ANALYSIS OF WATER USE IN NEW SINGLE-FAMILY HOMES

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EXECUTIVE SUMMARY

As populations grow and water resources become over appropriated we face some uncomfortable decisions. Should growth be curtailed and populations limited, or should new supplies continue to be developed, despite ever increasing costs? How do we reconcile damages to the environment and economic losses associated with reduced stream-flows for wildlife and sustaining the natural world? Should the environment be sacrificed in order to sustain growth? These are all difficult choices. One area where most people agree, however, is that if we could reduce household water demands through improved technologies we might mitigate some of the negative impacts of growth on the Nation's water resources.

Over the years the United States has sought to increase the efficiency of its domestic water use by passing laws such as the Energy Policy Act of 1992, which have mandated improved water use efficiencies for plumbing devices such as toilets, faucets and showerheads. More recently, the United States Environmental Protection Agency has sponsored the WaterSense Program, which seeks to promote water efficient products in the market through setting specifications and labeling products that meet them. Most states and major water agencies have active water conservation programs which seek to improve the efficiency of use and reduce growth in water demands, largely by implementing programs to adopt more efficient fixtures, appliances and landscape practices.

All of this begs the question as to how effective these efforts have been at reducing actual household water use, or whether savings in one end-use have been offset by increased uses elsewhere. This is a critical question since the core assumption of most water conservation programs is that savings gained by efficiency improvements will largely pass through to reduced household use. If this is true, then we should see definite downward trends in single family household water use (normalized for number of residents) in response to increased use of higher efficiency devices. This study provides answers to this question by examining water use data from three categories of homes: existing homes from the mid 1990's, new homes built after January 1, 2001 and high-efficiency new homes built to equal or exceed water use efficiency specifications very similar to those of the WaterSense program. It is encouraging to note that the results of the analysis confirm that there are clear and significant improvements in household water use in the newer and more efficient homes, compared to the baseline homes from pre-1995 period.

The US EPA provided funding for this study through a grant to the Salt Lake City Corporation. The grant was awarded in 2005 and work began in 2006. Working with nine participating utilities, some of which participated in earlier projects, this project was designed to measure baseline water use in "standard" new homes, built after January 1, 2001, and in "high-efficiency" new homes, built using the criteria that WaterSense New Home specification or better, and to compare this use to that from the Residential End Uses of Water Study (REUWS), done in 1999[1].

[1] Mayer, P. W., DeOreo, W. B., Opitz, E. M., Kiefer, J. C., Davis, W. Y., Dziegielewski, B., and Nelson, J. O. (1999). "Residential End Uses of Water." American Water Works Association Research Foundation, Denver.

The goal for this task was to determine whether household water use has been reduced over the years through use of high-efficiency devices.

The data collected for this study compare water use in new and existing housing in the United States and demonstrates how much water is used in homes for each of the major domestic end-uses both indoors and outdoors. The outdoor water use analysis compares the actual water use at each study site against the theoretical irrigation requirement that is based on the local evapotranspiration rate and landscape characteristics.

The research procedures for this study were developed by the project team with substantial input from the research team, advisory committee, and participating water agencies. The nine water utilities that participated in this study were:

- City of Aurora, Colorado
- Denver Water, Colorado
- Eugene Water and Electric Board, Oregon
- Southern Nevada Water Authority, Las Vegas, Nevada
- City of Phoenix, Arizona
- City of Roseville, California
- Salt Lake City Corporation, Utah
- St. John River Water Management District, Florida
- Tampa Bay Water, Florida

Selection of Initial Survey Group

Two separate random samples of approximately 1,000 homes each were selected from the population of single-family homes at each of the nine participating study sites for a total of 18 samples. The samples were selected from all active single family homes built prior to and after January 1, 2001. The first set was referred to as the existing homes and the second set as the standard new homes. In this context the term “standard new homes” means that these homes were those constructed to generally accepted standards after 1/1/2001, and were not specifically designed or built to enhance their levels of water use efficiency.

Survey Implementation

A mail survey of all customers in both of the survey samples was conducted. The survey implementation process was designed to maximize the response rate. The final survey for this study was five pages long and included 55 questions ranging from standard demographic queries to questions about the fixtures and appliances present in the home. Key results from the survey are summarized in Chapter 4.

End Use Study Site Selection

Fifty homes were selected from each of the nine study sites in order to arrive at a final sample of standard new homes for detailed data logging. Ten extra study homes at each site were selected in order to provide a reserve pool of study homes in case of a change in ownership, participant opt-out, or unavailability. Water use statistics for each sample of homes were checked to verify that each sub-sample of end use study homes was statistically similar to the original sample of 1000 customers from which they were drawn.

High-Efficiency New Homes

An important goal of this study was to examine the water use patterns of new homes intentionally built to use water efficiently in each of the nine participating study sites. These homes were built with fixtures and appliances that were the best available technologies with respect to water conservation. While these homes were selected prior to the official adoption of the WaterSense New Home specification, the study specifications closely mirrored the WaterSense Specification. The water use patterns in the new high-efficiency homes in this study should be quite similar to those built to the WaterSense New Home specification, and for practical purposes we consider the high efficiency new homes to be equivalent to WaterSense Specification homes.

Due to the economic downturn that occurred during the study timeframe, new housing construction slowed significantly in 2007 and came to a virtual standstill in 2008. This resulted in numerous extensions to the project timeline as the research team sought occupied high-efficiency new homes to study. In early 2009 the number of high-efficiency homes available for study participation and end use monitoring had dwindled to just 25 homes in Eugene, Oregon and Roseville, California. The research team worked closely with the utility staffs in Eugene and Roseville to solicit the participation of these homes in the study. In Eugene, 10 high-efficiency homes were studied. In Roseville, California 15 high-efficiency homes were studied. These homes were recently occupied and in most cases did not have established landscapes or a full year of metered consumption data. Consequently, the analysis presented in this report is focused on the disaggregated indoor uses measured at these 25 high-efficiency new homes.

Additional Site Specific Data

Several sources of data were used to characterize the water use patterns and efficiency level of the single family water customers in an agency's service area. Local weather data, tax assessor data, and information on lot size, irrigated area, and home value were combined with billing and survey data to improve the models of water use in the existing and new homes. Local weather data, lot size and irrigated area are important components of seasonal demand calculations.

Weather Data

Seasonal use is water use over and above the non-seasonal (indoor) use and includes water use for irrigation, swimming pools, and cooling. Local weather and evapotranspiration (ET_o) data combined with landscape information obtained from aerial photos (for the standard new homes) provided reasonable estimates of the irrigation requirements of existing landscapes. Both are essential elements needed for calculating the theoretical irrigation requirement for each site.

Monthly data for temperature, precipitation and ET_o were obtained for each study site from a variety of sources for the period of time covered by water billing records and end use data. These data were used to provide a comparison of estimated outdoor water use and ET_o for the existing and new houses in the various study sites.

Irrigated Area Data

Irrigated area data, when combined with local weather and evapotranspiration data, were used to establish the theoretical irrigation requirements for the homes. The irrigated area at each property selected for end use monitoring was measured using electronic mapping and/or aerial photos obtained from the participating agencies and/or other sources such as Google Earth and analyzed using ESRI[2] GIS software.

End Use Data Collection and Analysis

End use water data were obtained in this study using Aquacraft's well-established flow trace analysis technique. This technique employs a portable battery powered flow data recorder attached to the water meter at each home to record flows into the home at 10-second intervals. The flow recorder is left in place for two weeks and then downloaded. The resulting flow trace provides a detailed and continuous record of water flows into the home. Each flow trace is then disaggregated into component end uses by trained analysts using Aquacraft's copyrighted software *Trace Wizard.* A detailed description of the flow trace analysis technique is given in Chapter 3 and Appendix D.

Flow Data Recording

Flow data recording, also known as data logging, provides detailed information about indoor and seasonal water use in individual houses. A flow recorder, (commonly known as a data logger), was installed on the individual water meter at each home participating in the study. The recorders were left in place for a period of two weeks during which time the flow data through the water meter was recorded every 10 seconds creating a continuous flow trace file.

Flow Trace Analysis

Each flow trace file obtained during the site visits was disaggregated 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.

Trace Wizard Identification of Common Household Fixtures

The Trace Wizard program includes a visual tool that was used to identify individual events that take place during the two-week data logging period. The most common water use events found during trace analysis are toilets, faucets, showers, clothes washers, dishwashers and leaks. Flow trace analysis is a well-established and proven method for identifying the key household end-uses of water.

Comparison Studies

In order to gauge the water use efficiency of the study homes two other study groups have been used for comparison purposes. These studies are discussed and cited in the Literature Review, but, for convenience are summarized here.

Residential End Uses of Water Study

The Residential End Uses of Water Study (REUWS) is a group of approximately 1200 single family homes chosen at random from the service areas of 12 water providers across the country[3]. These homes provide a baseline for existing single family homes for the period from 1996-1998.

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[2] http://www.esri.com/
[3] This report can be downloaded at http://www.aquacraft.com/Publications/REUWS_final_report.pdf

The homes were selected only on the basis of having their water use match the water use of the populations from which they were drawn.

EPA Retrofit Study

The EPA Retrofit Study[4] comprised a group of approximately 100 homes that were chosen at random from the single family populations in Seattle, EBMUD and the Tampa Bay area. After baseline surveys and logging, approximately 30 of the homes were retrofit with high-efficiency fixtures and appliances at no cost to the home owner. The post retrofit data from the homes was used as a benchmark for high-efficiency single family indoor water use that might be obtained from retrofits and repair of major leaks. The homes in the study were existing homes in their respective service areas, and their only significant modifications were the high-efficiency toilets, showers, clothes washers and faucets installed. The homeowners in the retrofit group were volunteers and they were given the new fixtures and appliances at not cost, so this may have increased their level of commitment to the study. Aside from that, however, they were typical single family households.

Results

In brief, the results of this study show that there is a significant reduction in indoor household water use, normalized for the number of residents, in newer and high-efficiency homes. Outdoor water use in new homes does not show a clear pattern of reduction, but is impacted by the same factors that affect outdoor use in existing homes. Chapter 4 presents the detailed results. The key results of the study are summarized here.

Annual and Seasonal Use

Annual, seasonal and non-seasonal use for each of the study groups, calculated from periodic utility billing data are summarized in Table ES **1** below. The non-seasonal use is based on the average winter consumption[5] prorated to the entire year, and the seasonal use is the annual use minus the non-seasonal use. In this type of analysis any outdoor use occurring during the winter period would be classified as non-seasonal use. Consequently, non-seasonal use, particularly in warmer climates, is not strictly indoor use, but may often include winter irrigation. No seasonal/non-seasonal splits were calculated for the high-efficiency new homes since a full year of billed consumption data were not available.

[4] This report can be downloaded at http://www.aquacraft.com/Publications/EPA_Combined_Retrofit_Report.pdf

[5] Average winter consumption is the average of the three coldest months of the year in areas where utilities bill monthly and there is little likelihood of winter irrigation. In areas with a bi-monthly billing cycle the average winter consumption is based on the water use of the lowest two months. And, in warmer areas that are likely to have some outdoor use year round the average winter consumption is based on the month with the lowest demand.

Table ES 1: Summary of annual and seasonal water use from billing data*

Group	N	Annual Use (kgal)	Non-seasonal Use (kgal)	Seasonal Use (kgal)
Existing Homes (pre-2001)	8811	140 ± 2.2	63.4 ± 1.0	**76.1 ± 1.7**
Standard New Homes (post-2001)	**8695**	**145 ± 3.1**	**60.9 ± 1.5**	**84.0 ± 2.4**

*± values are the 95% confidence bounds of these measurements.

Based on billing data analysis alone the standard new homes appear to use slightly more water on an annual basis, less water for non-seasonal (indoor) uses and more water for seasonal uses than do the existing homes. The variability in the data result in an overlap of the 95% confidence intervals such that the average annual water use for the two groups is *not* statistically different at the 95% confidence level. This shows that the use of billing data alone it is not enough to obtain precise enough information to distinguish between existing and new homes.

Indoor Use

Indoor use, determined from flow trace analysis, provides a more precise picture of water demands in the standard new homes. In this study, flow trace analysis was not utilized on the existing home sample (built prior to 2001) because a substantial quantity of data on homes in this category was collected and analyzed for the 1999 Residential End Uses of Water Study (REUWS)[6].

Table ES 2 shows the average daily use per household of each major fixture and appliance found in the standard new homes, high-efficiency new homes, and from the 1999 REUWS sample of older homes, which are used as a proxy for the existing homes. Overall the REUWS homes used 177 gallons per household per day (gphd) for indoor purposes, the standard new homes used 140 gphd, and the high-efficiency homes used 110 gphd. This result suggests that the high-efficiency new homes studied here are 38% more efficient that the homes studied in the REUWS and 21% more efficient than the standard new home sample.

Toilet, clothes washer and faucet use declined at each step from older homes to standard new homes to high-efficiency new homes. Shower use did not decline in the standard new or high-efficiency homes, remaining between 30 and 35 gphd. Leaks and bathtub use also stayed fairly constant. Dishwasher use was lower only in the high-efficiency new home sample. Other/miscellaneous use which includes evaporative cooling, water softening, and humidification was substantially lower in the high-efficiency new homes, but this is likely due to the lack of such end uses in the high-efficiency new home sample.

[6] Mayer, Peter et al.. Residential End Uses of Water Study. AWWA Research Foundation. 1998.

Table ES 2: Comparison of average gallons per household per day (gphd)

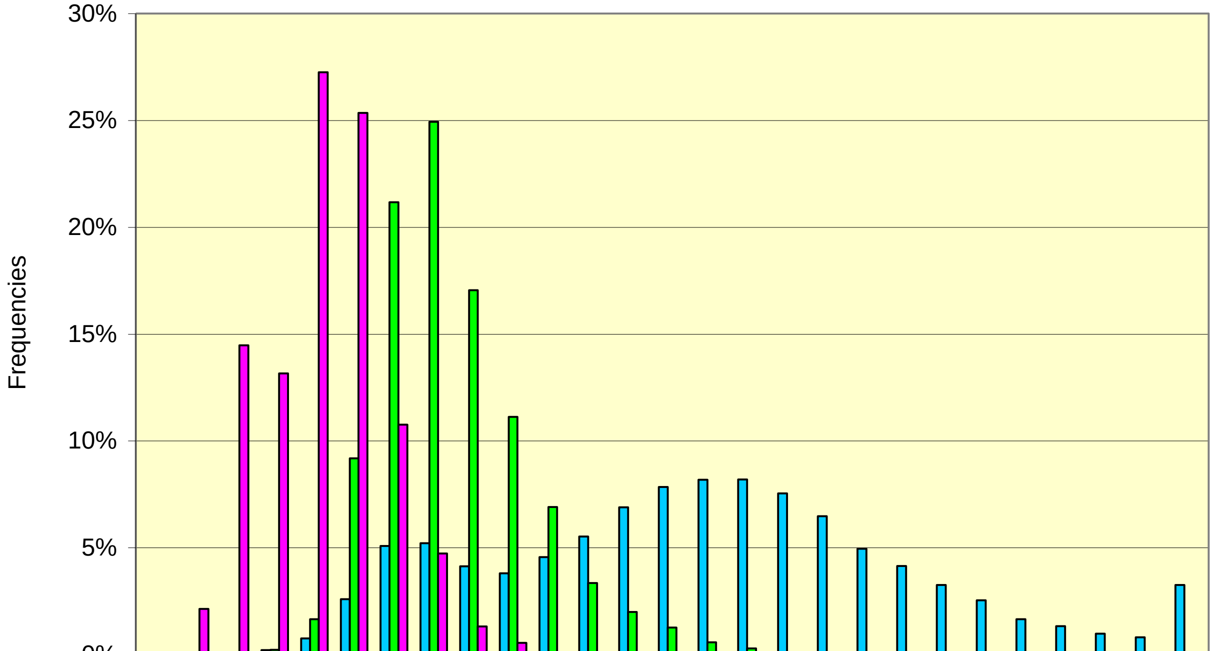
End Use	**REUWS (Homes built before 1995) (gphd)**	**Standard New Homes (Homes built after 2001) (gphd)**	High-efficiency New Homes (gphd)
Toilet	45.2	27.52	**16.2**
Clothes washer	39.2	28.91	**11.9**
Shower	30.8	29.88	**34.3**
Faucet	26.7	25.23	**18.1**
Leak	21.9	19.66	**19.2**
Other	7.4	3.02	**0.9**
Bathtub	3.2	3.45	**7.1**
Dishwasher	2.5	1.94	**1.9**
Total Daily Indoor Use	177	140	110

Improved Efficiency: Toilets and Clothes Washers

There are interesting comparisons made for the individual end-uses in the body of the report. The most striking, though, are for toilets and clothes washers, which clearly show the progress that has been made in these two key household end uses. Some key findings are summarized here.

Figure ES 1 shows the distributions for the entire set of toilet flushes from three sources: the Residential End Uses of Water Study, the Standard New Homes and the High-efficiency New Homes from this study. The REUWS represent a cross section of existing homes for the period from 1997-1998, and it contains over 348,000 flushes recorded in that study. The standard new homes distribution includes approximately 47,000 flushes from the new homes obtained as part of this study. The third group shows the distribution of the 3,461 toilet flushes logged in the high-efficiency new homes in this study.

The REUWS homes show a large percent of flushes (~60%) greater than 3 gallons and a long tail of large volume flushes at the right hand side of the graph. There is also a small but distinct group of flushes in the ULF range in these homes. The standard new homes show only around 10% of the flushes greater than 3 gallons and a much smaller portion of the flushes on the right hand side of the graph. There is no second peak at the 3 to 4 gpf level as there was in the REUWS homes. The graph from the high-efficiency new homes, which are equipped with WaterSense specification toilets, were tightly clustered around 1.4 to 1.6 gpf and had 99% of the flushes recorded at 2.5 gallons or less. This graph shows clear progress in toilet efficiency in the three groups.



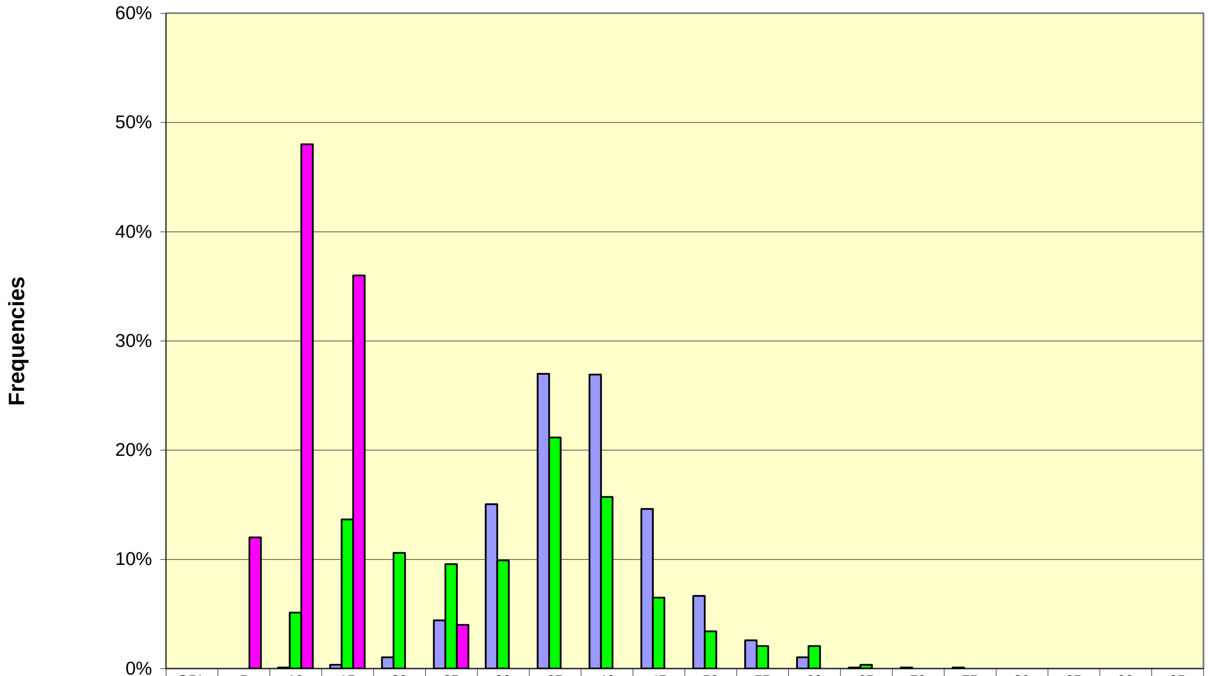
	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50
REUWS	0%	0%	0%	0%	1%	3%	5%	5%	4%	4%	5%	6%	7%	8%
Std NEW	0%	0%	0%	0%	2%	9%	21%	25%	17%	11%	7%	3%	2%	1%
HE New	0	2%	14%	13%	27%	25%	11%	5%	1%	1%	0%	0%	0%	0%

	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75
REUWS	8%	8%	8%	6%	5%	4%	3%	3%	2%	1%	1%	1%	3%
Std NEW	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
HE New	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Gallons per Flush

Figure ES 1: Comparison of toilet flush volume distributions

The analogous distributions of load volumes for clothes washers are shown in Figure ES 2. The REUWS homes have a single mode distribution with most of the loads using 30 to 40 gallons. The standard new homes have a bi-modal distribution, with one peak in the 15 to 20 gpl range and a second in the range of 30 to 40 gpl. The high-efficiency new homes have a single peak in the 15 to 30 gpl range. As was the case with the toilets, the comparisons of the clothes washer distributions show a dramatic improvement in efficiency among the three groups of homes.



	GPL	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
REUWS	0%	0%	0%	0%	1%	4%	15%	27%	27%	15%	7%	3%	1%	0%	0%	0%	0%	0%	0%	0%
Std New Homes	0%	0%	5%	14%	11%	10%	10%	21%	16%	6%	3%	2%	2%	0%	0%	0%	0%	0%	0%	0%
HE New Homes	0%	12%	48%	36%	0%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Gallons per Load

Figure ES 2: Comparison of clothes washer gallons per load distributions

Water Use Efficiency Rates

A key objective of this study was to characterize the overall water use efficiency of toilets, showers, and clothes washers, which are traditional targets of utility incentive programs. For purposes of this study we have used the criteria given in Table ES 3 as thresholds for distinguishing efficiency levels. These criteria represent the average performance of devices in each home and are not necessarily a guarantee that all fixtures in the home meet these criteria. For example, a home may meet the efficiency criteria for toilets even if only one of two toilets in the home is a ULF model, provided the ULF toilet is properly adjusted and is the predominantly utilized fixture. Conversely, a house may fail to meet the toilet criteria even though all of its toilets are ULF models, if the toilets are out of adjustment and flushing at more than 2 gpf.

Table ES 3: Efficiency criteria for penetration rate determination

Device	Criteria
Toilets	Ave gallons per flush $\leq$ 2.0 gpf
Showers	Ave shower flow rate $\leq$ 2.5 gpm
Clothes Washers	Ave load uses $\leq$ 30 gal

The percentages of standard new homes that met the conservation criteria used for this study for each device are shown in **Figure ES 3**. These percentages are shown for the high-efficiency new homes in **Figure ES 4**.

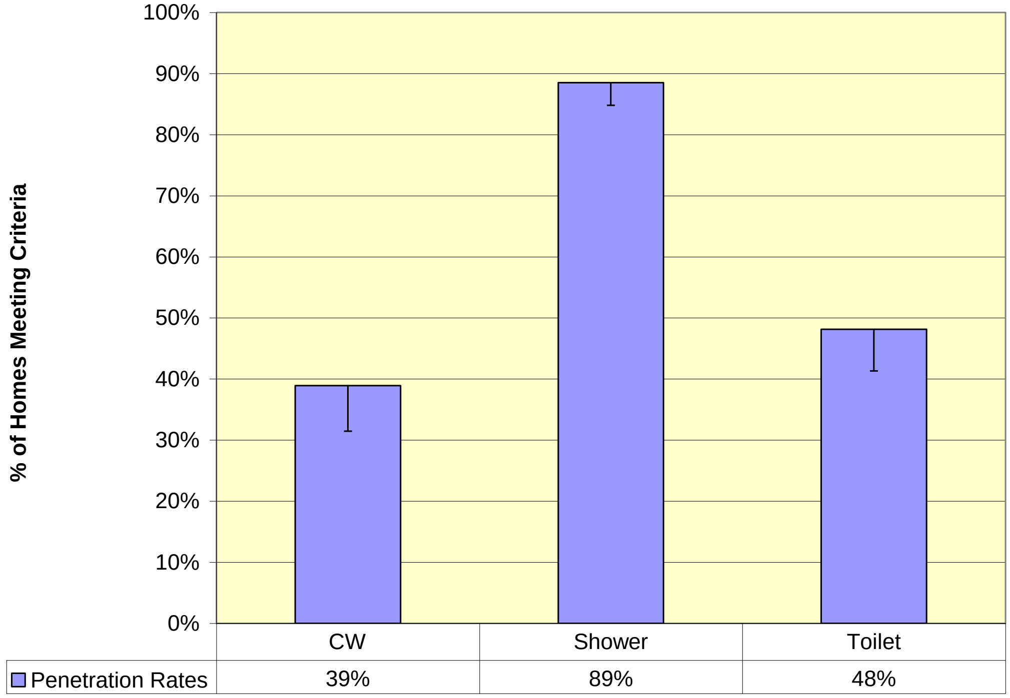


Figure ES 3: Household efficiency rates - standard new homes

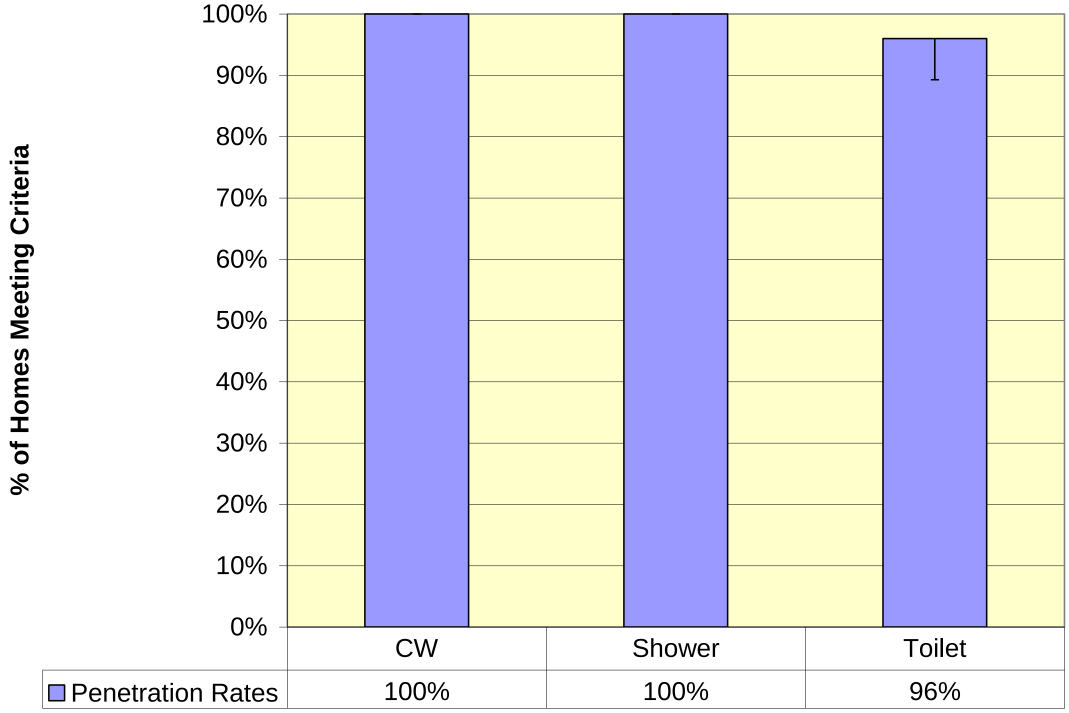


Figure ES 4: Household efficiency rates - high-efficiency new homes

Per Capita Use Patterns for Indoor Use

It is important to normalize indoor water use for single family residences on the basis of the number of persons living in the home because the number of residents is the most important variable and its value varies from home to home. As discussed in the body of the report all of the household use data were kept in the form of gallons per household per day, and then relationships were sought between household use and the key explanatory factors, which included but was not limited to the number of residents. The reason that this is important is because the relationships are not linear, and normalizing on the basis of the number of persons per home while the data are in raw form disguises the true relationship and distorts the results.

Figure ES 5 shows the relationships between household water use and the number of residents for the four groups of homes discussed in the report. This graph captures the two most important relationships in indoor single family homes water use: the number of persons living at the home and the nature of the fixtures and appliances present. There is a clear pattern of reduced per-capita use in the homes as one goes from existing homes, to standard new homes, the EPA Retrofit homes and the high-efficiency new homes. It is also interesting to note that the relationship between household use and residents becomes less pronounced in the more efficient homes. In other words the impact on household water use of adding new residents is diminished in the more efficient homes.

Table ES 4 summarizes the indoor water use data and also shows the project household and percapita use for a family of three in each home type. This is a striking relationship in which the household water use drops from 187 gphd to 107, and normalized per capita use drops from 62 to 36 gpcd.

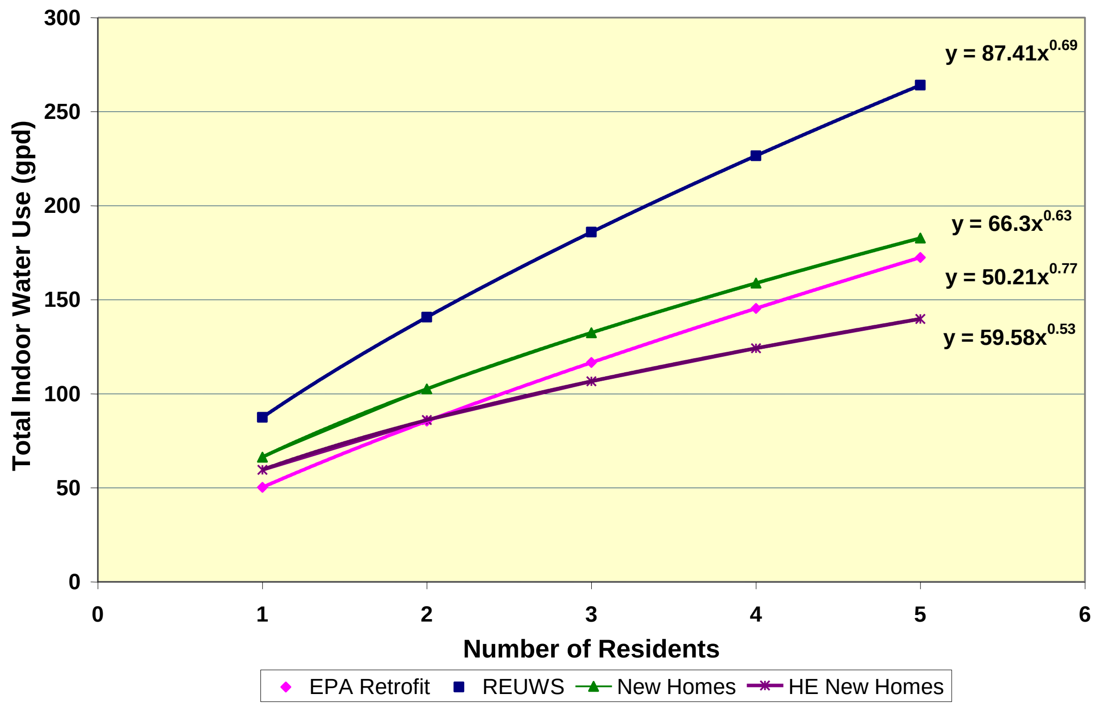


Figure ES 5: Indoor use versus residents for four research study groups

Table ES 4: Comparison of indoor per capita and household use patterns

Parameter	REUWS (built before 1995)	Standard New Homes (built since 2001)	EPA post-retrofit group	High-efficiency New Homes
N	1188	302	96	25
Mean ± 95% C.I. (gphd)	177 ± 5.5	140 ± 10.0	107 ± 10.3	105 ± 28
Median (gphd)	160	125	100	90
Per capita relationship (gphd=)	$87.41x^{0.69}$	$66.30x^{0.63}$	$50.21x^{0.77}$	$59.58x^{0.53}$
Household use for family of 3 (gphd)	187	132	117	107
Projected per capita use for family of 3 (gpcd)	62.18	44.15	39.0	35.6

Outdoor Use

Table ES 5 provides a comparison of outdoor use for the standard new homes with the REUWS. It is difficult to make a good comparison between these groups since the data were taken at different times and from so many different places and climates, but they do suggest that the new homes tend to use more water for outdoor purposes even though they may be irrigating smaller areas. The modeling data provide more insights into the factors that affect outdoor use in the new homes.

Table ES 5: Summary of Outdoor Use

Parameter	REUWS	**New Homes**
Annual Outdoor Use (kgal)	84	**93**
Net ETo (inches)	41	**34**
Irrigated Area (sf)	**7931**	**3749**

Predictive Models for Standard New Homes

Using the extensive data set developed for this study, predictive water use models were developed for standard new homes. The single most significant determinant of water use is number of residents in the home and when this information was combined with other explanatory variables the following relationship emerged for indoor water use. The parameters listed in the equation were the only four that proved significant for predicting indoor water use.

For predicting indoor use in new homes, the number of residents was the most important variable, followed by whether the home had a leak, a high-efficiency clothes washer or a water treatment system. Income was not a statistically significant factor in predicting indoor use. The reason that toilets did not show up as a factor is that almost all of the homes in the standard new home group were equipped with comparable ULF toilets so there was not enough variability in toilet use to relate to a change in indoor water use.

Equation ES 1: Indoor water use model for standard new homes

$$\boxed{\text{Indooor GPHD} = 71.2 * \text{Res\_No}^{0.63} * \text{significant\_leak} * \text{CW\_HE} * \text{softener} + 11.8}$$

Where:

- Indoor Use = Indoor water use (gphd) (the dependent variable).
- Res_No = Number of residents in household, raised to the 0.63 power
- Significant_leak = multiply by 191% if the household shows a leak over 50 GPD
- CW_HE = multiply by 77% if the household has a clothes washer using less than 30 gallons per load
- Softener = multiply by 112% if the household has a water softener

The model for outdoor water use in the new homes is shown in Equation ES 2. The factors that were useful for predicting outdoor use included income, the number of residents, the total irrigated area, the landscape ratio, whether the home showed excess irrigation use, and whether there was someone home during the day.

Equation ES 2: Outdoor use model of standard new homes

$$\text{Outdoor Kgal} = 2.02 * 10^{-4} * \text{Income}^{0.36} * \text{Net ET}^{0.85} * \text{Irr\_Area}^{0.61} * \text{LandscapeRatio}^{0.65} * \text{Excess} * \text{Person at home} - 15.20$$

Where:

Outdoor Kgal = dependent variable
Income = Household income, dollars
Net ET = Gross ET – effective precipitation
Total Irrigated Area = sq. ft. of irrigated area
Landscape Ratio = ratio of landscape coefficient to turf
Excess Irrigator = product of 3.23 times percent of homes that are irrigating above TIR
Person at Home = product of 1.15 times percent of homes with adult(s) at home during day

Conclusions

A key conclusion of this research study is that it is possible to develop reasonable efficiency benchmarks for both indoor and outdoor water use for existing and new single family homes, which are supported by empirical data. For indoor water use the data suggest three efficiency levels shown in Table ES-6. These values were projected from the relationships shown in Table 4-33, rounded to the nearest 10 gphd.

Table ES- 6: Efficiency benchmarks for indoor water use for a family of 3

Category	**Household Efficiency Benchmark for Family of 3**	Description
Baseline/Existing homes	190 gphd	Existing homes in the general population built prior to 2000.
Standard New Home Efficiency	130 gphd	Homes complying with the 1992 Energy Policy Act plus 40% equipped with HE clothes washers
High-efficiency New Homes	110 gphd	Homes closely matching the WaterSense New Home specification, plus Tier 3 clothes washer. and matching end use pattern from Figure 4-19
Estimated water savings going from baseline to high-efficiency homes	**26 kgal/yr indoor** **27 kgal/yr outdoor (see below)** **53 kgal/yr total household**	Average savings. Actual savings depend upon baseline demand.

The best efficiencies found in the study were from the high-efficiency new homes, which were estimated at 110 gphd for a family of 3. Achieving indoor water use levels comparable to these homes requires: (1) The use of indoor fixtures and appliances that meet or exceed the criteria similar to the WaterSense New Home specification; (2) the limitation of leakage to 20 gpd or less per household and (3) prevention of widespread adoption of new water using devices that would offset the savings from the high-efficiency devices.

Efficiency benchmarks cannot be so readily established for outdoor use because of the tremendous variability among residential landscapes and climate conditions across the country. The outdoor model shown above was used to test changing two of the parameters. It was found that if the percent of the population that is over-irrigating could be reduced from 64% to 50% and the landscape ratios could be reduced from 98% to 78% the average outdoor use would drop by 27 kgal per year. The sum of the indoor and outdoor potential savings from transforming baseline houses to high-efficiency houses was estimated to be 53 kgal per year on average.

This report focused on analysis of water use patterns and efficiency benchmarks. Analysis of policies and practices needed to achieve these efficiencies is a subject for another study. The data from this study do suggest some factors to consider in moving towards more effective water demand management programs. These include recognizing that water use is a highly skewed phenomenon, with a small number of large users influencing the mean use out of proportion to their numbers. Thus programs that are aimed at average users, may work well for mechanical devices like toilets and clothes washers, but they may not be applicable for excess irrigation and leakage. Water budgets, driven by marginal cost or penalty rate pricing or targeted interventions may work better for these cases. The report also did not address cost effectiveness of improving the water efficiency of the homes. Such an analysis was beyond the scope of the project, and would require obtaining information on the marginal cost of new water for each of the water agencies involved and the incremental costs for building new houses to high-efficiency standards.

The report showed that there are no technical reasons for not moving single family demands lower. The technologies for the key indoor fixtures and appliances are now available in the form of high-efficiency toilets, showers and clothes washers. There are some areas where breakthroughs are needed. First is a convenient and inexpensive way of giving the customer real-time water use data; second, is a way of interrupting long term leakage and third is a way to prevent over-irrigation of landscapes. If progress could be made on all three of these areas the data suggest indoor water use would drop to 100 gphd or less (36.5 kgal/year), and outdoor use would drop by an average of 26 kgal per year per household to 65 kgal. Such high-efficiency homes would have average annual water use around 101 kgal for a family of 3. The water savings should such an outcome be achieved would be enormous on a national level. Wastewater generated by the homes would also be reduced significantly as well. These data show that by implementing some fairly simple indoor and outdoor water efficiency improvements real reductions in water use should be achievable. Use of the demand benchmarks described in this study for planning of future water systems will greatly reduce projections for new capital facilities and supplies, and will avoid over-building of facilities and over sizing of raw water systems.

