that the projected savings at each site varies based on the current usage of each. Savings are shown for both efficiency benchmarks, but in reality the ultra efficient benchmark makes the most sense to use since it is based on the most current standards. On average the estimated potential savings 38.5 gallons per account per day, or 14.1 kgal per account per year.

Table 97: Projected indoor water savings

Site	Low Savings (gpad)	Hi Savings (gpad)
Clayton Co	33.4	45.2
Tacoma	8.7	22.3
Denver	20.6	33.6
Ft. Collins	29.9	41.3
San Antonio	37.1	50.4

Toho	31.2	43.5
Scottsdale	31.7	43.4
Waterloo	17.5	30.2
Peel	22.3	36.8
Average (gpad)	25.8	38.5
Annual (kgal/yr)	9.4	14.1

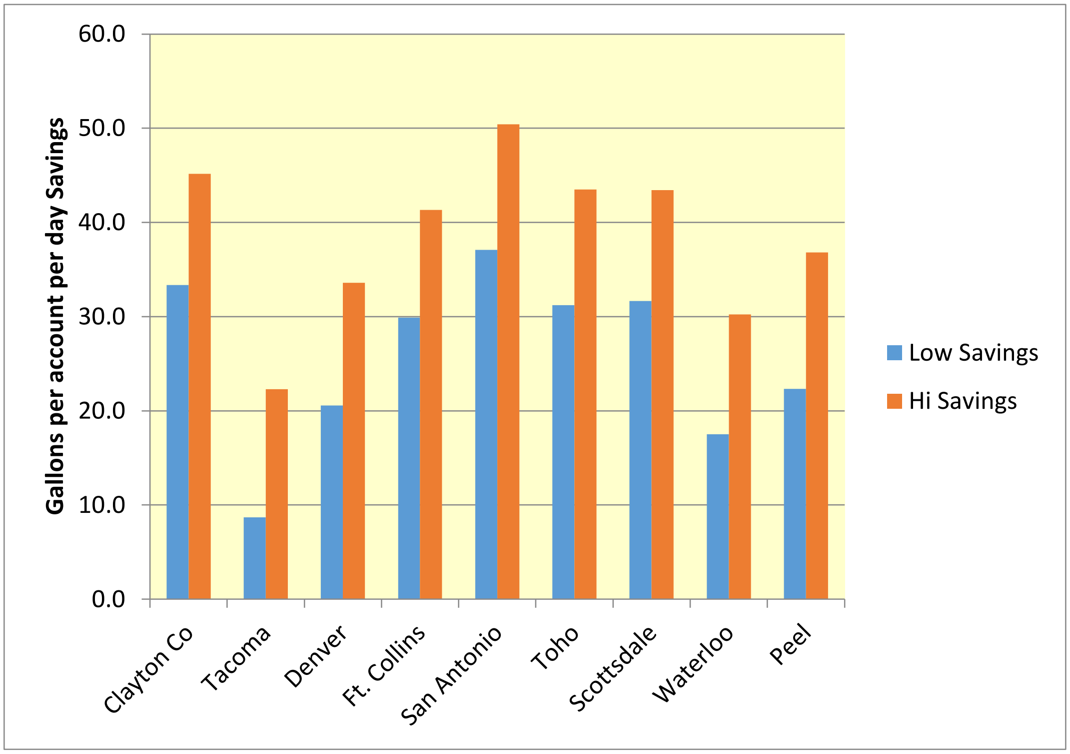

Figure 98: Estimated indoor water savings at two levels of efficiency

Outdoor Use Benchmarks from Landscape Analysis and End Use Logging Data

Single-family, sector-wide benchmarks for outdoor water use are difficult to establish because of the great variability of residential landscapes, differences in local climatic conditions as well as differences in actual irrigation practices of individual customers. Based on local climate and the size and composition of each residential landscape, it is possible to calculate site-specific (for each home) theoretical irrigation requirement (TIR). This has been done for the samples of homes at each of the Level 1 study sites and detailed results are described in the previous sections of this report. The main purpose of the discussion presented here is to consider the development of sector-wide benchmarks for outdoor use.

Feasibility of Developing Benchmarks for Outdoor Use

Assuming that total annual water use for outdoor purposes by the single-family sector in a given water service area is known (or can be estimated with satisfactory accuracy): Is it possible to determine how efficient is this use? In other words: Is it is possible to devise a benchmark value to which the observed use could be compared? Such sector-wide benchmark value could be obtained by summing up the TIR values for all single-family residential customers (or by estimating the “population sum” from a sample of customers). However, the great variability of irrigation practices among individual customers results in a situation where only a very small percentage of residential landscapes approach their theoretical water application rates. The majority of customers apply less water than their TIR amount (their watering practice is sometimes called “deficit irrigation” or “under-irrigation”) while the minority applies more than the TIR amount. If the volume of “excess irrigation” is approximately equal to the volume of deficit irrigation, the sector-wide ratio of the actual irrigation application to the theoretical requirement may be close to 1, thus implying (incorrectly) that overall irrigation water is used efficiently. Actually, only the homes with deficit irrigation can be considered “efficient”, all “excess” irrigation is inefficient.

The results of the earlier analysis show that this situation of compensating inefficiency with deficit irrigation may be taking case in Denver and Peel, where the estimated application ratios are close to 1 (0.97 and 0.91, respectively). In the case of Scottsdale, the estimated application ratio is 1.56 implying net excess irrigation of 56% above the total TIR volume. Among the remaining 6 service area, the application ratios range from 0.26 in Waterloo, ONT to 0.55 in Tacoma, WA, thus indicting that the volume of “deficit irrigation” is greater than the volume of excess irrigation (unless the calculated TIR values for these cities are overestimated by a significant margin). These low values of application ratios also imply that there is no water conservation potential in outdoor use. If all residential customers would become efficient irrigators by applying the amount determined by TIR, total outdoor water use would substantially increase. For example the application ratio of 0.35 in Ft. Collins can be interpreted to mean that presently only 35 percent of irrigation requirement is met and 65% of demand is unmet.

Given this situation, the implications for conservation policy would be to focus on improving irrigation efficiency only among customers with excess irrigation and developing procedures for identifying these customers and analytical tools for measuring the excess volume of water applied to the landscape. At the same, all deficit irrigators could be considered “efficient” since they appear to be satisfied with their landscapes. These landscapes are being maintained under deficit irrigation even if the plant material does not grow under optimal soil moisture conditions.

Estimating Conservation Potential in Outdoor Water Use

The actual volumes of deficit and excess irrigation were examined for the nine Level 1 sites and the results are presented in Table 9.

For the entire sample of the logging data for which landscape analysis was performed (n=838). 83% of homes apply less irrigation water than the theoretical requirement of their landscapes. For this group of customers, the volume of under-irrigation relative to TIR is nearly 70%. This means that deficit irrigators on average apply only 30% of the theoretical requirement (118.8 kgallons/account/year are needed but only 36.1 kgal./account/year is applied – thus, the deficit is -82.7 kgal./account/year).

The approximately 17% of the remaining customers apply irrigation water in excess of the theoretical requirement. They exceed the TIR by 66% (applying on average 47.5 kgal./account/year above their theoretical requirement of 73.4 kgal./account/year).

Table 98: Calculations for Deficit and Excess Irrigation (Outdoor Use) from REUWS #2 Logging and Landscape Data

	San Antonio	Scottsdale	Clayton Co	Waterloo	Peel	Toho	Tacoma	Denver	Ft. Collins	ALL
N	98	111	103	72	69	90	101	95	88	838
TIR-Theoretical Irrigation Requirement, kgal/y	14,433.1	13,651.5	14,289.2	4,873.8	2,623.8	10,959.0	6,049.7	9,453.3	15,468.4	92,772.0
TIR/account, kgal/y	147.3	123.0	138.7	67.7	38.0	122.0	59.9	99.5	175.8	110.7
Outdoor water use, kgal/y	6,072.0	13,360.9	1,976.1	938.2	1,66	3,005.0	2,557.5	7,316	4,915.3	42,197
Outdoor use/account, kgal/year	62	120.4	19.2	13	24.1	33	26.1	77	55.9	50.5
Outdoor use/TIR Ratio	0.42	0.98	0.14	0.19	0.63	0.27	0.42	0.77	0.32	0.45
N – Deficit irrigators	90	63	99	67	48	75	85	69	88	693
N – Percent of homes, %	91.8%	56.8%	96.1%	93.1%	69.6%	83.3%	84.2%	72.6%	100.0%	82.7%
Volume of deficit, kgal/y	-8,733.1	-4,106.9	-12,331.5	-4,076.3	-1,402	-8,256	-3,902	-3,363	-10,553	-57,324
Deficit/account, kgal/y	-97.0	-65.2	-124.6	-60.8	-29.2	-110.1	-45.9	-48.8	-119.9	-82.7
TIR volume for deficit irrigators, kgal/y	13650.1	8,707.2	14,162.9	4,589.9	2,058	9,992	5,316.0	7,503	15,468.4	82,349
TIR/account, kgal/y	151.7	138.2	143.1	68.5	42.9	133.0	62.5	108.7	175.8	118.8
Deficit as percent of TIR, %	-64.0%	-47.2%	-87.1%	-88.8%	-68.1%	-82.6%	-73.4%	-44.8%	-68.2%	-69.6%
N – Excess irrigators	8	46	3	5	21	15	16	26	0	142
N _ Percent of all homes, %	8.2%	41.4%	2.9%	6.9%	30.4%	16.7%	15.8%	27.4%	0.0%	16.9%
Volume of excess irrigation, kgal/y	372.4	3,816.4	18.5	140.7	443.2	303.0	544.8	1,227	0.0	6,883
Excess/account, kgal/y	46.5	83.0	6.2	28.1	21.1	20.2	34.0	47.2	0.0	47.5
TIR volume for excess irrigators, kgal/y	783.0	4,944.3	126.3	283.9	565.3	967.0	733.7	1,950	0.0	10,422
TIR/account, kgal/y	97.9	107.3	42.1	56.8	26.9	64.0	45.9	75.0	0.0	73.4
Excess as percent of TIR, %	47.6%	77.2%	14.7%	49.6%	78.4%	31.3%	74.3%	62.9%	0.0%	66.0%
Excess irrig. as percent of total outdoor use,%	6.1%	28.6%	0.3%	15.0%	26.6%	10.1%	21.3%	16.8%	0.0%	16.3%