CHAPTER 1. INTRODUCTION

Single-family residential customers typically comprise the largest water demand sector in utilities across the United States. Regional variations impact the relative consumption of the single-family residential customer class as well as its end use demand patterns. The water use characteristics of the single-family sector remain of key importance in planning for a safe and secure water supply for future needs.

This study provides data on the water use patterns of new single-family homes in the United States and compares these demands against measurements made in other recent end use studies. Efficiency benchmarks for single-family households are proposed in aggregate and by specific end use. These fundamental water use benchmarks can be used to forecast future demand, assess conservation program effectiveness, identify areas for future water savings, improve overall water system planning, and inform customers.

The American Society of Civil Engineers recently estimated that it will take over $1.3 *trillion* to upgrade the nation's infrastructure, including water and wastewater facilities. Utilities have discovered that one of the easiest and least expensive ways to reduce the cost for new and upgraded water and wastewater infrastructure is to reduce water demands. As the single-family sector is typically the largest and most homogenous customer demand category, demand management programs often begin by targeting single-family homes. But what about the new homes that are constructed and joined to the water system each year? Do new homes use more or less water than existing housing stock? Are differences in water use between new and existing homes the result of technological or demographic differences? What are the efficiency opportunities in new homes?

Planning and management of urban water resources are improved with better information. This study specifically aims to provide essential information on the water use patterns in new homes. Currently this information is not available. The purpose of this research project was to collect data from a number of water utilities across the United States to answer fundamental questions and provide an empirical basis for understanding household water use, particularly in homes constructed after 2001.

This study investigates both indoor and outdoor residential water use patterns through a combination of billing data, surveys, and flow trace analysis. New homes were divided into "standard" new homes, defined as those that simply comply with the 1992 Energy Policy Act[7], and "high-efficiency" new homes, defined as those that employ water conservation measures that go beyond those mandated by the 1992 National Energy Policy Act (NEPA).

Household indoor uses measured in this study are also compared against usage patterns measured in the 1999 Residential End Uses of Water Study (REUWS)[8] and other more recent end use studies. The study also investigated relationships between household indoor use and key

[7] The 1992 Energy Policy Act mandated the manufacture of 1.6 gpf toilets, 2.5 gpm showerheads, and 2.2 gpm faucet aerators.
[8] The data for this study were collected between 1996 and 1998.

variables such as the number of residents, size of the home, and the types of fixtures and appliances present. Outdoor use was quantified both from the perspective of total annual use and application rate.

High-efficiency homes that employ conservation measures above and beyond those mandated by NEPA 1992 were studied to determine the additional water saving benefits available from new technologies. These results provide important information for the green building movement which has sought to increase water efficiency in recent years. The US Environmental Protection Agency's WaterSense program has developed a specification for water efficient new homes. The results from this study will help improve the estimates of water savings that might be achieved through this program.

Project Team

This project was conducted by a team of consultants lead by Aquacraft, Inc. of Boulder, Colorado. The team included the National Research Center, Inc. also of Boulder, a leading survey research firm. Peter Yost of Building Green Inc. was part of the team for the first 18 months of the study (before changing jobs) and assisted in developing the specifications for builders and in recruiting builders to the project. From the outset of the project, the team worked closely with Stephanie Duer of Salt Lake City Department of Public Utilities, the utility project manager as well as representatives from all participating study cities.

Aquacraft, Inc. led the research effort and handled project management. Aquacraft was also responsible for working with the participating water providers, coordinating sampling and data acquisition, collecting and analyzing billing data and end use data, working with local builders and developers, establishing minimum standards for high-efficiency homes, statistical analysis and modeling, and preparing the final report.

National Research Center, Inc. was responsible for the survey component of the research effort including developing the survey instrument, implementing the survey, tabulating responses, and conducting any necessary follow-up.

CHAPTER 2. LITERATURE REVIEW

The water demands of the single-family residential sector are of great interest and importance to water providers, planners, and conservation professionals. The scientific study of these demands has been underway for many years, but only in the past 20 years have data sets from large random samples of residential customers in cities across the US been assembled. Since the publication of the *Residential End Uses of Water* study (Mayer, et. al. 1999), 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, and many other countries.

Historically there have been a number of research studies that have attempted to measure how much water is devoted to the main residential end uses and determine the key factors that affect the end-use patterns. Billing data analysis, customer interviews, home audits, retrofit studies, and more recently data-logging, are among the tools that have been used by utilities to evaluate customer demands and estimate the effectiveness of conservation measures. As noted by Dr. Thomas Chesnutt, "Conserved water cannot be counted on as a reliable water source if water mangers lack a good estimate of potential savings. Hence evaluation is a crucial component of any conservation program. The use of water conservation estimates in regulatory decision-making processes makes accurate evaluations even more important."[9]

In 1940 Roy B. Hunter developed some of the earliest peak demand profiles – known as Hunter curves – used for sizing meters and service lines. Hunter relied on knowledge of the water uses within a given structure, their peak demands, the theoretical estimates of the frequency of use, and the probability of simultaneous use to derive estimates of the peak instantaneous demands for water in buildings. This approach grossly over-estimated the peak demands in most buildings because he lacked accurate information on the probabilities of multiple and simultaneous uses of fixtures within the buildings.[10]

Knowledge of demand patterns is interwoven with an understanding of the end uses of water. According to the American Water Works Association (AWWA) Technical Manual M22: "Demand profiles help to identify service size requirements, clarify meter maintenance requirements, define water use characteristics for conservation programs, assist in leakage management, enhance customer satisfaction and awareness, improve hydraulic models, and establish equitable and justifiable rate structures. Additionally, with increased water scarcity and cost of water, conservation and loss control have become important industry issues. For many utilities conservation and loss control have become the most cost-effective means to improve water resource availability."[11]

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[9] Chesnutt, T.W., C.N. McSpadden, 1991. Improving the Evaluation of Water Conservation Programs, Santa Monica, CA.
[10] Hunter, R. (1940). "Methods of Estimating Loads in Plumbing Systems." National Bureau of Standards, Washington, D.C.
[11] AWWA, 2004. Sizing Water Service Lines and Meters 2nd Edition, Denver.

The importance of flow profiles (i.e. high resolution time series flow rates that allow individual uses to be identified) was recognized for accurate analysis of end uses of water. By the mid-1970's advances in portable data loggers allowed actual demand data to be collected from the customers' water meter using mechanical loggers and circular chart recorders. While cumbersome, these data allowed *actual* peak demand information to be collected from meters serving specific customers, whose size and other characteristics were known. The 1975 version of the M22 Manual used data from these empirical observations to replace the original Hunter curves to estimate peak demands.[12]

Increased attention on demand management created the need to evaluate the effectiveness of various conservation programs and verify savings estimates made at the time of their inception. During the 1980's it was becoming increasingly clear that water conservation offered an economic way to reduce urban water demands thus reducing the need for continued new water supply projects, which were becoming both more expensive and difficult to find. In 1981 the AWWA published one of the first books on water conservation[13] and in 1984 Brown and Caldwell published one of the first detailed efforts at measuring end uses of water in residential structures by instrumentation[14]. This national study of 200 homes, in nine cities, provided better estimates of potential savings from conservation efforts on residential demands than had been available to date. "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."[15]

Although the Brown and Caldwell study resulted in significant improvement in estimating use patterns and potential savings the results were limited by the fact that participation in this study was voluntary. In addition the equipment used required significant intrusion into the normal operation of the homes. Of significance was the finding that water savings from retrofits did occur, but in many cases the actual savings were less than those predicted from theoretical calculations. The variance of actual water savings from theory can be due to a number of factors: misestimates of actual volumes used by the old and new devices, behavior of the occupants may vary from predicted behavior, frequencies of use may be over or under estimated, and modification or removal of conservation devices may have occurred over the course of the three year study period. In addition, the data in this study suggested some of the savings found initially tended to decrease with time. All of this highlighted the importance of having accurate and unobtrusive ways to measure the actual water use and water savings of conservation devices rather than relying on theoretical predictions and laboratory measurements.

[12] AWWA, 1975. Sizing Water Service Lines and Meter, Denver, CO.
[13] AWWA, 1981. *Water Conservation Management*. AWWA, Denver.
[14] Brown & Caldwell, 1984. Residential Water Conservation Projects---Summary Report. HUD-PDR-903, Washington, D.C.
[15] Brown & Caldwell, 1984. Residential Water Conservation Projects---Summary Report. HUD-PDR-903, Washington, D.C.

In 1991 the Stevens Institute of Technology published a study on the water conservation program in East Bay MUD.[16] This study involved a much more extensive data collection effort on residential end uses, but again, one that relied on individual sensors and loggers placed on targeted fixtures and appliances. The Stevens Institute study showed that disaggregating residential water use into end-uses greatly increased the accuracy of water use measurements and water savings calculations. The disaggregated use data segregated water use by end-use. This prevented changes in use in one category during the study from masking the effects of a program for another category. For example, if a toilet retrofit study was being evaluated and increased but unrelated leakage occurred this could mask the savings associated with the toilet program. Disaggregating data prevented this from happening. Also, having disaggregated data reduced the inherent variability in the water use for each category. This greatly reduced the noise of the measurements and allowed smaller changes to be accurately detected with less data. While the data were useful for evaluation of the conservation program, the process itself was cumbersome.

A significant step in the process of evaluating the real impact of retrofits on residential water use was the study done by Anderson et al in Tampa.[17] 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, Florida. Water use data were monitored for 30 days at which point the toilets and showers were replaced, and the process was repeated. The authors pointed out that this type of data was necessary to account for the way the residents behaved. For example, if they flushed their new toilets more, or took longer showers, then the actual water savings would be much reduced from the theoretical savings calculated from product flow and volume data. Using this technique the authors measured an actual reduction in water use in the homes of 7.9 gpcd, or 15.6% savings. This was less than the predicted savings, which they concluded was due to increases in other water use in the homes.

The development of data loggers provided utilities and researchers with an effective tool for examining and measuring both daily and peak demand. The data loggers could be installed on residential water meters without requiring access to the home and were significantly less intrusive then previous methods.

In 1993 a study of the feasibility of using a single data logger attached to the customers' water meter was conducted in the Heatherwood neighborhood of Boulder, Colorado. In this study event loggers wired to Hall effect sensors were attached to the customers' water meters. The sensors recorded the passage of the magnets used to couple the meter to the register as water flowed. The design of the meter and magnetic coupling provided approximately 80 magnetic pulses per gallon of flow. The data logger produced a record of water flows (a flow trace), 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 results of this study were published in 1996.[18] This technique was used to disaggregate the water use in a sample of 16 homes for a baseline analysis.

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[16] Aher, A., A. Chouthai, L. Chandrasekhar, W. Corpening, L. Russ and B. Vijapur, 1991. East Bay Municipal Utility District Water Conservation Study, Oakland, CA.

[17] Anderson, D. L., D. Mulville-Friel, and W.L. Nero. (1993). "The Impact of Water Conserving Fixtures on Residential Water Use Characteristics in Tampa, Florida." Proceeding of Conserve93.

[18] DeOreo, W. (1996). "Disaggregating Residential Water Use Through Flow Trace Analysis." *Journal American Water Works Association, January 1996*.

These homes were later retrofit with high-efficiency fixtures and appliances and the process was repeated, which provided data on the water savings attributable to residential retrofits.[19]

In 1996 the AWWARF[20] funded a detailed and comprehensive study of water use patterns in single family customers in North America using data loggers.[21] The study was called the Residential End Uses of Water Study, or REUWS, and was sponsored jointly by twelve water agencies in the U.S. and Canada. It provided detailed information on the end uses of water in residential settings and developed predictive models to forecast residential water demand. Prior to this study, utilities relied largely on theoretical calculations to predict baseline end uses and the water savings of conservation programs. The participants for the REUWS were selected from the residential customer base of twelve utilities across North America and "the predictive models developed as part of this study to forecast indoor demand significantly increase the confidence in explaining the water use variations observed. The major benefit of modeling is to provide a predictive tool with a high transfer value for use by other utilities." (Aquacraft)

The predictive value of any tool is only as good as its ability to provide an accurate assessment of the data. As with any new data measurement technology, questions have been raised as to the accuracy and reliability of data-loggers to measure volumetric end uses[22]. Brainard data-loggers record analog data directly from the customer's water meter which is then evaluated graphically in Trace Wizard©, a proprietary software program developed by Aquacraft. The results from an independent study in 2004 showed that discreet toilet events can be accurately quantified at the 95% confidence level plus or minus 3% of the mean volume[23]. Although extremely accurate for isolated events, early versions of the Trace Wizard program was limited in its ability to disaggregate simultaneous end-use events without accessing the original database – a cumbersome and time consuming process. Improvements to the software, however, eliminated the difficulty of disaggregation and provided a powerful tool for analyzing residential end uses.

In 2001 an engineering report was published by the Water Corporation of Western Australia in which data collected from 600 in-home surveys was used to validate end-use data collected using flow trace analyses in a separate group of 120 homes. The study showed that the flow trace analysis was capable of determining the percent of showers, toilets and clothes washers falling into normal and high-efficiency categories; these results were then confirmed by in-home audits. Studies of this kind, that combine both flow trace analysis and in-home audits, provide excellent validation of the flow trace technique for measuring both the volumes used by individual end-uses and the efficiency levels of the fixtures and appliances found in the homes.

Three studies in Yarra Valley, Australia showed the benefits of data-logging when compared to surveys, as a tool for developing predictive models that were both accurate and more cost effective than other data collection methodologies. The first of these studies, the 1999

[19] DeOreo, W. (2001). "Retrofit Realities." Journal American Water Works Association, March 2001.
[20] The American Water Works Association Research Foundation, now known as the Water Research Foundation (WRF).
[21] The REUWS was for its time the most detailed study of single family residential end uses of water that had been conducted in the U.S.
[22] Koeller, J. & Gauley, W., 2004. Effectiveness of Data Logging Residential Water Meters to Identify and Quantify Toilet Flush Volumes: A Pilot Study, Los Angeles.
[23] Ibid.

Residential Forecasting Study, involved a telephone survey of 1,000 Yarra Valley Water single-family customers. 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.

The Residential Forecasting Study was followed by the Yarra Valley Water (YVW) 2003 Appliance Stock and Usage Pattern Survey (ASUPS) which was designed to address these issues. In-home surveys were performed by a team of trained technicians who obtained detailed customer information as well as flow data and verification of the penetration of efficient appliances in 840 homes. "These types of 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."[24]

One hundred of the 840 homes in YVW were selected to participate in The Residential End Use Measurement Study in 2004[25]. In this study data loggers were used to disaggregate the indoor use in the home following the same approach as in the Heatherwood and REUWS studies. The results of the 100 home data logged group were compared to the in-home surveys and showed remarkable consistency with data that had been acquired by technicians during the ASUPS. The data logging study also provided information about leakage, fixture replacement, and behavior that was not yielded by the survey. Data-loggers were installed for two two-week periods in each of the homes in order to capture both indoor and irrigation usage. According to the authors, "The findings from REUWS 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."[26]

As the value of the data-logging technology became apparent, the EPA funded three residential water conservation studies over a three-year period, from 2000 to 2003. These studies provided important information on the effectiveness of water conserving fixtures and appliances in reducing indoor water use. Baseline water use data were collected from a sample of 96 homes in Seattle, the Tampa Bay area, and East Bay Municipal Utility District in California that provided information on household and per capita usage of toilets, showers, clothes washers, dishwashers, faucet use, leakage, and other indoor uses. These same homes were then retrofitted with conserving toilets, clothes washers, showerheads, faucet aerators, and hands free faucet controllers; six months later household and per capita use of the various end uses was again examined. The results of the studies clearly showed the ability to achieve significant reduction in household water use with the installation of water conserving fixtures and appliances. Average daily household indoor use was reduced by 39% from 175 gpd to 107 gpd in the homes that were retrofitted with conserving fixtures and appliances. These studies were important in setting

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[24] Ibid.
[25] Roberts, P., 2005. Yarra Valley Water 2004 Residential End Use Measurement Study, Melbourne.
[26] Ibid.

benchmarks for water use with best available technology[27] and provided a tool with which utilities could gauge their progress in achieving long-term water savings.

The participants in the EPA residential conservation studies were customers located in three water agencies spread across the United States. Because the participants were volunteers and not selected at random, the study data did not provide information on penetration rates of water using fixtures and appliances that could be generalized to their respective populations. There has also been concern about degradation in savings over time, particularly from toilets. As one of the most consumptive indoor uses, toilets have been the subject of considerable scrutiny.

In 2000, the City of Tucson participated in a data-logging study of residential customers who had received toilet rebates for low-consumption toilets in 1991 and 1992. The data from the 170 study participants "revealed that nearly half of aging low-consumption toilets had problems with high flush volumes, frequent double flushing, and/or flapper leaks. Data logging revealed that the average flush volume for all low-consumption rebate 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 had at least one low-consumption rebate toilet with an average flush volume greater than 2.2 gpf[28]. Other studies have shown that chemical degradation of toilet flappers[29] and poorly fitting after-market toilet flappers[30] have contributed to increased leakage and toilet volume which has contributed to the uncertainty of conservation savings.

These uncertainties led California utilities to recognize the importance of having more specific information for their state. In 2004 a group of California water agencies, led by Irvine Ranch Water District[31], submitted an application to the California Department of Water Resources to fund an update and expansion of the REUWS that would be conducted entirely within the State of California. The work on this study, funded by the California Department of Water Resources, began in 2006.

The overall goal of the California project was to provide detailed water use data on a statewide sample of single family homes in order to provide an updated snapshot of their water use patterns. The study supplied information on the penetration rates of conserving fixtures and appliances that met or exceeded current conservation standards. In addition it provided an updated benchmark for their water use efficiency, a comparison of their status with respect to the demands from 1996, and a gauge of how much untapped water conservation potential existed in this major customer category.

As a way to encourage and promote conservation, the EPA has developed WaterSense, a partnership program "with interested stakeholders, such as product manufacturers, retailers, and

[27] That is best available technology for 2000-2002. As new technologies are implemented the BAT standards will also shift to reflect them. These might include devices like recirculation systems, real time customer feedback devices, leak detection devices, and better hands-free faucet controllers.
[28] Henderson, J. & Woodard, G., 2000. Functioning of Aging Low-Consumption Toilets in Tucson A Follow-up with Rebate Program Participants. Issue Paper #22, Phoenix.
[29] Metropolitan Water District of Southern California. Toilet Flapper Materials Integrity Tests, 1998.
[30] Henderson, J. & Woodard, G., 2000. Functioning of Aging Low-Consumption Toilets in Tucson A Follow-up with Rebate Program Participants. Issue Paper #22, Phoenix.
[31] http://www.irwd.com/. Irvine Ranch Water District. Contact: Fiona Sanchez, Conservation Supervisor.

water utilities."[32] The WaterSense program is interested in promoting cost effective products and technologies that are measurably more water efficient than conventional products. Products must be certified by an independent third party and show significant water savings without sacrificing performance.

In order to measure the effectiveness of the WaterSense program, EPA provided funding for this study, the Efficiency Benchmarking for the New Single Family Homes, which began in 2005. Working with nine participating utilities[33], some of which participated in the earlier REUWS project, this project was designed to measure both baseline water use in new homes, built after January 1, 2001, and to demonstrate how high-efficiency new homes, using advanced water efficient technologies, can reduce water use below levels sought in the 1992 National Energy Policy Act (NEPA).

[32] http://www.epa.gov/WaterSense/docs/program_guidelines508.pdf. February 2009. WaterSense Program Guidelines. Roles and Functions. Accessed May 1, 2009.

[33] The nine participating agencies are: Aurora, Denver, Eugene, Las Vegas, Phoenix, Roseville, Salt Lake City, St. John's Regional Water Management District (SJRWM), and Tampa Bay. The purpose of this report is to provide an analysis of the group from which data has already been collected for future comparison and will be referred to as the "standard new home study group".

CHAPTER 3. RESEARCH PROCEDURES

The primary goals of this study, as specified in the work plan were to:

- Provide data and comparisons on the water use patterns of single-family homes in the United States including:
  - Existing homes built before 1/1/2001
  - Standard new homes built after 1/1/2001
  - High-efficiency new homes built to the draft of WaterSense New Home specification[34]
- Compare demands in new homes against existing/older homes and against measurements made in other recent end use studies.
- Propose efficiency benchmarks for single-family households – both in aggregate and by specific end use.
- Identify areas for future water savings in the residential sector.
- Provide essential water use data to help improve overall water system planning and forecasting, and to better inform customers.

In this study, the research team worked with nine participating water utilities and collected billing data from samples of homes built before and after 1/1/2001 and detailed water use profiles from samples of "standard" new homes built after 1/1/2001. In addition, profiles from a limited number of "high-efficiency" new homes built in several cities were also obtained. The number of high-efficiency new homes was limited by the crisis in the housing and credit industries following the banking panic in 2008.

The data collected for this study compares water use in new and existing housing in the U.S. and demonstrates how much water is used in homes for each of the major domestic end-uses both indoors and outdoors. Some of the analyses conducted on indoor use profiles provide detailed information on the average gallons per flush for toilets, the average flow rates for showers and faucets, and the gallons per load for clothes washers. The outdoor water use analysis compares the actual water use at each study site against the theoretical irrigation requirement (TIR) which is based on the local evapotranspiration (ET) rate.

This study also provides useful comparisons of residential water use from homes of different ages in different regions of the country and addresses the conservation potential that exists both in older and newer homes.

Overview of the Research Process

The research process for this study was developed by the project team with substantial input from the project manager, advisory committee, and participating water agencies. Once funding for the project was approved by the EPA, a detailed work plan was developed to implement the research described in the initial grant proposal.

[34] The WaterSense New Home Specification was a "work in progress" and thus a moving target for the entire duration of this study. The intent of the study was to monitor high-efficiency homes built as close to this specification as possible. The extent to which these homes did and did not comply with this specification is discussed later in this report.

The general flow of the research effort moved from preparing the work plan and formally contracting with participating water agencies through study group selection, survey implementation, data collection, data analysis, and report preparation. Quality control and assurance measures (QAQC) were implemented at each critical stage of the research process to ensure a high level of accuracy in all aspects of the project.

Work on the project moved through an orderly development process for each study site based on the work plan developed at the beginning of the project and approved by all participants. Most of the process was repeated for each individual study site. Progress of this project was delayed significantly by the economic recession of 2008 and its impacts on the housing industry. The project team waited for months on many occasions for high-efficiency homes to be constructed and occupied only to watch as developers went out of business or declared bankruptcy and homes stood vacant and unsold. Ultimately, the decision was made to move forward with the analysis with the smaller number of high-efficiency homes that were occupied and available for the study.

Once study sites were finalized, the general research process went as follows:

1. **Initial samples of standard new homes built before and after 1/1/2001.** The historic billing data were obtained from each participating water agency for two random samples of approximately 1,000 single-family detached accounts built before and after 1/1/2001($Q1000_{pre}$ and $Q1000_{post}$). **QAQC** – Statistical tests were performed to ensure the water use characteristics of each sample were statistically similar at the 95% confidence level to that of the population from which it was drawn. The homes built after 2001 were classified as “standard new homes” because they represent homes being built with no special emphasis by the builder on water conservation. Attempts were made to identify “high-efficiency homes” for comparison, which are homes that were built with special high-efficiency water using devices, as described below.
2. **Survey implementation and coding.** A mail survey of all customers in both of the Q1000 samples ($Q1000_{pre}$ and $Q1000_{post}$) was conducted. The survey responses were entered into a database file. **QAQC** – Detailed survey and re-survey implementation process was established to maximize response rates. Accuracy of the survey input process was verified by National Research Center. Site visits were conducted to ensure accuracy regarding the fixtures and appliances and number of residents in each home.
3. **End use study group selection – “standard” new homes.** A sample of 50 standard new homes (from $Q1000_{post}$) was selected from the survey respondents to participate in end use measurement. The study goal was to obtain data from 40 standard new homes per site. **QAQC** – Statistical tests were performed to ensure that water use characteristics of each sample were statistically similar to water use characteristics of the $Q1000_{post}$.
4. **Develop guidance specification for “high-efficiency” new homes.** A detailed guidance specification, including a set of minimum requirements for the high-efficiency homes, was prepared and distributed to the agencies that were to use this in selecting high-efficiency new homes for the study. These requirements were developed to align as closely as possible with the draft WaterSense New Home specifications. A copy of these specifications is included in Appendix C. **QAQC** – An extensive peer review process

with study participants and builders was conducted to ensure that the minimum requirements could be reasonably implemented.

5. **End use study group selection – "high-efficiency" new homes.** Each participating agency contacted local builders in an attempt to find approximately 20 homes that could meet the project specifications. The agencies met with varying degrees of success in this effort.
6. **Site visits to "standard" and "high-efficiency" new homes.** Field technicians visited most of the high-efficiency new homes and about 70% of the standard new homes to verify the fixtures and appliances and number of residents.
7. **Collection of additional site data.** Significant additional data from each study site were obtained by the research team including: historic climate data from local weather stations, irrigated area data from each study site from aerial photographs and GIS analysis, demographic information from US Census databases, and parcel level tax assessor data sets (where available).
8. **End use data collection and analysis.** Data loggers were installed on the 40 to 50 standard new home samples in each of the nine participating study sites and on all available high-efficiency homes constructed and occupied for this study. Two weeks of continuous flow data was collected from each study home. The collected flow traces were analyzed using Aquacraft's flow trace analysis software, Trace Wizard. No flow trace data were collected on the pre-2001 homes because there have already been a large number of these homes included in a previous study, so additional flow trace data was not needed.
9. **Disaggregated water use data were placed into an Access database**. **QAQC** – Tests were performed to ensure the logging equipment was operating properly, that the loggers recorded flow through the water meter accurately, and that there was agreement between the water meter and data logger. Each analyzed flow trace was carefully reviewed by two trained analysts. Quality control checks were performed on the assembled database.
10. **Data analysis.** Billing data, survey response data, and end use data were assembled into an analytic database and detailed analyses were done on the indoor and outdoor water use patterns. The indoor analyses were based primarily on the flow trace data in conjunction with billing data. The outdoor analyses were based on the landscape analyses done with the GIS data and the estimated outdoor water use determined from the billing data minus the estimated indoor use determined from indoor analyses. **QAQC** – Aquacraft senior engineers reviewed all statistical analyses and calculations.
11. **Final products and deliverables.** The final products of this research project include this final report and the analytic database. **QAQC** – The internal review process ensured high quality final products and deliverables.

Selection of Participating Agencies and Study Sites

Recruitment and selection of participating water utilities began even before the funding grant from the EPA was approved. The research team developed key documents describing the study and utility participation and then sent out invitations to water utilities across the country. Each participating agency was asked to contribute $20,000 in cash and up to $20,000 in in-kind services to the project. Ultimately nine water agencies chose to participate in the study, lead by Salt Lake City which put together an inter-governmental agreement to formalize the arrangements.

The nine participating water utilities in this study were:

- City of Aurora, Colorado
- Denver Water Board, Colorado
- Eugene Water and Electric Board, Oregon
- Southern Nevada Water Authority, Las Vegas, Nevada
- City of Phoenix, Arizona
- City of Roseville, California
- Salt Lake City Department of Public Utilities, Utah
- St. John River Water Management Distrcit, Florida
- Tampa Bay Water, Florida

Selection of Initial Survey Group Samples ($Q1000_{pre}$ and $Q1000_{post}$)

The main question that this research sought to answer is whether new homes use more or less water than older homes on average, and if so, what factors explain the observed variances. To tackle this question, two separate random samples of approximately 1,000 homes each were selected from the population of single-family homes at each of the nine participating study sites.

The first random sample consisted of single-family homes built prior to January 1, 2001 and the second random sample consisted of single-family homes built after January 1, 2001. The 01/01/01 demarcation date was selected because it occurred well after key regulatory actions such as the adoption of the Energy Policy Act of 1992, and is the date of the beginning of the new century which gives it symbolic value. This date was still early enough however to provide a sufficient number of new homes with a long enough occupancy period to establish regular water use patterns. Selecting this cutoff date also assured that most of the participating water utilities could provide sufficient historic billing data required for the project. Furthermore, by January 1, 2001 the 1992 NEPA standards had been in place for nearly a decade and it was expected that homes built after this date should all have been equipped at a minimum with 1.6 gpf toilets, 2.5 gpm showerheads, and 2.2 gpm faucet aerators.

The research team developed a series of detailed instruction memos to assist the staffs of the participating water agencies to select the initial Q1000 samples of older and newer homes. One of the sampling memos developed for this study is presented in Appendix A. Participating agencies were asked to use a systematic random sampling procedure (described in Appendix A) which virtually ensures the sample selected will have identical water use characteristics to the population from which it was drawn.

Historic billing data from calendar year 2005 was sought and provided for all of the homes in each sample ($Q1000_{pre}$ and $Q1000_{post}$) from each participating agency. Summary consumption statistics from the population from which the sample was drawn were also provided. This allowed the researchers to perform a statistical comparison to ensure that each sample was representative of the population from which it was drawn at the 95% confidence level.

Calculation of Summary Statistics

The research team calculated basic summary statistics for each Q_{1000} sample in the study. These summary statistics included the average annual, monthly and daily water use, and the median water use, per account. The variability of the water use was determined by constructing frequency diagrams (histograms) of annual, seasonal and non-seasonal use for each sample and by examining the variance of the data.

Indoor (non-seasonal) and outdoor (seasonal) use were disaggregated using a minimum month or average winter consumption technique to estimate annual indoor use. Use of minimum month water consumption as a measure of indoor use works reasonably well in areas with negligible winter irrigation, but is less accurate in areas where irrigation is a year round activity. In some select cases it was preferable to use a fixed estimate of indoor use developed from Aquacraft water use studies (DeOreo, et. al. 2008), (Mayer et. al. 1999).

Using the summary statistics calculated from these samples it was possible to examine and compare demand patterns between existing homes and new homes, between agencies, and against previous multi-city studies that obtained similar data. This analysis revealed overall changes in average water use, but did not reveal what factors best explained observed differences.

Survey Design and Implementation

National Research Center, Inc. (NRC), a well respected survey research firm based in Boulder, CO, was contracted to conduct the survey for this study. NRC and Aquacraft have worked together on a number of research studies over the past ten years.

Working in close consultation with participating water agencies, the research team developed a draft survey instrument to be utilized for all study sites. The draft survey was reviewed by all participants and underwent numerous revisions before it was finalized. The final survey for this study was five pages long and included 55 questions ranging from standard demographic queries to questions about the fixtures and appliances present in the home. A copy of the survey instrument is provided in Appendix B. In addition to the survey instrument, an introductory postcard and a detailed survey cover letter were developed.

The survey implementation process at each participating agency was a multi-stage process designed to maximize the response rate. In general survey response rates (to both mail and telephone implementations) have been declining in recent years. The procedures implemented for this study were designed to allow maximum opportunity for responses while still remaining economical. The survey implementation process generally followed these steps at each study site:

1. **Customize survey materials for study site.** This involved obtaining necessary logos, electronic signatures for cover letters and post cards, and approvals for survey implementation.
2. **Mail pre-survey announcement postcard to $Q1000_{pre}$ and $Q1000_{post}$ samples.**
3. **Mail survey package #1 to $Q1000_{pre}$ and $Q1000_{post}$ samples.** The survey package included a customized cover letter, survey instrument, and a self-addressed stamped

envelope for returning the survey. All surveys were returned to the National Research Center's offices.

4. **Mail survey package #2 to $Q1000_{pre}$ and $Q1000_{post}$ samples.** The second survey package was sent approximately two weeks after the first survey was sent out. This package was sent to all households in the sample with instructions that it should be ignored if the first survey had already been completed.
5. **Assemble and code returned surveys.** NRC organized all of the returned surveys and determined which responses were sufficiently completed and which were not. All completed survey responses were entered into an electronic database and provided to Aquacraft and to the appropriate water agency.

The overall response rate to the survey across all study sites was 34.3%. More detailed information is presented in the results section.

End Use Study Site Selection

An important goal of this study was to obtain detailed water use data from 40 standard new homes built after 1/1/2001 within each of the nine participating study sites. In order to arrive at a final sample of 40 standard homes a random sample of 50 homes were selected from the group of survey respondents from each participating agency. Fifty homes at each site were selected in order to provide a few extra study homes in case of a change in ownership since the original survey, participant opt-out, or unavailability. Water use statistics from each sample of homes were checked to verify that the sample was statistically similar to the $Q1000_{post}$ sample from the service area.

Once the final sample was selected, invitation letters were mailed to each of the selected homes on utility letterhead informing the customers that they had been selected for participation in the study. Those customers who agreed to participate fully in the study indicated their willingness by returning the self-addressed stamped postcard that had been included with the letter.

High-Efficiency New Homes

The goal of this study was to work with builders in each of the nine participating study sites to ensure 20 (or more) new homes in each city would be built to a water efficiency specification designed to be as close as possible to the WaterSense New Home specification under development. The high-efficiency new home specification developed for this study is provided in Appendix C.

Due to an unforeseen economic downturn new housing construction was slowed significantly in 2007 and came to a virtual standstill in 2008. Although the project was repeatedly delayed to allow homes to be constructed, sold, and occupied, the original goal of 20 homes with similar features from each agency was simply not possible to achieve. In a few cases high-efficiency homes were constructed and occupied, but the residents declined to participate in the end use portion of the study which effectively precluded their participation.

In early 2009 the research team determined that only two of the nine study sites had sufficient high-efficiency homes for end use monitoring. In Eugene, Oregon, 10 high-efficiency homes were audited and monitored. In Roseville, California 12 high-efficiency homes were studied. What the research team originally hoped would be between 150 and 180 high-efficiency homes across nine cities in the study dwindled to just 22 homes in two cities.

The research team worked closely with the utility staff in Eugene and Roseville to solicit the participation of these homes in the study. Detailed information about the study was provided to each household by the utility and participants consented to a brief water audit conducted by the research team and the end use monitoring.

Additional Site Specific Data

Another research objective was to construct useful predictive models of water use in existing and new homes within each service area. Several sources of data were used to characterize the water use patterns and efficiency levels of the single family water customers in an agency's service area. In addition to the billing data the researchers used a variety of sources to obtain local weather data, tax assessor data, as well as information on lot size and home value. This additional data was combined with billing and survey data to improve the models of water use in the existing and new homes.

Determination of Net ET

In order to estimate irrigation requirements for the study sites it was necessary to develop estimates of net evapotranspiration (Net ET) for each. When used in this form the term ET simply refers to evapotranspiration. When expressed as ET_o the abbreviation refers to the reference ET calculated for cool season turf grass. Two methods were employed to do this. Where local ET_o weather stations were present we obtained data for the sites from these stations. Where there was no local ET_o data available we obtained data from NOAA weather stations and applied the Blaney-Criddle technique. The analyses were done at a monthly time step, and estimates of effective precipitation were subtracted from the gross ET_o data to derive estimates of monthly and annual net ET for each study site.

Table 3-1 shows the data used for estimating the Net ET_o for each study site. In order to estimate the effective precipitation a factor of 40% was applied to total annual precipitation. Effective precipitation was subtracted from gross ET_o to estimate net ET_o. This table reflects changes to the ET_o rates made in response to comments from the reviewers in 2010.

Table 3-1: ET data used for study sites

Site	Annual Precip	Effective Precip in	% Effec.	Gross Eto	Net ET	Data Source
Denver	15.8	6.3	40%	34.4	28.8	Blaney-Criddle on NOAA 30-year averages
St. John's	52.3	20.9	40%	55.0	35.4	Blaney-Criddle on NOAA 30-year averages
Tampa	44.8	17.9	40%	61.1	43.2	Blaney-Criddle on NOAA 30-year averages
Las Vegas	4.5	1.8	40%	84.0	82.3	Blaney-Criddle on NOAA 30-year averages
Eugene	50.9	20.4	40%	31.7	23.4	Blaney-Criddle on NOAA 30-year averages
Phoenix	7.3	2.9	40%	75.2	72.3	AZMET (2005)
Roseville	28.4	11.4	40%	51.9	43.5	CIMIS (2005-06)
Salt Lake City	21.6	8.6	40%	62.3	53.6	Utah State University
Aurora	15.8	6.3	40%	34.4	28.8	Blaney-Criddle on NOAA 30-year averages

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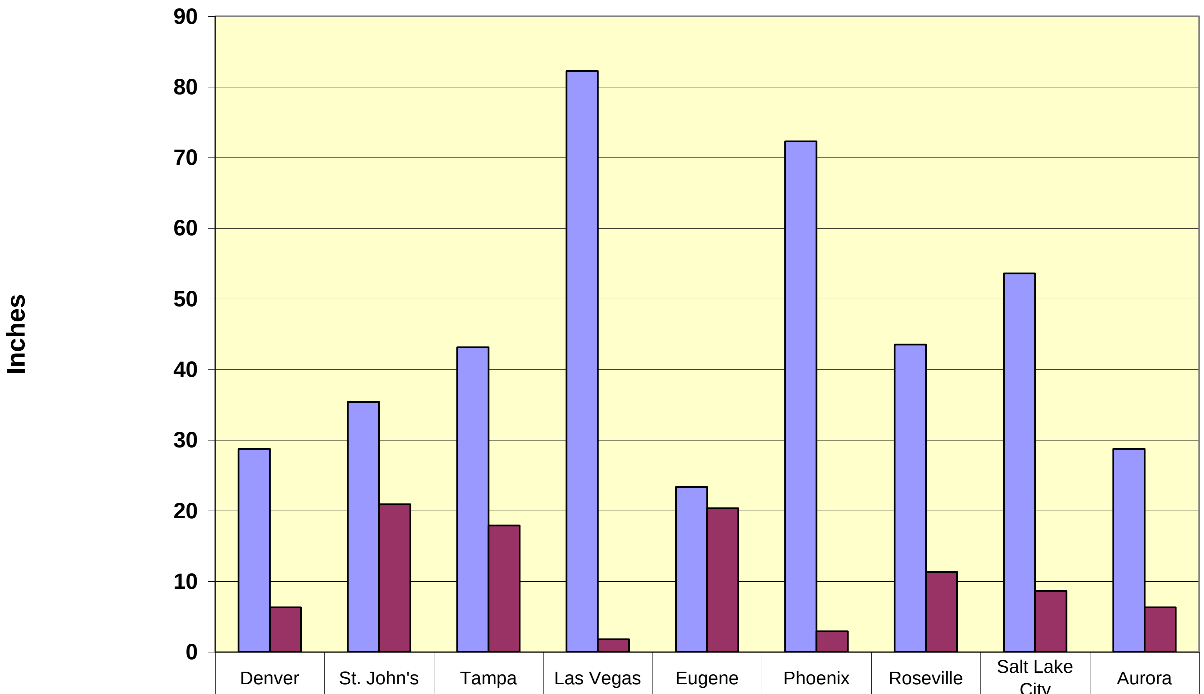
Data for Roseville were obtained from California Irrigation Management Information System (CIMIS). CIMIS is a network of 120 weather stations located throughout the state of California and managed by the California Department of Water Resources.