Source: Data set "REUWS2_Combined Outdoor_AllStudies", kgal/y = 1000 gallons per year

The last row of Table 98 shows the percentage conservation potential for outdoor water use, which is calculated by dividing the annual volume of excess irrigation by the actual total outdoor water use. For the entire sample of 838 homes, this conservation potential is 16.3%. This potential reduction is very reasonable considering that deficit irrigation is more of a "norm" for residential landscapes and if the excess irrigators were to convert to deficit irrigation the savings would be considerably higher.

For individual study sites the calculated conservation potential vary considerably. In Ft. Collins and Clayton County all or nearly all homes in the sample are deficit irrigators and the potential savings are close to zero. Two sites with the highest conservation potential are Scottsdale, Arizona and the Region of Peel in Ontario, CA (28.6% and 26.6%, respectively).

In Denver, the outdoor conservation potential is 16.8%, although the average (un-weighted) application ratio was calculated earlier to be 0.87 and the ratio of the total volume of outdoor use to the volume of theoretical requirement is 0.77.

Long-Term Conservation Potential and Short-Term Drought Contingency Curtailment

The long term conservation potential (or potential improvements in efficiency of water use) are those related to the ultra-efficiency benchmarks for indoor use presented above plus the potential improvements in outdoor use efficiency. As mentioned earlier, these improvements will likely be achieved during a long time horizon, probably 15 to 25 years or more.

Table 99: Estimated Conservation Potential by Study Site

Study Site	Mid-Term Indoor Savings Potential	Long-Term Indoor Savings Potential	Mid-Term Outdoor Savings Potential
Clayton Co	26.3%	35.6%	0.3%
Denver	15.6%	25.5%	16.8%
Ft. Collins	22.3%	30.9%	0.0%
Peel	14.1%	23.3%	26.6%
San Antonio	26.6%	36.2%	6.1%
Scottsdale	21.6%	29.6%	28.6%
Tacoma	6.8%	17.4%	21.3%
Toho	22.1%	30.8%	10.1%
Waterloo	11.9%	20.6%	15.0%
All Sites	18.7%	30.3%	16.3%

The estimated percentage reductions in indoor water use represent the potential gains in water use efficiency that will take place over time as consumers adopt the high- and ultra-efficiency indoor fixtures and appliances through a process of natural replacement. The rate of adoption can be accelerated through utility sponsored conservation programs.

For outdoor water use, the potential savings represent the currently estimated levels of excess irrigation for each study site. These savings can be achieved instantly through short-term drought contingency curtailments. As efficiency improvements over longer term, these reductions will require utility programs that target over-irrigators. However, as the excessive irrigation is gradually eliminated, the potential for short-term drought contingency curtailments will also diminish. Additional long-term outdoor savings (beyond the percentage reductions shown in Table 10) are possible if the current over-irrigators become deficit irrigators. Theoretically, the maximum short-term drought curtailment potential can be reached by temporarily eliminating all residential irrigation with potable city water.

CONCLUSIONS

The overall conclusion of this study is that if one wishes how much water a typical North American home requires the question should be qualified with the phrase "for what purpose?" What starts out as a dizzying array of values for annual use begins to show consistent patterns when the uses are disaggregated. The research team offers some of the salient conclusions that we draw from each of the topic areas.

From the Agency Surveys

The nine Level 1 study sites included in this project were located in a diverse set of climate types. There were 2 in humid, sub-tropical zone, 2 in the humid continental zone, 2 in the warm oceanic zone, 2 in the cold semi-arid zone, and one in the warm dessert zone. The maximum mean monthly temperatures In the group ranged from around 68 ^{o}F to 92 ^{o}F, and the minimum monthly temperatures ranged from around 20 to 60 ^{o}F It is not surprising then that outdoor water use patterns were also very diverse.

In most cases the water use for the Level 1 study sites was not impacted by drought restrictions during the study year. Two sites, Peel and Toho had mandatory outdoor restictions limiting irrigation to 1 or 2 days per week during 2010. San Antonio also had restrictions, but billing data for 2008 were used for the study (for determining outdoor use), which was free from restrictions. None of the other sites reported any outdoor use restrictions in place during 2010.

When the total billed consumption from 2006 through 2010 is plotted for the participating agencies the general trend in use was downward over the period.

The most common form of rate structure found in the group was the increasing block rate, with the most common number of blocks being 4 and the average volume in the first block being 6 kgal.

Many agencies include fixed charges as part of their water bills. The effect of these charges is to make the average rate in $/kgal decrease as customers increase their use—even though they may pay an increasing block for water use. There were only five agencies in which the average cost of water was greater in the top tier than in the first tier.

When fixed charges are excluded the average marginal price for water in the top tier of consumption averaged $6.16/kgal and ranged from $2.01 (in Chicago) to $17.14 (in Santa Fe).

There was only a single agency that did not have a budget for water conservation. The average number of staff reported in water conservation was 6 and the average budget was just over $3million.

Most of the agencies reported that they view water conservation as a method of increasing the reliability of their system, and they track the impact that their conservation programs have on annual household and/or per capita water use. By tracking costs and benefits of water conservation the agencies can evaluate demand management on an equal basis with supply site options. From this one has to conclude that the skepticism that was present about the efficacy of water conservation during the preparation of the first REUWS study has disappeared.

Every agency in the study group reported having an active water loss control program and in almost all cases they use the AWWA M36/IWA accounting procedure for estimating losses.

From the Customer Surveys

The results of this study indicate that approximately 1 in 3 households who received a survey took the time to fill it out and return it. Given the fact that this was a five page document this response rate is excellent and shows that people will make an effort to assist in this type of research.

On average, the number of residents per home has remained stable since the first REUWS. There was an average of 2.6 persons per household in this study compared to 2.8 persons in REUWS1.

Two thirds of the homes reported having a high efficiency clothes washers and the flow trace analysis showed that approximately half of the homes had clothes washer load volumes of less than 30 gpl. This makes sense since it is possible to operate a nominally high efficiency washer with settings that will use more than 30 gallons. Also, some residents will naturally be uncertain about exactly what type of washer they may have so some miss-reporting is expected.

The average number of toilets in the homes was 2.5, in REUWS1 the average was 2.3.

A surprising number of homes reported having recirculation pumps on their hot water lines in order to reduce the wait for hot water at the tap. The site with the greatest number of these devices was Scottsdale, where 30% of the homes reported having one.

There was not any site in which swimming pools were absent. Fort Collins and Denver had the lowest percentages of homes with pools and Scottsdale and Toho had the highest.

On average around 30% of the homes in the group did not irrigate their landscapes at all. Sites in the humid climates tended to have less irrigation which sites in the drier climates Denver, Fort Collins and Scottsdale had the highest percentage (>90%) of irrigators.

When people reported irrigating around 25% said they watered exclusively by hand and the rest had at least a portion of their landscape under an automatic irrigation system. This equates to around 53% of all homes that were equipped with in-ground irrigation systems. In the REUWS1 study the percent of homes with in-ground systems was 41%. We would not draw any conclusions from this since the nature of the study groups was different in the two studies with respect to climate.

One thing that can be concluded from the information on irrigation controllers is that significantly more systems are equipped with weather based or smart controllers. In some sites overs half of the customers reported having smart controllers.

Indoor uses have clearly declined over time, primarily as a result of the introduction of high efficiency toilets and clothes washers. These two categories of indoor use have shown unambiguous decreases.

Water use for the other indoor categories has also shown decreases, but these are not as statistically robust as those for the toilet and clothes washer categories.

Customers showed a fairly good understanding of the drought situations in their area. There are five levels in the office drought monitor report (no drought, mild drought, moderate drought, severe drought and extreme drought. In most cases the customers were within one level of the official status in their understanding. That is, if the official status was moderate, the customers tended to either rate the drought at moderate or mild.

From Water Use Statistics

The average annual water use for the Level 1 and 2 sites was 88 kgal (333 M^3), which is equivalent to 241 gpad (910 lpac) or 95 gpcd (359 lpcd) for all uses. The range of annual use was from 44 kgal to 175 kgal per account (166 to 662 M^3/acct).

Indoor use averaged 138 gpad (521 lpad) or approximately 53 gpcd (200 lpcd). (This includes leakage, which is really not a "use" of water, and is considered equivalent to a parasitic load in an electric system.)

The relationship between household water use and the number of residents is not a linear one, but follows a power curve Indoor use = 67.3 $\cdot \text{Res}^{0.654}$ (gpd). Knowing this is important in order to avoid over estimating domestic demands for larger households.

Indoor use has declined significantly since the REUWS1, from 177 gpac (670 lpac) in the former to 138 gpad (521 lpad) in the latter.

The two main driving forces in the observed reduction in indoor use were toilets and clothes washers, both of which showed statistically significant reductions.

There were decreases in use for the other indoor categories, but these were not statistically significant. Even though these changes were not statistically significant (at the 95% confidence level) the fact that reductions were seen in virtually all categories is suggestive that real reductions are occurring.

The largest reductions in water use were seen in clothes washer use and toilet use. The smallest changes were in the shower and faucet categories. The fact that the categories of use that are based on behavior showed the smallest changes suggests that even with more efficient showerheads and faucet aerators there is a base use level, below which it is difficult to drive demands.

The usage rate for toilets and clothes washers did not change significantly between REUWS1 and 2, so we know that the observed changes in the daily use are not due to changes in how frequently people are washing clothes or flushing toilets.

In the REUWS1 study only 16% of all flushes were in the efficient range (<2.2 gpf 8.3 lpf), but in the REUWS2 study 51% of flushes were in this range. The average flush volumes dropped from 3.66 gpf (13.8 lpf) to 2.60 gpf (9.8 lpf).

In the study group there were around 30% of the homes with very few flushes in the efficient range, implying that these homes are equipped exclusively with older, inefficient toilets. At the same time there were around 33% of the homes that appear to be equipped exclusively with efficient toilets. The remaining homes contain a mixture of old and new toilets.

The average number of showers per household per day was precisely the same in both the REUWS1 and 2 studies—1.8 showers per day. The duration of the showers was 7.8 minutes in both studies. The average flow rate for showers was slightly lower, at 2.1 versus 2.2 gpm (~7.9 lpm). Overall, except for houses with ultra-efficient showers there was no observable change in shower use between the two studies.

Between the two studies over 1.5 million faucet events were logged, which accounted for over 1 million gallons of water use. The number of faucet uses per day per person was between 15 and 20 uses, and the average daily use for faucets was 26-27 gpad (~100 lpad). Ninety percent of all faucet events were less than 90 seconds in duration and used less than 1.2 gallons of water. Overall, it was not possible to detect a significant change in miscellaneous faucet use between the two studies.

Clothes washer use in terms of loads per day was virtually identical between the two studies, but the volume of water required for a load dropped from 41 to 31 gallons (155 to 117 liters). Water efficient clothes washers have been critical at reducing domestic water use.

While dish washers do not account for a large percentage of total domestic use the volume of water used for a load of dishes has dropped significantly. In REUWS1 an average load of dishes used 10 gal (37.9 l), while in REUWS2 an average load consumed 6.1 gal (23 l), which is a 40% reduction.

In this study the presence of a dish washer had no impact on average faucet use.

Bathtub use is infrequent. On average a bathtub filling was recorded only once every 5.5 days, but in most houses no tub use was recorded at all. The average volume of water per bath was 20 gal (76 l).

The data on leakage are clear: a small percentage of homes contribute the bulk of the leakage. Two thirds of the homes in the study were leaking at 10 gpd or less, but these accounted for just 17% of the total volume of leakage. The one third of homes with leakage greater than 10 gpd accounted for 83% of the total leak volume. The top 10% of homes were leaking at more than 50 gpd, and they accounted for 53% of all leakage.

The large leak volumes were associated with continuous low flow rate leaks, not short intermittent leaks. If plumbing controls or AMI systems could identify homes with continuous low flows the leakage rate could be cut in half.

Homes in the study group used an average of 45 gpd (170 lpd) of hot water, which represents approximately 1/3 of the total water us in the home.

The biggest two users of hot water in the home were showers and faucets. Clothes washers used less than 5 gpd of hot water.

On average the homes used 753,000 BTU/month for water heating during the study.

Hot was use was found to increase during the winter months.

Outdoor use was similar to leakage in the degree to which the use was skewed by a few heavy users. Overall, the ratio of actual landscape use to theoretical requirements was 58%, but only 20$ of the homes in the study group were over-irrigating. This means that the entire conservation potential from improve landscape management (as opposed to wholesale changes to landscape such as turf removal) is expected to derive from just 20% of the customers.

Because so many homes are under-irrigating any general attempt to bring everyone into compliance with ET requirements (such as with WBICs) could lead to major increases in landscape water use. The data collected as part of this study clearly suggest that irrigation programs must be targeted to customer who are heavy users of landscape water.

The diurnal use pattern for indoor uses follows the typical two peak pattern, with a large peak occurring in the morning and a smaller peak occurring in the evening.

Showers and toilets drive the morning peak while faucets and toilets drive the evening peak.

From Models

The regression models prepared from the study data showed that the most important predictor of indoor water use was the number of persons residing in the home.

Children account for a lower water use than do adults.

Indoor water use rises with the size of the lot and with the presence of a swimming pool, and both of these may be the effect of additional faucet events occurring for pools and landscape use which are classified as indoor use by the analysis.

The cost for water was not found to be a determinant for indoor water use, but the cost for sewer service was.

High efficiency toilets and clothes washers were found to decrease indoor use, as was the presence of a hot water circulation system for on-demand hot water.

If the three variables that were found to decrease indoor water use: high efficiency toilets, clothes washers and hot water systems were all set to 100% saturation the model predicts that the household use for the group would decrease from 138 gpd to 108 gpd, or from 53 gpcd to 41.5 gpcd—a 21% reduction in indoor use.

The model does not deal with leakage rates explicitly, but if leakage control system could be implemented household use could easily drop below 100 gpd.

The regression analysis for outdoor, landscape uses found that the chief predictors of outdoor use for landscape were the size of the parcel, the percent that is irrigated, whether the home was built after 2006, the local weather and the presence of a pool or in-ground irrigation system. The model did not deal with the presence of excess irrigation explicitly.

Since most of the terms in the outdoor model are related to factors that the utility can not control it is difficult to use it to predict conservation potential. The factors that could be controlled in the model are the percent of the lot that is irrigable, which could be limited, the presence of a pool, which could be discouraged, and the presence of an in-ground irrigation system. Of the three, the only item which really lends itself to regulation is the percent of the lot that is irrigable, or in turf. Local agencies could require landscapes to be less turf intensive and have less irrigated area. It seems improbable that banning pools or in-ground irrigation systems would gain much favor.

The un-named item in this list is eliminating or reducing excess irrigation. As discussed in the benchmarking section, elimination of excess irrigation is the single biggest source of landscape conservation available.

From Benchmarks

By examining the current water use patterns in light of known benchmarks based on levels of efficiency of indoor and outdoor use it is possible to derive estimates of potential water conservation savings.

By use of the benchmark method the target level of indoor use was shown to be 96 gpad and this assumes no change in the average leakage rate, but it does assume that over time water sense standard fixtures and appliances will be fully utilized.

Given the fact that both modelling and benchmark analysis both point towards indoor domestic use around 100 gpad makes this a very compelling planning value. If leakage could be addressed then indoor use as low as 90 gpad is not unreasonable.

Starting from the existing indoor use of 138 gpad a reduction to 100 gpad represents a 27% reduction in indoor use over time from current levels, and a reduction of approximately 44% compared to the indoor use levels from the REUWS1 study, of 177 gpcd.

The benchmark for outdoor use is based on elimination of excess irrigation where it is occurring while leaving the deficit irrigators to carry on. If excess irrigation could be eliminated in the study group then the average outdoor use for the entire study group would drop by 8.2 kgal. (It would decrease by ~48 kgal on the homes that were over-irrigating.)

A savings of 8.2 kgal/year in outdoor use represents a 16% reduction.

It is really not possible to project these precise savings volumes onto the country as a whole since irrigation rates vary so much. It is necessary to do local studies of irrigation use for each community in order to get savings estimates that pertain to any particular service area.

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APPENDICES

APPENDIX A: HOUSEHOLD WATER USE SURVEY TABLES OF RESPONSES

Table 100: Utility*

Utility	Number of Completed Surveys
Aurora Water	135
Austin Water	115
Town of Cary Water	106
City of Chicago Department of Water Management	128
Cobb County Water System	119
EPCOR Water Services	122
City of Henderson Department of Utility Services	122
Miami-Dade Water	77
City of Mountain View Water	147
Otay Water District	88
Philadelphia Water Department	92
Portland Water Bureau	93
City of Santa Barbara, Public Works	131
City of Santa Fe Sangre de Cristo Water	157
South Central Connecticut Regional Water	109
Clayton County	369
Denver	356
Fort Collins	476
San Antonio	280
Scottsdale	349
Tacoma	347
Toho	147
Peel	231
Waterloo	347
Unknown (ID was scratched or torn off)	14
Total	4,657

** Note: Where there were duplicate survey IDs, the wave 2 survey was eliminated.*

Table 101: Question #1

Please indicate how many of each of the following types of water-using appliances or fixtures you have in your home. Circle the appropriate number for each.	None	One	Two	Three	Four	Five	Six	Seven or more	Total
Toilet	.2%	11.6%	43.8%	31.6%	10.2%	1.7%	.5%	.3%	100.0 %
Bathtub with shower	4.6%	63.1%	27.6%	4.1%	.4%	.2%	.0%	.0%	100.0 %
Standard bathtub only	66.2%	29.6%	3.6%	.5%	.1%	.0%	.0%	.0%	100.0 %
Large bathtub tub w/jets	73.0%	26.0%	.9%	.0%	.0%	.0%	.0%	.0%	100.0 %
Shower stall only	27.1%	58.2%	12.7%	1.6%	.4%	.1%	.0%	.0%	100.0 %
Indoor utility/garage sink	58.1%	39.0%	2.1%	.4%	.3%	.0%	.0%	.1%	100.0 %