Data for Salt Lake City were obtained from the Utah State University Climate Center. The weather station, located in the northwest area of the city, provides daily data such as minimum and maximum temperatures, precipitation and ET_o. The station has been in operation since January 1985.

The Arizona Meteorological Network (AZMET) has provided meteorological and weather-based data since for southern and central Arizona since 1987. Data is collected daily from a network of 28 rural and urban weather stations. These data provide tools for better water management of agricultural and horticultural sites.

Data for the remaining sites were obtained from National Oceanic and Atmospheric Administration (NOAA) Climate Center and ET_o was calculated using the Blaney-Criddle formula. While ET_o data was not available for these sites, the Climate Center does track hourly temperature and daily rainfall which is sufficient for calculating ET_o and the theoretical irrigation application.



	Denver	St. John's	Tampa	Las Vegas	Eugene	Phoenix	Roseville	Salt Lake City	Aurora
Net ET	28.8	35.4	43.2	82.3	23.4	72.3	43.5	53.6	28.8
Effective Precip in	6.3	20.9	17.9	1.8	20.4	2.9	11.4	8.6	6.3

Figure 3-1: Annual ET_o and precipitation for the study sites

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Irrigated Area Data

The irrigated area at each property selected for end use monitoring was measured using electronic mapping and/or aerial photos. Maps and photos were obtained from the participating agencies and/or other sources such as Google Earth. These data were analyzed using ESRI[35] GIS software to evaluate the landscape materials at the site (i.e. turf, shrubs, trees, etc.) and the irrigated area for each site. These data, when combined with local weather and evapotranspiration data were used for establishing theoretical irrigation requirements at each study site.

Census Data

Data from the 2000 Census and more recent updates were used to fill in missing information and add more detail for the billing analysis. The Census information provided useful demographic and economic data down to the zip code level.

End Use Data Collection and Analysis

End use water data was obtained in this study using Aquacraft's well established flow trace analysis technique. This technique, which has been the de facto industry standard world-wide for end use analysis since its inception in 1994, uses a portable battery powered flow data recorder attached to the water meter at each home to record flows into the home at 10-second intervals. The flow recorder is left in place for two weeks and then downloaded. The resulting flow trace is then disaggregated into component end uses by trained analysts using Aquacraft's copyrighted software *Trace Wizard.* A detailed description of the flow trace analysis technique is provided in Appendix D.

Water Meter Information

Each agency provided the make, model, and size of the water meter for each study site. These data were used to calibrate and determine compatibility with the flow recording equipment.

Flow Data Recording

Indoor water uses have been found to be stable over different seasons so knowing the indoor water use of each home, even for a short period of time, provides better estimates of indoor/outdoor water use from the billing data by subtracting the logged indoor use from the monthly metered data. This information is particularly useful at sites where winter watering does not occur and consumption can be attributed solely to indoor use.

A flow recorder, (commonly known as a data logger), like the one shown with a sensor attached in Figure 3-2, was installed on the individual water meter at each home participating in the study. During the installation of the recorder the meter size and model, unit of flow[36], meter reading, and date and time of installation were noted. The recorders were left in place for a period of two weeks during which time flow data through the water meter was recorded in 10 second intervals. At the end of the two week data-logging period the date, time, and meter reading were again recorded and any inconsistencies noted. Data logging allowed us to obtain detailed information

[35] http://www.esri.com/

[36] Flows were recorded in either cubic feet or gallons. Knowing the unit of flow through the water meter is essential for calibrating the data loggers.

about water use in the individual houses. In cases where there were separate indoor and irrigation meters every effort was made to identify and install a data logger on the indoor meter.

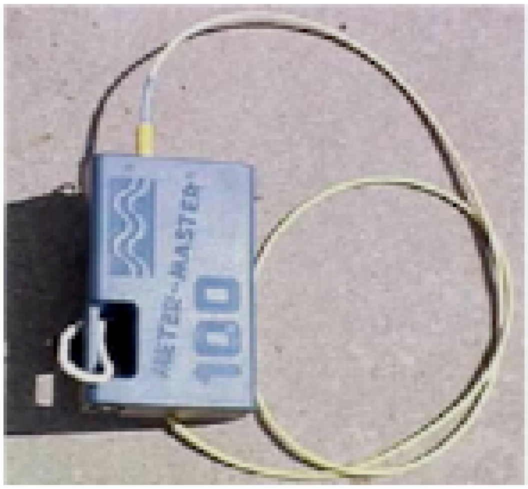


Figure 3-2: Brainard Meter Master data logger and sensor for installation on residential water meters

Flow Trace Analysis

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, frequently caused by 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.

After the volumes are evaluated and, if needed, correction factors are applied, each of the traces with usable data is disaggregated into individual events. The Trace Wizard program contains templates of indoor fixtures and appliances that serve as the starting point for the analysis. If these templates are carefully set up they are able to identify many of the fixtures 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 washers and dishwashers events in a trace and assigns an "@" in the name: e.g. clotheswasher@. This allows the number of clothes washers and dishwasher events to be counted, 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. 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 NEPA 2005[37] criterion, which requires a flow rate of 2.5 gpm @ 80 psi. Toilets with average flush volumes of 2.0 gpf or less are deemed to meet a performance criterion for efficient toilets[38]. It is possible that a number of these toilets are standard units that have had displacement devices installed or modified in some way to make them flush at 2 gpf or less. Conversely, there may be 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 the analysis.

Following the initial disaggregation and analysis process the trace is 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.

[37] NEPA 2005: Energy Policy Act of 2005 National Efficiency Standards and Specifications for Residential and Commercial Water-Using Fixtures and Appliances

[38] The NEPA 2005 standard for ULF toilets is 1.6 gpf; the study used

During the logging of the Northern sites a series of traces was sent to another consultant, who provided analysis of the traces independently from our staff. The results of the two analyses were compared to see if there were differences that would affect the characterization of the home. While there were minor variations in the volumes assigned to individual events there were no differences in how the homes were characterized with respect to toilet, shower or clothes washer efficiencies.

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.

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 and leaks. Examples of these events follow, along with a description of a typical profile. While flow trace 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 increase the variability of the data.

Trace Wizard is at its best in identifying anything that is controlled by a timer or a mechanical device. These include toilets, dishwashers, clothes washers, irrigation timers and water treatment regeneration systems. Fixtures that are limited by a valve or flow restrictor (showers) or which operate in repeatable fashion 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. Trace Wizard also has the ability to split out contiguous events; these events frequently require the analyst to manually identify the point at which one event ends and another begins. The situation where a faucet is turned on before a toilet stops filling is an example of this.

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

Toilets

Trace Wizard provides graphical representations of the data recorded during the logging period. These include 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 is in the home. However, this inference process is not perfect, and must be used with discretion. For example, Trace Wizard can not tell if a 3.0 gallon flush is coming from a malfunctioning ULF toilet or a modified standard toilet.

There are two ways of looking at toilets data. 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, a key finding is the actual toilet model[39]. The flow trace data can be helpful in making *judgments* about the market penetration rates but it is not designed to identify actual toilet models. The other complicating factor about toilet analysis is that houses often 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 3-3 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).

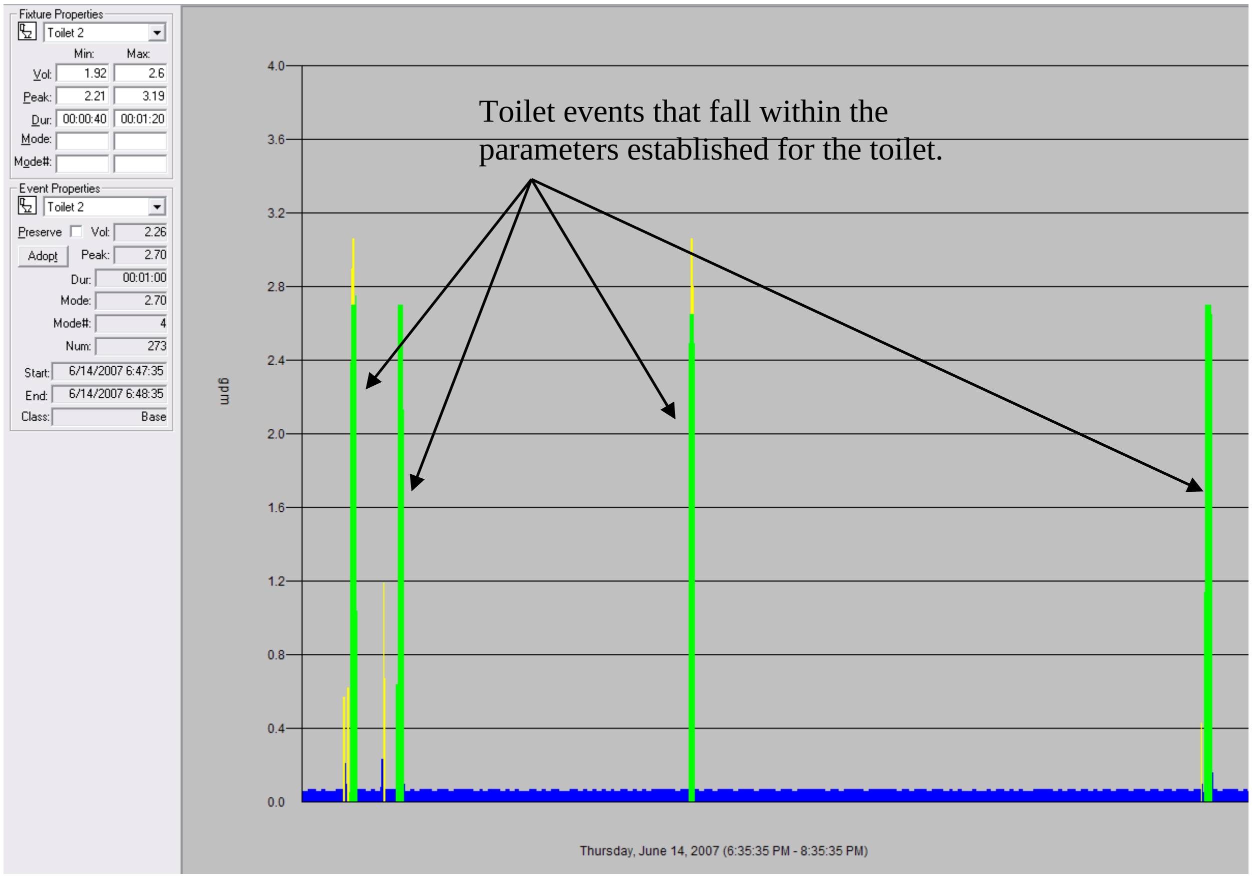


Figure 3-3: An example of four toilet flushes, faucet use, and baseline leak identified using the Trace Wizard program

[39] In other words, is the toilet a 1.6 gpf ULF, a 1.6/0.8 dual flush toilet, or a 1.28 HE toilet?

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 3-4 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 what has been called a standard toilet with a flush volume of 2.7 gallons.

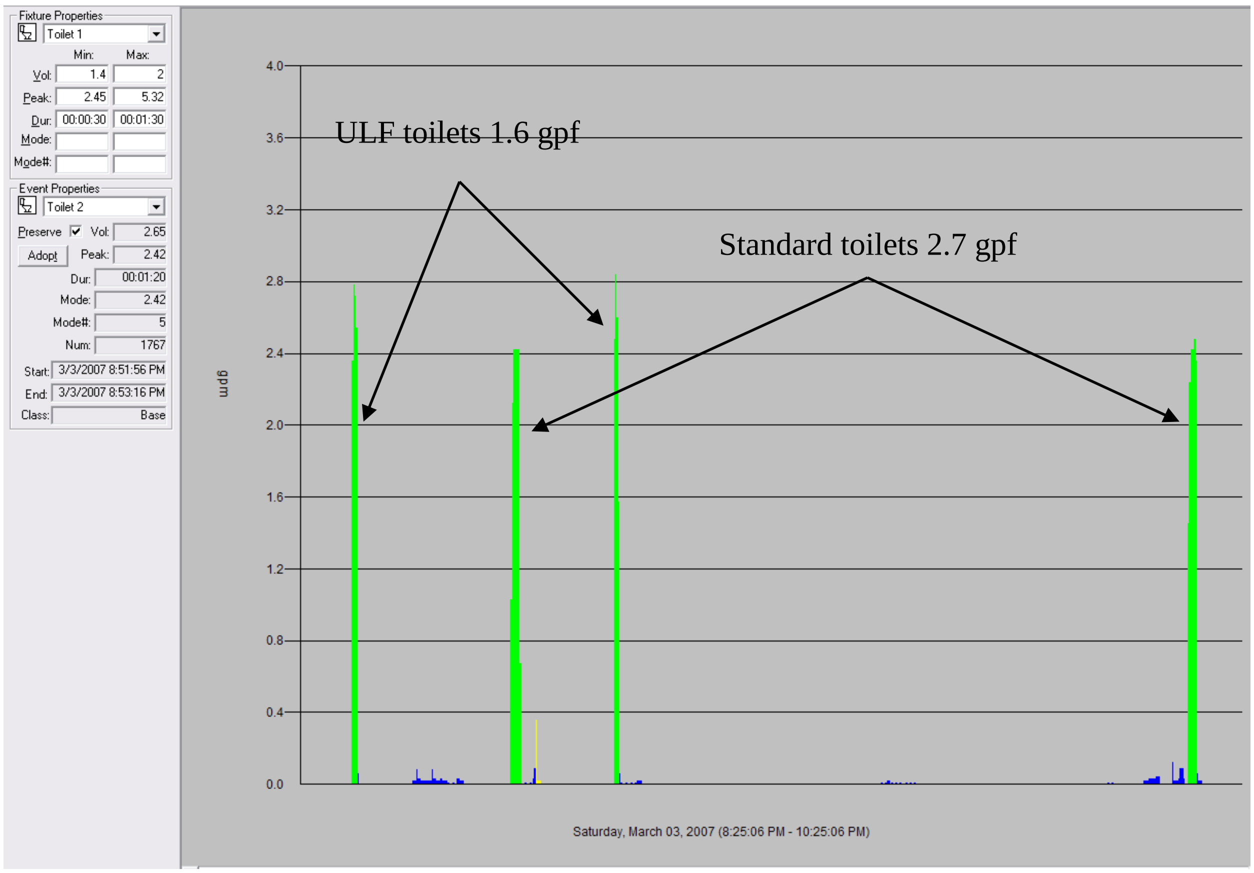


Figure 3-4: Four toilet flushes with two different profiles identified in Trace Wizard

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 3-5 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 labeled clothes washer @ and 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 can be from dripping faucets, evaporative cooling, or valves that flow at a low rate, and might not be picked up by AMI systems. These types of leaks are very common.

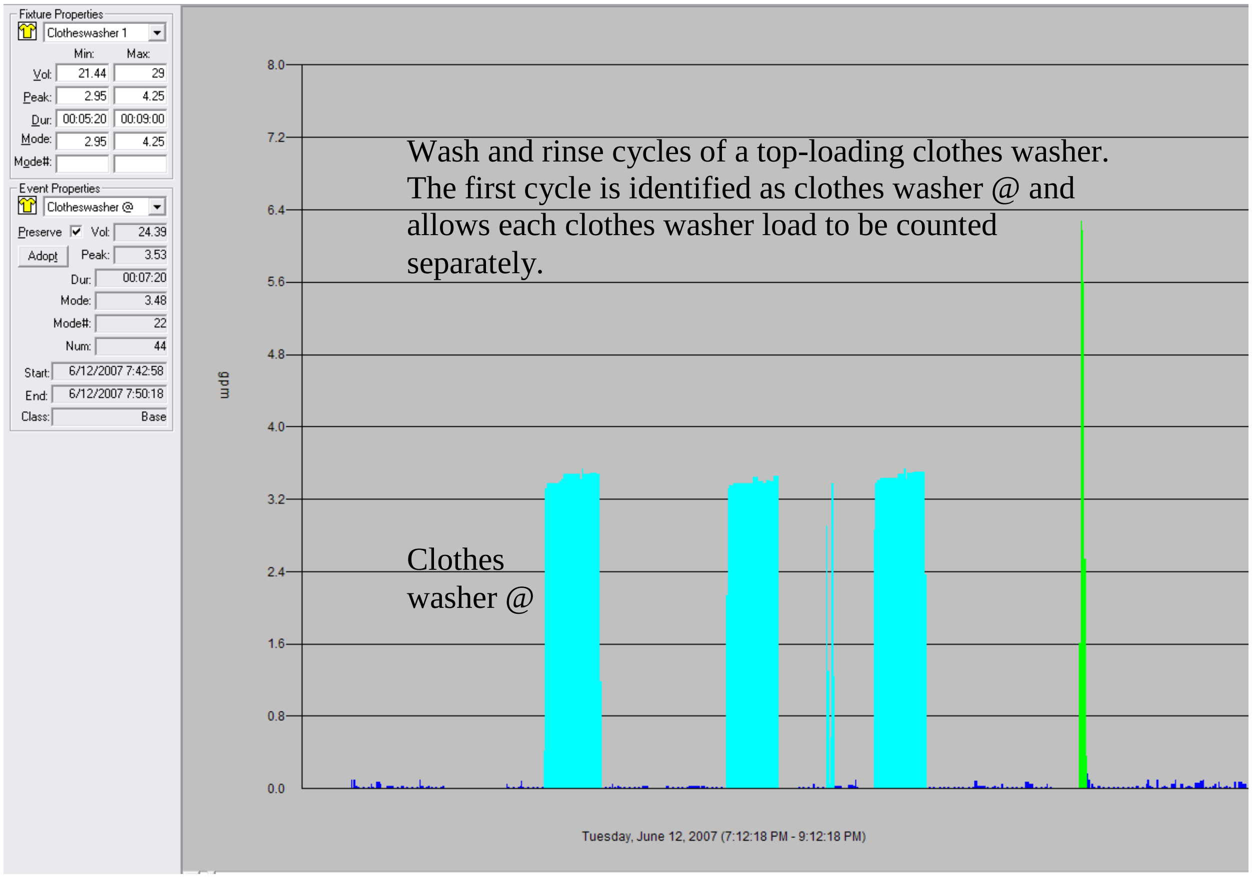


Figure 3-5: Typical profile of a top-loading clothes washer

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 3-6, use less than 15 gallons per load. As with a standard top-loading clothes washer, the initial cycle is labeled clothes washer @ which allows the volume of each cycle to be identified.

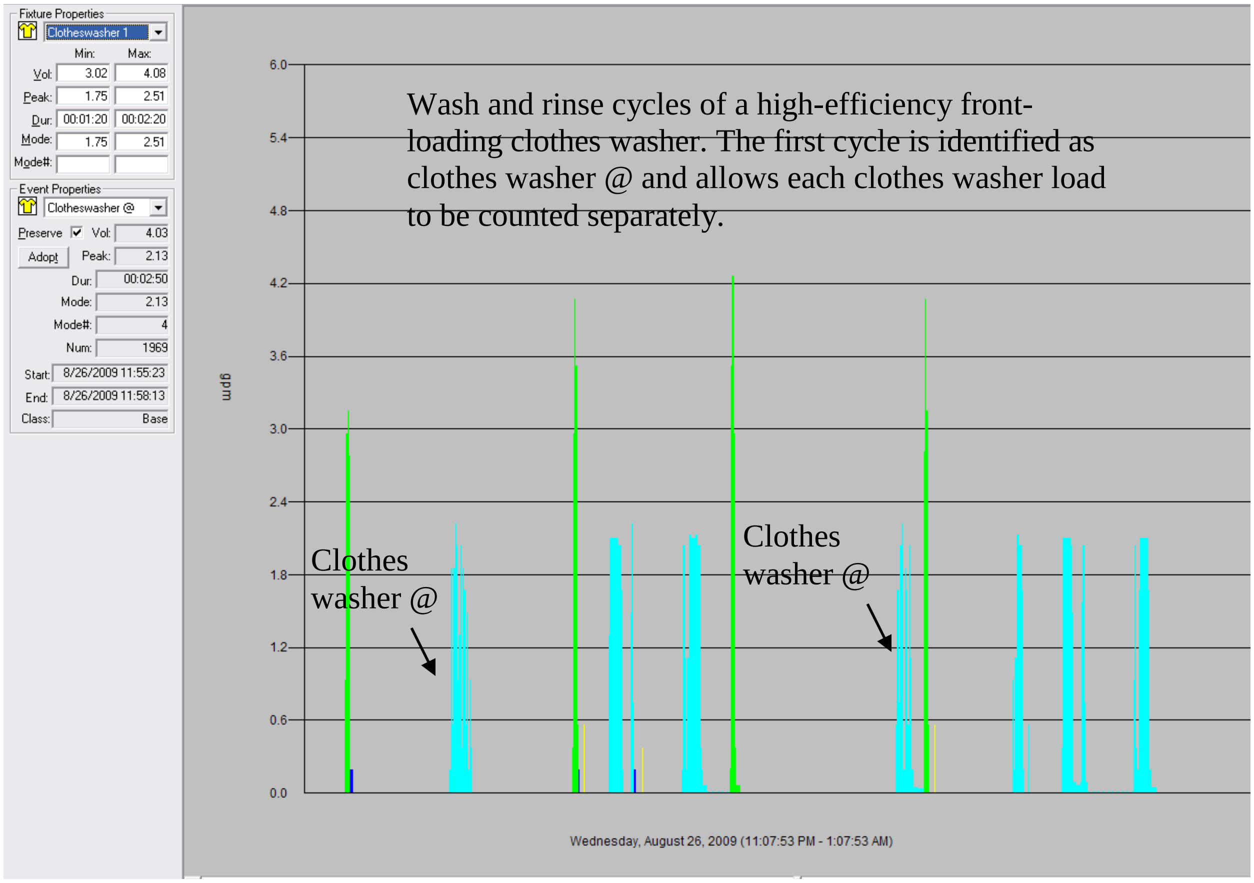


Figure 3-6: Typical profile of two high-efficiency clothes washer loads identified in Trace Wizard

Showers

Showers typically have one of two profiles. The profile shown in Figure 3-7 is representative of homes that have what is commonly referred to as 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 3-7 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 HE toilet flush events (1.28 gpf) that occur during the two-hour time period shown in the figure, one of which occurred during and has been separated from the shower.

The second shower profile, shown in Figure 3-8, is typical of a stall shower where the flow goes directly through the showerhead and is therefore restricted 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 3-8 is 14 minutes in duration with a flow rate of 1.7 gpm. Also shown are a clothes washer event and several toilet and faucet events.

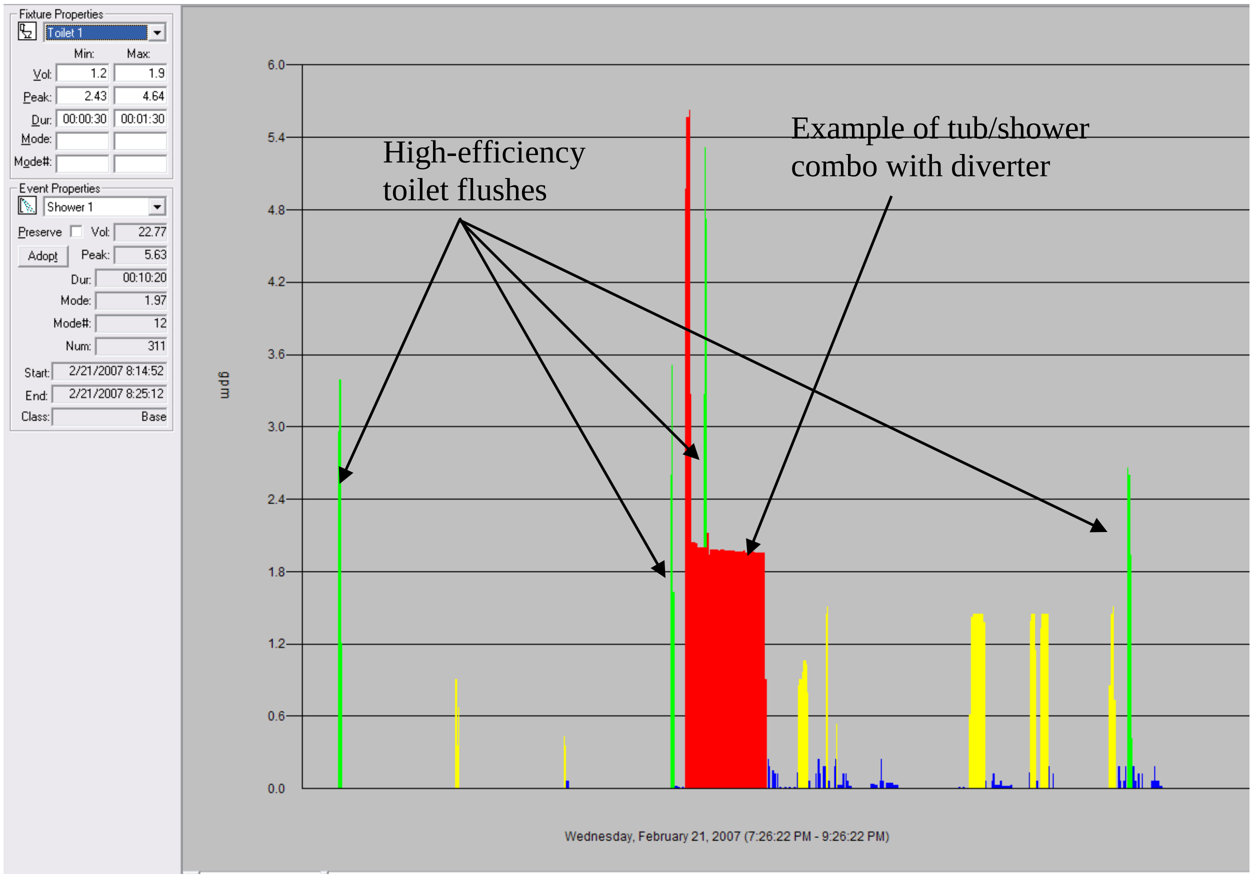


Figure 3-7: Profile typical of tub/shower combo with HE toilet events and some faucet use

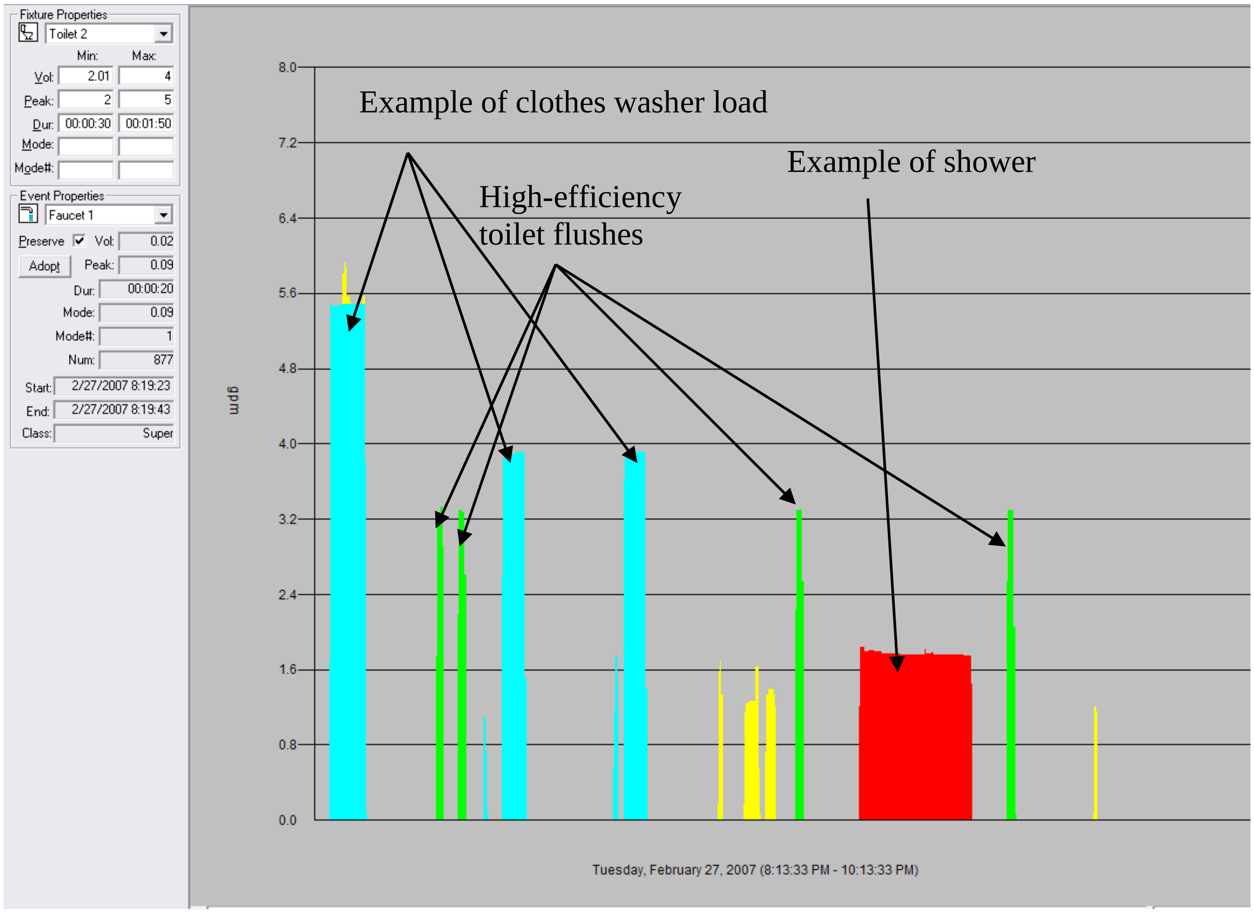


Figure 3-8: Profile typical of a stall shower with clothes washer, faucet, and clothes washer events

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 in a trace to be counted. Figure 3-9 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.

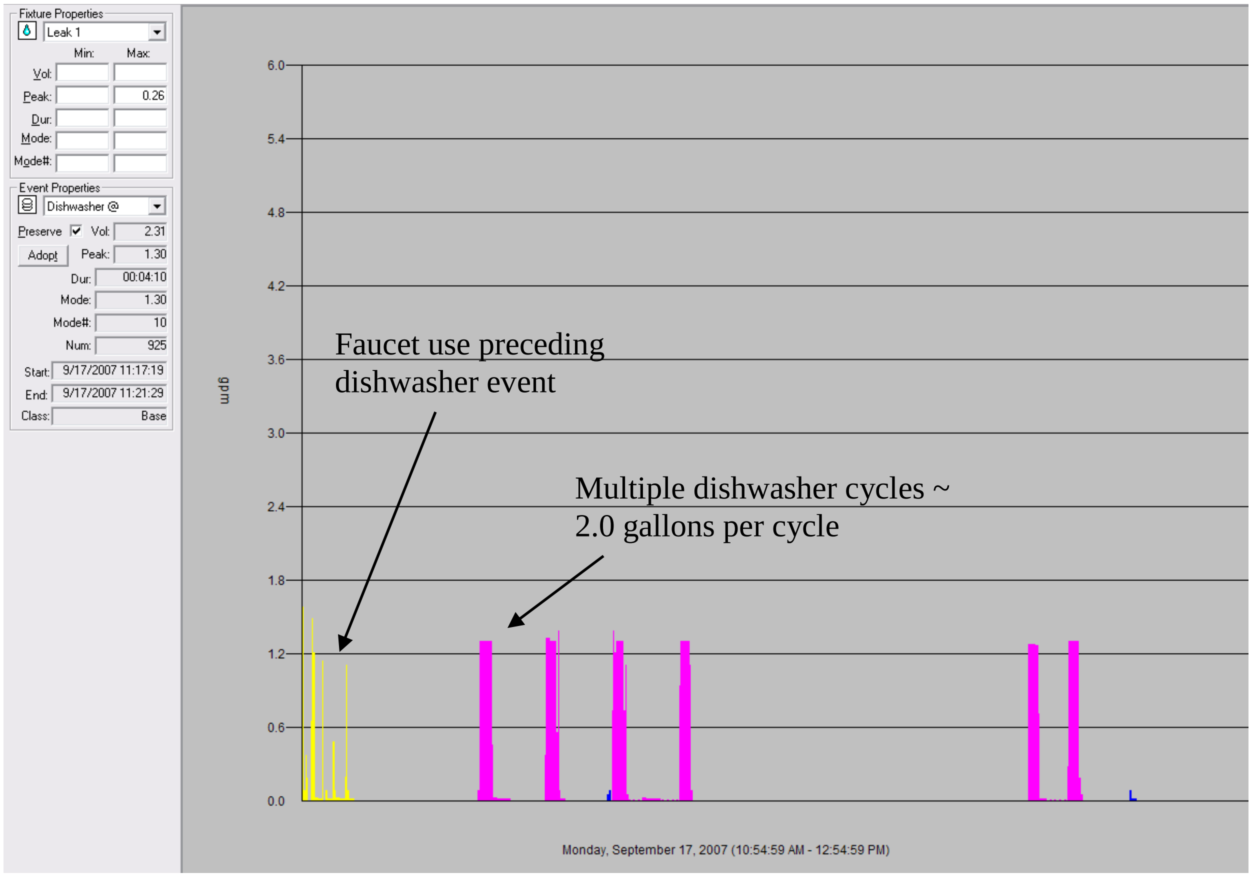


Figure 3-9: Multiple cycles typical of dishwasher usage

Water Softening

Water softening is often found in areas where it is needed to treat high concentrations of minerals in the water supply. Although there are several methods of removing minerals such as reverse osmosis or filtration, water softening is one of the most cost effective.

Water treatment is usually controlled in one of two ways; either by a timer (similar to an irrigation timer) or volumetrically using a computer or mechanical device. There are several events that occur as part of softening process. Hard water passes through resin beads in a mineral tank in which magnesium and calcium ions in the water are replaced with sodium ions.

Backwashing or regeneration of the system becomes necessary as the beads become saturated with calcium and magnesium. Figure 3-10 is an example of a three-phase regeneration process for a residential water softener. The first phase occurs as the brine tank is filling – the water from the brine tank will then be used to backwash the ion exchanger. Water from the brine tank flows into the mineral tank and replaces magnesium and calcium ions with sodium ions. Finally the mineral tank is flushed of excess brine.

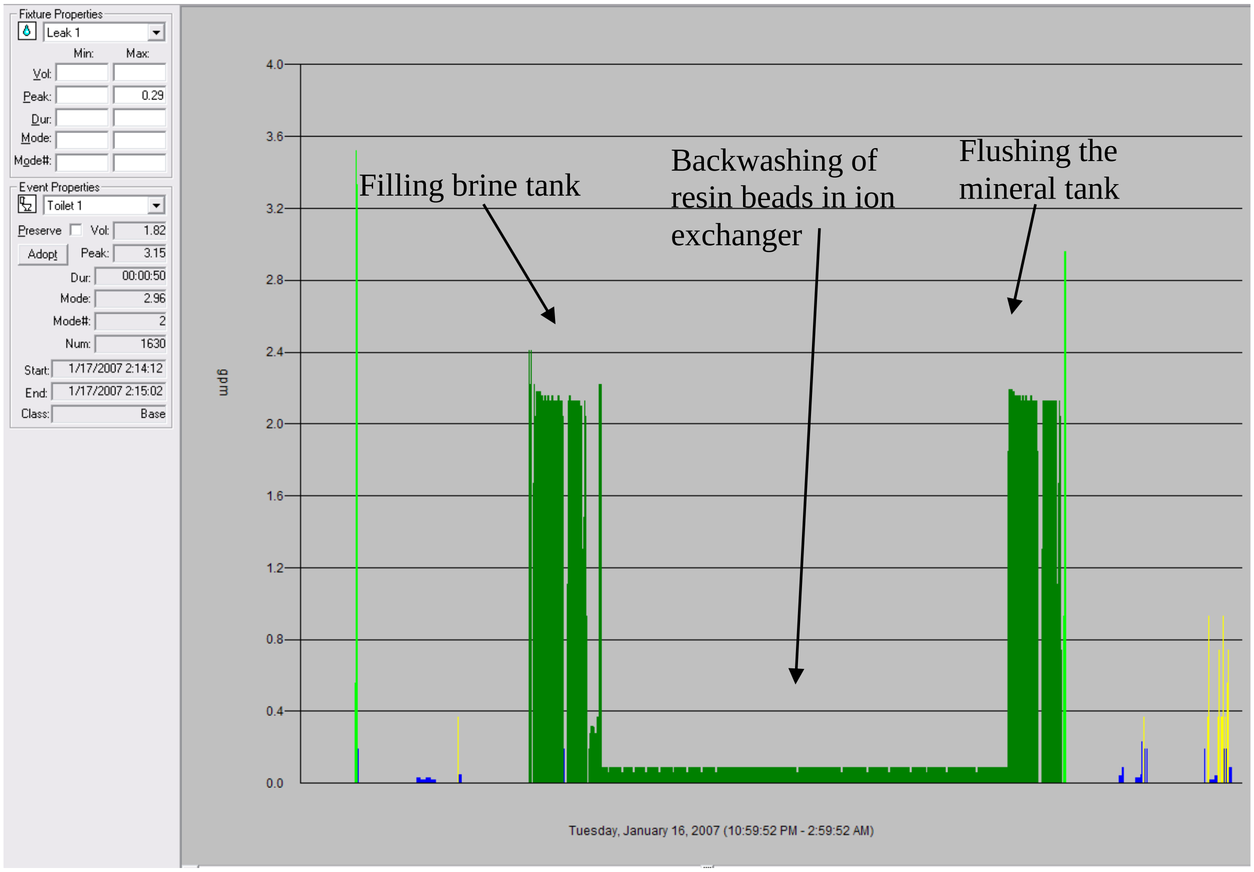


Figure 3-10: An example of residential water softening in Trace Wizard

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, as discussed in reference to Figure 3-5; the second type is continuous leaks. 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 because they occur too frequently to assume that someone is 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, which usually average 10 gallons or less per day.

Constant leaks, on the other hand are continuous events. In some cases these may not be leaks at all, but represent a device that has a constant water demands, such as a reverse osmosis system, a once through cooler, or some sort of medical device. 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 3-11 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 can not be easily classified as a typical fixture, such as use for toilet flushing, clothes washing, faucets, showering, irrigation or other commonly found household uses. 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 return provided 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, further study into the causes of these types of events would be beneficial.