Table 102: Question #2

Please indicate whether you have any of the following inside your home. Check the appropriate box for each.	Yes	No	Total
In-sink garbage disposal	64.9%	35.1%	100.0%
Automatic ice maker	61.8%	38.2%	100.0%
Dishwasher	83.7%	16.3%	100.0%
Water & energy efficient (EnergyStar) clothes washer	67.3%	32.7%	100.0%
Tankless water heater	7.8%	92.2%	100.0%
On-demand hot water system (recirculating pump)	13.4%	86.6%	100.0%
Evaporative/swamp cooler	6.2%	93.8%	100.0%
Whole house humidifier (usually attached to furnace)	18.5%	81.5%	100.0%
Whole house water treatment system like a water softener or a reverse osmosis system	13.1%	86.9%	100.0%
Fish aquarium larger than 10 gallons	5.4%	94.6%	100.0%
Pets (e.g., dogs, cats, or other medium to large size animal)	51.9%	48.1%	100.0%
Indoor spa or hot tub with jets (if hot tub is NOT usually filled with water, indicate "no")	3.2%	96.8%	100.0%
A built-in indoor water feature (like a water fountain or water pond)	1.9%	98.1%	100.0%
Indoor garden or greenhouse	1.2%	98.8%	100.0%

Table 103: Question #3

Do you have any water-using appliances and fixtures that were not listed in Questions #1 and #2?	Percent of Respondents
No	90.6%
Yes	9.4%
Total	100.0%

Table 104: Question #4

How many of the toilets in your home are one of the following (total should equal the number of toilets indicated in Question #1)	None	One	Two	Three	Four or more	Don't know	Total
Older toilet with a flush volume greater than 1.6 gallons	35.4%	19.5%	18.8%	8.6%	2.5%	15.3%	100.0%
Flush volume of 1.6 gallons/6.1 liters	19.1%	20.0%	24.0%	13.7%	6.0%	17.3%	100.0%
Flush volume of 1.28 gallons/4.84 liters or less	34.3%	17.2%	15.4%	8.9%	3.1%	21.1%	100.0%
Dual Flush (~1.6/0.8 gallons/ 6.1/0.3 liters)	59.8%	9.6%	4.7%	2.9%	.9%	22.1%	100.0%

Table 105: Question #5

How many of the showers in your home have any of the following?	None	One	Two	Three	Four or more	Don't know	Total
Multiple showerheads	82.6%	10.1%	4.8%	1.0%	.2%	1.3%	100.0%
Rain panels (on the ceiling)	95.8%	2.1%	.7%	.1%	.1%	1.3%	100.0%
Body spray panels (on the wall)	87.1%	5.9%	4.4%	1.0%	.3%	1.4%	100.0%

Table 106: Question #6

Please indicate whether you have replaced any of the following in the past 10 years. Check the appropriate box for each.	Yes	No	Total
Toilets	54.2%	45.8%	100.0%
Showerheads	73.4%	26.6%	100.0%
Clothes washer	64.3%	35.7%	100.0%
Dishwasher	49.1%	50.9%	100.0%

Table 107: Question #7

Please indicate whether you have any of the following. (Check all that apply.)	Percent of Respondents*
Leaking toilet (you may hear it running when not in use)	7.4%
Dripping faucet	7.9%
Leaks in your swimming pool system	1.2%
Leaks in your irrigation system	2.9%
Other water leaks	2.7%
Did not check any	83.5%

** Percents add to more than 100% as respondents could give more than one answer.*

Table 108: Question #8

What energy source does your water heater use? (Check all that apply.)	Percent of Respondents*
Gas	74.9%
Electric	22.8%
Other	.7%
Don't know	2.0%
Propane	.3%
Solar	.5%
Did not check any	2.0%

** Percents add to more than 100% as respondents could give more than one answer.*

Table 109: Question #9

Does hot water take longer to reach some places in your house than others?	Percent of Respondents
No, hot water reaches all fixtures in about the same amount of time	46.0%
Yes, some places take longer than others for hot water to reach	54.0%
Total	100.0%

Table 110: Question #9a

Which rooms does it take hot water longer to reach? (Check all that apply.)	Percent of Respondents Who Said Hot Water Takes Longer to Reach Some Places Than Others*
kitchen	32.6%
master bathroom	60.5%
other bathroom	39.0%
other room	3.1%
Did not check any	3.9%

** Percents add to more than 100% as respondents could give more than one answer.*

Table 111: Question #10

Thinking of the room where it takes hot water the longest to reach, how long would you say you have to wait for hot water?	Percent of Respondents
Almost no time at all	15.4%
Not very long, we just have to let the water run for a few seconds	46.0%
Pretty long, we have to let the water run a minute or two before it gets hot	34.8%
Very long, we have to let the water run more than two minutes before it gets hot	3.8%
Total	100.0%

Table 112: Question #11

Does the wait for hot water bother you?	Percent of Respondents
Yes, very much	12.6%
Yes, a little bit	27.7%
No, not really	59.6%
Total	100.0%

Table 113: Question #12

Do you regularly water your outside landscape? (Includes hand watering, irrigation system, hose and sprinkler, or other method.)	Percent of Respondents
Yes	70.0%
No	30.0%
Total	100.0%

Table 114: Question #13

How do you maintain your landscape and garden?	Percent of Respondents Who Water Their Landscape
Not applicable – my/our landscape does not require maintenance.	1.9%
I/We hire a company (or individual) to handle most or all of our landscape maintenance.	12.9%
I/We do most of the work ourselves.	70.1%
A combination, some I/we do ourselves, some I/we hire out for.	15.1%
Total	100.0%

Table 115: Question #14

Is your landscape service provider responsible for adjusting your outdoor landscape watering schedule?	Percent of Respondents Who Water Their Landscape
Yes	32.6%
No	67.4%
Total	100.0%

Table 116: Question #15

In addition to the water purchased from your water utility, do you use any of the following sources of water for your outdoor water needs? (Check all that apply.)	Percent of Respondents Who Water Their Landscape*
No additional sources of water used	76.0%
Well water	.8%
Canal/ditch	.2%
Stream/river	.1%
Rain barrel or cistern (rainwater harvesting)	9.7%
Directing roof/rain water towards plants in the yard	6.0%
Graywater reuse from indoor fixtures	2.4%
Other	.8%
Did not check any	9.4%

** Percents add to more than 100% as respondents could give more than one answer.*

Table 117: Question #16

About how much of your outdoor irrigation water comes from the source(s) above (assuming the rest comes from water supplier)?	Percent of Respondents Who Water Their Landscape and Use Sources Other Than Water Utility
Less than 25%	54.8%
About 25% to 50%	10.0%
About 51% to 75%	4.8%
More than 75%	8.9%
Don't know	21.5%
Total	100.0%

Table 118:

Question #17

Which types of landscape are present in your yard? (Check all that apply.)	Percent of Respondents Who Water Their Landscape*
Lawn/grass/turf (any variety)	81.1%
Trees and shrubs	80.1%
Vegetable garden	29.3%
Flower garden	53.8%
Low-water use trees, shrubs, and plants	44.0%
Non-watered ground cover (mulch, gravel, rocks, artificial turf, etc.)	41.6%
Did not check any	2.1%

** Percents add to more than 100% as respondents could give more than one answer.*

Table 119: Question #18

About how much of your outdoor landscape is watered by hand/manually?	Percent of Respondents Who Water Their Landscape
All of it (100%)	27.3%
More than half	10.4%
Less than half	36.0%
None	26.3%
Total	100.0%

Table 120: Question #19

Do you have an in-ground irrigation/sprinkling system?	Percent of Respondents Who Water Their Landscape
Yes	53.0%
No	47.0%
Total	100.0%

Table 121: Question #20

Does your in-ground irrigation system have the following? (Check all that apply.)	Percent of Respondents Who Water Their Landscape and Have an In-Ground Sprinkler System*
Automatic timer/controller	87.9%
Weather-based "smart" controller	16.4%
Master valve	48.6%
Back-flow preventer (anti-siphon device)	49.9%
Drip irrigation, micro spray and/or bubbler	40.1%
Other	1.9%
Did not check any	7.3%

** Percents add to more than 100% as respondents could give more than one answer.*

Table 122: Question #21

Does your automatic irrigation system have an override shut-off device such as a soil moisture sensor or rain shut-off sensor? (Check all that apply.)	Percent of Respondents Who Water Their Landscape and Have an In-Ground Sprinkler System*
No override shut-off device/sensor	42.2%
No, but I manually try and turn it off when it rains	42.5%
Yes, soil moisture sensor installed	1.2%
Yes, rain shut-off sensor installed	13.4%
Other	1.4%
Don't know	7.2%
Did not check any	8.1%

** Percents add to more than 100% as respondents could give more than one answer.*

Table 123: Question #22

How frequently do you (or your landscape company) adjust the run times on your irrigation timer?	Percent of Respondents Who Water Their Landscape and Have an In-Ground Sprinkler System
I use the factory settings that came with the timer	3.9%
My timer automatically adjusts to the weather	.9%
About once a year, at the start of the irrigation season	28.5%
About 4 times a year/quarterly	37.6%
About once a month	13.9%
About once a week or more	6.4%
Don't know	8.9%
Total	100.0%

Table 124: Question #23

Does your home have an outdoor spa or hot tub?	Percent of Respondents
Yes	8.4%
No	91.6%
Total	100.0%

Table 125: Question #24

Is the outdoor spa or hot tub usually filled?	Percent of Respondents with an Outdoor Spa or Hot Tub
Yes, usually filled	76.3%
No, sometimes filled	14.2%
No, it is never filled	9.5%
Total	100.0%

Table 126: Question #25

Do you have an outdoor water feature like a fountain or pond that is filled regularly?	Percent of Respondents with an Outdoor Spa or Hot Tub
Yes	22.0%
No	78.0%
Total	100.0%

Table 127: Question #26

Does your home have a swimming pool (indoor and/or outdoor)?	Percent of Respondents
Yes	11.5%
No	88.5%
Total	100.0%

Table 128: Question #27

What type of filling/re-filling system does the swimming pool have?	Percent of Respondents with Swimming Pool
Manual	61.9%
Automatic	38.1%
Total	100.0%

Table 129: Question #28

What type of swimming pool cover, if any, do you use?	Percent of Respondents with Swimming Pool
No pool cover	69.5%
Chemical pool cover	.4%
Physical pool cover removed and replaced regularly (e.g., overnight)	14.6%
Physical pool cover removed and replaced seasonally (e.g., during the winter)	15.5%
Total	100.0%

Table 130: Question #29

On average, about how often does your household do each of the following?	Never	More than once a week	About once a week	About twice a month	About once a month	Less than once a month	Don't know	Total
Wash a car / personal vehicle at home	50.7%	.5%	2.4%	7.0%	10.2%	27.3%	1.9%	100.0%
Use a hose to clean the sidewalks, patios and driveways around your home	46.0%	.7%	2.2%	3.7%	8.0%	36.0%	3.5%	100.0%

Table 131: Question #30

In the past three years, have you participated in a water conservation program sponsored by your local water utility?	Percent of Respondents
Yes	13.3%
No	86.7%
Total	100.0%

Table 132: Question #31

In what type of water conservation program did you participate? (Please check all that apply.)	Percent of Respondents Who Have Participated in a Water Conservation Program*
A water fixture give-away or exchange program	20.9%
A water fixture or water appliance rebate program (i.e., get reimbursed some or all of the cost of purchasing a high efficiency water fixture or appliance)	27.7%
A landscape rebate for removing lawn or high water use plants or increasing the efficiency of the irrigation system	3.2%
Followed water conservation guidelines set by the water utility	49.0%
Other	5.7%
Did not check any	18.1%

** Percents add to more than 100% as respondents could give more than one answer.*

Table 133: Question #32

In the last several years, has your household taken any action to conserve water, or are you currently engaging in water conservation practices?	Percent of Respondents
Yes	72.6%
No	27.4%
Total	100.0%

Table 134: Question #33

If yes, what types of action have you taken or are you taking to conserve water? (Please check all that apply.)	Percent of Respondents Who Have Conserved Water*
Installed water-efficient clothes washer	44.0%
Take shorter showers	52.0%
Installed low-flow showerheads	46.2%
Installed water savers (inserts) in toilet	12.3%
Installed new toilet(s)	43.7%
Use garbage disposal less often	31.0%
Use dishwasher less/use fuller loads	62.7%
Use clothes washer less/use fuller loads	59.6%
Repaired leaks in faucet/toilet	46.0%
Had a home water audit/survey done	2.5%
Catch water in bucket to re-use while waiting for water to get hot	10.6%
Other	2.9%
Installed water-efficient dishwasher	28.6%
Wash car less often	29.9%
Water lawn and shrubs less often	49.4%
Avoid watering lawn and shrubs during the heat of the day	72.3%
Installed low-water-use landscaping/plants	23.9%
Reduced run-times on automatic sprinklers	25.4%
Repaired damaged or leaking irrigation system	22.3%
Monitor irrigation system for leaks, blown heads, etc.	24.6%
Cycle irrigate lawns (e.g., 5 min. on, 1 hour off, repeated several times or similar arrangement)	4.3%
Use graywater/reuse household water	7.3%
Installed a rain barrel or cistern	9.9%
Did not check any	3.3%

** Percents add to more than 100% as respondents could give more than one answer.*

Table 135: Question #34

At the present time, would you say that your community is experiencing:	Percent of Respondents
No drought	26.1%
Mild drought	21.7%
Moderate drought	25.8%
Severe drought	9.2%
Don't know	17.2%
Total	100.0%

Table 136: Question #35

Please indicate the extent to which you AGREE or DISAGREE with each of the following statements. Please check the appropriate box for each.	Strongly agree	Somewhat agree	Somewhat disagree	Strongly disagree	Not applicable	Total
Most households in my community know where their water comes from when they turn on the tap.	20.3%	40.9%	21.6%	13.7%	3.4%	100.0%
Residents should be allowed to track their household water use via the web or by reading their own water meter.	40.6%	43.8%	8.4%	3.6%	3.6%	100.0%
Households would conserve more water if they had an easier way to monitor their water use.	38.9%	44.2%	11.5%	3.8%	1.5%	100.0%
Without looking at past bills, I know about how much my average (typical) household water bill was (in dollars) last year.	34.4%	38.6%	14.2%	10.5%	2.3%	100.0%
Without looking at past bills, I know about how much water my household used in an average (typical) billing period last year.	23.2%	33.5%	22.7%	18.2%	2.4%	100.0%
The cost of water is an important factor for me when deciding how much water to use indoors (e.g. for washing dishes, washing clothes, showering/bathing, etc.).	32.0%	36.0%	19.5%	11.0%	1.5%	100.0%
The cost of water is an important factor for me when deciding how much water to use outdoors (e.g., for watering the lawn or garden, etc.).	41.1%	35.7%	13.7%	6.3%	3.2%	100.0%
I take into account the cost of wastewater (sewer) service when deciding how much water to use.* *If you are charged a flat rate for wasterwater/sewer service, mark "not applicable."	18.2%	23.0%	19.3%	13.9%	25.6%	100.0%
Conservation of water is critical for the future of my community.	60.7%	31.7%	4.6%	1.8%	1.2%	100.0%
There should be strong financial penalties for people who use too much water.	20.2%	33.5%	26.6%	17.8%	1.9%	100.0%
I am aware of rebates offered by my water utility.	11.8%	21.8%	21.0%	38.7%	6.6%	100.0%
Water rates should be increased to encourage water conservation.	6.6%	14.6%	25.8%	50.6%	2.4%	100.0%
I conserve water to save money.	39.3%	38.7%	13.4%	6.8%	1.7%	100.0%
I conserve water to save energy.	40.0%	40.6%	12.2%	5.4%	1.7%	100.0%
I conserve water because it is the right thing to do.	56.6%	36.4%	3.9%	2.1%	1.0%	100.0%
People who use more water should pay more per gallon for their water.	19.3%	31.7%	24.5%	22.1%	2.4%	100.0%
My water utility should be more active in promoting water conservation on the part of households and businesses.	29.1%	50.2%	13.8%	4.2%	2.6%	100.0%
My water utility should provide financial incentives to conserve water.	42.1%	43.2%	9.3%	3.7%	1.7%	100.0%
My water utility should promote water use guidelines.	38.0%	48.0%	9.2%	2.8%	2.1%	100.0%

Table 137: Question #36

Is your household responsible for paying the water bill, OR does a landlord or homeowners’ association pay it?	Percent of Respondents
Household pays	98.2%
Landlord or a homeowner's association pays	1.4%
Don't know	.3%
It's a combination, the household pays for inside water use and the HOA pays for all or part of the landscape irrigation	.1%
Total	100.0%

Table 138: Question #37

When was your home built?	Percent of Respondents
Before 1940	9.0%
In the 1940s	4.0%
In the 1950s	12.1%
In the 1960s	11.5%
In the 1970s	15.9%
In the 1980s	16.6%
Between 1990 and 1994	8.0%
Between 1995 and 2000	12.2%
Between 2001 and 2005	7.5%
After 2006	3.2%
Total	100.0%

Table 139: Question #38

In what year did you move to this home?	Percent of Respondents
1912	.0%
1913	.0%
1914	.0%
1915	.0%
1918	.0%
1920	.0%
1922	.0%
1923	.0%
1927	.0%
1928	.0%
1933	.0%
1935	.0%
1936	.0%
1938	.0%
1940	.1%
1942	.0%
1943	.1%
1945	.0%
1946	.0%
1947	.0%
1948	.1%
1950	.1%
1951	.0%
1952	.1%
1953	.1%
1954	.2%
1955	.1%
1956	.3%
1957	.2%
1958	.1%
1959	.3%
1960	.6%
1961	.3%
1962	.4%
1963	.3%
1964	.4%
1965	.4%
1966	.6%
1967	.7%
1968	.5%
1969	.7%
1970	.6%
1971	.6%
1972	.6%

1973	.8%
1974	.7%
1975	.9%
1976	.8%
1977	1.0%
1978	1.7%
1979	.8%
1980	1.3%
1981	.7%
1982	.9%
1983	.9%
1984	.8%
1985	1.7%
1986	2.1%
1987	1.6%
1988	1.7%
1989	2.0%
1990	2.1%
1991	1.7%
1992	2.0%
1993	2.1%
1994	2.3%
1995	2.7%
1996	3.1%
1997	3.7%
1998	3.4%
1999	3.7%
2000	4.0%
2001	4.1%
2002	3.3%
2003	3.1%
2004	3.7%
2005	3.8%
2006	3.9%
2007	3.8%
2008	3.8%
2009	4.1%
2010	2.8%
2011	2.8%
2012	.9%
Total	100.0%