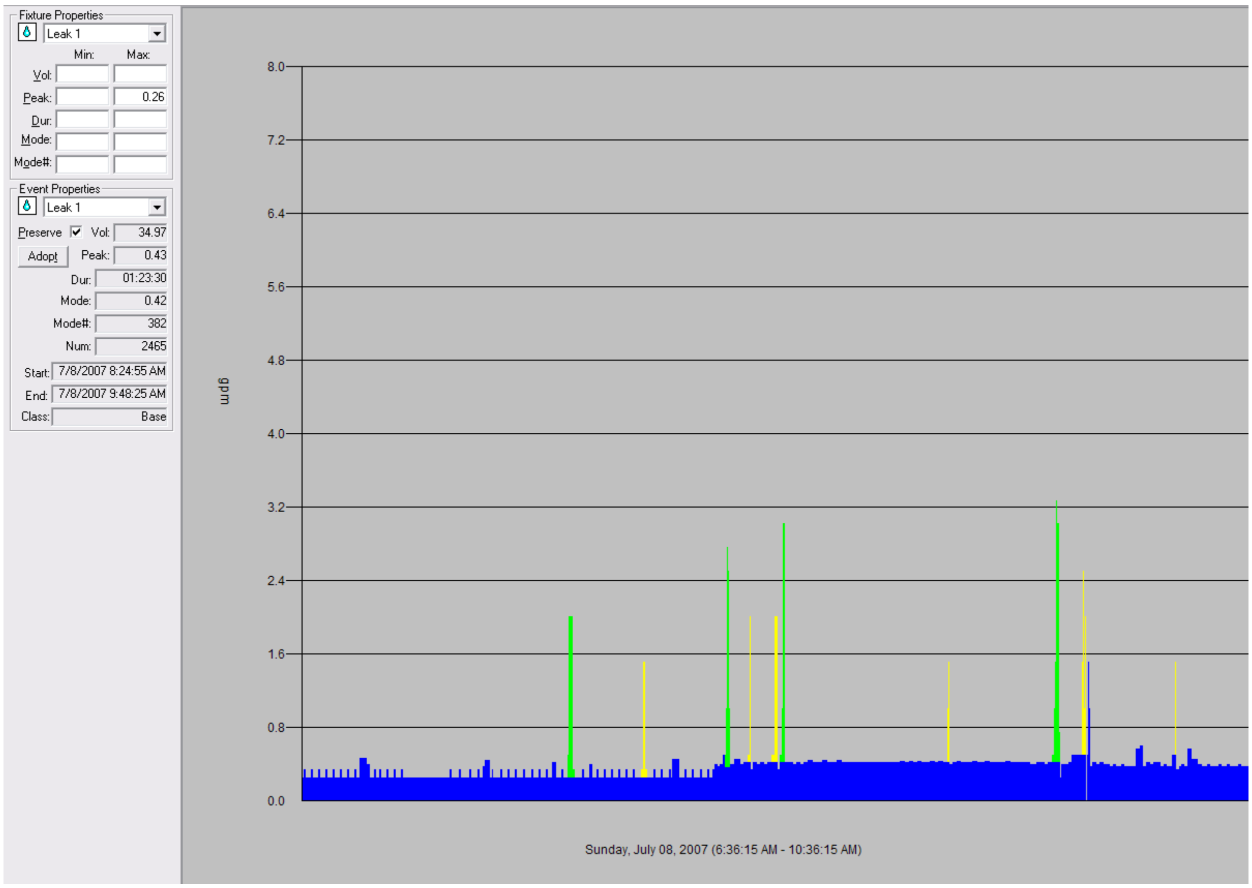


Figure 3-11: Four-hour period showing a continuous event classified as a leak

Irrigation

Overhead irrigation events are the easiest type of irrigation 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 3-12 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 duration of

1 hour and 12 minutes. This event is repeated daily throughout the duration of the data logging period. The change in flow rate occurs 7 times during the irrigation event and is indicative of different zones.

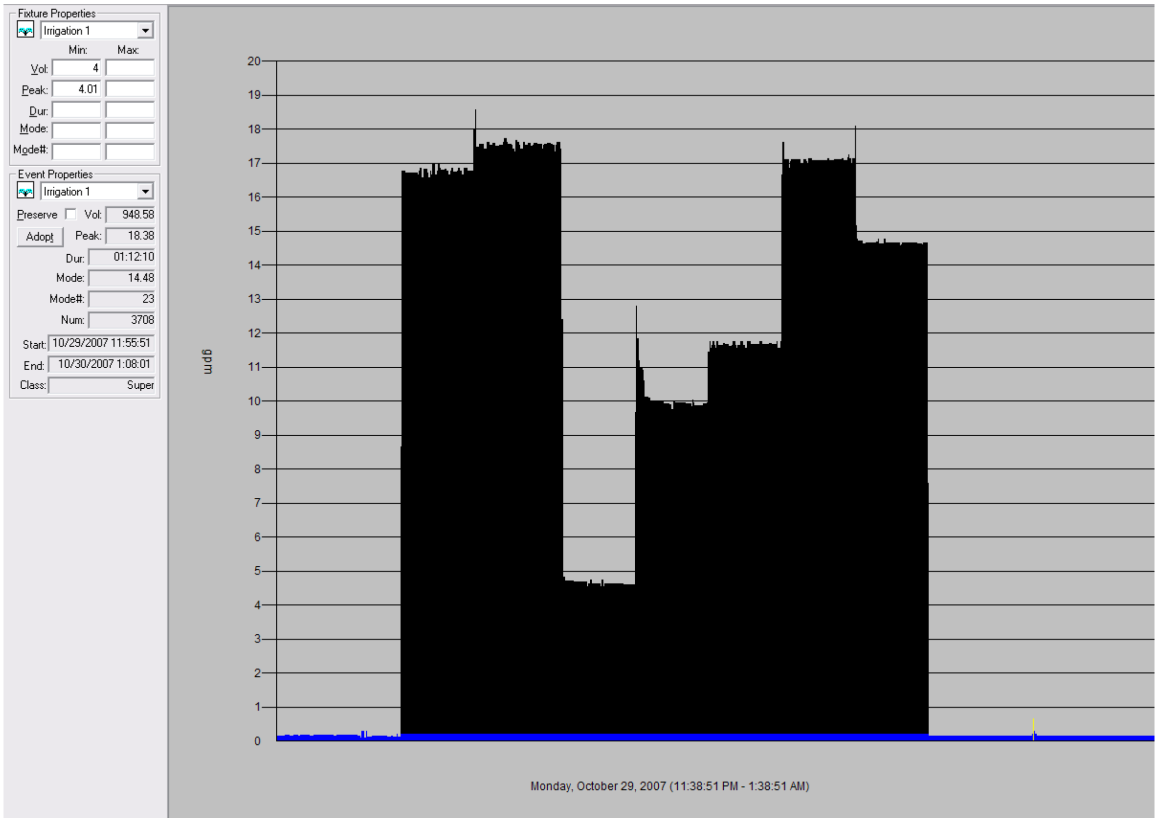


Figure 3-12: Irrigation event with multiple zones

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-needs plants. Figure 3-13 is an example of a drip irrigation event with a flow rate of 2.5 gpm and 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 with the irrigation event.

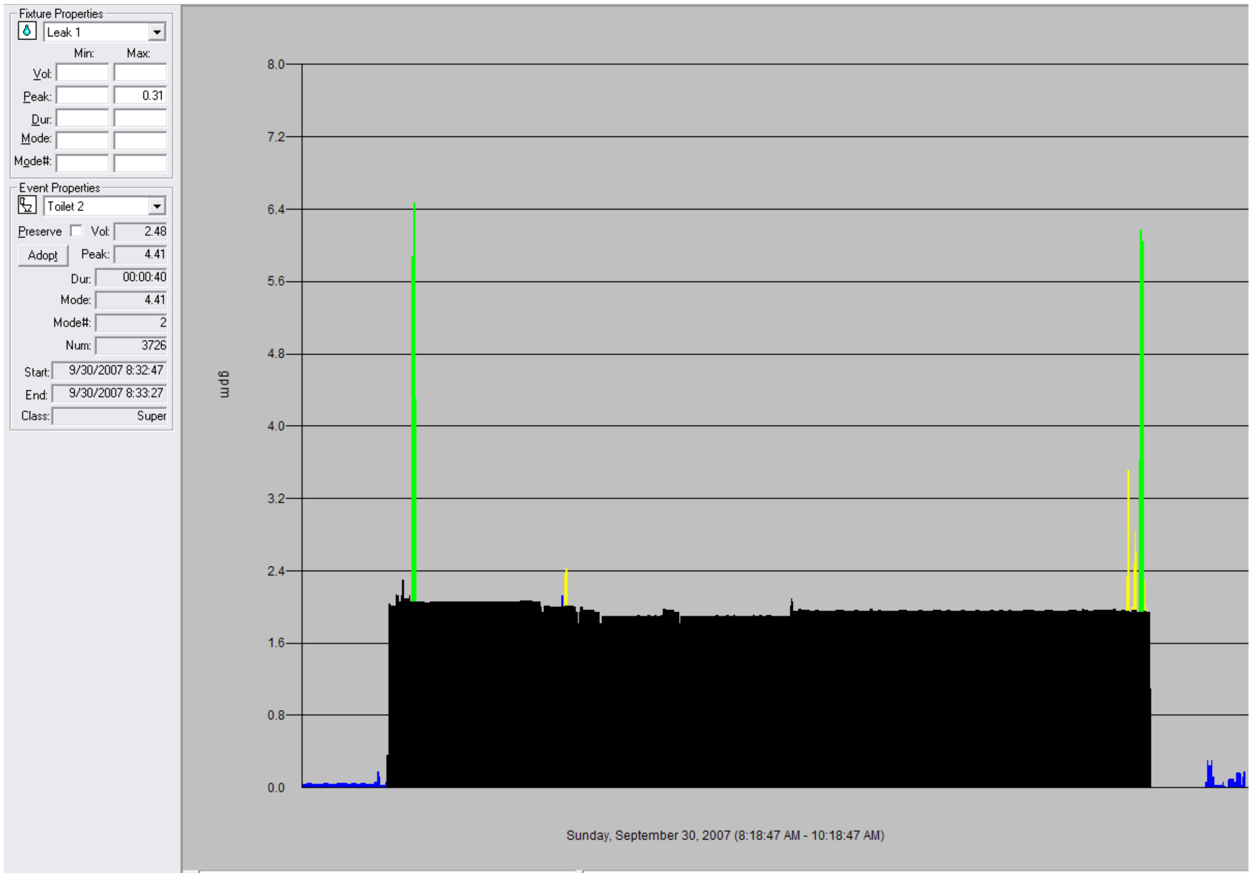


Figure 3-13: Trace Wizard profile of drip irrigation

Site Visits

Site visits were an additional tool used for refining water use data at individual sites. They were particularly useful for identifying water use or water use behavior that differed from "typical" use and might not have been explained by the survey data provided by the customer. Pool filling with an auto-float device, evaporative coolers, and water treatment are uses that are not found in all homes and may look like irrigation or leakage on flow trace analysis.

The site visits were scheduled at the convenience of the homeowner which involved some work both at night and on weekends. All of the homes selected for data logging had already completed a survey form which was available to the site auditor. The site audit was used to confirm the information in the survey and to verify the landscape areas and characteristics.

Statistical Analysis

All data collected for this study including historic billing data, survey response data, disaggregated end use data, climate data, landscape area data, and other relevant information was assembled into a format that allowed the research team to conduct statistical analysis. Software packages including the Statistical Package for Social Science (SPSS), Access, and Excel were utilized by the research team.

A range of statistical analyses were applied to the data, in order to determine the current level of water efficiency at each home and to establish reasonable benchmarks of residential demand. The statistical analyses included simple descriptive statistics and various modeling techniques to quantify household water use. Models of household water use were created against the explanatory parameters such as size and age of the house, number of occupants and the cost of the water. Overall analysis was conducted on the household level, but per capita demands were determined as well.

The event level data, created as an Access database from the flow trace analysis, contains one record for each water use event. These data were summarized into tables of average daily water use for each study home. Daily use was broken down into end-use categories such as clothes washers, showers, toilets, etc. Information from the surveys was also recorded for each home. Participating households were identified only by a code number to ensure the anonymity of the customers.

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

Graphs were made of the historic billing and end use data and trend lines were fit where appropriate. These trend lines were used to develop models that can be used by the utilities to predict future demands and to estimate conservation potential and savings.

Report Preparation

The research team began working on the final report early in the project, but the delays associated with the construction of the high-efficiency new homes kept the writing effort on the back burner until most of the data collection effort was complete. Once datasets were assembled, the research team prepared this final report to describe the work completed on the project and the key findings related to age of housing, current efficiency, conservation potential and water use benchmarks.

CHAPTER 4. RESULTS

This section of the report includes the following results:

- Key findings from the surveys
- Statistical analysis of the annual and seasonal water use from billing data
- Comparisons of pre and post-2001 water use in the samples from participating agencies
- Disaggregated end use results from standard new homes in each study site
- Disaggregated end use results from the high-efficiency new homes
- Analysis of outdoor water use patterns in the standard new homes
- Comparisons of standard new homes and high-efficiency homes

Survey Results

The following tables provide summaries of the customers' responses to the survey questions. These indicate what the customer understood to be the case for their households, and may reflect errors based on misinformation on their parts. A complete listing of survey responses is provided in the appendix.

Response Rates to Surveys

Table 4-1 shows the response rates to the surveys that were mailed to the pre and post samples. The overall rate of returns showed a slight advantage to the existing homes, who returned 40% of their surveys, while the new homes returned 33%. The City of Roseville returned the highest percent while the lowest response rate was in the Tampa Bay area. In all, the survey response rates were very good and more than adequate for our data needs.

Table 4-1: Pre and post-2001 sample size for each of the nine participating agencies

City	Number Sent Out		Responses		Response Rate (%)	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	1000	1000	541	439	54%	44%
Denver	1000	1000	425	323	43%	32%
Eugene	1000	1000	459	418	46%	42%
Las Vegas	998	1000	324	285	32%	29%
Phoenix	998	1000	395	308	40%	31%
Roseville	817	697	530	406	65%	58%
Salt Lake City	1000	1000	333	202	33%	20%
St, John's RWMD	997	998	305	282	31%	28%
Tampa	1000	1000	248	227	25%	23%
Overall	8810	8695	3560	2890	40%	33%

Household Characteristics

Table 4-2 shows the number of persons per household in the survey respondents. One thing that stands out is that the new homes tended to have more children than the existing homes, while the number of adults was approximately the same for both group. The end result was that the new homes had an average of 2.88 persons per home, while the existing homes had 2.49 persons. The per capita data was used for developing relationships between indoor water use and persons per home, which are the strongest explanatory relationships for residential indoor water use. Having the relationships between household use and number of residents allow us to normalize household water use and properly correct for the impact of the different number of persons per household in the different cities.

Table 4-2: Comparison of persons per household across study sites (Q41)

	Adults		**Children**		**Mean HH Size**	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	2.08	2.11	0.53	0.73	2.61	2.84
Denver	1.96	1.94	0.57	0.77	2.53	2.71
Eugene	1.88	1.90	0.38	0.70	2.26	2.61
Las Vegas	2.05	2.07	0.35	0.63	2.41	2.70
Phoenix	1.95	2.11	0.61	0.85	2.56	2.96
Roseville	1.93	2.18	0.54	1.23	2.48	3.40
Salt Lake City	2.15	2.25	0.59	0.83	2.74	3.08
St. John's RWMD	1.89	2.05	0.44	0.72	2.33	2.77
Tampa	2.07	2.10	0.46	0.72	2.53	2.82
Overall	1.99	2.07	0.50	0.81	2.49	2.88

The income reported by the occupants of the new homes was significantly higher than that of the existing homes. Overall the median income reported by the occupants in the new homes was 30% greater than that reported by the existing home occupants. The highest reported incomes were in Roseville and Salt Lake City, while the lowest reported incomes were in Phoenix.

Table 4-3: Comparison of Household Incomes (Q45)

City	Average Income		Median Income	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	$ 82,460	$ 110,101	$ 75,000	$ 95,000
Denver	$ 95,526	$ 104,841	$ 75,000	$ 85,000
Eugene	$ 73,734	$ 99,303	$ 55,000	$ 85,000
Las Vegas	$ 93,918	$ 99,243	$ 75,000	$ 85,000
Phoenix	$ 81,775	$ 93,068	$ 65,000	$ 75,000
Roseville	$ 85,655	$ 120,384	$ 75,000	$ 110,000
Salt Lake City	$ 70,644	$ 134,886	$ 55,000	$ 110,000
St. John's RWMD	$ 73,353	$ 97,262	$ 65,000	$ 85,000
Tampa	$ 100,857	$ 101,031	$ 85,000	$ 85,000
Overall	$ 83,605	$ 106,318	$ 65,000	$ 85,000

The education levels tended to be fairly consistent. Around 15% of the primary wage earners had high school only, 62% had some college, and 23% had some graduate school. Salt Lake City had the highest percentage of respondents with graduate school, and it is difficult to say who had the lowest.

Table 4-4: Comparison of Education (Q44)

	% High School		% Some College		% Some Graduate School	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	15%	12%	58%	62%	25%	25%
Denver	14%	13%	53%	58%	29%	25%
Eugene	12%	11%	62%	61%	24%	26%
Las Vegas	22%	14%	59%	70%	17%	15%
Phoenix	17%	11%	60%	67%	17%	16%
Roseville	11%	7%	67%	69%	22%	22%
Salt Lake City	21%	9%	52%	48%	25%	40%
St. John's RWMD	23%	11%	61%	63%	13%	24%
Tampa	14%	8%	68%	68%	18%	23%
Overall	16%	11%	60%	63%	22%	24%

As shown in **Table 4-5** the majority of the existing homes were built prior to 1980. The newest homes were found in Las Vegas, that had 93% of its homes built after 1980, while the oldest homes were in Salt Lake City, which had only 7% of its homes built after that date.

Table 4-5: Age comparison of existing homes (Q37)

Water Agency	% Built before 1980	% Built 1980-1994	% Built 1995-2000
Aurora	65%	31%	4%
Denver	78%	13%	9%
Eugene	76%	13%	10%
Las Vegas	7%	46%	47%
Phoenix	51%	34%	15%
Roseville	13%	29%	58%
Salt Lake City	93%	2%	6%
St. John's RWMD	56%	30%	14%
Tampa	25%	49%	26%
Overall	52%	26%	21%

On average there were approximately 3.3 bedrooms in the existing homes and 3.5 in the new homes. The range in bedroom numbers was between 3.06 in the existing homes in Eugene to 3.98 in the new homes in Roseville. The number of bedrooms is not as good a predictor for water use as is the number of residents, but can serve as a proxy when occupancy data are not available.

Table 4-6: Comparisons of number of bedrooms (Q39)

	Bedrooms	
	Existing (pre-2001)	New (post- 2001)
Aurora	3.61	3.36
Denver	3.39	3.31
Eugene	3.06	3.18
Las Vegas	3.33	3.49
Phoenix	3.29	3.53
Roseville	3.26	3.98
Salt Lake City	3.27	3.77
St. John's RWMD	3.14	3.66
Tampa	3.47	3.61
Overall	3.32	3.53

The reported median home values ranged from a low of $175,000 for the existing homes in St. John's River up to $475,000 for the new homes in Salt Lake City. On average, as one would expect, the new home values tended to be significantly higher than those of the existing homes.

Table 4-7: Comparison of self reported home values (Q43b)

	Median Value		**Average Value**	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	$225,000	$325,000	$249,457	$371,562
Denver	$275,000	$325,000	$379,818	$396,575
Eugene	$275,000	$325,000	$282,412	$375,545
Las Vegas	$325,000	$425,000	$419,117	$483,914
Phoenix	$275,000	$325,000	$351,780	$385,486
Roseville	$475,000	$550,000	$489,465	$603,176
Salt Lake City	$275,000	$475,000	$304,368	$593,716
St. John's RWMD	$175,000	$275,000	$230,545	$320,865
Tampa	$275,000	$275,000	$327,631	$340,338
Overall	$275,000	$375,000	$339,742	$428,465

Fixtures and Appliances

Table 4-8 shows the number of toilets in the homes and the percent of the toilets that the users believe to be ULF or better models. The data show that nearly 60% of the toilets in the existing homes are ULF or better. If the residents are correct then this implies a fairly high penetration rate for ULF or better toilets in the existing homes. It should be kept in mind that because some homes have all ULF toilets and some homes have none, one would not find 58% of toilets in all homes ULF. Even with 58% of the toilets at ULF or better models there could still be a sizeable number of homes with no high-efficiency toilets.

Table 4-8 also begs the question of whether the residents are accurate in having 7% of the toilets in the post 2001 homes that do not meet ULF criteria. If the residents correctly identified the presence of non-ULF toilets then this implies that a fairly large percentage of the toilets in new homes do not meet ULF criteria. If the residents are not correct then we would assume that the new homes show a 100% penetration of ULF or better toilets.

When the percent of ULF or better toilets in the homes is compared to the ages of the homes an interesting pattern emerges. As shown in **Figure 4-1**, as one would expect there is a significant increase in the percentages of ULF toilets starting in home built after 2001. The age of the homes built prior to 2001, however, has virtually no impact on the percentage of their ULF toilets. The oldest homes tend to have nearly the same percentage of ULF toilets as do the homes built 15 years ago. This implies that the retrofit rate is fairly constant in older homes, and older homes are not replacing their toilets faster than newer homes.

Table 4-8: Comparison of Toilets (1a, 3)

	Toilets		**ULF Toilets** (or better)		**% ULF** (or better)	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	2.88	3.15	1.23	2.91	43%	92%
Denver	2.54	3.02	1.32	2.78	52%	92%
Eugene	2.07	2.60	0.91	2.48	44%	95%
Las Vegas	2.58	2.93	1.84	2.72	71%	93%
Phoenix	2.21	2.52	1.32	2.30	60%	91%
Roseville	2.42	2.94	1.86	2.88	77%	98%
Salt Lake City	2.10	3.46	1.18	3.00	56%	87%
St. John's RWMD	2.02	2.51	1.19	2.36	59%	94%
Tampa	2.50	2.60	1.70	2.38	68%	92%
Overall	2.39	2.85	1.38	2.66	58%	93%

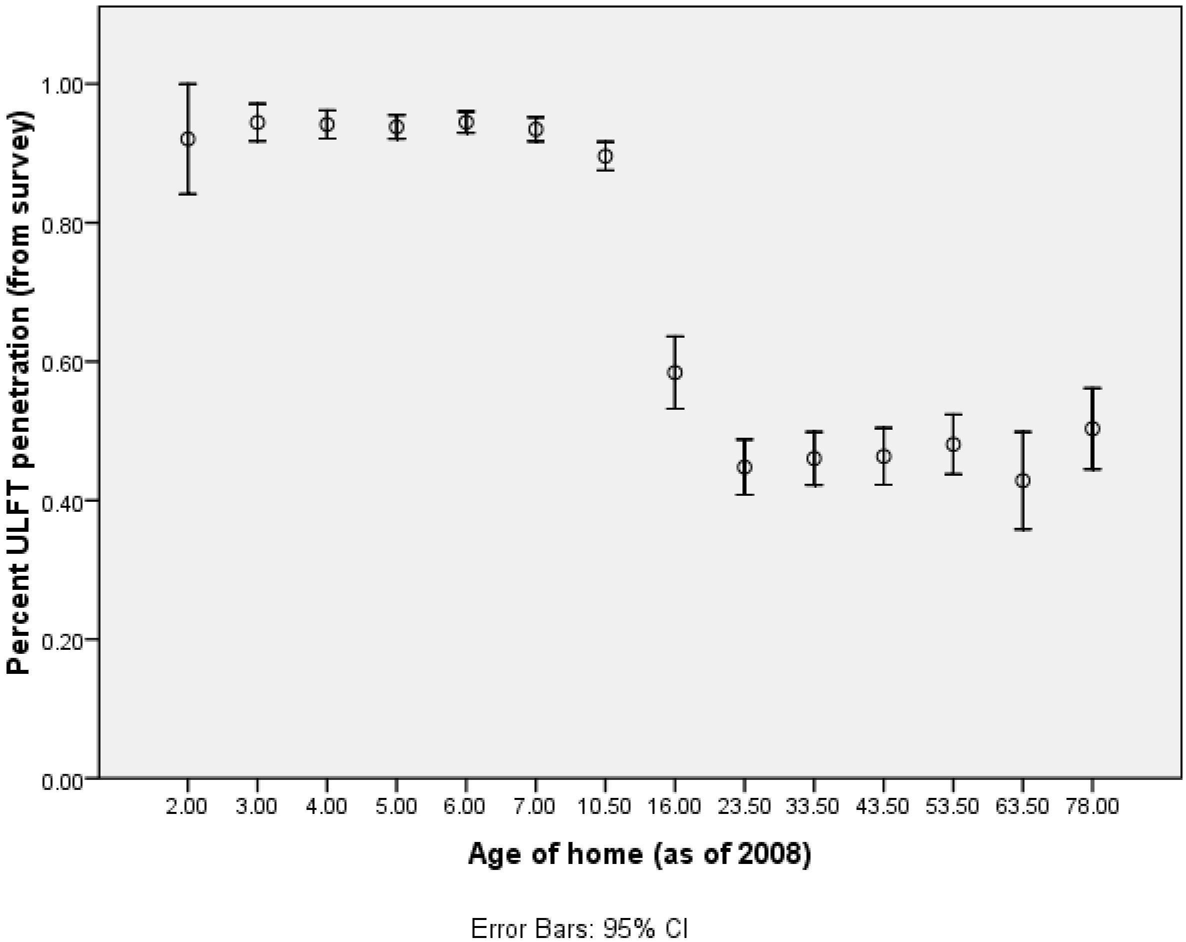


Figure 4-1: Percent of reported ULFT versus age of home

Generally, the homes in the survey group had over 2 showers per home, and the newer homes tended to have slightly more: 2.39 verses the existing homes with 2.06 showers per home. The respondents reported around 60% of the showerheads in the existing homes and 76% in the new homes are low flow models. Again, one would expect 100% of the homes built after 2001 to have ULF showers, and the discrepancy could be due to either a mis-identification or the fact that 24% of the showerheads being installed in new homes really are designed with flow rates that do not meet the National Energy Policy Act of 1992 standards.

Table 4-9: Comparison of showers (Q 1b, 1d, 4)

	Number of showers		Number of ULF Showers		% of Showers ULF	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	2.37	2.49	1.23	1.78	52%	71%
Denver	2.02	2.38	1.06	1.67	53%	70%
Eugene	1.73	2.14	1.10	1.64	64%	77%
Las Vegas	2.30	2.40	1.59	2.03	69%	84%
Phoenix	2.04	2.21	1.10	1.60	54%	72%
Roseville	2.19	2.63	1.58	2.21	72%	84%
Salt Lake City	1.77	2.68	0.93	2.11	52%	79%
St. John's RWMD	1.80	2.34	1.07	1.60	60%	68%
Tampa	2.22	2.34	1.35	1.75	61%	75%
Overall	2.06	2.39	1.23	1.82	60%	76%

Garbage disposals and dishwashers are highly present in both existing and new homes. Utility sinks are present in around a third of the homes, as shown in **Table 4-10**.

Table 4-10: Comparison of disposals, dishwashers, utility sinks (Q 2a, 2d, 1e)

	Garbage Disposals		Dishwashers		Utility Sinks	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	96%	95%	96%	99%	23%	33%
Denver	93%	95%	84%	98%	35%	27%
Eugene	69%	97%	86%	98%	37%	44%
Las Vegas	98%	95%	98%	98%	27%	23%
Phoenix	80%	95%	80%	96%	18%	24%
Roseville	96%	97%	95%	99%	40%	52%
Salt Lake City	74%	90%	74%	97%	17%	39%
St. John's RWMD	52%	93%	70%	98%	16%	26%
Tampa	91%	97%	92%	99%	41%	34%
Overall	84%	95%	87%	98%	29%	34%

Clothes washers are just as prevalent in both existing and new homes as are garbage disposals and dishwashers. On average 98-99% of the homes report having a clothes washer. Approximately 20% to 30% of these are front loading, high-efficiency models according to the respondents.

Table 4-11: Clothes washer comparisons (Q: 2b, 2c)

	Clothes Washer		**Front Loader**		**% Front Loaders**	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	100%	98%	19%	28%	19%	29%
Denver	98%	98%	24%	38%	24%	38%
Eugene	98%	99%	28%	40%	29%	40%
Las Vegas	98%	99%	18%	26%	18%	26%
Phoenix	98%	98%	21%	25%	21%	26%
Roseville	98%	98%	19%	35%	20%	35%
Salt Lake City	97%	99%	19%	41%	19%	42%
St. John's RWMD	98%	100%	11%	18%	11%	18%
Tampa	100%	99%	21%	24%	21%	25%
Overall	98%	99%	20%	31%	21%	31%

There is a wide range in the presence of evaporative coolers and whole house water treatment systems. The evaporative coolers tend to be found in drier areas like Denver, Phoenix and Salt Lake City. The water treatment systems tend to be found in systems with higher salinity water. There are two types of water treatment systems of interest. There are ion exchange water softeners, that remove calcium and magnesium ions to soften the water, but have little impact on overall TDS of the product water. These devices use water only when they are recharged, as salt water is flushed back through the resin to recharge them and discharged to a drain. Reverse osmosis systems use water constantly when they are treating water. Usually around 20% of the water goes to a tank of product water and 80% goes down the drain (or, hopefully, in some cases to irrigation) as reject water. If only water for drinking is treated with RO the overall water use will be small, but in some cases if all of the water used indoor is treated the water use can be several hundred gallons per day.

Table 4-12: Comparison of Evaporative coolers, water treatment and indoor spas (Q: 2g, 2i, 2f)

	Evaporative Cooler		**Whole House Water Treatment**		**Indoor Spa**	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	25%	2%	8%	8%	4%	3%
Denver	25%	3%	3%	4%	2%	1%
Eugene	0%	1%	0%	2%	3%	3%
Las Vegas	7%	2%	52%	64%	2%	1%
Phoenix	21%	2%	22%	32%	2%	1%
Roseville	1%	0%	2%	2%	1%	2%
Salt Lake City	38%	7%	18%	39%	2%	5%
St. John's RWMD	0%	1%	23%	27%	2%	1%
Tampa	0%	0%	38%	34%	3%	3%
Overall	14%	2%	15%	20%	2%	2%

The rate of whirlpool baths in new homes is approximately twice that found in existing homes. New homes have these devices 21% of the time while existing homes have them around 11%. Multi-headed showers appear in 6%-9% of existing and new homes respectively, while indoor fountains and water features are relatively rare in both groups.

Table 4-13: Comparison of whirlpool tubs, multi showers and indoor fountains (Q: 2e, 7, 2h)

	Whirlpool bathtubs		**Multi-headed Showers**		**Indoor Fountain**	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	10%	31%	6%	7%	2%	3%
Denver	12%	20%	8%	7%	3%	2%
Eugene	10%	15%	5%	15%	2%	2%
Las Vegas	20%	19%	10%	10%	3%	4%
Phoenix	8%	8%	5%	6%	2%	4%
Roseville	10%	20%	3%	5%	2%	4%
Salt Lake City	14%	56%	7%	18%	1%	3%
St. John's RWMD	10%	15%	5%	6%	1%	4%
Tampa	11%	11%	7%	9%	2%	4%
Overall	11%	21%	6%	9%	2%	3%

The percentage of homes that report irrigation is very high in both existing and new homes. Overall, 93% of the existing homes report irrigating their landscape and 96% of the new homes make a similar report. The lowest rate of irrigation in new homes was 80%, and this was reported in Florida. Generally, the irrigation rate in the new homes was over 90%. The rate of homes with alternate water supplies for irrigation (wells primarily) averages less than 10%, but this varies, with up to 219% of the existing homes in the St John's River service area having alternate supplies. A significant majority of the homes that irrigate do so with automatic sprinkler systems. Sprinklers are found in 73% of the existing homes and 88% of the new homes.

Table 4-14: Comparison of irrigation and sprinklers (Q: 13, 18, 22)

	% of homes that irrigate		**% with alternative supplies**		**% with automatic sprinkler systems**	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	97%	98%	4%	3%	78%	93%
Denver	97%	93%	2%	3%	70%	84%
Eugene	92%	95%	10%	2%	48%	86%
Las Vegas	92%	96%	1%	2%	90%	96%
Phoenix	92%	94%	7%	4%	70%	87%
Roseville	99%	98%	2%	1%	93%	96%
Salt Lake City	97%	96%	10%	8%	61%	78%
St. John's RWMD	79%	98%	29%	9%	59%	82%
Tampa	80%	92%	22%	17%	80%	80%
Overall	93%	96%	8%	5%	73%	88%

Outdoor spas, ponds and pools are all present, but are highly variable based on geography. The Denver area has the lowest rate of these features, while warmer cities like Las Vegas, Tampa and Phoenix have a much higher percentage.

Table 4-15: Comparison of pools and fountains (Q: 26, 28,29)

	Outdoor Spa or Hot tub		**Outdoor pond or fountain**		**Swimming Pool**	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	10%	10%	8%	12%	2%	1%
Denver	8%	3%	10%	7%	2%	0%
Eugene	14%	11%	13%	17%	2%	3%
Las Vegas	24%	26%	12%	13%	28%	30%
Phoenix	13%	14%	8%	11%	38%	32%
Roseville	18%	24%	19%	27%	23%	35%
Salt Lake City	6%	12%	10%	15%	3%	5%
St. John's RWMD	5%	7%	4%	9%	15%	16%
Tampa	22%	17%	7%	8%	58%	29%
Overall	13%	14%	11%	14%	17%	16%

Table 4-16 shows that a lot more people believe they know the cost of their water than how much water they typically use. There is also very strong belief that water should be conserved to aid the environment.

Table 4-16: Attitudinal comparisons (Q34a,b,e)

	% who know cost of water		**% who know typical volume used**		**% who conserve for environmental reasons**	
	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)	Existing (pre-2001)	New (post- 2001)
Aurora	80%	88%	58%	59%	78%	78%
Denver	76%	78%	53%	51%	86%	86%
Eugene	62%	70%	52%	43%	79%	75%
Las Vegas	84%	86%	65%	64%	88%	87%
Phoenix	84%	86%	59%	58%	83%	80%
Roseville	62%	64%	45%	42%	79%	78%
Salt Lake City	80%	87%	57%	61%	83%	85%
St. John's RWMD	80%	79%	69%	69%	81%	75%
Tampa	90%	82%	64%	55%	83%	79%
Overall	76%	79%	57%	55%	82%	80%

The results from the survey responses are an important input into the analysis of the factors that affect water use. The responses were entered into the statistical package used for the data analysis and relationships between the responses and water use were examined.

Annual and Seasonal Use from Billing Data

Annual single family billing data were obtained from each of the nine participating agencies for the purpose of statistical analysis of annual water use and selection of the pre and post 2001 survey groups. As described in the methodology section of this report, random samples of 1,000 homes each were selected in each agency for pre and post-2001 billing data. These samples were checked to verify that their water use patterns matched the respective populations from which they were drawn at the 95% confidence level.

Not all agencies had enough single-family homes constructed and joined to the billing system post-2001 to provide a random sample of 1,000 homes, so in those agencies the entire population of post-2001 homes was obtained. The sample size of the pre and post-2001 homes in each agency is shown in Table 4-1. There were 8,811 homes selected from pre-2001 billing data and 8,695 homes selected from post 2001 billing data. Surveys were sent to every home selected in both sample sets.

Following the selection of the Q_{1000} samples, the billing data provided by each agency were analyzed and seasonal and non-seasonal water use calculated for each home. Annual water use in the new homes was compared against that of the existing homes to look for differences. Annual water use in each service area was examined for regional variations as well.

Table 4-17 provides the average and median annual, seasonal, and non-seasonal water use for the entire pre and post-2001 sample from the billing data. The average non-seasonal (indoor use) decreased from 63.4 kgal annually to 60.9 kgal annually, average seasonal (irrigation, pool use, cooling) increased from 76.1 kgal annually to 84.0 kgal annually resulting in an increase in average annual use between pre and post-2001 homes from 140 kgal to 145 kgal. All of these changes in mean use, while modest in size, were statistically significant at the 95% confidence level.

Table 4-17: Annual water use statistics for the existing and standard new home study groups

Category		N (sample size)	Average (kgal) ± 95% CI	Median
Existing Homes (Pre-2001)	**Total**	8811	140 ± 2.2	117.4
	Non-Seasonal (indoor)	8811	63.4 ± 1.0	53.9
	Seasonal (outdoor)	8811	76.1 ± 1.7	55
New Homes (post-2001)	**Total**	8695	145 ± 3.1	121
	Non-Seasonal (indoor)	8695	60.9 ± 1.5	49.4
	Seasonal (outdoor)	8695	84.0 ± 2.4	63

Figure 4-2 presents a comparison of the average annual water use in the new and existing home samples for each of the nine participating agencies. Average annual water use in the post 2001 homes is not uniformly greater than the pre 2001 homes, as shown in Figure 4-2. Although water use decreased or remained constant in three of the study sites, the new homes used significantly more water than older homes at six of the sites, which resulted in the overall increase in average annual water use between the two groups of homes. These results are presented numerically in Table 4-18.

Table 4-18: Comparison of pre and post-2001 annual, seasonal, and non-seasonal water use from participating agencies

City	Avg. Annual Use (kgal)		Avg. Non-Seasonal Use (kgal)		Avg. Seasonal Use (kgal)	
	Pre 2001	**Post 2001**	**Pre 2001**	**Post 2001**	**Pre 2001**	**Post 2001**
Aurora	134.2 ± 3.8	138.5 ± 3.6	63.7 ± 2.3	56.4 ± 1.8	70.5 ± 3.2	82.13 ± 3.0

Denver	132.7 ± 5.8	131.9 ± 12.2	64.3 ± 2.6	55.1 ± 2.4	68.4 ± 5.1	76.8 ± 11.4
Eugene	95.9 ± 3.7	122.0 ± 4.4	54.3 ± 2.9	41.9 ± 1.6	41.6 ± 1.7	80.1 ± 3.7
Las Vegas	190.8 ± 8.5	161.3 ± 9.8	86.0 ± 3.0	82.5 ± 4.1	104.8 ± 6.7	78.8 ± 7.1
Phoenix	150.2 ± 7.6	120.9 ± 5.7	62.1 ± 2.9	58.8 ± 3.1	88.0 ± 5.8	62.2 ± 3.4
Roseville	176.6 ± 4.0	202.8 ± 4.6	66.6 ± 2.1	84.6 ± 2.7	110.0 ± 3.3	118.3 ± 3.6
Salt Lake	217.1 ± 10.8	230.5 ± 24.2	98.3 ± 6.0	61.1 ± 14.1	118.8 ± 9.0	169.5 ± 17.1
St John's	86.8 ± 4.1	122.9 ± 5.8	44.6 ± 2.0	51.0 ± 2.6	42.3 ± 3.0	71.9 ± 4.5
Tampa	85.5 ± 3.6	99.2 ± 4.4	49.8 ± 2.1	57.2 ± 2.6	35.7 ± 2.3	42.0 ± 2.7

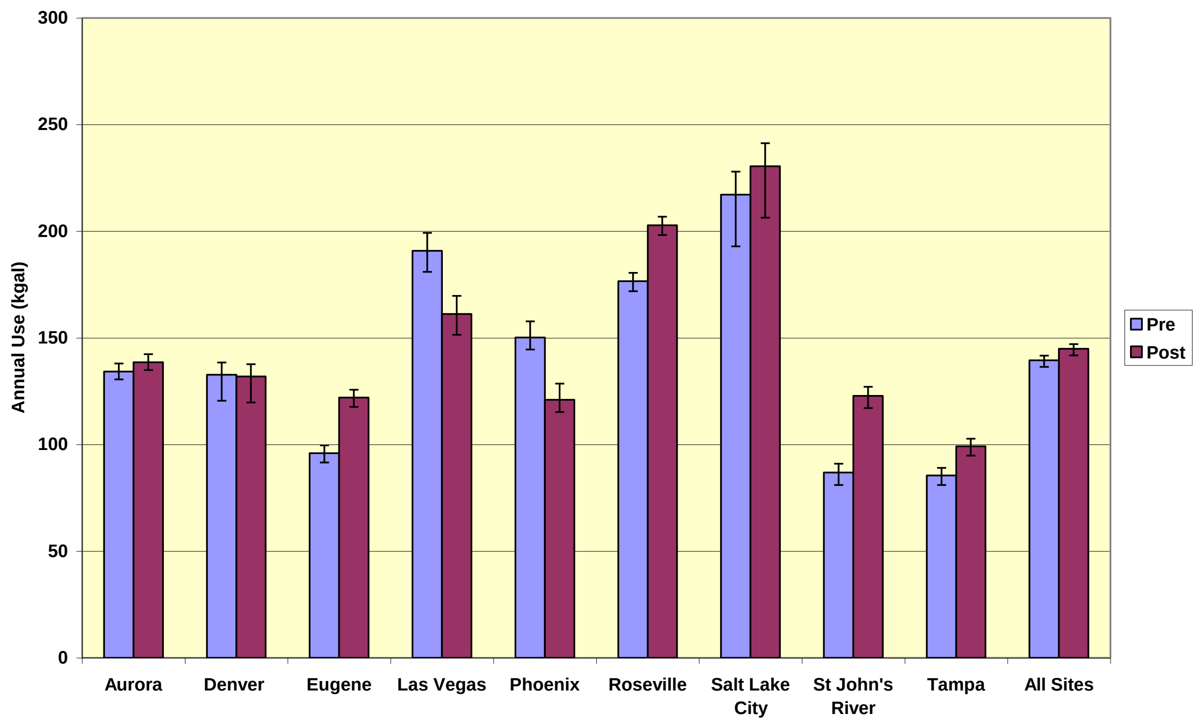


Figure 4-2: Average annual water use for the Q_{1000} pre and post-2001 by participating agency

Indoor Use - Standard New Homes

Flow trace data were collected from a total of 302 standard new homes in the 9 study sites. These data were disaggregated into individual water use events and categorized by end-uses. This allowed statistical analyses to be performed on the indoor uses, as explained in the following sections.

Table 4-19: Indoor use statistics for standard new homes

	REUWS Homes	**Standard New Homes**
Sample Size	1188	302
Average Indoor Use (gphd)	177 ± 5.5	140 ± 10

Median Indoor Use (gphd)	159	124

Using the event database created from the flow traces it was possible to segregate indoor and outdoor water use in the study homes and examine each end use of water separately. This section of the analyses looks at indoor uses. Leakage is included among indoor uses, but it should be understood that some leaks may be due to faulty irrigation systems and it is usually impossible to determine the exact location of a leak from this type of analysis. The daily demand analysis was primarily conducted on the household level (rather than per capita level) because the research team did not wish to normalize consumption on the number of residents separately from the other important explanatory variables. As many utilities do not know the actual number of residents living in each home, household level analysis allows for easy comparison with existing billing data sets.

Figure 4-3 is a frequency distribution (histogram) of the total indoor water use for the standard (post-2001) study homes. These data show that 35 percent of the homes in this study used more than 150 gpd and approximately 8% of the homes used more than 250 gpd for indoor uses. These are homes with likely the greatest potential for indoor water conservation.

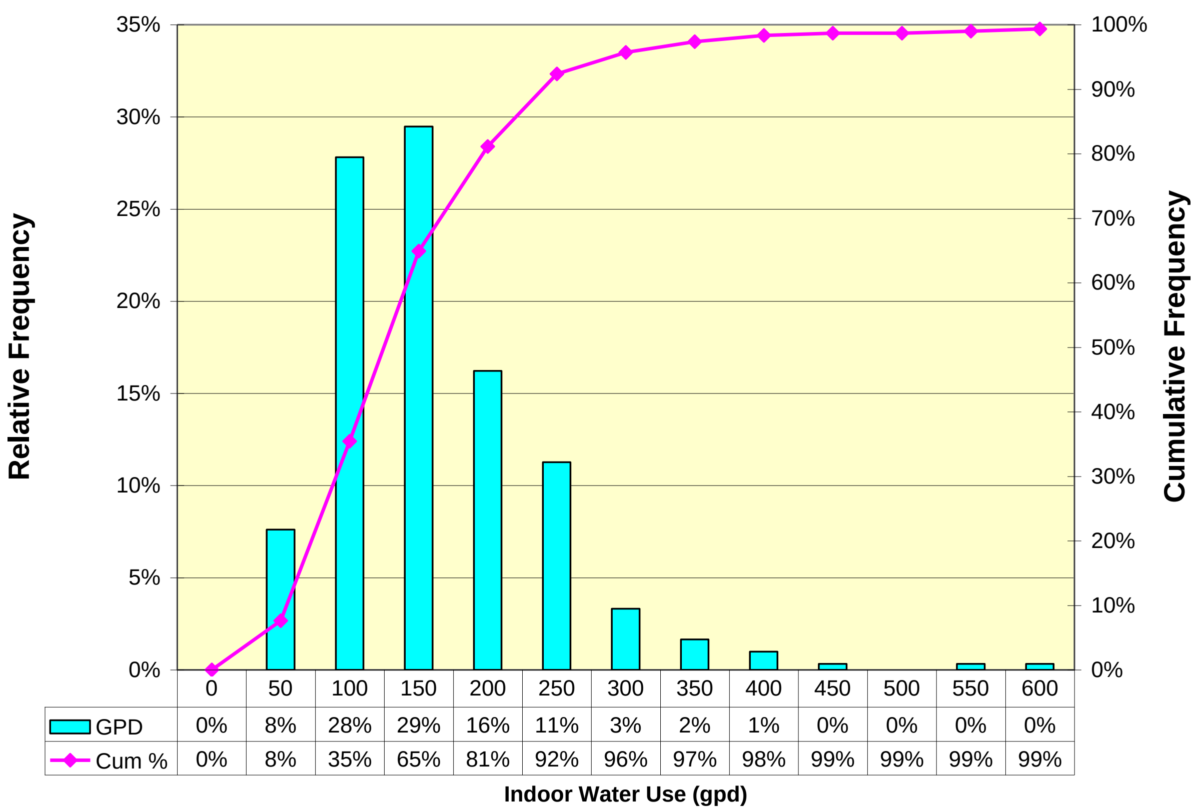


Figure 4-3: Frequency distribution of indoor household use among standard post-2001 homes

Disaggregated Household Indoor Use

A pie chart showing the relative contribution of each indoor end use category measured from the standard (pre-2001) new homes is presented in Figure 4-4. In this study group, clothes washer use was the single largest indoor end use accounting for 22 percent of indoor demand. Showers were the next largest at 21 percent of indoor use. Toilet flushing, normally the largest category dropped to third place at 20 percent and faucet use at 18 percent. Leaks accounted for 14 percent of indoor use.

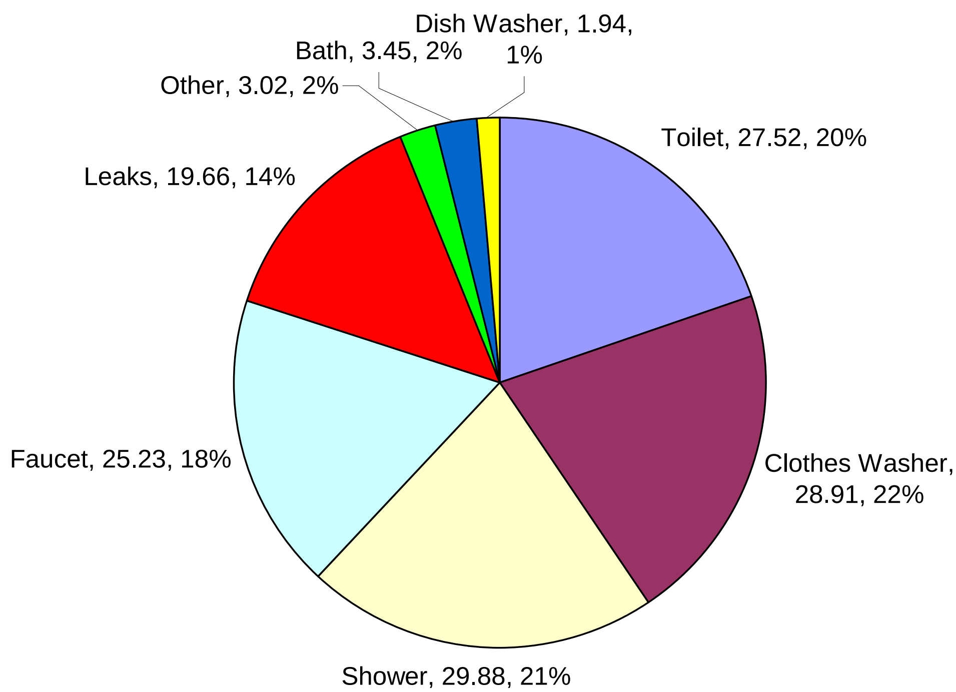
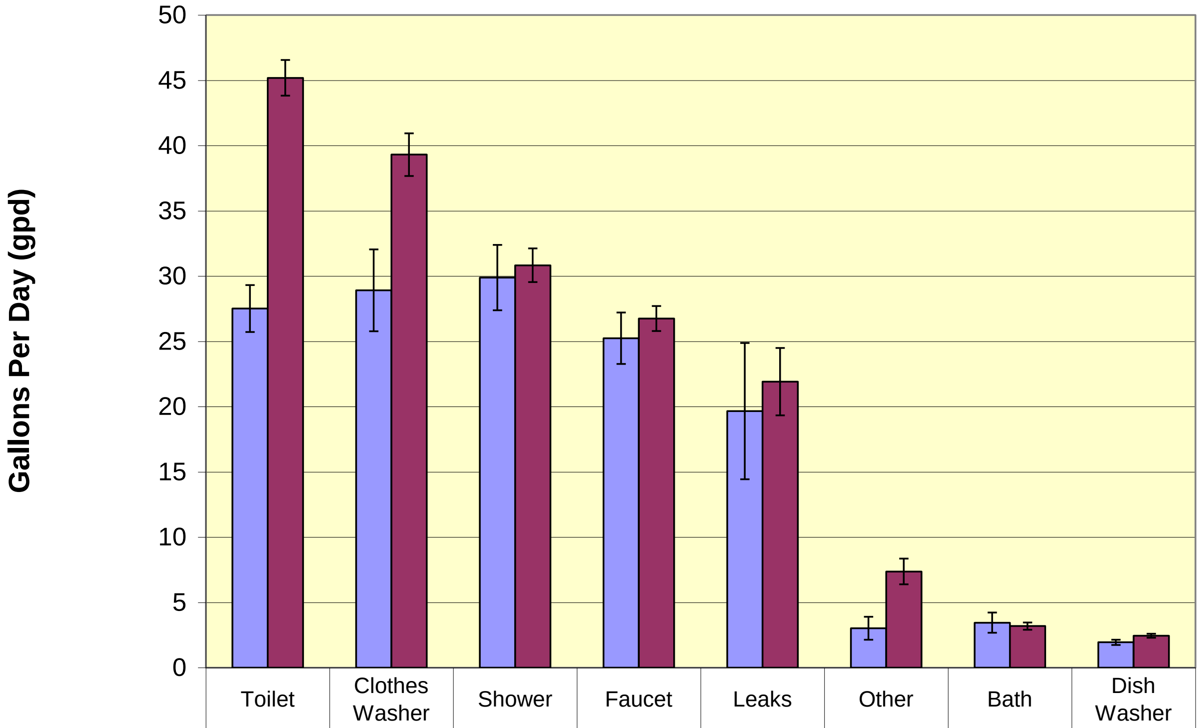


Figure 4-4: Indoor per household use percent – standard (post-2001) new home study group[40]

Figure 4-5 shows the breakdown of indoor water use into its components in comparison to the REUWS group. This figure shows both the average daily use and the 95% confidence intervals for each category. The data show that the water use in the standard new home study group was significantly lower than that from the REUWS group for toilets and clothes washers, and the same or lower for the remaining categories of indoor use with the exception of baths and other (used to categorize miscellaneous faucet use not identified as any other indoor use). The reduction in toilets and clothes washer is almost certainly related to the increased presence of new equipment in the homes. The leakage rate in these homes was 12.8% of all indoor use, at

[40] File: "Stand New Homes_indoor.xls"

19.7 gpd. While this is a slight decrease over the REUWS group leakage still needs to be addressed further. The amount of leakage nearly negates the gains that have been made in clothes washers and toilets.



	Toilet	Clothes Washer	Shower	Faucet	Leaks	Other	Bath	Dish Washer
Standard Homes	27.52	28.91	29.88	25.23	19.66	3.02	3.45	1.94
REUWS	45.19	39.31	30.83	26.75	21.92	7.37	3.18	2.45

Figure 4-5: Comparison of average daily use for each indoor end use category – standard new home study group and REUWS[41]

Toilets

The toilet data are presented in terms of individual toilet flushes, which show the distribution of flush volumes in all toilets, irrespective of which homes they are in, and average household flush volumes, which shows the average flush volume for all the toilets in each home. The former is better for determining the mixture of individual toilets in the population, and the latter is useful for assessing household water use patterns and efficiencies.

There were a total of 46,717 separate toilet flushes recorded from the standard (post-2001) homes during the 3,645 logged days in this study. An average of 12.9 flushes per household per day was measured and the average volume was 2.13 gallons per flush (gpf). By comparison, in the REUWS, an average of 12.4 flushes per household per day was measured and the average volume was 3.48 gpf.

Summary statistics for individual toilet flushes measured from the standard new homes are shown in Table 4-20. There were 46,717 individual flushes recorded during the logging period.

[41] ibid

The average flush volume, calculated by dividing the total volume used for toilet flushing at each home by the number of flush events recorded was 2.13 gallons. On average, each home recorded 12.9 flushes per day. A histogram of the distribution of the individual toilet flushes is shown in Figure 4-6.

The data in Figure 4-6 can be used to estimate the penetration rates in the study group of ULF or better toilets if one assumes that all of the toilets are flushed with approximately the same frequency. Because it is not uncommon for any toilet to be poorly adjusted and consequently flush at a higher volume than the design, the volume that divides ULF or better flushes from "standard" flushes is a matter of judgment. In this sample of 302 new homes 65.8% of the toilet flushes were at or below the 2.2 gpf and 89% of the flushes measured in this study were less than 3.0 gallons per flush. It is likely that all of these flushes are associated with ULF or better devices, but the exact reason why 11% of flushes are greater than 3.0 gpf is uncertain. These results indicate that a significant number of toilets in these new homes are flushing at more than the anticipated flush volumes, and even allowing for a margin of error there may be some toilets in the group that are not ULF models.

Table 4-20: Toilet flush volume statistics from standard (post-2001) new homes

Parameter	Value
Total number of flushes in standard new home study group	46,717
Average flushes per household per day (flushes)	12.9
Average toilet flush volume (gal)	2.13
Median flush volume (gal)	2.01
% of flushes < 2.2 gal	65.8%
% of flushes < 3.0 gal	89%

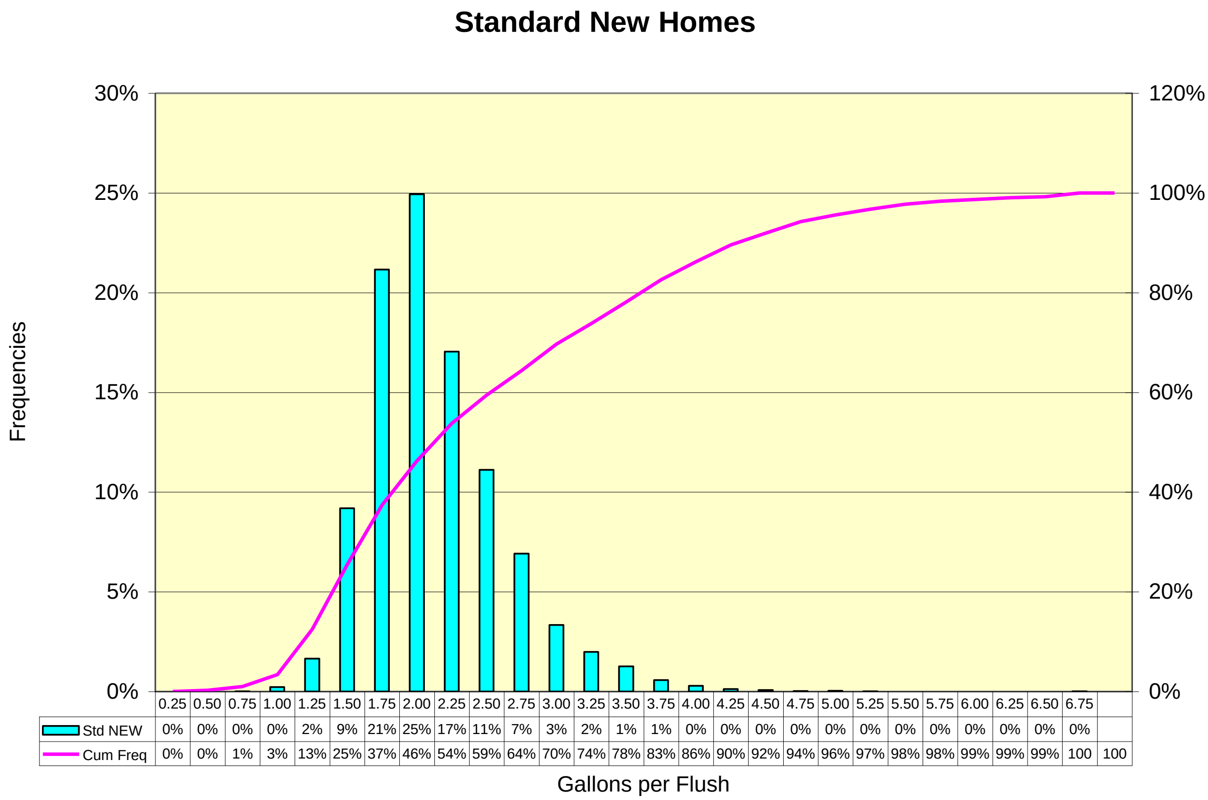


Figure 4-6: Histogram of individual toilet flushes in standard new homes[42]

Figure 4-7 shows the distribution of average household flush volumes in the standard new homes. Since these data are based on averages in each home they show less variability that do the individual flush data. The most common average flush volume is between 1.8 and 2.0 gpf. Aside from the tail on the right hand side the data appear nearly normal in their distribution. This shows a high degree of uniformity in the flush volumes of the toilets in the group. Again, this is as one would expect.

[42] File: "histToiletVclume.xls"

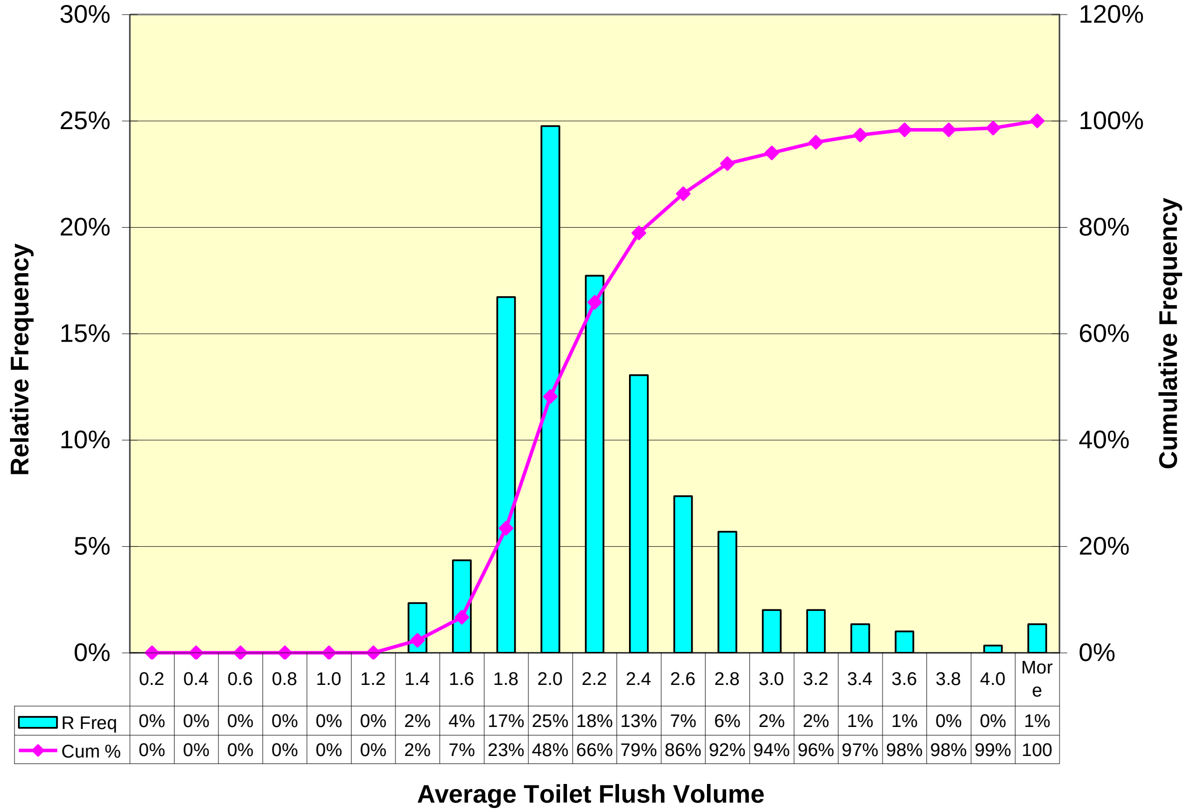


Figure 4-7: Histogram of average household flush volumes in standard new homes[43]

To further examine the degree of toilet flush heterogeneity, the percent of flushes in each home that was less than 2.2 gallons was determined. This analysis is an attempt to measure the percent of flushes in each home attributable to properly performing ULF or better toilets. If all homes had properly functioning ULF or better toilets - a perfectly compliant system - all of the homes would have 100% of their flushes less than 2.2 gpf. The toilet heterogeneity results shown in Figure 4-8 indicate that 16% of the study homes had all measured toilet flushes less than 2.2 gallons, and 41% had 85% or more of their flushes in this range. In 7% of the study homes, fewer than 5% of the toilet flushes used 2.2 gallons or less and in 21% of the study homes less than 30% of the toilet flushes used less than 2.2 gallons. This indicates that in this group of homes, 70% of the flushes were greater than 2.2 gallons. These results suggest that while the majority of homes appear to be equipped with ULF or better designs there are still unresolved issues with toilet flush volumes relating to both the higher than expected volumes and the possibility that some new homes may not be equipped with NEPA compliant toilets at all.

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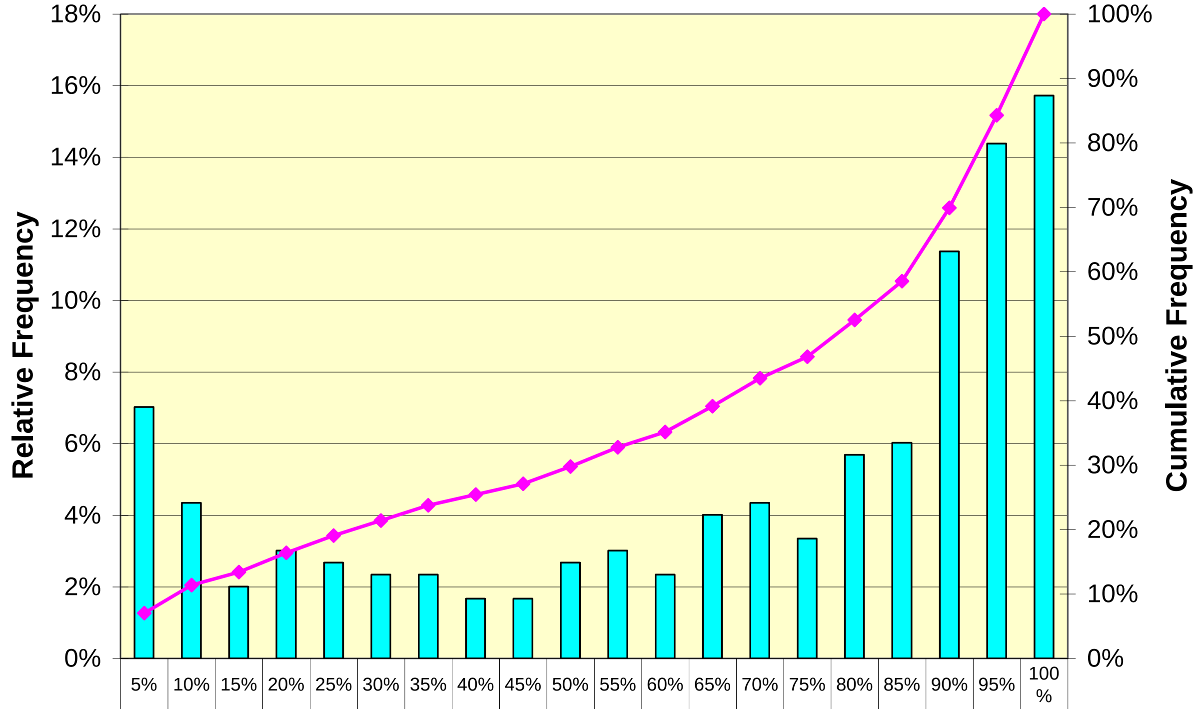
[43] File: "Stand New Homes_indoor.xls"



	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100 %
% Houses	7%	4%	2%	3%	3%	2%	2%	2%	2%	3%	3%	2%	4%	4%	3%	6%	6%	11%	14%	16%
Cum %	7%	11%	13%	16%	19%	21%	24%	25%	27%	30%	33%	35%	39%	43%	47%	53%	59%	70%	84%	100

Percent of flushes < 2.2 gal

Figure 4-8: Toilet heterogeneity chart – standard (post-2001) new home study group[44]

Clothes Washers

During the logging period a total of 3,189 full clothes washer loads were recorded from 293 homes. Nine study homes did not operate their clothes washer during the data collection period and consequently were excluded from the clothes washer analysis.

Table 4-21 shows the summary statistics for clothes washers, and Figure 4-9 is a histogram of the average gallons per load in the standard (post-2001) study homes. These study homes averaged 0.9 loads of laundry per household per day. The average volume per load of laundry was 33.5 gallons per load (gpl) and the median was 35.6 gpl. In the REUWS, the average clothes washer load volume was 40.9 gpl. When compared to the current Tier 3 standard for clothes washers of 15.0 gpl from the Consortium for Energy Efficiency[45], the clothes washers in the standard new home sample used more than twice as much on average. However, the volumetric use of clothes washers in the standard new homes still represents an 18% improvement in efficiency over the clothes washers measured in the REUWS. A total of 39% of the homes had clothes washer use of less than 30 gpl, the benchmark being used in this study for high-efficiency machines. Examining the distribution of average household clothes washer volumes shows that there appear to be two distinct groups: one that uses around 20 gpl and one that uses 40. This suggests that there was mixture of clothes washers with varying efficiencies

[44] Ibid

[45] CEE Super Efficient Home Appliances Initiative. High-efficiency specifications for residential clothes washers. January 1, 2007. http://www.cee1.org/resid/seha/rwsh/reswash_specs.pdf

used in the homes. The standard type machines still appear to dominate (given the higher percentages of homes centered on the 40 gpl bin), but there are a substantial number of homes with high-efficiency machines centered on the 20 gpl bin.

Table 4-21: Clothes washer statistics – standard (post-2001) new home study group

Parameter	Value
Total number of clothes washer loads	3,189
Average loads per household per day	0.9
Average gallons per load	33.5
Median gallons per load	35.6
% of houses with < 30 gpl	39%

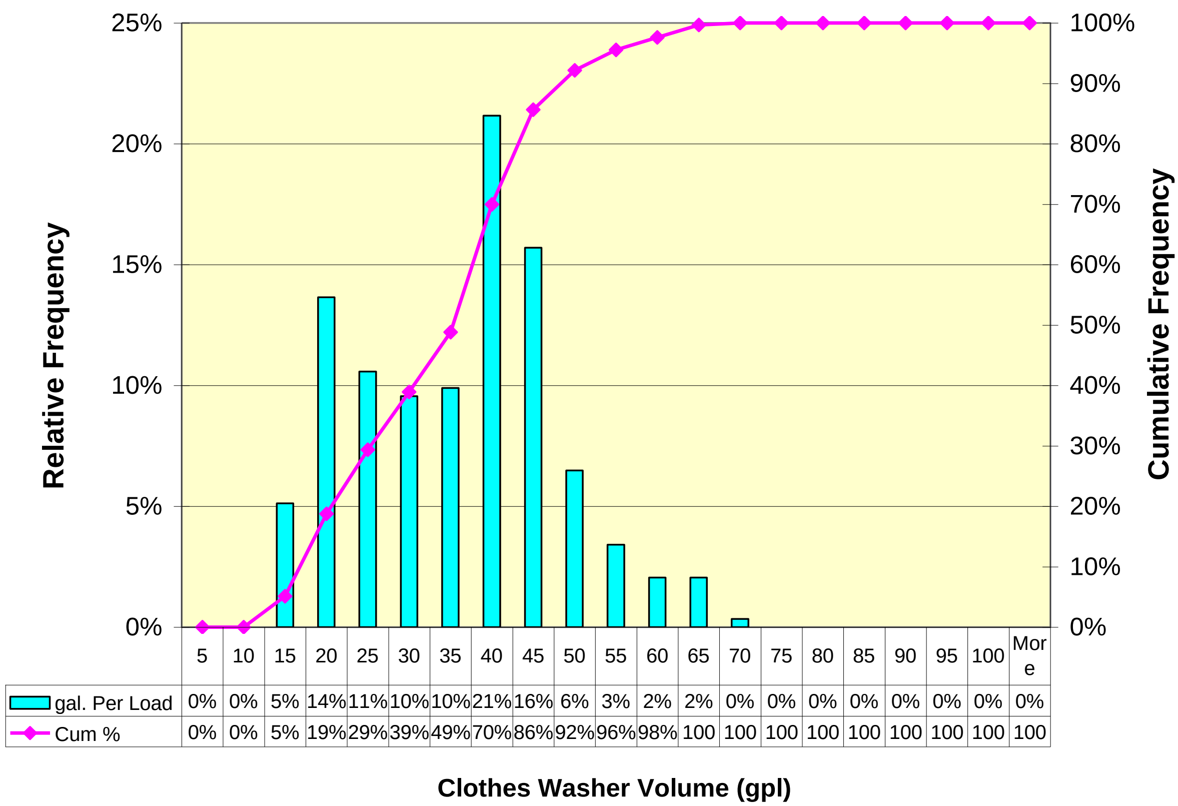


Figure 4-9: Frequency distribution of clothes washer loads – standard (post-2001) study homes[46]

[46] Ibid

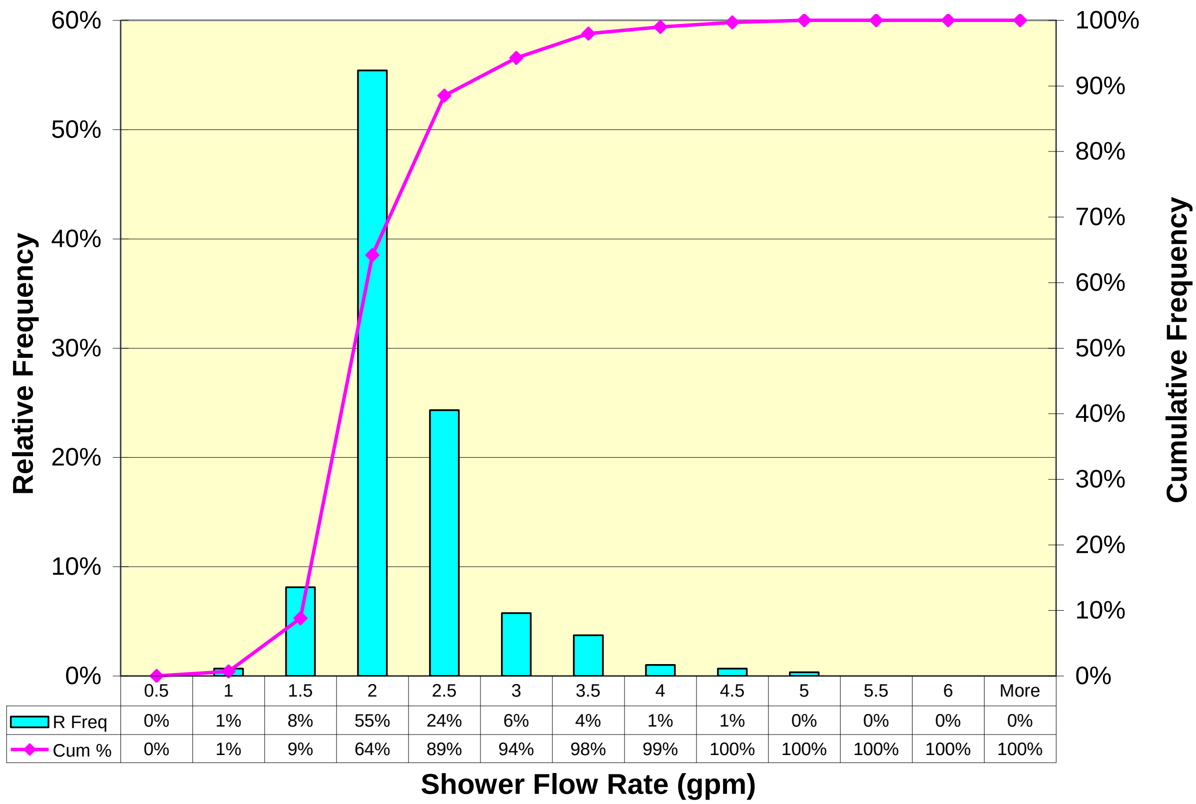
Showers

There were a total of 6,744 showers recorded during the study period in the standard new home study group. On average there were 1.9 showers taken per household per day. The average shower used 15.9 gallons of water, and the average shower flow rate was 2.0 gpm. Average shower use and related statistics for shower use are shown in Table 4-22.

Table 4-22: Shower statistics – standard (post-2001) new home study group

Parameter	Value
Total number of showers recorded	6,744
Average showers per day per household	1.9
Average gallons per shower	15.9
Average shower duration (minutes)	8.2
Average shower flow rate (gpm)	2.0
Median shower flow rate (gpm)	1.9
% of showers < =2.5 gpm	89

Fifty-five percent of the standard new home study group had showers that flowed between 1.5 and 2 gpm and 89% of the showers in group flowed at 2.5 gpm or less. Although it is clear that there are still some homes with showers that have a greater flow than the NEPA standard the reason for the higher flows is unknown. Showerheads are designed to reach their maximum flow at a specific flow rate. It's possible that some of the showers have a higher flow rate due to pressure that exceeds the design pressure of the showerhead. Showers that have multiple showerheads or showerheads that have had the flow restrictor removed may have flow rates in excess of 2.5 gpm. Homeowners may have replaced the showerhead installed when the home was built with an older showerhead that had a higher flow rate.

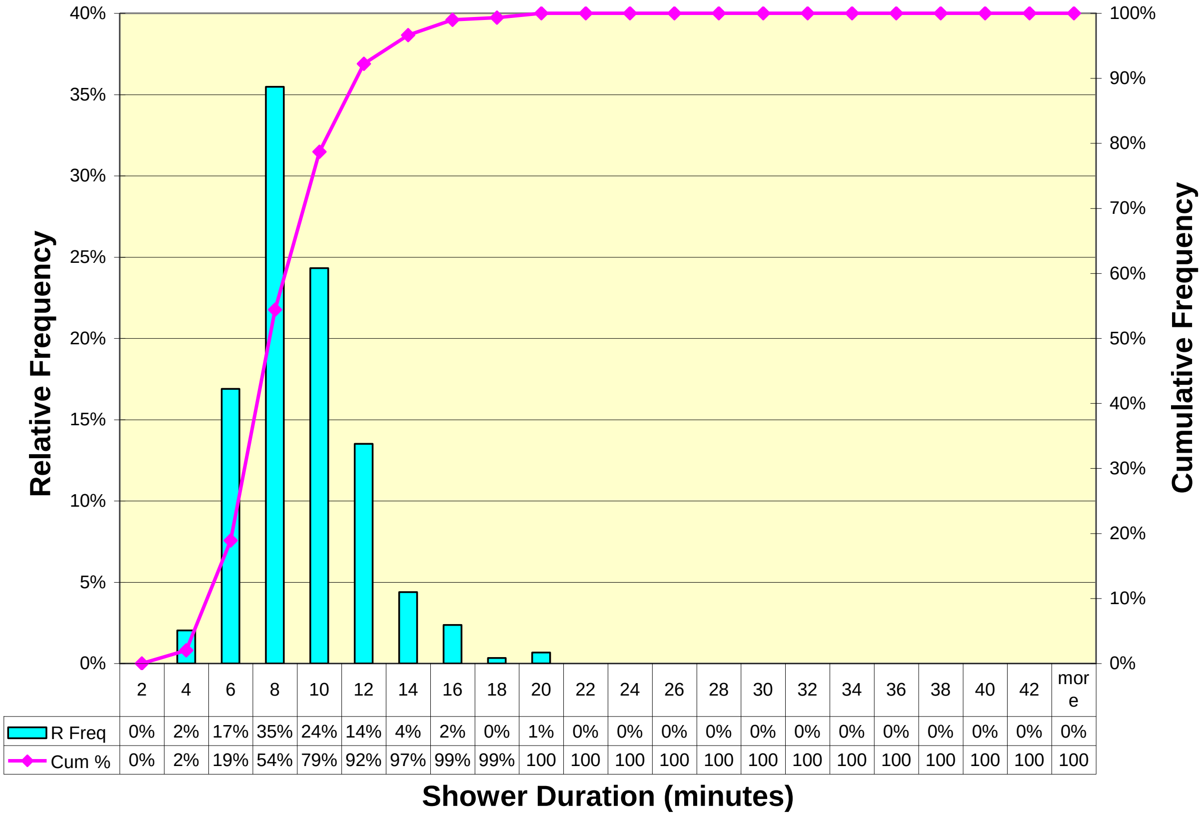


	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	More
R Freq	0%	1%	8%	55%	24%	6%	4%	1%	1%	0%	0%	0%	0%
Cum %	0%	1%	9%	64%	89%	94%	98%	99%	100%	100%	100%	100%	100%

Figure 4-10: Distribution of shower flow rates – standard (post-2001) new home study group [47]

The average shower duration was 8.2 minutes and nearly 80% of the showers were 10 minutes or less in duration as shown in Figure 4-11. Only 1% of the showers lasted longer than 16 minutes and 17% of showers were 6 minutes or shorter in duration.