Table 140: Question #39

Do you rent or own your home?	Percent of Respondents
Rent	5.4%
Own	94.6%
Total	100.0%

Table 141: Question #40

How many bedrooms does this house have?	Percent of Respondents
1	1.0%
2	12.3%
3	50.0%
4	28.6%
5	6.9%
6 or more	1.2%
Total	100.0%

Table 142: Question #41

How many people, including you, live full time at this address?	None (0)	One (1)	Two (2)	Three (3)	Four (4)	Five (5)	Six (6) or More	Total
Adults, including you (age 18+)	.0%	20.1%	58.1%	14.8%	4.9%	1.5%	.7%	100.0%
Teenagers (age 13-17)	87.6%	8.7%	3.3%	.3%	.0%	.0%	.0%	100.0%
Children (age 3-12)	84.1%	8.3%	6.1%	1.2%	.2%	.0%	.0%	100.0%
Infants or Toddlers (under age 3)	95.2%	4.3%	.4%	.1%	.0%	.0%	.0%	100.0%
Total Persons in Household	.0%	18.3%	41.9%	16.9%	14.3%	5.3%	3.3%	100.0%

Table 143: Question #41

How many people, including you, live full time at this address?	Average Number
Adults, including you (age 18+)	2.118
Teenagers (age 13-17)	.165
Children (age 3-12)	.252
Infants or Toddlers (under age 3)	.055
Total Persons in Household	2.590

Table 144: Question #42

What number of adults living at this address are usually at home during the day on a weekday (i.e., not at work outside the home or a full-time student)?	Percent of Respondents
None (0)	26.6%
1	45.3%
2	24.5%
3	2.7%
4	.5%
5 or more	.3%
Total	100.0%

Table 145: Question #43

What is the number of adults living at this address who are employed full or part-time?	Percent of Respondents
None (0)	26.3%
1	32.5%
2	32.5%
3	6.6%
4	1.6%
5 or more	.4%
Total	100.0%

Table 146: Question #44

About how many times per week does someone take a bath (in a bathtub) in your household?	Percent of Respondents
None (0)	57.8%
1	11.2%
2	6.9%
3	6.1%
4	3.9%
5 or more	14.2%
Total	100.0%

Table 147: Question #45

About how many times per week does someone in your home take a shower at an athletic club or recreation center instead of at home?	Percent of Respondents
None (0)	79.3%
1	4.6%
2	4.3%
3	4.2%
4	2.0%
5 or more	5.5%
Total	100.0%

Table 148: Question #46

What is the highest level of education in the household?	Percent of Respondents
12th grade or less, no diploma	5.3%
High school diploma	11.1%
Some college, no degree	15.8%
Associate's degree (e.g. AA, AS)	8.3%
Bachelor's degree (e.g. BA, AB, BS)	28.1%
Graduate degree or professional degree	31.4%
Total	100.0%

Table 149: Question #47

About how much was your household's total income before taxes for all of 2010? (Please include in your total income money from all sources for all persons living in your household.)	Percent of Respondents
Less than $25,000	11.3%
$25,000 to under $50,000	22.0%
$50,000 to under $75,000	19.0%
$75,000 to under $100,000	17.0%
$100,000 to under $150,000	16.4%
$150,000 to under $200,000	7.4%
$200,000 or more	6.9%
Total	100.0%

APPENDIX B: DATABASE KEYS

Table 150: Key for Common Survey Questions table

Question No.	Description
CSQ01	Number of Toilets
CSQ02	Bath w/shower
CSQ03	Tub only
CSQ04	Tub w/jets
CSQ05	Shower stall only
CSQ06	Utility Sink
CSQ07	Disposal
CSQ08	ice maker
CSQ09	Dishwahser
CSQ10	HE CW
CSQ11	On Demand HW
CSQ12	Evap Cooler
CSQ13	W.H. Water Treatment
CSQ14	Pets
CSQ15	Indoor Spa
CSQ16	Indoor Water Feature
CSQ17	Indoor greenhouse
CSQ18	# of 1.6 gpf toilets
CSQ19	# of HET's
CSQ20	# of Dual Flush
CSQ21	# of hydra showers
CSQ22	# of Body Sprays
CSQ23	Are leaking toilets present?
CSQ24	Are dripping faucets present?
CSQ25	Do you have a leaking pool?
CSQ26	Do you have a leaking irrigation system?
CSQ27	other leaks
CSQ28	Do you water your landscape
CSQ29	How do you maintain landscape?
CSQ30	Does contractor schedule irrigation?
CSQ31	No additional irrigation sources
CSQ32	Is inground sprinkler present?
CSQ33	Auto timer for irrigation present
CSQ34	Weather based controller present
CSQ35	No over-ride devices on irrigation system
CSQ36	Is Outdoor spa present?
CSQ37	Outdoor water feature present
CSQ38	Swimming pool?

CSQ39	How is pool filled?
CSQ40	Pool Cover?
CSQ41	How often are cars washed at home?
CSQ42	Wash walks and drives
CSQ43	Who pays the water bill?
CSQ44	Year home built?
CSQ45	Year moved into home
CSQ46	Rent or own home?
CSQ47	How many Bedrooms
CSQ48	No of adults in home
CSQ49	Teenagers
CSQ50	Children
CSQ51	Infants/todlers
CSQ52	# of adults homes in day
CSQ53	# of adults employed full or part time
CSQ54	Number of baths per week in home
CSQ55	showers in clubs
CSQ56	highest grade of school
CSQ57	HH income pre tax

Table 151:Key for REUWS2 All Customer Surveys table

SurveyID	Description
Utility	
Service City	
Service State	
Service ZIP	
AnnualKgal	
SeasonalKgal	
NonseasonalKgal	
PctSeasonal	
Log_AnnualKgal_Bin	
survey_year_moved_in	In what year did you move to this home?
survey_number_of_bedrooms	How many bedrooms does this house have?
survey_number_of_adults	Adults, including you (age 18+)
survey_number_of_teenagers	Teenagers (age 13-17)
survey_number_of_children	Children (age 3-12)
survey_number_of_infants	Infants or Toddlers (under age 3)
survey_year	
survey_number_of_toilets	Toilet

survey_number_of_bathtub_showers	Bathtub with shower
survey_number_of_bathtub_only	Standard bathtub only
survey_number_of_whirlpools	Large bathtub tub w/jets
survey_number_of_shower_only	Shower stall only
survey_number_of_utility_sink	Indoor utility/garage sink
survey_number_of_bathtubs	Bathtubs
survey_number_of_showers	Showers
survey_disposal	In-sink garbage disposal
survey_ice_maker	Automatic ice maker
survey_dishwasher	Dishwasher
survey_clothes_washer_HE	Water & energy efficient (EnergyStar) clothes washer
survey_hot_water_tankless	Tankless water heater
survey_hot_water_on_demand	On-demand hot water system (recirculating pump)
survey_evap_cooler	Evaporative/swamp cooler
survey_humidifier	Whole house humidifier (usually attached to furnace)
survey_treatment	Whole house water treatment system like a water softener or a reverse osmosis system
survey_aquarium	Fish aquarium larger than 10 gallons
survey_pets	Pets (e.g., dogs, cats, or other medium to large size animal)
survey_spa_indoor	Indoor spa or hot tub with jets (if hot tub is NOT usually filled with water, indicate "no")
survey_water_feature_indoor	A built-in indoor water feature (like a water fountain or water pond)
survey_greenhouse_indoor	Indoor garden or greenhouse
survey_other_features	Do you have any water-using appliances and fixtures that were not listed in Questions #1 and #2?
survey_number_of_toilets_GT16	Older toilet with a flush volume greater than 1.6 gallons
survey_number_of_toilets_16	Flush volume of 1.6 gallons/6.1 liters
survey_number_of_toilets_HET	Flush volume of 1.28 gallons/4.84 liters or less
survey_number_of_toilets_dual	Dual Flush (~1.6/0.8 gallons/ 6.1/0.3 liters)
survey_number_of_showers_hydra	Multiple showerheads
survey_number_of_showers_rain	Rain panels (on the ceiling)
survey_number_of_showers_spray	Body spray panels (on the wall)
survey_replaced_toilets_10	Toilets
survey_replaced_s	Showerheads