[47] Ibid



	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	more
R Freq	0%	2%	17%	35%	24%	14%	4%	2%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cum %	0%	2%	19%	54%	79%	92%	97%	99%	99%	100	100	100	100	100	100	100	100	100	100	100	100	100

Figure 4-11: Distribution of shower duration – standard (post-2001) new home study group

The average shower volume is 15.9 gallons which is supported by an average flow rate of 2 gpm and an average duration of 8 minutes. The median shower volume is 13.7 gallons. Nearly 90% of all showers are less than 23 gallons as shown in Figure 4-12.

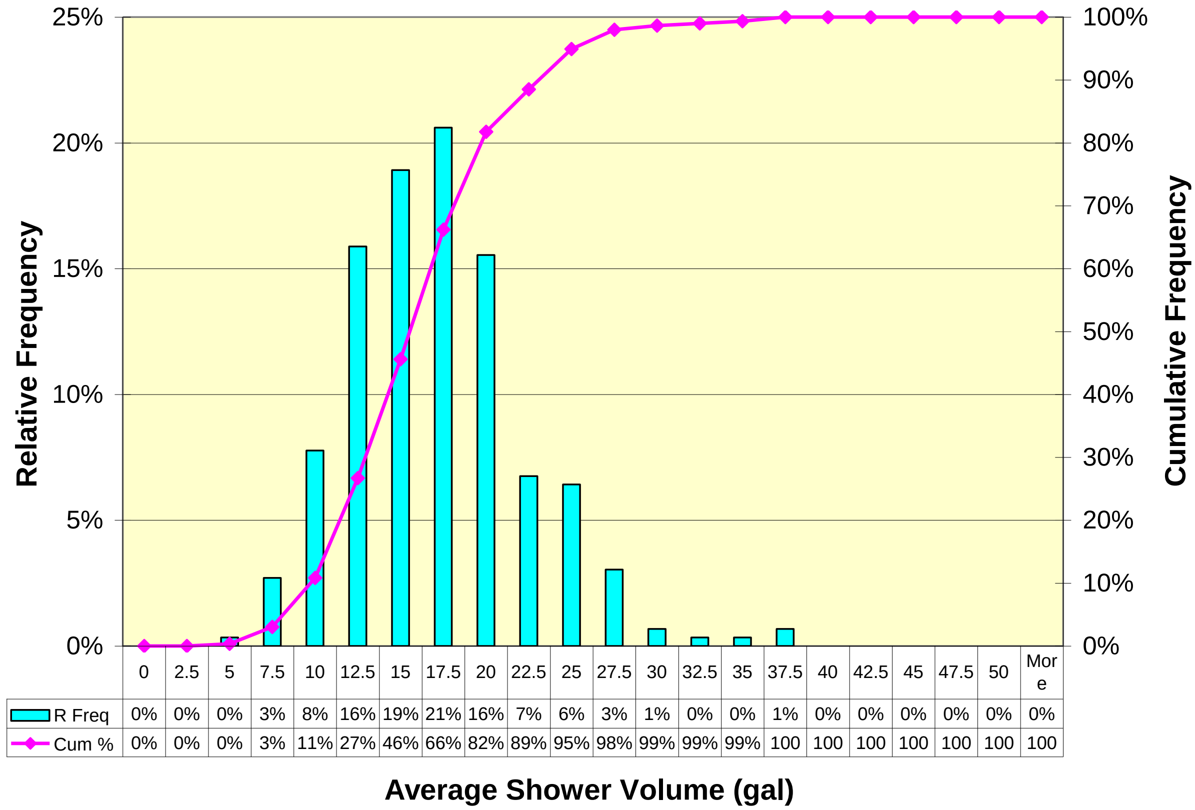


Figure 4-12: Distribution of shower volumes – standard (post-2001) new home study group [48]

Leaks

During the logging period some level of leakage was measured in virtually all of the standard new homes in the study. Summary statistics on leakage are presented in Table 4-23. The average per household leakage rate was 19.7 gpd and the median per household leakage rate was 5.4 gpd. The median rate indicates that 50% of the study homes leaked less than 5.4 gpd and 50% leaked more than 5.4 gpd. In this sample, a few homes with very high leakage rates elevated the mean. It is not possible to identify the location of the leakage through the analytic techniques employed in this study. The most significant leakage rates are often caused by toilets with faulty flapper valves, but other sources of leaks include faucets and bathroom fixtures, irrigation systems, and occasionally the service line which brings water into the home.

[48] Ibid

Table 4-23: Statistics on leakage – standard (post-2001) new home study group

Parameter	Value
Total number of logged days from standard new home sites	3645
Average daily household leakage (gpd)	19.7
Median daily household leakage (gpd)	5.4
% study houses w/ leakage > 50 gpd	9%
% of study houses w/ leakage > 100 gpd	4%

Figure 4-13 shows the frequency distribution of daily leakage which illustrates the small number of households with high leakage rates. More than 65% of the study homes leaked less than 10 gpd. When viewed by the numbers of customers in each leakage bin the high leakage rate groups appear to be of minor significance. When viewed by the percent of the total leak volume each group is responsible for, as is shown in Figure 4-14, it becomes clear that the small number of homes in the large volume bins have a highly disproportionate impact on leakage. For example, the 1% of homes, with leakage greater than 200 gphd, were responsible for 17% of the total leakage volume, and the 35% of houses leaking at more than 10 gpd are responsible for 84% of the leak volume.

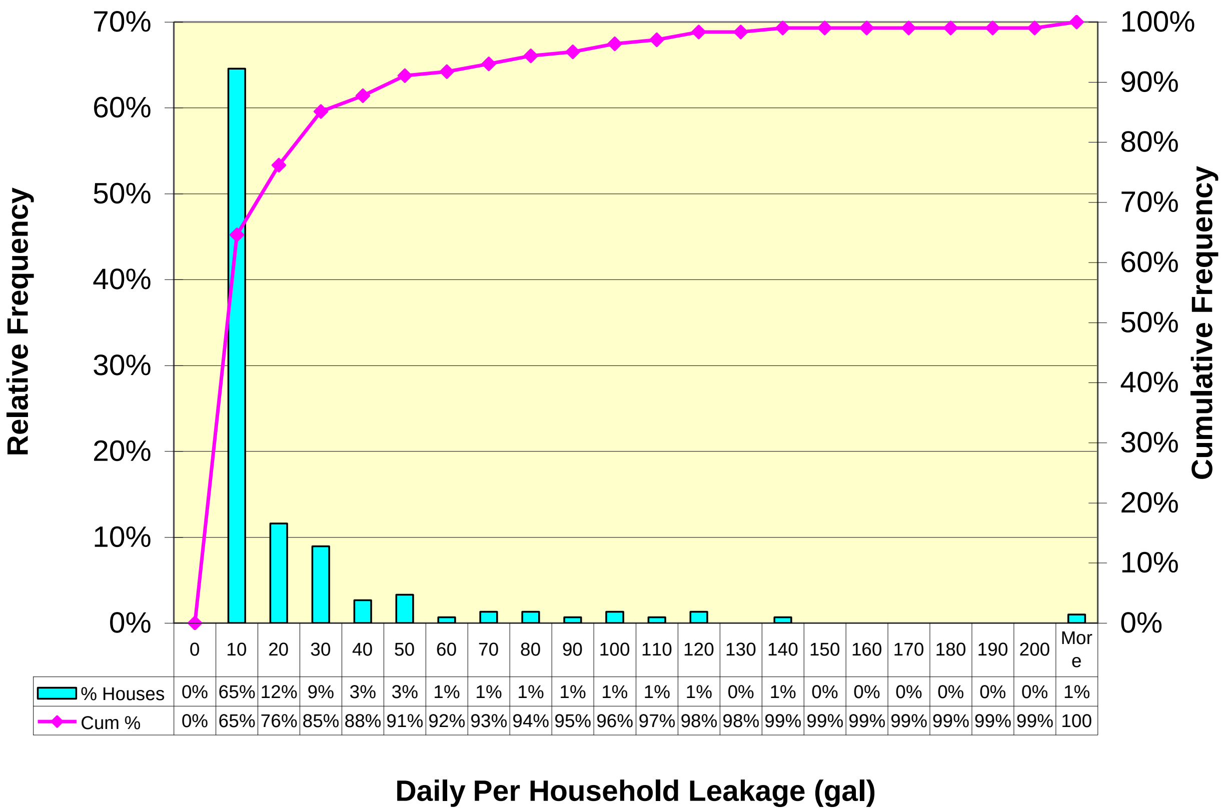
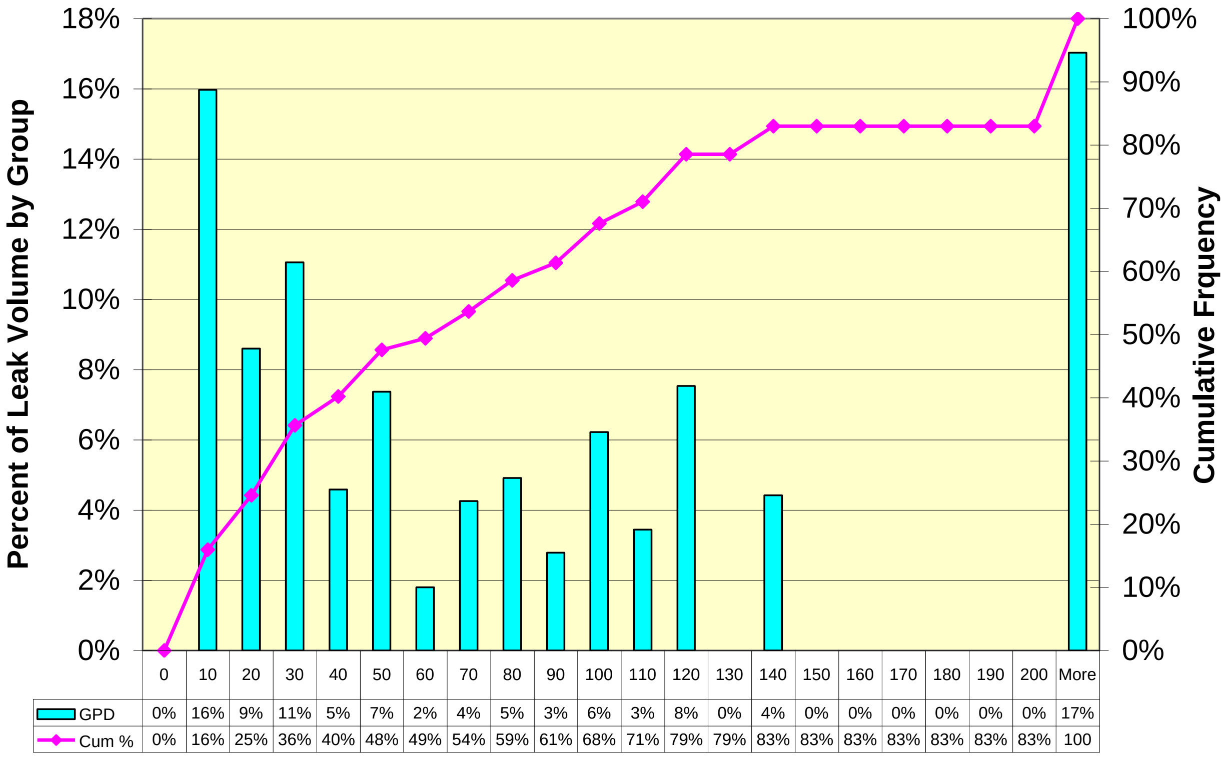


Figure 4-13: Distribution of number of homes by leakage bin



	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	More
GPD	0%	16%	9%	11%	5%	7%	2%	4%	5%	3%	6%	3%	8%	0%	4%	0%	0%	0%	0%	0%	0%	17%
Cum %	0%	16%	25%	36%	40%	48%	49%	54%	59%	61%	68%	71%	79%	79%	83%	83%	83%	83%	83%	83%	83%	100

Figure 4-14: Distribution of total leak volume by leakage bin

Faucets

The miscellaneous faucet use category contains faucet use as well as other relatively low flow events (<4 gpm) that do not fit into another end use category. Examples of water uses that are included in this category: Filling a glass of water, running the sink while brushing teeth, washing dishes by hand, rinsing vegetables, filling a basin to bathe a child, filling a bucket to wash a car, filling a small aquarium or indoor water sculpture. The faucet end use category represents general domestic uses in the home drawn from all of the faucets in the home. Summarized faucet use results for the standard new home study group are presented in Table 4-24.

The average home in the standard new home study group used 25.3 gallons per day for miscellaneous faucet uses, while the median use was 22.8 gpd. Faucets were used for an average of 24.8 minutes per day and the average flow rate for faucet fixtures in this study group was 1.02 gpm.

Figure 4-15 shows the distribution of daily household faucet use in the study homes. Faucet use appears to be a log-normal distribution with about 30% of the site using more than 30 gallons per day on average.

Table 4-24: Faucet statistics – standard (post-2001) new home study group

Parameter	Value
Total number of logged days from standard new home sites	3645
Average daily household faucet use (gpd)	25.3
Median daily household faucet use (gpd)	22.9
Average daily duration of household faucet use (min./day)	24.8
Average flow rate from faucet fixtures (gpm)	1.02

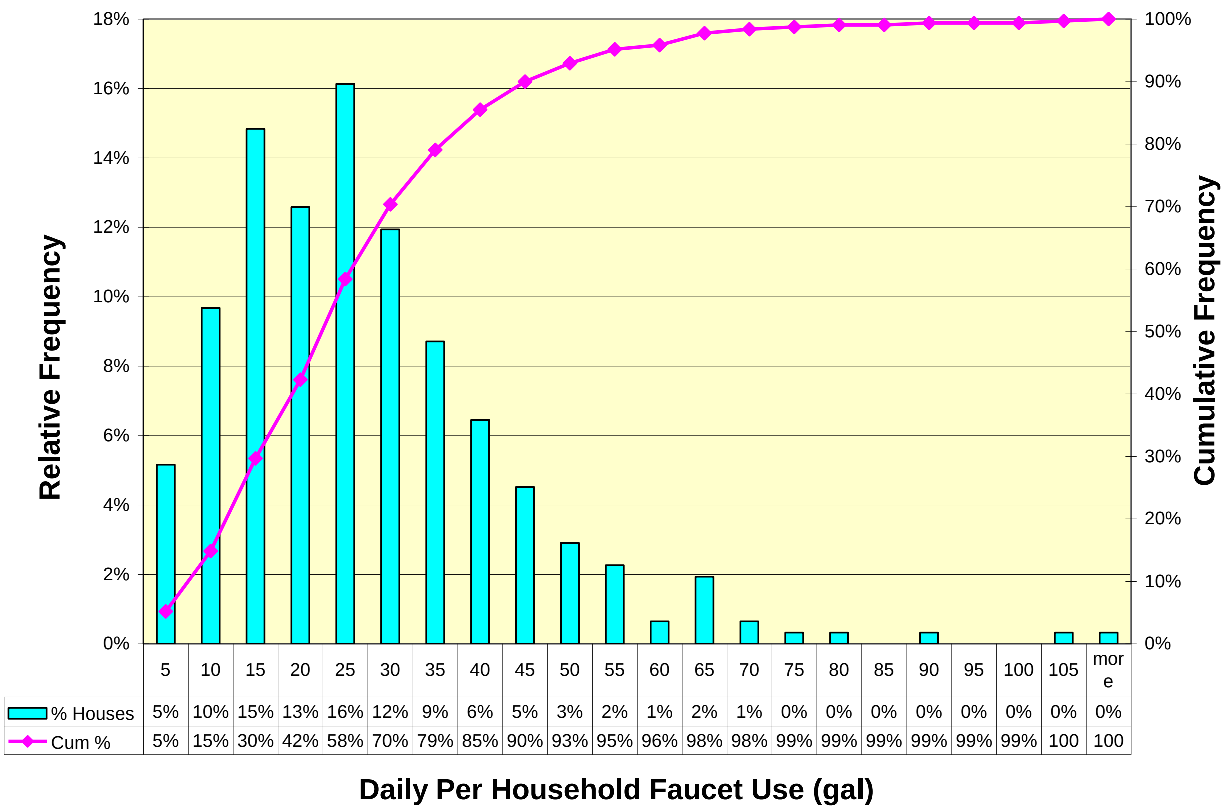


Figure 4-15: Distribution of household faucet use (gpd) in standard (post-2001) new home study group

Efficiency Rates in Standard New Homes

A primary goal of this study was to measure indoor water use in homes that were built since 2001. Since these homes were built well after the current NEPA plumbing codes took effect in 1994 it was hypothesized that they would be fully equipped with low-flow showers and faucets and ULF toilets. This study also afforded the opportunity to examine the penetration rate of high-efficiency clothes washers and to revisit the vexing issue of household leakage to determine if progress has been made since the publication of the *Residential End Uses of Water* study in 1999.

For clothes washers, where the norm is one device per house, the results from this study are true penetration rates. Toilets and showers are a little different. In the case of toilets and showers, where multiple fixtures are found in homes with more than one bathroom, the results from this study represent the overall efficiency rates for all toilets and showers in each home. Overall efficiency can be measured by comparing the water use from the sample homes in this study against the homes in REUWS group and the high-efficiency homes examined in this study.

Data logging provides information on flow rates or volumetric uses of household appliances and fixtures. In addition to data logging the study volunteers, where possible, site visits were performed to verify the installation of fixtures and appliances that met or exceeded the NEPA 1992 efficiency standards. All of the houses had toilets in the traces, but not all had showers or clothes washers, so the percentages for these devices was based on a ratio of the number of homes with high-efficiency showers and clothes washers to the total number of homes having showers and clothes washers present in the trace.

In order to qualify as high-efficiency each home had to meet the criteria for each device shown in
Table 4-25. The results of the analyses for the baseline new home study group are shown in Figure 4-16. This figure shows both the mean penetration rate and the minimum expected rate at a 95 % confidence level.

Table 4-25: Efficiency criteria for penetration rate determination

Device	**Criteria**
Toilets	Ave gallons per flush < 2.0 gpf
Showers	Ave shower flow rate < 2.5 gpm
Clothes Washers	Ave load uses < 30 gal

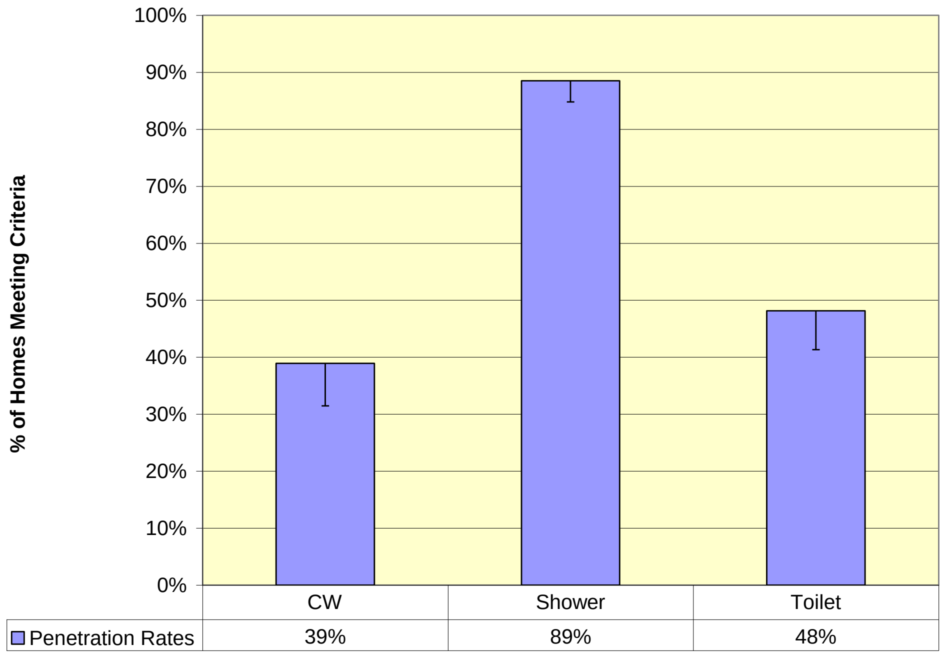


Figure 4-16: Household compliance rates for toilets, showers and clothes washers in the standard new home study group

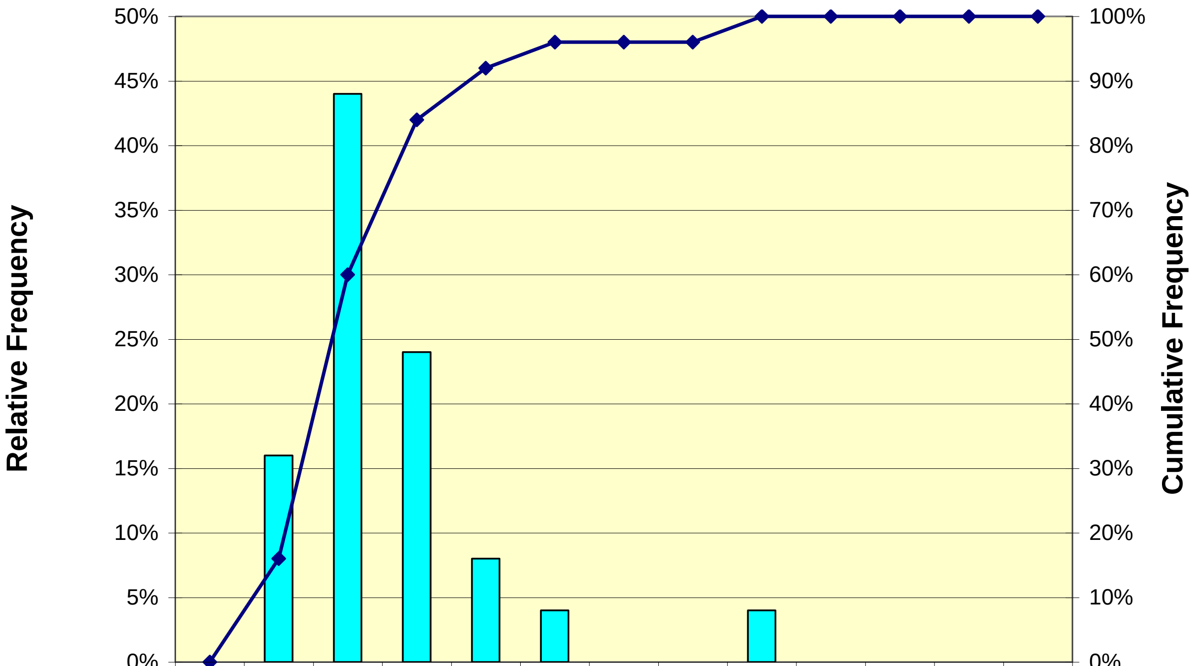
Indoor Use – High-efficiency New Homes

This section presents detailed analyses on the high-efficiency new homes for which data were collected during the study. The results are presented in the same order as was used for the standard new homes in order to facilitate the comparisons.

Table 4-26 shows the indoor water use for the high-efficiency new homes, and compares it to the standard new homes. The average indoor use for these homes was 105 gphd and compares well with the EPA Retrofit homes shown in Table 4-33. Figure 4-17 shows the frequency distribution (histogram) of the total indoor water use for the high-efficiency study homes. Only 16% of the high-efficiency homes used more than 150 gphd.

Table 4-26: Indoor water use statistics for high-efficiency homes

	REUWS Homes	Standard New Homes	High-efficiency New Homes
Sample Size	1188	302	25
Average Indoor Use (gphd)	177 ± 5.5	140 ± 10	105 ±28
Median Indoor Use (gphd)	159	124	90



	0	50	100	150	200	250	300	350	400	450	500	550	600
GPD	0%	16%	44%	24%	8%	4%	0%	0%	4%	0%	0%	0%	0%
Cum %	0%	16%	60%	84%	92%	96%	96%	96%	100%	100%	100%	100%	100%

Indoor Water Use (gpd)

Figure 4-17: Frequency distribution of indoor household use among high-efficiency homes

Disaggregated Household Indoor Use

A pie chart showing the relative contribution of each indoor end use category measured from the high-efficiency new homes is presented in Figure 4-18. Shower use was the single largest indoor end use accounting for 34% of indoor demand. Leaks were the second highest use, at 18%, followed by faucets at 17%. Toilets and clothes washers, normally the top two categories in older homes, were 15% and 11% respectively. Baths dishwashers and “other” uses make up the remaining 9%, which is typical in most homes.

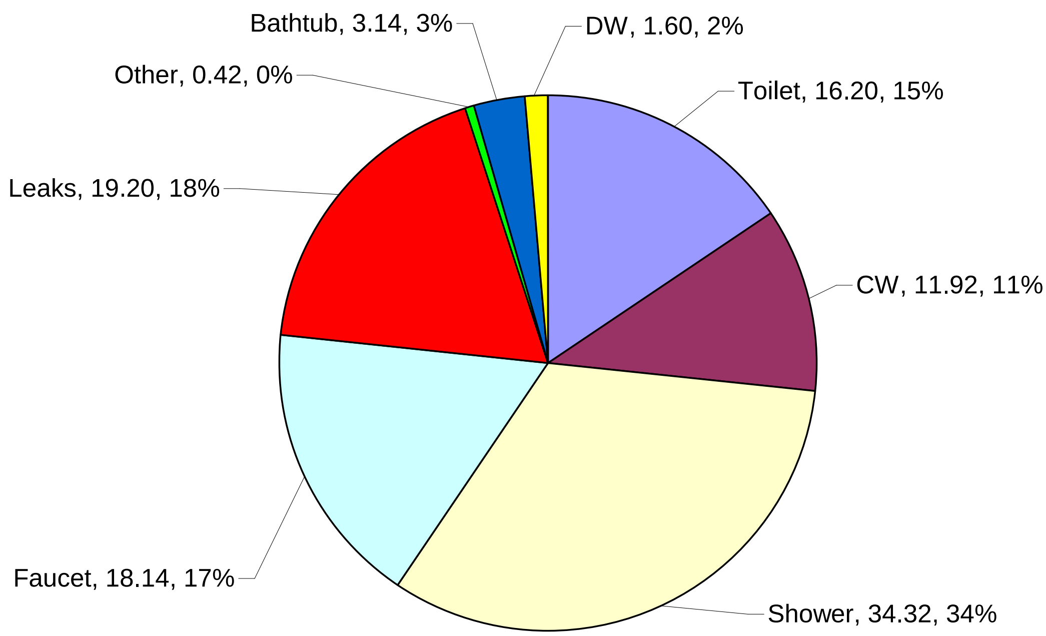


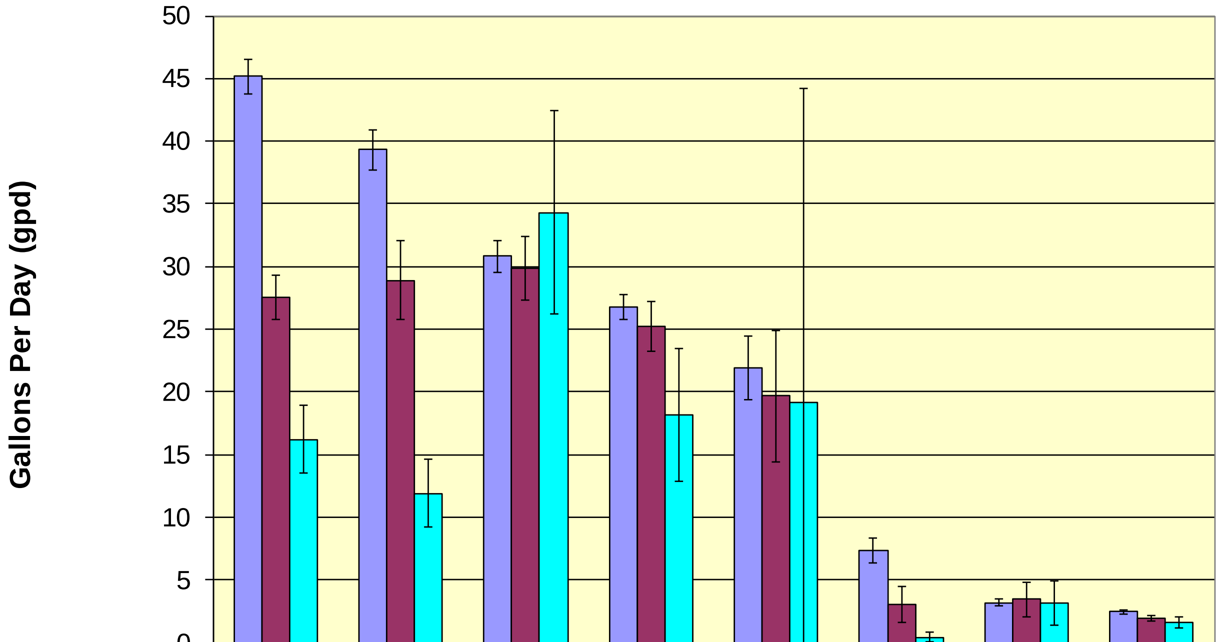
Figure 4-18: Indoor household use percents – high-efficiency homes

Figure 4-19 shows the breakdown of indoor water use for the high-efficiency homes into its components in comparison to both the REUWS group and the standard new homes. This figure shows both the average daily use and the 95% confidence intervals for each category. The data show that the water use in the high-efficiency new homes was lower than that of the REUWS and standard groups for all categories of use except for showering. The reduction in water use for toilet use and clothes washing is quite dramatic. Toilets in the standard new homes use 39% less water than the REUWS homes; the high-efficiency homes achieve an additional 26% decrease in water use. The water use for clothes washing is even more dramatic. The standard new home use 26% less water than home in the REUWS study; the high-efficiency homes achieve an additional 44% savings. This reflects the improvement in and use of new standards and technology. While the standard new homes have a mix of top-loading and front-loading clothes[49] all of the high-efficiency homes have were supplied with Tier 3 clothes washers.

With the exception of showers water use in the other categories is lower as well. Overall, the net reduction in average indoor use between the high-efficiency homes and the REUWS homes was 72 gpd. Of this amount 56 gpd or 78% was due to the reductions in toilets and clothes washers.

[49] The clothes washers in the standard new homes varied in their level of efficiency. Some of the homes had top loading clothes washers and some were front loading The Consortium of Energy Efficiency ranks clothes washers according to a water factor (and energy efficiency). The water factor represents the gallons required to clean 1 cubic foot of laundry. Tier 1 clothes washers have a water factor of 7.5, Tier 2 have a water factor of 6.0 and Tier 3 have a water factor of 4.5.

The average leakage rate was of 18 gpd higher than expected, but this is due to one or two large leaks rather than a general situation. If a way could be found to prevent the large leaks, which raise the average for the group, the water use for the group could have easily dropped below 100 gphd.



	Toilet	Clothes Washer	Shower	Faucet	Leak	Other	Bathtub	Dishwasher
REUWS	45.19	39.31	30.83	26.75	21.92	7.37	3.18	2.45
Standard Homes	27.52	28.91	29.88	25.23	19.66	3.02	3.45	1.94
HE homes	16.20	11.92	34.32	18.14	19.20	0.42	3.14	1.60

Figure 4-19: Comparison of indoor end uses – high-efficiency new home study group and REUWS[50]

Toilets

There were a total of 3641 toilet flushes recorded from the high-efficiency homes during the 318 logged days in this study. An average of 11.5 flushes per household per day was measured and the average volume was 1.43 gallons per flush (gpf). By comparison, in the REUWS there was an average of 12.4 flushes per household per day and an average volume of 3.48 gpf. The standard new homes averaged 12.8 flushes per household per day with an average flush volume of 2.13. The average flush volume for each house in the study was calculated by dividing the total volume used for toilet flushing at each home by the number of flush events recorded. Summary statistics for individual toilet flushes measured from the high-efficiency homes are shown in Table 4-27.

Figure 4-21 is a histogram of the average flush volumes determined for each of the 25 logged homes in the high-efficiency new home study group. The distribution of toilet flush volumes

[50] File: "he_home_indoor_stats.xls"

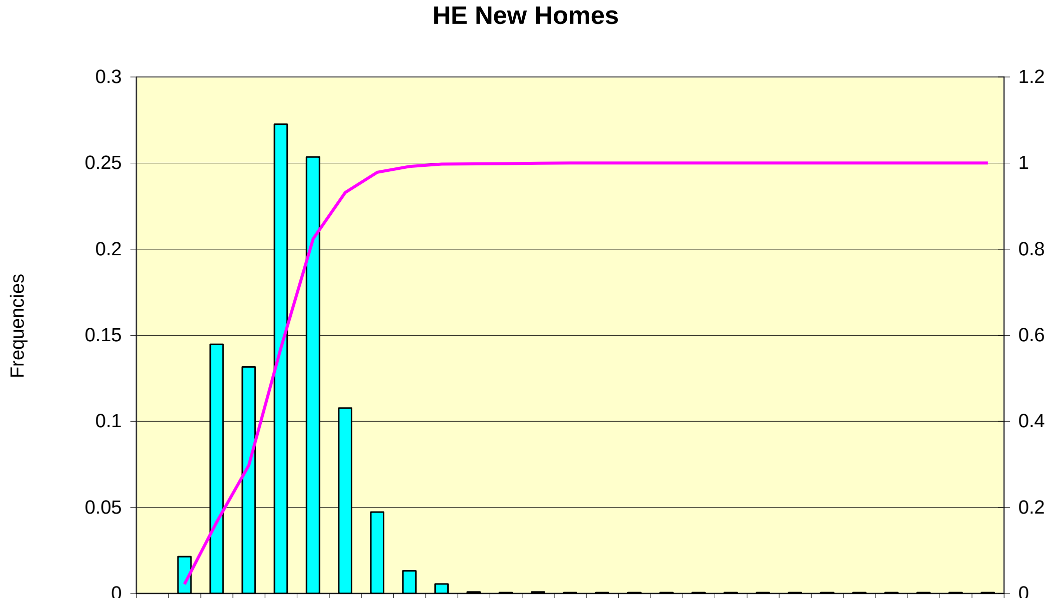
shown in Figure 4-21 approximates a normal (Gaussian) distribution with the mean (1.43 gpf) and median (1.38 gpf) flush volumes closely matched.

Unlike the toilets in the REUWS and standard new homes the saturation rate of high-efficiency toilets (HETs) is assumed to be 100%. There was, however a mixture of HETs. Some of the homes in Eugene were equipped with single-flush 1.0 gpf toilets and some with dual flush models. The dual flush models had full flush volumes of 1.6 and half flush volumes of 0.8. All of the homes in Roseville were equipped with dual flush toilets which had flush volumes of 1.6 for solid waste and 1.1 for liquid waste. Theoretically, the flush volume of the dual flush toilets should average 1.3 gallons or less assuming that there are more low-volume flushes than high volume flushes. However, achieving the lower flush volume average with dual flush toilets is dependent on human behavior. In other words, using a full flush or partial flush is dependent on the user learning how to use the toilet correctly and making a decision at the time of use about which type of flush is needed. This, combined with the fact that the high-efficiency toilets may not be perfectly adjusted could account for an average flush volume greater than 1.3.

Because of these potential influences on average flush volume all flushes less than or equal to 1.6 gpf were classified as HET flushes in this study. In this small sample of 25 high-efficiency homes 80% of the flushes were 1.6 gallons or less and all of the flushes were less than 2.2 gallons as shown in Figure 4-21. These larger flush volumes could be the result of double flushing, poorly adjusted toilets or leakage. It is encouraging however that 80% of the flushes were 1.6 gallons or less.

Table 4-27: Toilet flush volume statistics from high-efficiency home study group

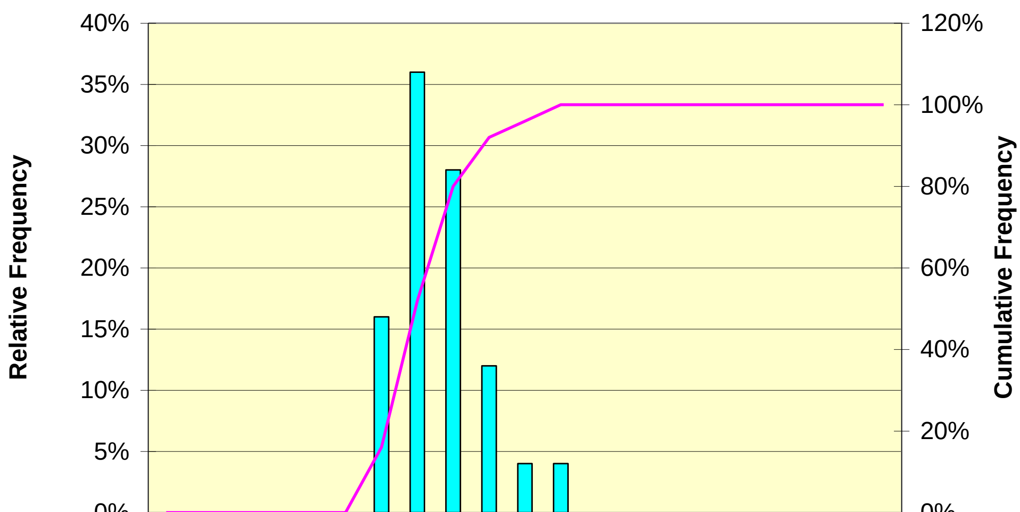
Parameter	**Value**
Total number of flushes in standard new home study group	3,641
Average flushes per household per day (flushes)	11.5
Average toilet flush volume (gal)	1.43
Median flush volume (gal)	1.38
% of flushes < 2.2 gal	95%
% of homes with average flush volume <2.2 gal	100%



	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75
HE New	0	2%	14%	13%	27%	25%	11%	5%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cum Freq		2%	17%	30%	57%	82%	93%	98%	99%	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Gallons per Flush

Figure 4-20: Histogram of individual toilet flushes in HE New Homes



	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	More
R Freq	0%	0%	0%	0%	0%	0%	16	36	28	12	4%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cum %	0%	0%	0%	0%	0%	0%	16	52	80	92	96	100	100	100	100	100	100	100	100	100	100

Figure 4-21: Average Household Toilet flush volume histogram – high-efficiency home study group

To further examine the degree of toilet flush heterogeneity, the percent of flushes in each home that were less than 2.2 gallons was determined. This analysis measures compliance with current plumbing codes. In this analysis, if all homes met current plumbing code - a perfectly compliant system - all of the homes would have 100% of their flushes less than 2.2 gpf. Toilet heterogeneity results are shown in Figure 4-22. These results indicate that 100% of the high-efficiency study homes had all measured toilet flushes less than 2.2 gallons

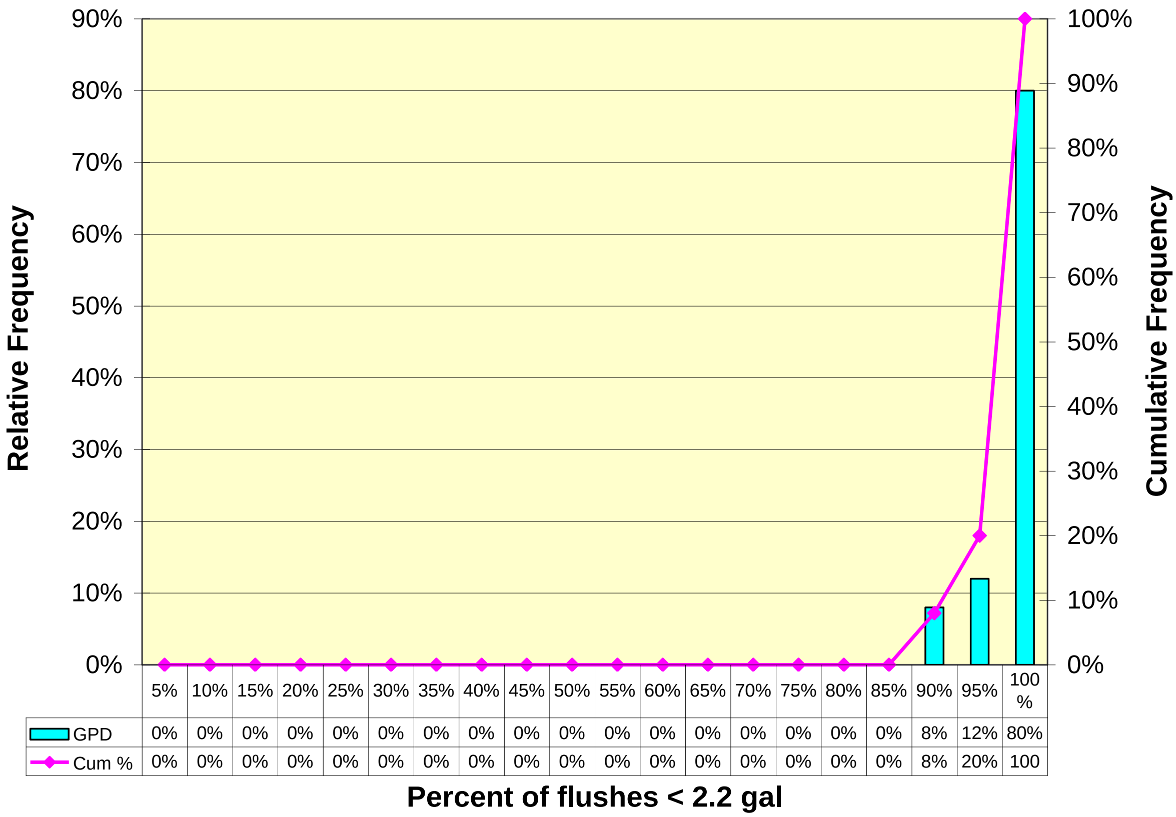


Figure 4-22: Toilet heterogeneity chart – high-efficiency new home study group

Clothes Washers

During the logging period a total of 258 clothes washer loads were recorded from 25 homes. All of the high-efficiency homes operated their clothes washer at some point during the data collection period and were included in the clothes washer analysis.

Table 4-28 shows the summary statistics for clothes washers in the high-efficiency homes, and Figure 4-23 is a histogram of the average gallons per load in the high-efficiency study homes. These study homes ran an average of 0.8 loads of laundry per household per day which is comparable to the standard new homes that averaged 0.9 loads of laundry per household per day. The average volume per load of laundry was 15.1 gpl and the median was 14.8 gpl. This meets the current Tier 3 standard for clothes washers of 15.0 gpl from the Consortium for Energy Efficiency and represents an improvement of 55% over the clothes washers measured in the standard new homes.

Table 4-28: Clothes washer statistics – high-efficiency home study group

Parameter	Value
Total number of clothes washer loads	258
Average loads per household per day	0.8
Average gallons per load	15.1
Median gallons per load	14.8
% of houses with < 30 gpl	100%

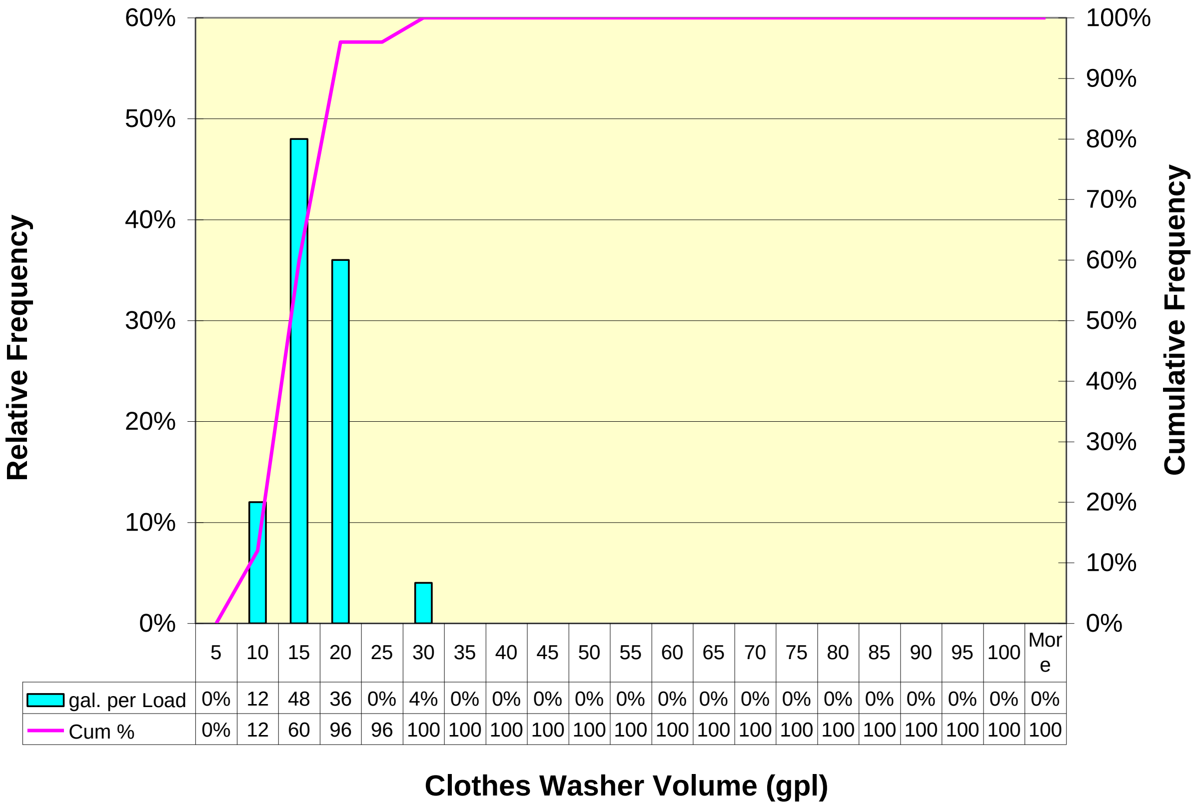


Figure 4-23: Frequency distribution of clothes washer loads – high-efficiency study homes

Showers

There were a total of 688 showers recorded during the study period in the high-efficiency new home study group. On average there were 2.2 showers taken per household per day. Average shower use and related statistics for shower use are shown in Table 4-29.

Table 4-29: Shower statistics – high-efficiency home study group

Parameter	Value
Total number of showers recorded	688
Average showers per day per household	2.2
Average gallons per shower	15.9
Average shower duration (minutes)	9.6
Average shower flow rate (gpm)	1.64
Median shower flow rate (gpm)	1.51
% of showers < =2.5 gpm	100

The average shower used 15.9 gallons of water, and the average shower flow rate was 1.64 gpm. One hundred percent of the homes in the high-efficiency new home study sample used less than 2.5 gpm for showers. Histograms of flow rates and volumes are provided in Figure 4-24 and Figure 4-25.

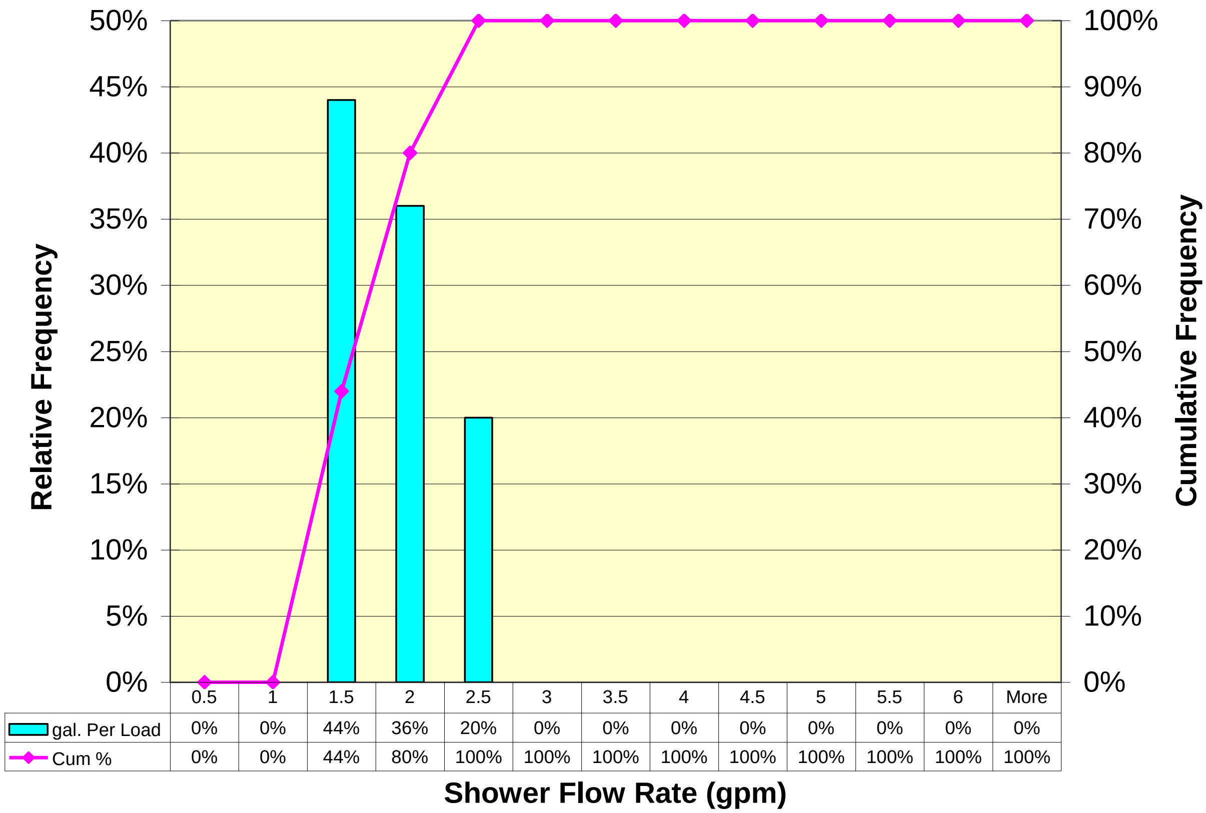


Figure 4-24: Distribution of shower flow rates – high-efficiency home study group

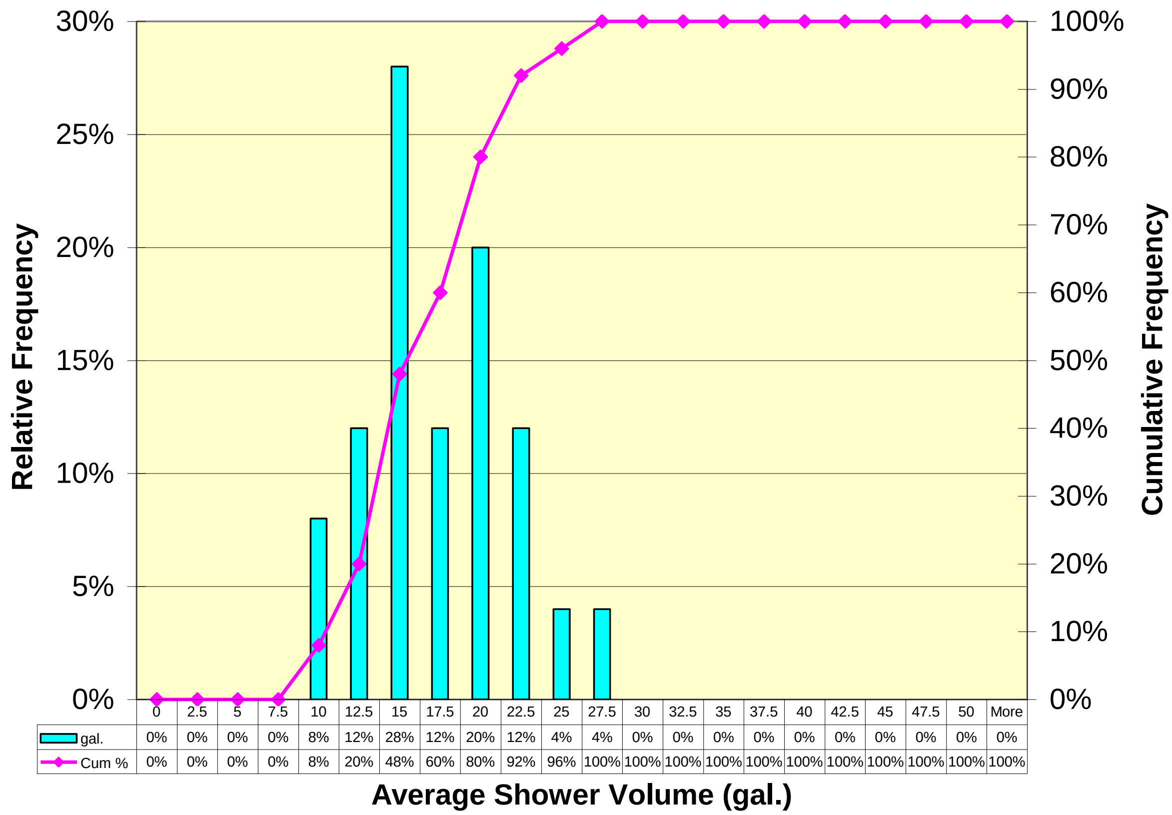


Figure 4-25: Distribution of shower volumes – high-efficiency new home study group

Leaks

During the logging period 84% of the homes had leakage rates of 10 gphd or less. Unfortunately, there were still a few homes with high leakage that skewed the mean. Summary statistics on leakage are presented in Table 4-30. The average per household leakage rate was 19.2 gpd and the median per household leakage rate was 2.8 gpd. The median rate indicates that 50% of the study homes leaked less than 2.8 gpd and 50% leaked more than 2.8 gpd. In this sample, one home with a very high leakage rate elevated the mean. It is not possible to identify the location of the leakage through the analytic techniques employed in this study. The most significant leakage rates are associated with continuous flows lasting for several hours at a time to several days. These can be due to a number of faults such as toilet flappers, broken valves, faulty irrigation systems or leaks in the service lines. The key thing that these high volume leaks have in common is that they are long duration events.

Table 4-30: Statistics on leakage – high-efficiency new home study group

Parameter	Value
Total number of logged days from high-efficiency new home sites	318
Average daily household leakage (gpd)	19.2
Median daily household leakage (gpd)	2.8
% study houses w/ leakage > 50 gpd	8%
% of study houses w/ leakage > 100 gpd	4%

Figure 4-26 shows the frequency distribution of daily leakage which illustrates the small number of households with high leakage rates. When viewed by the numbers of customers in each leakage bin the high leakage rate groups appear to be of minor significance. When viewed by the percent of the total leak volume each group is responsible for, as is shown in Figure 4-27, it becomes clear that the small number of homes in the large volume bins have a highly disproportionate impact on leakage. For example, the 4% of homes with leakage greater than 200 gphd were responsible for 32% of the total leakage volume, and the 16% of houses leaking at more than 10 gpd were responsible for 66% of the leak volume.

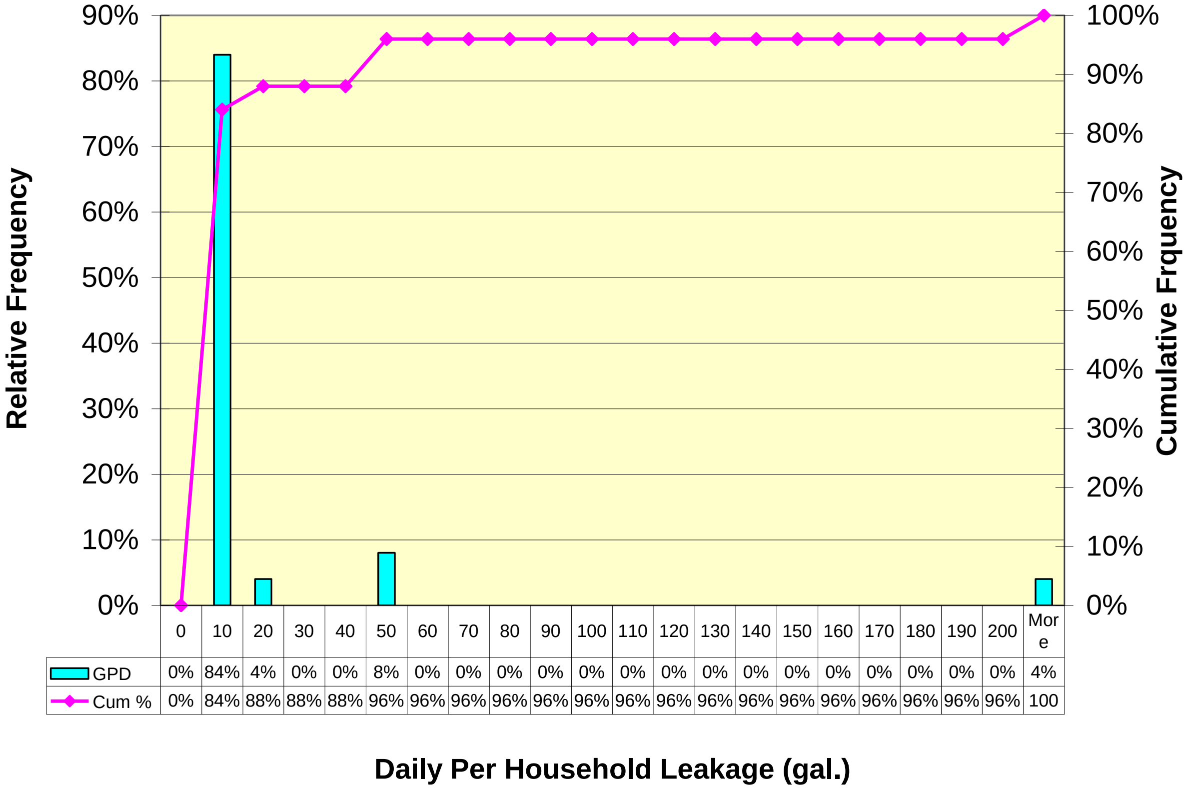


Figure 4-26: Distribution of number of homes by leakage bin

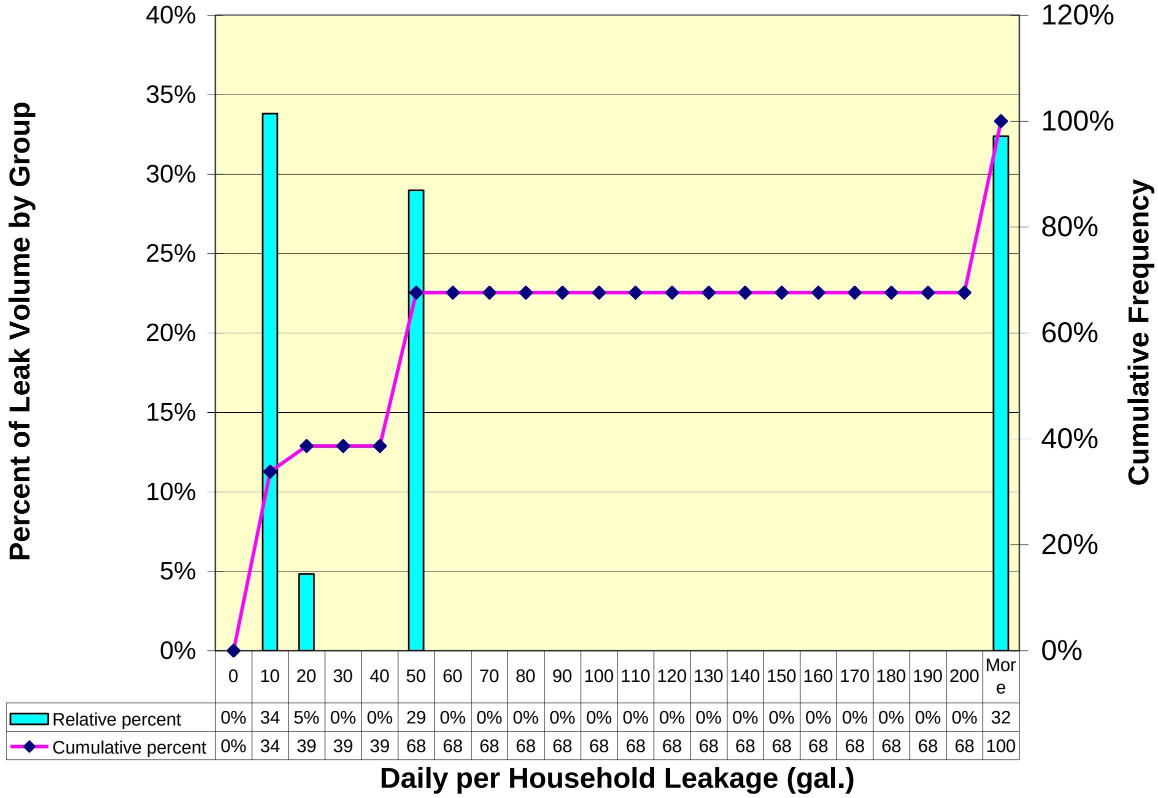


Figure 4-27: Distribution of total leak volume by leakage bin

Faucets

The miscellaneous faucet use category contains faucet use as well as other relatively low flow events (<4 gpm) that do not fit into another end use category. Examples of water uses that are included in this category: filling a glass of water, running the faucet while brushing teeth, washing dishes by hand, rinsing vegetables, filling a basin to bathe a child, filling a bucket to wash a car, or filling a small aquarium or indoor water feature. The faucet end use category represents general domestic uses in the home drawn from all of the faucets in the high-efficiency homes. Summarized faucet use results for the high-efficiency study group are presented in Table 4-31.

The high-efficiency new home study group used 19.4 gallons per day for miscellaneous faucet uses, while the median use was 15.1 gpd. Faucets were used for an average of 19.4 minutes per day and the average flow rate for faucet fixtures in this study group was 0.9 gpm.

Figure 4-28 shows the distribution of daily household faucet use in the high-efficiency study homes. Faucet use appears to be a log-normal distribution with only about 12% of the site using more than 30 gallons per day on average.

Table 4-31: Faucet statistics – high-efficiency new home study group

Parameter	Value
Total number of logged days from standard new home sites	318
Average daily household faucet use (gpd)	18.1
Median daily household faucet use (gpd)	15.1
Average daily duration of household faucet use (min./day)	19.4
Average flow rate from faucet fixtures (gpm)	0.9

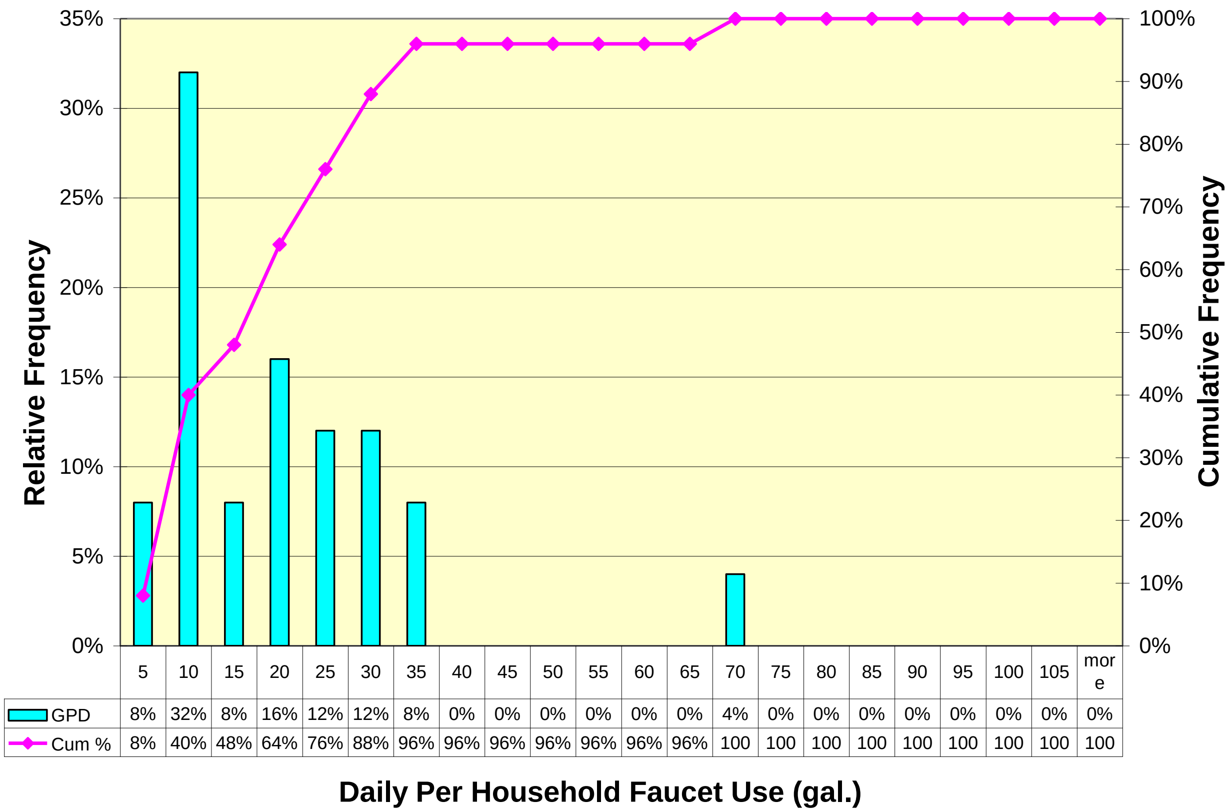


Figure 4-28: Distribution of household faucet use (gpd) in the high-efficiency home study group

Efficiency Rates in High-efficiency Homes

A primary goal of including high-efficiency homes is to measure indoor water use in homes using new technology that is readily available to all homeowners and compare that use with the standard new homes and the REUWS homes. The fixtures and appliances installed in these homes met or exceeded the current EPA WaterSense Partnership Program standards[51]. The builders who participated in this project specified the fixtures and appliances that were installed so it was assumed that the penetration rate of high-efficiency toilets, clothes washers, showerheads and faucet aerators was 100%. Overall efficiency can be measured by comparing

[51] http://www.epa.gov/WaterSense/

the water use from the sample homes in this study against the homes in REUWS group and the high-efficiency homes examined in this study.

In order to make a direct comparison of the penetration rate of high-efficiency devices in the high-efficiency homes with those of the standard new homes the criteria for these devices was not changed. The criteria for each device are shown in Table 4-32.

Table 4-32: Efficiency criteria for penetration rate determination

Device	Criteria
Toilets	Ave gallons per flush < 2.0 gpf
Showers	Ave shower flow rate < 2.5 gpm
Clothes Washers	Ave load uses < 30 gal

Data logging provides information on flow rates or volumetric uses of household appliances and fixtures. In addition to data logging the study volunteers, where possible, site visits were performed to verify the installation of fixtures and appliances that met or exceeded WaterSense, NEPA, and/or Energy Star efficiency standards. All of the houses had toilet, shower and clothes washer events at some time during the data logging period which confirmed the presence of these devices in the home even when site visits were not performed.

The numbers of homes with use of each device was evident from the flow traces and the percentages of homes which met the high-efficiency criteria are shown Figure 4-29. The data from the high-efficiency study group indicate that approximately 96% of the houses[52] meet the criteria for ULF toilets, while 100% meet high-efficiency criteria for clothes washers, and 100% meet the shower criteria.

[52] Because the sample is so small 96% of the homes means that 24 out of 25 homes met the criteria for ULF toilets, i.e. 24 of the homes had flush volumes that were less than 2.0 gpf.

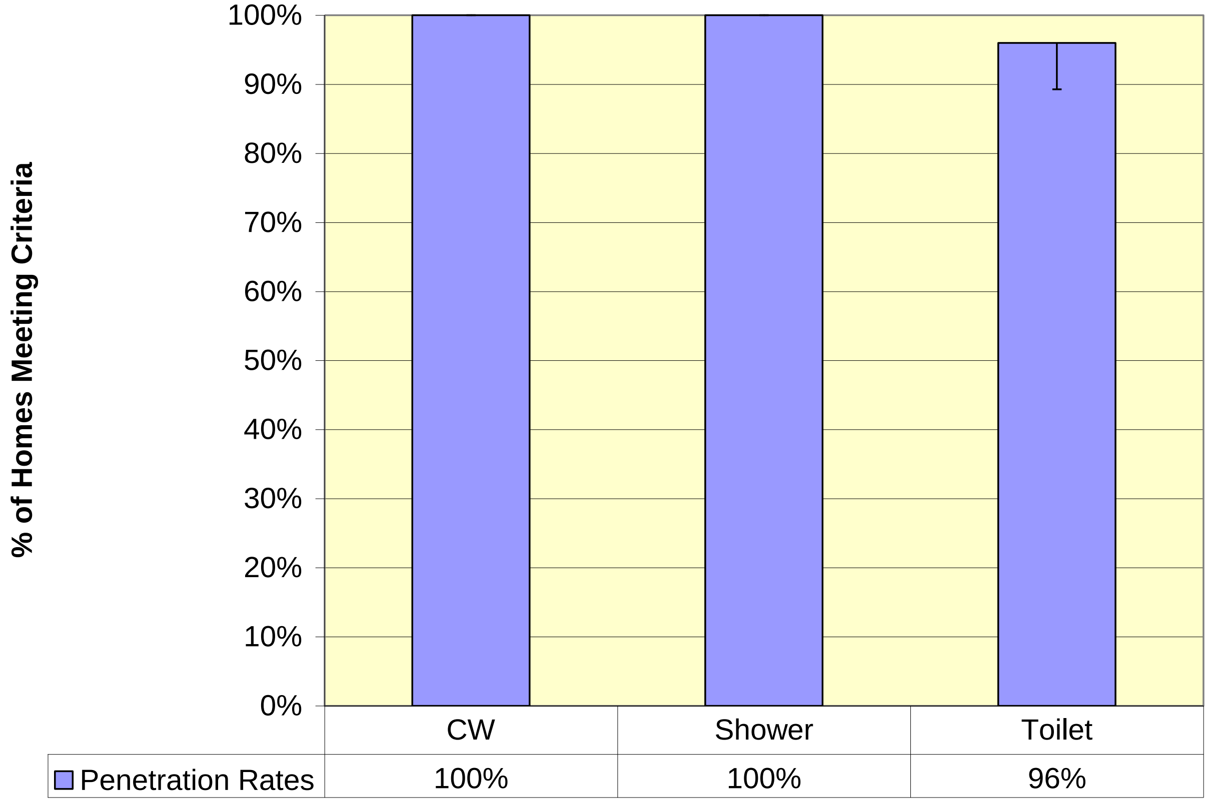


Figure 4-29: Household compliance rates for toilets, showers and clothes washers in the high-efficiency new home study group

Per Capita Indoor Use Relationships

Table 4-33 compares the indoor water use on a per capita basis in the 25 high-efficiency homes to the results from the REUWS[53] and the EPA[54] retrofit study and the 309 homes in the standard new home group. These data show that indoor water use among high-efficiency homes is lower than the homes from all of the other study groups including the consumption levels measured in the EPA retrofit study group. The third row of the table shows the relationship between indoor water use and the number of persons in the home. In all cases this is a non-linear equation of the form $Y=CX^e$, where Y = average daily household water use (gphd), C = a constant, X = the number of residents in the home and e = an exponential coefficient. The fact that C is always less than 1.0 shows that as additional residents are added to the home the water use increases at a decreasing rate. The implication of this is that doing nothing but increasing the number of residents in the home will tend to decrease the per capita water use.

[53] Mayer, Peter et al.. Residential End Uses of Water Study. AWWA Rese

arch Foundation. 1998.
[54] DeOreo, William, et.al. Residential Retrofit Study. EPA. 2003.

The per capita use relationship can be used to correct for differences in the number of residents per home by expressing household water use for a consistent number of residents. If this is done for a family of 3 and the resulting household water use is divided by 3 then the per capita use for each group for a family of three can be determined. The last row of the table shows that when indoor use is corrected for the number of residents the High-efficiency new homes achieve the best per capita performance, of 35.6 gpcd.

Table 4-33: Indoor water use comparisons between four study groups

Parameter	REUWS (gphd)	Standard (post-2001) study group	EPA post-retrofit group	High-efficiency new homes
N	1188	302	96	25
Mean ± 95% C.I. (gphd)	177 ± 5.5	140 ± 10.0	107 ± 10.3	105 ± 28
Median (gphd)	160	125	100	90
Percapita relationship (gphd=)	$87.41x^{0.69}$	$66.30x^{0.63}$	$50.21x^{0.77}$	$59.58x^{0.53}$
Household use for family of 3 (gphd)	187	132	117	107
Projected Percapita use for family of 3 persons (gpcd)	62.18	44.15	39.0	35.6

On of the complicating factors in the household analysis performed with all of the data sets discussed in this report is that the relationship between indoor water use and the number of residents in non-linear. As additional residents are added to the homes the water use does not increase proportionally. This is important when creating demand projections based on populations. Using average per capita use values as scalar values will over-estimate household demands for larger households and under-estimate them for smaller households. This situation is shown below in comparisons of household use versus residents.

Figure 4-30 is a graph of total indoor water use versus the number of residents in the home for each of the four study groups. Each group follows the same trend where indoor water use per capita decreases as the number of household residents increases. This is due to economies of scale where the average per person indoor use decreases as the number of people in the home increases. The effect becomes more pronounced as the efficiency of the fixtures and appliances in the homes increases as shown by comparing the four curves in Figure 4-30. It is interesting to note that the average daily indoor use is higher in the high-efficiency homes when there is only one person in the home but is identical to that of the EPA retrofit study when there are two residents in the home. As the number of people in the high-efficiency homes increase the average indoor water use per person decreases more rapidly than in any of the other study groups. This probably relates to the fact that in these high-efficiency homes the devices that people most directly use (toilets, showers, faucets and clothes washer) contribute less water demand compared to the baseline water used to operate the house, so the impact of additional people is lessened.

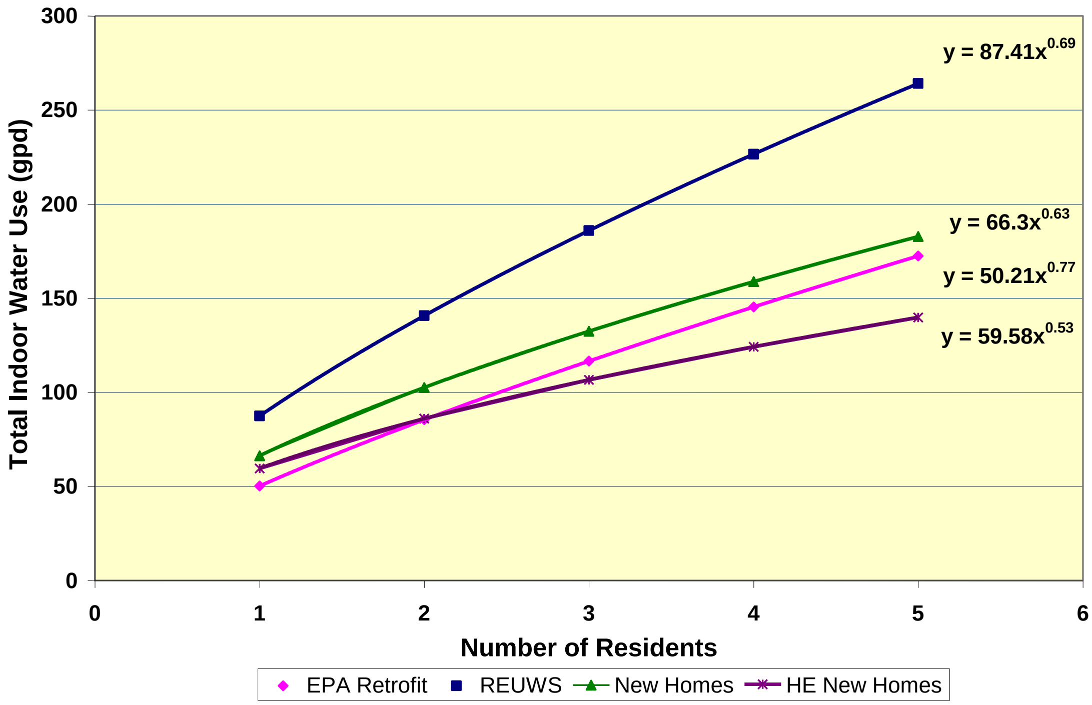


Figure 4-30: Comparison of indoor use versus residents

Outdoor Use – Standard New Homes

Outdoor water use and landscape analyses were performed on the 235 study homes for which rectified aerial photographs and billing data were available. All of the homes included in the outdoor water use and landscape analyses came from the standard new home study group. Although it was hoped that a comparison of outdoor water use could be made between the standard homes and the high-efficiency homes many of the high-efficiency home were only partially landscaped or had no landscaping during the data logging period of the study. The high-efficiency new homes that did have landscape had been landscaped recently and had their irrigation controller adjusted to "establishment mode." Irrigation application during "establishment mode" is presumably higher than for a mature, well-established landscape. Further, many of the homes had been occupied for less than a year which meant that it was not possible to determine seasonal use from billing data.