howerheads_10	
survey_replaced_clothes_washer_10	Clothes washer
survey_replaced_dishwasher_10	Dishwasher
survey_leak_toilet	Leaking toilet (you may hear it running when not in use)
survey_faucet_drips	Dripping faucet
survey_leak_pool	Leaks in your swimming pool system
survey_leak_irrigation	Leaks in your irrigation system
survey_leak_other	Other water leaks
survey_hot_water_gas	Gas
survey_hot_water_electric	Electric
survey_hot_water_propane	Propane
survey_hot_water_solar	Solar
survey_hot_water_wait	Does hot water take longer to reach some places in your house than others?
survey_hot_water_wait_kitchen	kitchen
survey_hot_water_wait_master_bath	master bathroom
survey_hot_water_wait_other_bath	other bathroom
survey_hot_water_wait_other_room	other room
survey_hot_water_waiting	Thinking of the room where it takes hot water the longest to reach, how long would you say you have to wait for hot water?
survey_hot_water_wait_bother	Does the wait for hot water bother you?
survey_irrigation	Do you regularly water your outside landscape? (Includes hand watering, irrigation system, hose and sprinkler, or other method.)
survey_landscape_no_maintenance	
survey_landscaper	How do you maintain your landscape and garden?
survey_landscaper_waters	Is your landscape service provider responsible for adjusting your outdoor landscape watering schedule?
survey_well	Well water
survey_canal_ditch	Canal/ditch
survey_stream	Stream/river
survey_rain_barrel	Rain barrel or cistern (rainwater harvesting)
survey_roof_direction	Directing roof/rain water towards plants in the yard
survey_gray_water	Graywater reuse from indoor fixtures
survey_other_sources_pct	About how much of your outdoor irrigation water comes from the source(s) above (assuming the rest comes from water supplier)?
survey_landscape_turf	Lawn/grass/turf (any variety)
survey_landscape_trees_and_shrubs	Trees and shrubs

survey_garden_veggie	Vegetable garden
survey_garden_flower	Flower garden
survey_landscape_low_water	Low-water use trees, shrubs, and plants
survey_landscape_nonirrigated	Non-watered ground cover (mulch, gravel, rocks, artificial turf, etc.)
survey_manual_irrigation_pct	About how much of your outdoor landscape is watered by hand/manually?
survey_irrigation_inground	Do you have an in-ground irrigation/sprinkling system?
survey_irrigation_inground_timer	Automatic timer/controller
survey_irrigation_inground_master	Master valve
survey_irrigation_inground_bfp	Back-flow preventer (anti-siphon device)
survey_irrigation_inground_drip	Drip irrigation, micro spray and/or bubbler
survey_irrigation_manual_override	No, but I manually try and turn it off when it rains
survey_irrigation_sensor_soil	Yes, soil moisture sensor installed
survey_irrigation_sensor_rain	Yes, rain shut-off sensor installed
survey_irrigation_inground_timer_adjusted	How frequently do you (or your landscape company) adjust the run times on your irrigation timer?
survey_irrigation_inground_wbic	Weather-based "smart" controller
survey_spa_or_hot_tub_outdoor	Does your home have an outdoor spa or hot tub?
survey_spa_or_hot_tub_outdoor_filled	Is the outdoor spa or hot tub usually filled?
survey_water_feature_outdoor	Do you have an outdoor water feature like a fountain or pond that is filled regularly?
survey_pool	Does your home have a swimming pool (indoor and/or outdoor)?
survey_pool_fill_automatic	Automatic swimming pool filling/re-filling system
survey_pool_cover_chemical	Chemical pool cover
survey_pool_cover	What type of swimming pool cover, if any, do you use?
survey_pool_cover_overnight	Physical pool cover replaced overnight
survey_car_washed	Wash a car / personal vehicle at home
survey_walk_washed	Use a hose to clean the sidewalks, patios and driveways around your home
survey_program_participation_3	In the past three years, have you participated in a water conservation program sponsored by your local water utility?
survey_conservation_last_few	In the last several years, has your household taken any action to conserve water, or are you currently engaging in water conservation practices?
survey_giveaway_3	A water fixture give-away or exchange program
survey_retrofit_reb	A water fixture or water appliance rebate program (i.e., get reimbursed some or

ate_3	all of the cost of purchasing a high efficiency water fixture or appliance)
survey_landscape_rebate_3	A landscape rebate for removing lawn or high water use plants or increasing the efficiency of the irrigation system
survey_followed_guidelines	Followed water conservation guidelines set by the water utility
survey_replaced_clothes_washer_HE	Installed water-efficient clothes washer
survey_conservation_shower_short	Take shorter showers
survey_replaced_showerheads_LF	Installed low-flow showerheads
survey_toilet_inserts	Installed water savers (inserts) in toilet
survey_replaced_toilets_last_few	Installed new toilet(s)
survey_disposal_used_less	Use garbage disposal less often
survey_dishwasher_used_less	Use dishwasher less/use fuller loads
survey_clothes_washer_used_less	Use clothes washer less/use fuller loads
survey_faucet_drips_repaired	Repaired leaks in faucet/toilet
survey_audit_last_few	Had a home water audit/survey done
survey_shower_bucket	Catch water in bucket to re-use while waiting for water to get hot
survey_replaced_dishwasher_HE	Installed water-efficient dishwasher
survey_car_washed_less_often	Wash car less often
survey_irrigation_less_often	Water lawn and shrubs less often
survey_irrigation_avoid_heat	Avoid watering lawn and shrubs during the heat of the day
survey_landscape_low_water_last_few	Installed low-water-use landscaping/plants
survey_irrigation_timer_shortened_last_few	Reduced run-times on automatic sprinklers
survey_leak_irrigation_repaired	Repaired damaged or leaking irrigation system
survey_irrigation_inground_monitor	Monitor irrigation system for leaks, blown heads, etc.
survey_irrigation_inground_cycle	Cycle irrigate lawns (e.g., 5 min. on, 1 hour off, repeated several times or similar arrangement)
survey_gray_water_last_few	Use graywater/reuse household water
survey_rain_barrel_last_few	Installed a rain barrel or cistern
survey_drought	At the present time, would you say that your community is experiencing:
survey_household_pays	Is your household responsible for paying the water bill, OR does a landlord or homeowners' association pay it?
survey_year_built	When was your home built?
survey_age_of_ho	House age (years)

me	
survey_years_in_home	Residency (years)
survey_renter	Do you rent or own your home?
survey_homies	What number of adults living at this address are usually at home during the day on a weekday (i.e., not at work outside the home or a full-time student)?
survey_adults_employed	What is the number of adults living at this address who are employed full or part-time?
survey_baths_per_week	About how many times per week does someone take a bath (in a bathtub) in your household?
survey_showers_not_at_home	About how many times per week does someone in your home take a shower at an athletic club or recreation center instead of at home?
survey_highest_grade	What is the highest level of education in the household?
survey_income	About how much was your household's total income before taxes for all of 2010? (Please include in your total income money from all sources for all persons living in your household.)
survey_participant	Agree to participate
reuws2_attitude_A	Most households in my community know where their water comes from when they turn on the tap.
reuws2_attitude_B	Residents should be allowed to track their household water use via the web or by reading their own water meter.
reuws2_attitude_C	Households would conserve more water if they had an easier way to monitor their water use.
reuws2_attitude_D	Without looking at past bills, I know about how much my average (typical) household water bill was (in dollars) last year.
reuws2_attitude_E	Without looking at past bills, I know about how much water my household used in an average (typical) billing period last year.
reuws2_attitude_F	The cost of water is an important factor for me when deciding how much water to use indoors (e.g. for washing dishes,
reuws2_attitude_G	The cost of water is an important factor for me when deciding how much water to use outdoors (e.g., for watering the lawn or garden, etc.).
reuws2_attitude_H	I take into account the cost of wastewater (sewer) service when deciding how much water to use.* *If you are charged a flat rate for wasterwater/sewer service, mark "not applicable."
reuws2_attitude_I	Conservation of water is critical for the future of my community.
reuws2_attitude_J	There should be strong financial penalties for people who use too much water.
reuws2_attitude_K	I am aware of rebates offered by my water utility.
reuws2_attitude_L	Water rates should be increased to encourage water conservation.
reuws2_attitude_M	I conserve water to save money.
reuws2_attitude_N	I conserve water to save energy.
reuws2_attitude_O	I conserve water because it is the right thing to do.
reuws2_attitude_P	People who use more water should pay more per gallon for their water.
reuws2_attitude_Q	My water utility should be more active in promoting water conservation on the part of households and businesses.
reuws2_attitude_R	My water utility should provide financial incentives to conserve water.
reuws2_attitude_S	My water utility should promote water use guidelines.

Table 152: Key for Combined Indoor All Studies table

Question No.	Description
1	Study
2	Keycode
3	Serv_Add
4	City
5	State
6	Zip5
7	SurveyID
8	Type
9	Cooling Deg Days this month (Deg F)
10	Cooling Degree Days previous month (Deg F)
11	Mean Monthly TEMP_LOG MONTH (Deg F)
12	Total PRECIP_LOG MONTH (IN)
13	TEMP_PREV MONTH (Deg F)
14	PRECIP_PREV MONTH (IN)
15	Total Volume
16	TraceBegins
17	TraceEnds
18	Trace Length Days
19	Total GPD
20	Indoor GPD
21	Outdoor GPD
22	Indoor total gal
23	Outdoor total gal
24	Bathtub total gal
25	Clotheswasher total gal
26	Dishwasher total gal
27	Faucet total gal
28	Leak total gal
29	Other total gal
30	Shower total gal
31	Toilet total gal
32	Bathtub events
33	Clotheswasher events
34	Dishwasher events
35	Faucet events
36	Leak events
37	Other events
38	Shower events
39	Toilet events

40	Bathtub gpd
41	Clotheswasher gpd
42	Dishwasher gpd
43	Faucet gpd
44	Leak gpd
45	Other gpd
46	Shower gpd
47	Toilet gpd
48	Average clotheswasher load gal
49	Clotheswasher loads per day
50	Total shower minutes
51	Average shower seconds
52	Total shower gal
53	Average shower gal
54	Average shower mode flow gpm
55	Showers per day
56	Shower minutes per day
57	Average toilet flush volume
58	Toilet flush stdev
59	Flushes > 2.2gal
60	Flushes < 2.2 gal

Table 153: Key for REUWS2 Combined Outdoor All Studies table

Question No.	Description
1	Study
2	Keycode
3	SurveyID
4	City
5	Type
6	Annual_kgal
7	Nonseas_kgal
8	Seas_kgal
9	Projected Indoor_kgal
10	Lot Area_sf
11	Hardscape_sf
12	House_sf
13	Non-irrigated Vegetation_sf
14	NonTurfPlants_sf
15	TreeCanopy_sf
16	Pool_sf
17	Turf_sf

18	Veggie_sf
19	Xeri_sf
20	Gross Eto_in
21	Annual Precip_in
22	Net ET_in
23	ET Source
24	Indoor_kgal
25	Outdoor_kgal
26	Tot_Irri_area_sf
27	Average application_in
28	Reference Demand_kgal
29	placeholder
30	TIR_kgal
31	TIR_in
32	Application Ratio
33	Excess Irrigation_kgal
34	Net application_kgal
35	Landscape Ratio
36	Placeholder
37	Placeholder
38	Placeholder
39	Placeholder
40	Is Excess

Table 154: Key for REWUS2 Level 1 Survey and Water Use Table

Question No.	Keycode
1	SurveyID
2	utility
3	ServiceCity
4	ServiceState
5	ServiceZip
6	ServiceProvince
7	ServicePostalCode
8	MeterSize
9	AnnualKgal
10	SeasonalKgal
11	NonseasonalKgal
12	PctSeasonal
13	survey_year_moved_in
14	survey_number_of_bedrooms
15	survey_number_of_adults
16	survey_number_of_teenagers
17	survey_number_of_children
18	survey_number_of_infants

19	capita
20	survey_year
21	survey_number_of_toilets
22	survey_number_of_bathtub_showers
23	survey_number_of_bathtub_only
24	survey_number_of_whirlpools
25	survey_number_of_shower_only
26	survey_number_of_bathtubs
27	survey_number_of_showers
28	survey_disposal
29	survey_ice_maker
30	survey_dishwasher
31	survey_clothes_washer_HE
32	survey_hot_water_tankless
33	survey_hot_water_on_demand
34	survey_evap_cooler
35	survey_humidifier
36	survey_treatment
37	survey_aquarium
38	survey_pets
39	survey_spa_indoor
40	survey_water_feature_indoor
41	survey_greenhouse_indoor
42	survey_other_features
43	survey_number_of_toilets_GT16
44	survey_number_of_toilets_16
45	survey_number_of_toilets_HET
46	survey_number_of_toilets_dual
47	survey_number_of_showers_hydra
48	survey_number_of_showers_rain
49	survey_number_of_showers_spray
50	survey_replaced_toilets_10
51	survey_replaced_showerheads_10
52	survey_replaced_clothes_washer_10
53	survey_replaced_dishwasher_10
54	survey_leak_toilet
55	survey_faucet_drips
56	survey_leak_pool
57	survey_leak_irrigation
58	survey_leak_other
59	survey_hot_water_gas
60	survey_hot_water_electric
61	survey_hot_water_propane
62	survey_hot_water_solar
63	survey_hot_water_wait
64	survey_hot_water_wait_kitchen
65	survey_hot_water_wait_master_bath
66	survey_hot_water_wait_other_bath
67	survey_hot_water_wait_other_room
68	survey_hot_water_waiting

69	survey_hot_water_wait_bother
70	survey_irrigation
71	survey_landscape_no_maintenance
72	survey_landscaper
73	survey_landscaper_waters
74	survey_well
75	survey_canal_ditch
76	survey_stream
77	survey_rain_barrel
78	survey_roof_direction
79	survey_gray_water
80	survey_other_sources_pct
81	survey_landscape_turf
82	survey_landscape_trees_and_shrubs
83	survey_garden_veggie
84	survey_garden_flower
85	survey_landscape_low_water
86	survey_landscape_nonirrigated
87	survey_manual_irrigation_pct
88	survey_irrigation_inground
89	survey_irrigation_inground_timer
90	survey_irrigation_inground_master
91	survey_irrigation_inground_bfp
92	survey_irrigation_inground_drip
93	survey_irrigation_manual_override
94	survey_irrigation_sensor_soil
95	survey_irrigation_sensor_rain
96	survey_irrigation_inground_timer_adjusted
97	survey_irrigation_inground_wbic
98	survey_spa_or_hot_tub_outdoor
99	survey_spa_or_hot_tub_outdoor_filled
100	survey_water_feature_outdoor
101	survey_pool
102	survey_pool_fill_automatic
103	survey_pool_cover_chemical
104	survey_pool_cover
105	survey_pool_cover_overnight
106	survey_car_washed
107	survey_walk_washed
108	survey_program_participation_3
109	survey_conservation_last_few
110	survey_giveaway_3
111	survey_retrofit_rebate_3
112	survey_landscape_rebate_3
113	survey_followed_guidelines
114	survey_replaced_clothes_washer_HE
115	survey_conservation_shower_short
116	survey_replaced_showerheads_LF
117	survey_toilet_inserts
118	survey_replaced_toilets_last_few

119	survey_disposal_used_less
120	survey_dishwasher_used_less
121	survey_clothes_washer_used_less
122	survey_faucet_drips_repaired
123	survey_audit_last_few
124	survey_shower_bucket
125	survey_replaced_dishwasher_HE
126	survey_car_washed_less_often
127	survey_irrigation_less_often
128	survey_irrigation_avoid_heat
129	survey_landscape_low_water_last_few
130	survey_irrigation_timer_shortened_last_few
131	survey_leak_irrigation_repaired
132	survey_irrigation_inground_monitor
133	survey_irrigation_inground_cycle
134	survey_gray_water_last_few
135	survey_rain_barrel_last_few
136	survey_drought
137	survey_household_pays
138	survey_year_built
139	survey_age_of_home
140	survey_years_in_home
141	survey_renter
142	survey_homies
143	survey_adults_employed
144	survey_baths_per_week
145	survey_showers_not_at_home
146	survey_highest_grade
147	survey_income
148	reuws2_attitude_A
149	reuws2_attitude_B
150	reuws2_attitude_C
151	reuws2_attitude_D
152	reuws2_attitude_E
153	reuws2_attitude_F
154	reuws2_attitude_G
155	reuws2_attitude_H
156	reuws2_attitude_I
157	reuws2_attitude_J
158	reuws2_attitude_K
159	reuws2_attitude_L
160	reuws2_attitude_M
161	reuws2_attitude_N
162	reuws2_attitude_O
163	reuws2_attitude_P
164	reuws2_attitude_Q
165	reuws2_attitude_R
166	reuws2_attitude_S
167	TraceBegins
168	TraceEnds

169	TraceLengthDays
170	TraceDaily
171	TraceIndoorDaily
172	TraceOutdoorDaily
173	Bathtubevents
174	Clotheswasherevents
175	Dishwasherevents
176	Faucetevents
177	Leakevents
178	Otherevents
179	Showerevents
180	Toiletevents
181	BathtubDaily
182	ClothesWasherDailyVolume
183	DishwasherDaily
184	FaucetDaily
185	LeakDaily
186	OtherDaily
187	ShowerDailyVolume
188	ToiletDailyVolume
189	ClothesWasherUseVolume
190	ClothesWasherDailyUses
191	ShowerUseVolume
192	ShowerMode
193	ShowerDailyUses
194	ShowerDailyMinutes
195	ToiletUseVolume
196	ToiletUseStDev
197	ToiletDailyUses
198	pct_flushes_lt_2_2
199	pct_flushes_gt_2_2
200	TraceIndoorDailyHot
201	BathtubDailyHot
202	ClothesWasherDailyVolumeHot
203	DishwasherDailyHot
204	FaucetDailyHot
205	LeakDailyHot
206	OtherDailyHot
207	ShowerDailyVolumeHot
208	ToiletDailyVolumeHot
209	ClothesWasherUseVolumeHot
210	Averageshowerseconds
211	ShowerUseVolumeHot
212	House_Footprint
213	NonIrrigated_Vegetation
214	Veggie_Garden
215	IndoorKgal
216	OutdoorKgal
217	TotalIrrigatedAreaSqFt
218	ApplicationIn

219	ReferenceDemandKgal
220	TIRKgal
221	TheoreticalDemandIn
222	ApplicationRatio
223	ExcessApplicationKgal
224	NetApplication
225	LandscapeRatio
226	IsExcess
227	Parcel_Area
228	Tree_Shrub_Area
229	Turf_Area
230	Pool_Area
231	Xeriscape_Density
232	Xeriscape_Area
233	Annual_Precip
234	ETo_Source
235	CoolingDegDaysthismonthDegF
236	CoolingDegreeDayspreviousmonthDegF
237	Annual_ETo
238	MeanMonthlyTEMP_LOGMONTHDegF
239	Net_ET
240	PRECIP_PREVMONTHIN
241	TEMP_PREVMONTHDegF
242	TotalPRECIP_LOGMONTHIN
243	Billingstructure
244	WinterBillingStructureType
245	SummerBillingStructureType
246	FixedCharges
247	Billfor5kgal
248	Billfor25kgal
249	Billfor50kgal
250	AvgCost@5kgal
251	AvgCost@25kgal
252	AvgCost@50kgal
253	MarginalRate
254	TopTierBreakVolumekgal
255	BillingStructureType