The volume of outdoor water use for each analyzed home was estimated by subtracting the best estimate of annual indoor use from the total annual billed consumption. The indoor use estimate was based on the projected indoor use determined from the flow trace analysis (indoor gphd x 365), or, in cases where the logged indoor use gave unrealistic results, it was determined from winter water consumption. A total of 234, or nearly 100%, of the study homes appeared to be irrigating. The analyses that follow are based on the sample for which aerial photos were available, and which are thought to be representative of the irrigators in the group.

The major parameters that were used as inputs for the landscape analysis are:

- Annual outdoor water use (kgal)
- Irrigated area of lot (sf)
- Landscape coefficient (weighted average of crop coefficients for landscape)
- Reasonable irrigation efficiencies for well designed and maintained sprinkler systems
- Net ET_o[55]

Using monthly billing data it was possible to estimate the seasonal and non- seasonal water use data for each customer. Non-seasonal use was calculated as 12 times the average winter consumption. The seasonal use was the annual use minus the non-seasonal use. Figure 4-31 shows the average seasonal use for each of the agencies based on the billing data for the irrigating customer group.

The landscape data consisted of the total area of each landscape type on each lot. The landscape types consisted of turf, non-turf trees and shrubs, xeriscape, vegetable gardens, and non-irrigated native landscape. Swimming pools were measured and included in the outdoor (seasonal) analysis although swimming pools were not considered irrigated area. The landscape table consisted of the areas by plant type for each of the lots listed by keycode. These areas were used along with the ET data and allowances for irrigation efficiencies to estimate the theoretical irrigation requirements for each lot. In this study the term theoretical irrigation requirement is the volume of water in Kgal required to satisfy the irrigation needs of the landscapes observed on each lot.

During site visits the study homes were compared to the aerial image used for the landscape analysis in order to verify that the correct image was used. The landscape was also observed in the field and the types of landscape material present were compared to the landscape types chosen during GIS analysis to catch situations were landscape types were mismatched. Other than taking measurements to check scale no attempt was made to obtain field measurements of the landscapes, as this was not deemed as accurate as the aerial photo analysis.

Outputs from the outdoor analysis were:

- Theoretical irrigation requirement (kgal)
- Actual irrigation application (kgal)
- Excess or deficit irrigation (kgal)

Annual Outdoor Use Volumes

The annual amount of water used for outdoor purposes in homes ranged from a low of 4 kgal to a high of 620 kgal. The average outdoor use for all of the sites was 90.3 kgal per year. Outdoor use statistics are shown in Table 4-34. The average amount of outdoor use in the REUWS sample was 84 kgal per year.

[55] The ET_o data were updated in October 2010 based on comments from several agencies. The final version contains the latest ET data.

Table 4-34: Outdoor water use statistics for irrigating homes[56]

Parameter	Outdoor Water Use (kgal)
Average outdoor water use	90.3 ± 9.2
Median outdoor water use	77.8
Minimum outdoor water use	4
Maximum outdoor water use	620

The seasonal demand (a sometimes proxy for outdoor use) of the sites included in the outdoor analysis is shown in Figure 4-31. Aurora, Eugene, and Phoenix had similar seasonal demand, between 75 and 82 kgal annually, while Roseville had the highest demand of 138 kgal. The demand in the Tampa Bay area was the lowest at 59 kgal annually.

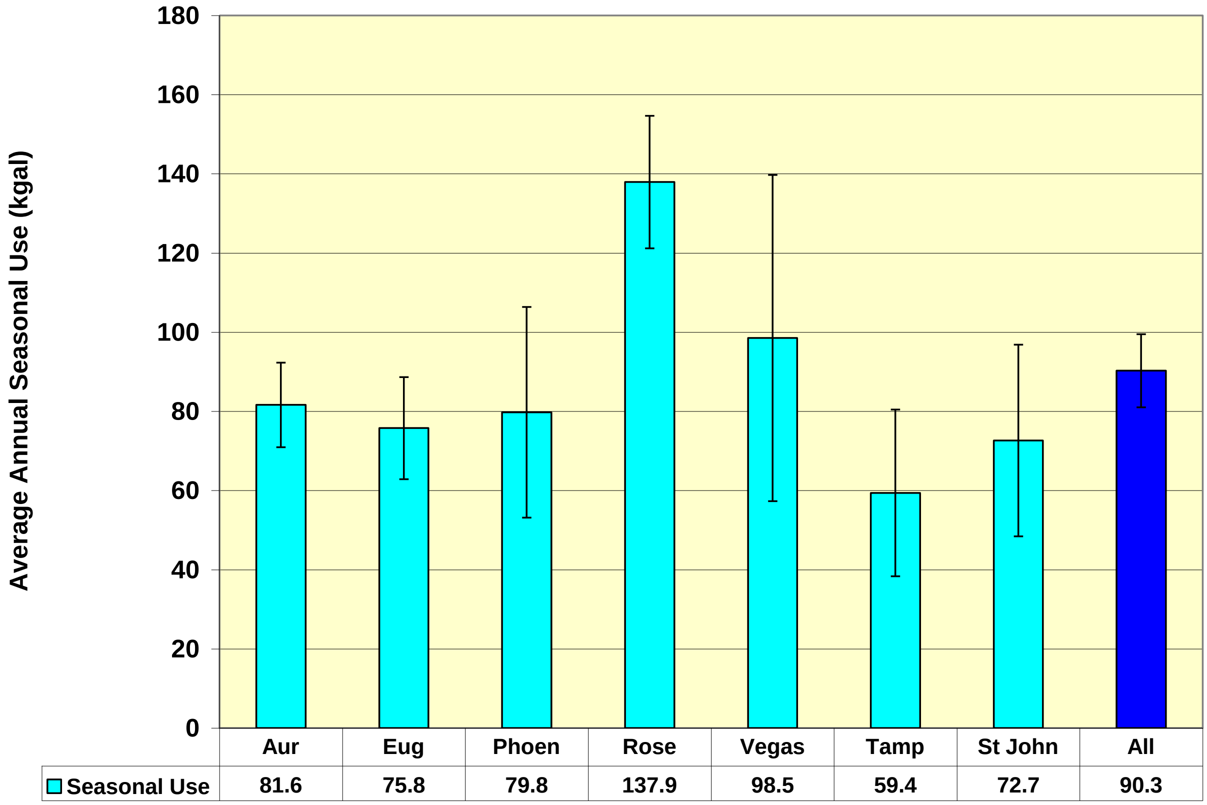


Figure 4-31: Average seasonal use of irrigating homes by study area[57]

[56] Source EPA Outdoor Variables 102610
[57] Ibid

The distribution of outdoor use in the study homes follows a log normal pattern as shown in

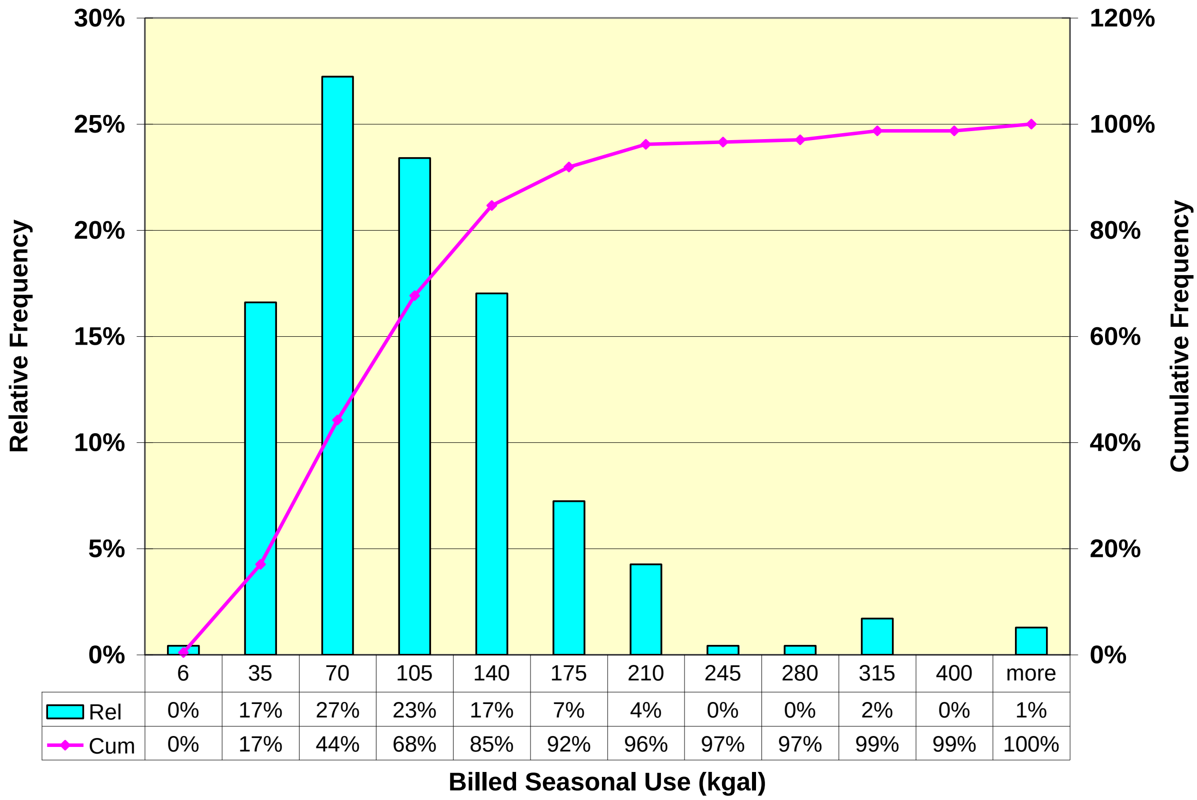
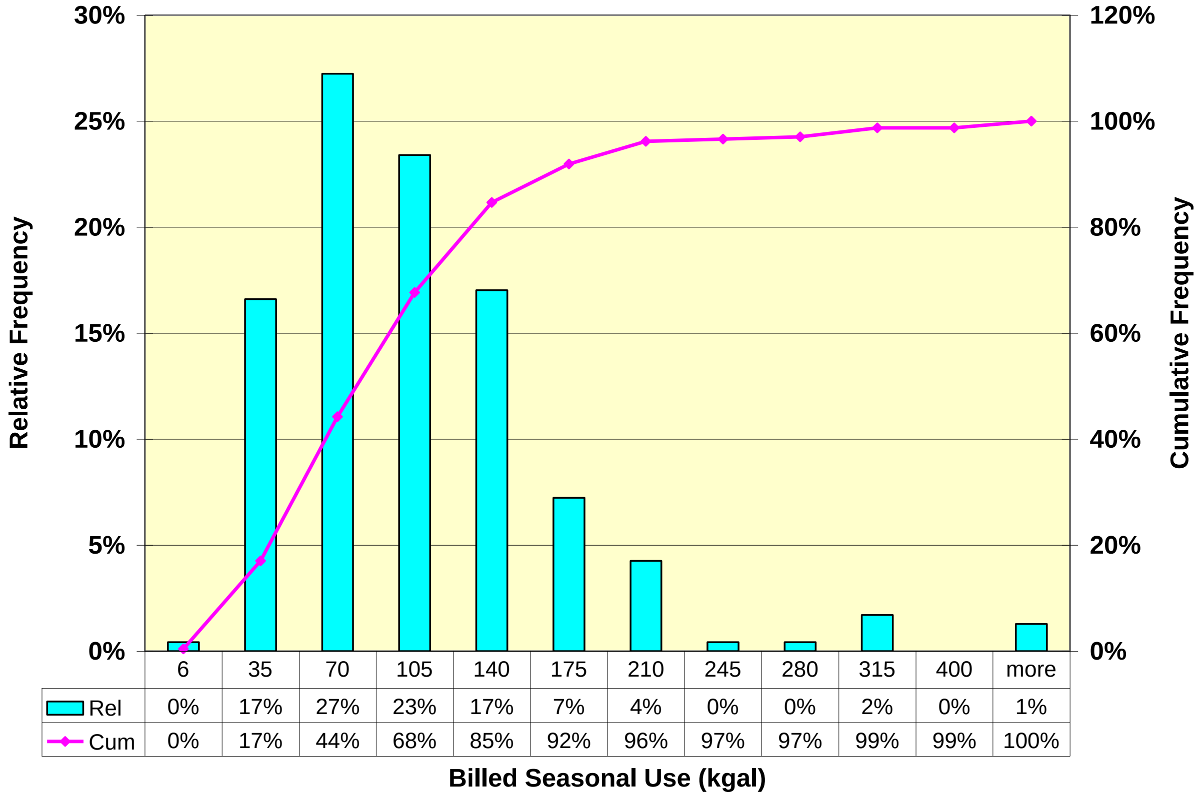


Figure 4-32 shows the percent of the study group that is using various volumes of water for outdoor purposes. Seventy-eight percent of customers used 105 kgal or less while only 4% used 200 kgal or greater. When based on the number of customers, the large users appear of little significance since they make up a small percentage of the customers. However, when viewed from the perspective of the percent of the total outdoor water use each consumption bin accounts for, the situation appears different. As shown in Figure 4-33 the large users account for a percent of the total volume of outdoor use out of proportion to their numbers. For example, only 22% of the customers use more than 105 kgal per year for outdoor uses, but these customers account for 44% of the total outdoor use.



	6	35	70	105	140	175	210	245	280	315	400	more
Rel	0%	17%	27%	23%	17%	7%	4%	0%	0%	2%	0%	1%
Cum	0%	17%	44%	68%	85%	92%	96%	97%	97%	99%	99%	100%

Figure 4-32: Percent of homes by seasonal use volume[58]

[58] Ibid

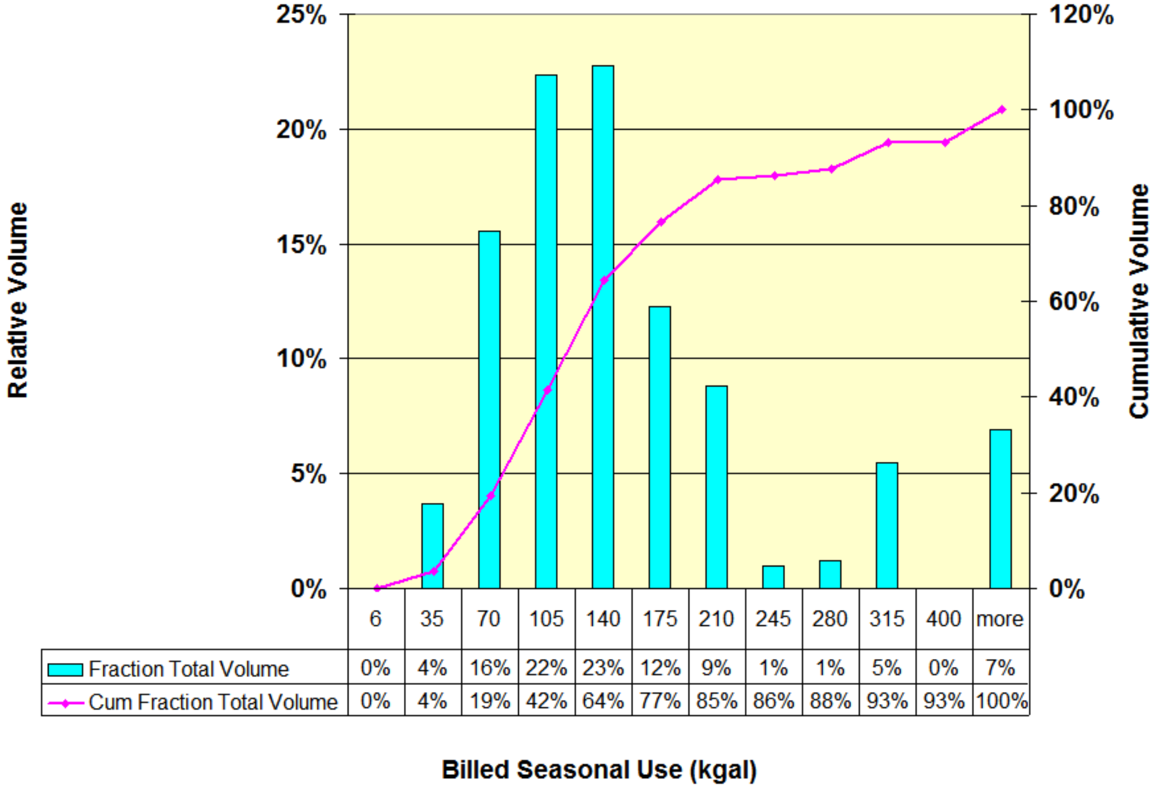


Figure 4-33: Percent of total seasonal use by outdoor use bin

Lot Size

Lot size is an important piece of data for determining the theoretical irrigation requirement. Although customers with large lots may use more water for landscaping purposes than those with small lots, higher water use does not, by itself, mean inefficient use. The average lot size for the irrigating homes was 10,146 sq ft, and the median lot size was 8,178 sq ft. The largest lot in the study group was 121,822 sq ft and the smallest was 1,405 sq ft. Lot size statistics are provided in Table 4-35. The average lot sizes for each of the study groups for which lots sizes were calculated are shown in Figure 4-34. The largest lots are located in St. John's RWMD and the smallest are in Las Vegas. The average lot size is very similar in Aurora, Eugene, Phoenix, and Roseville with a difference of only 800 sq ft. The distribution of the lot size for the study group is shown in Figure 4-35. Although there are several very large lots in the study group over 82% of the lots are 12,000 sq ft or less.

Table 4-35: Lot size statistics

Parameter	Lot Size (sf)
Average lot size	10,146 ± 1,295
Median lot size	8,178
Minimum lot size	1,405
Maximum lot size	121,822

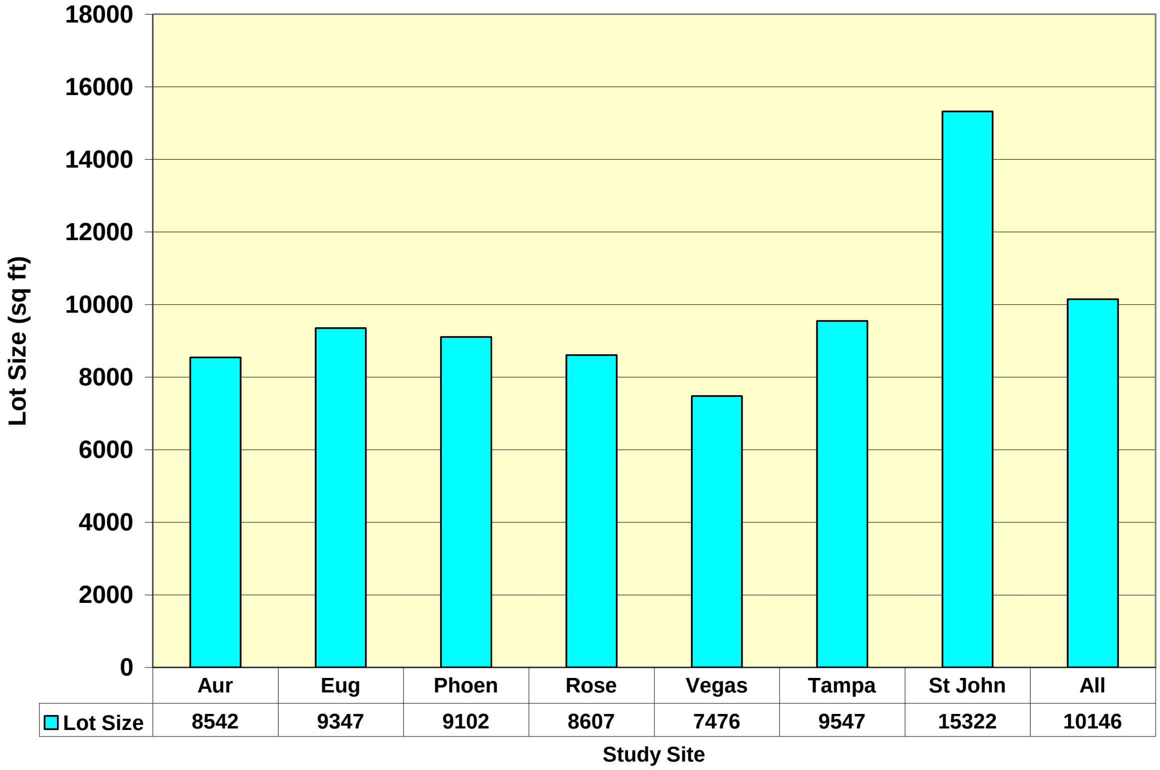


Figure 4-34: Lot sizes for study homes

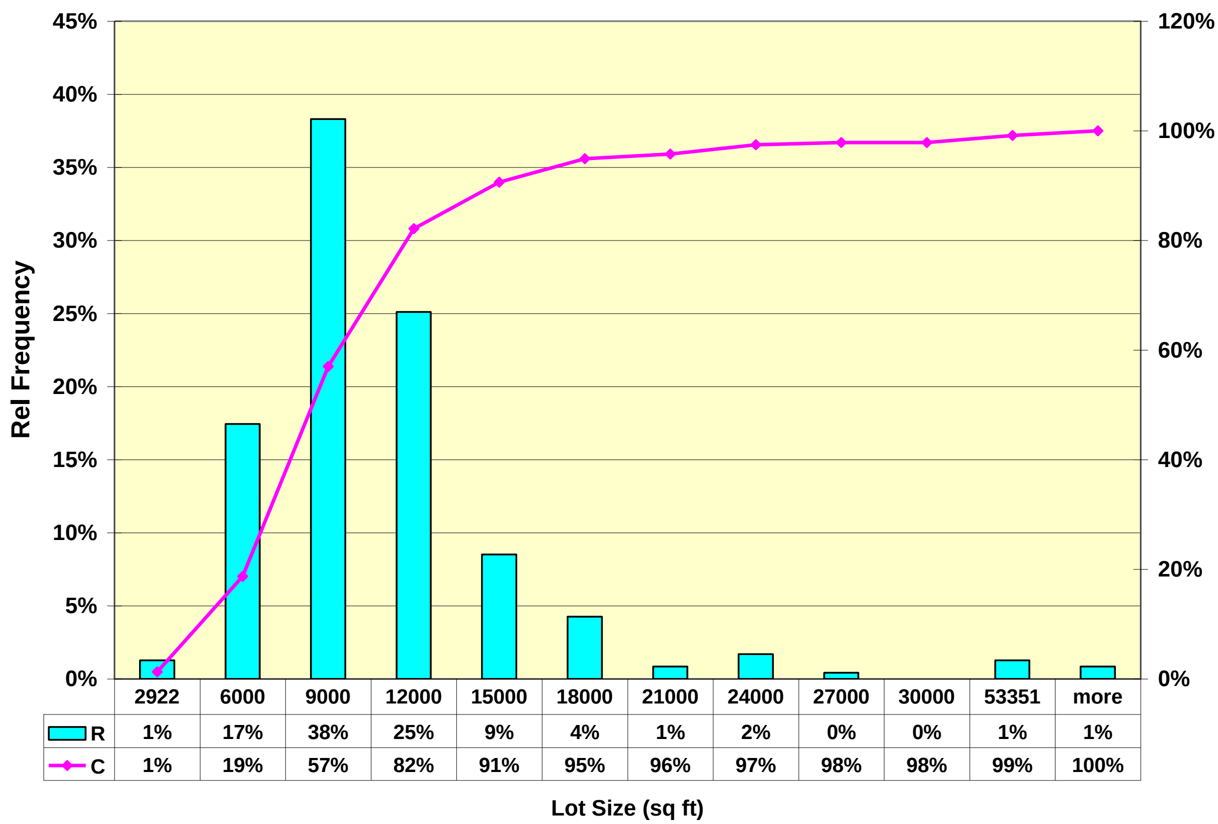


Figure 4-35: Distribution of lot sizes in EPA study group

Irrigated Area

Irrigated area is another critical parameter of irrigation analysis. The average irrigated area for the study homes was 3,714 sq ft; the largest irrigated area was 17,576 sq ft and there was one lot with no irrigation. The statistics for the irrigated area of the study sites are provided in Table 4-36.

Table 4-36: Irrigated area statistics

Parameter	Irrigated Area (sf)
Average irrigated area	3,714 ± 346
Median irrigated area	3,028
Minimum irrigated area	0
Maximum irrigated area	17,576

Figure 4-36 shows the average irrigated area for each of the study sites for which we had data. Las Vegas homes had the smallest average irrigated area of 1878 ft^2, just slightly more than half of the average irrigated area for the group as a whole. Phoenix, Roseville, and Aurora, also had irrigated area that was smaller than the average while homes in St. John's RWMD water district were nearly twice the average lot size.

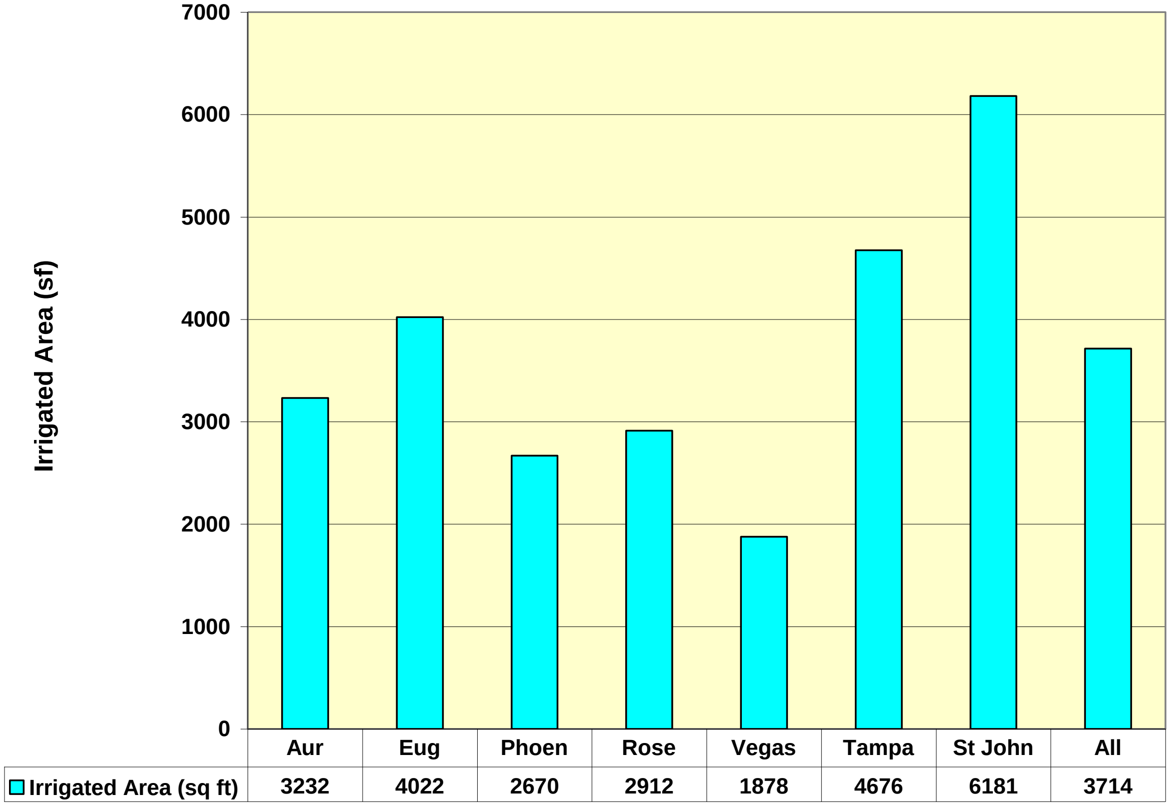
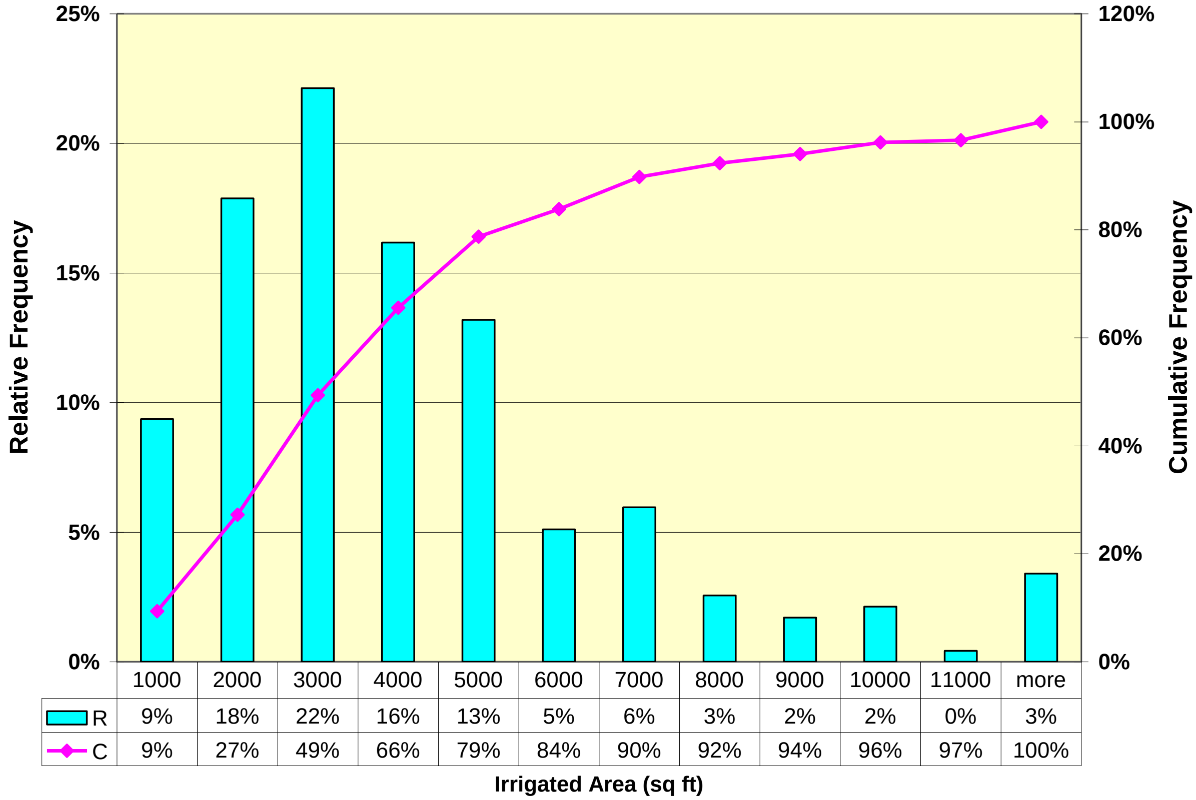


Figure 4-36: Irrigated area for study homes[59]

Figure 4-37 is a histogram showing that the distribution of lot sizes follows a log normal distribution. Twenty-two percent of homes have between 3,000 and 4,000 sf of irrigated area; nearly half of the homes have less than 4,000 sf of irrigated area. Only 10% of the homes had area greater than 8,000 sf.

For conservation planning it is useful for utilities to know if there is a correlation between lot size and irrigated area. The relationship between irrigated area and lot size for the study homes is shown in Figure 4-38 and the data demonstrate a fairly strong correlation between irrigated area and total lot size. This is useful because it is much easier to obtain lot size information than irrigated area information, and having a relationship to predict irrigated area makes it possible to do projections more easily.

[59] Ibid



	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000	11000	more
R	9%	18%	22%	16%	13%	5%	6%	3%	2%	2%	0%	3%
C	9%	27%	49%	66%	79%	84%	90%	92%	94%	96%	97%	100%

Figure 4-37: Distribution of irrigated areas[60]

The correlation between lot size and irrigated area is represented by the formula on the graph where irrigated area is shown to equal 0.38 times the lot size plus 123 square feet. This relationship does not pass through the origin, and provides a higher R^2 value than one that does. The reason for this is that until lots reach a certain size there is not enough room on them for a house and a yard. In this study irrigated areas do not start showing up until the lot sizes reach 2,133 sq ft. After that point approximately 38% of the lot is irrigated. Three of the sites were eliminated from this analysis because they were not representative of the sample as a whole. These were “double sites” where half or more of the property was left as native vegetation and unirrigated.

[60] Ibid

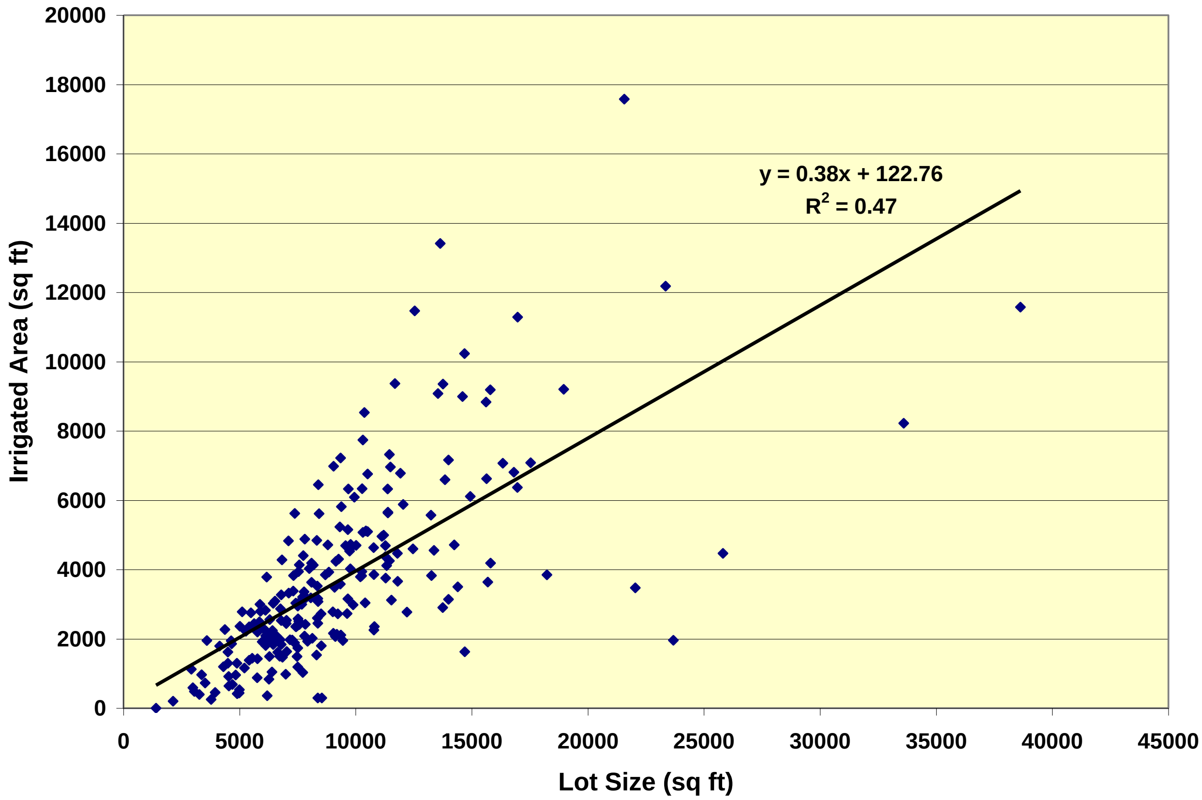
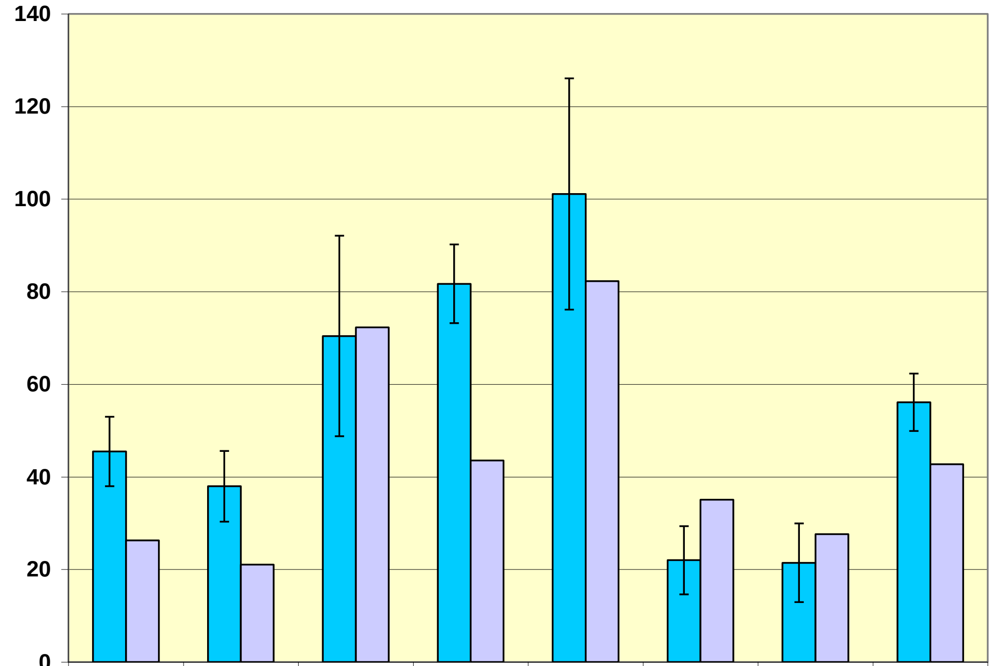


Figure 4-38: Irrigated area versus lot size

Irrigation Application Rates

The volume of water applied, measured in gallons and divided by the irrigated area, yields a value of gallons per square foot, which can be converted to inches per square foot based on the relationship that 0.623 inches equals 1 gpsf. This value is the application rate for the landscape. The actual application rates were determined for each home from which the average application rate for the group as a whole was calculated. These rates are shown in Figure 4-39[61]. The graph shows that the study site with the lowest average application rate was St. John's RWMD, and the site with the highest average application rate was Las Vegas. Also shown in the figure are the average net ET_o values for the sites, which are closely correlated to the irrigation requirements, although not necessarily to the application rates. Two of the seven sites were applying less than the net ET_o and five were applying more, on average.

[61] Source: EPA Outdoor Variable 102610.xls



	Aur	Eug	Phoen	Rose	Vegas	Tamp	St John	All
Average Application (in)	45	38	70	82	101	22	21	56
Average of Net ET	26	21	72	44	82	35	28	43

Study Site

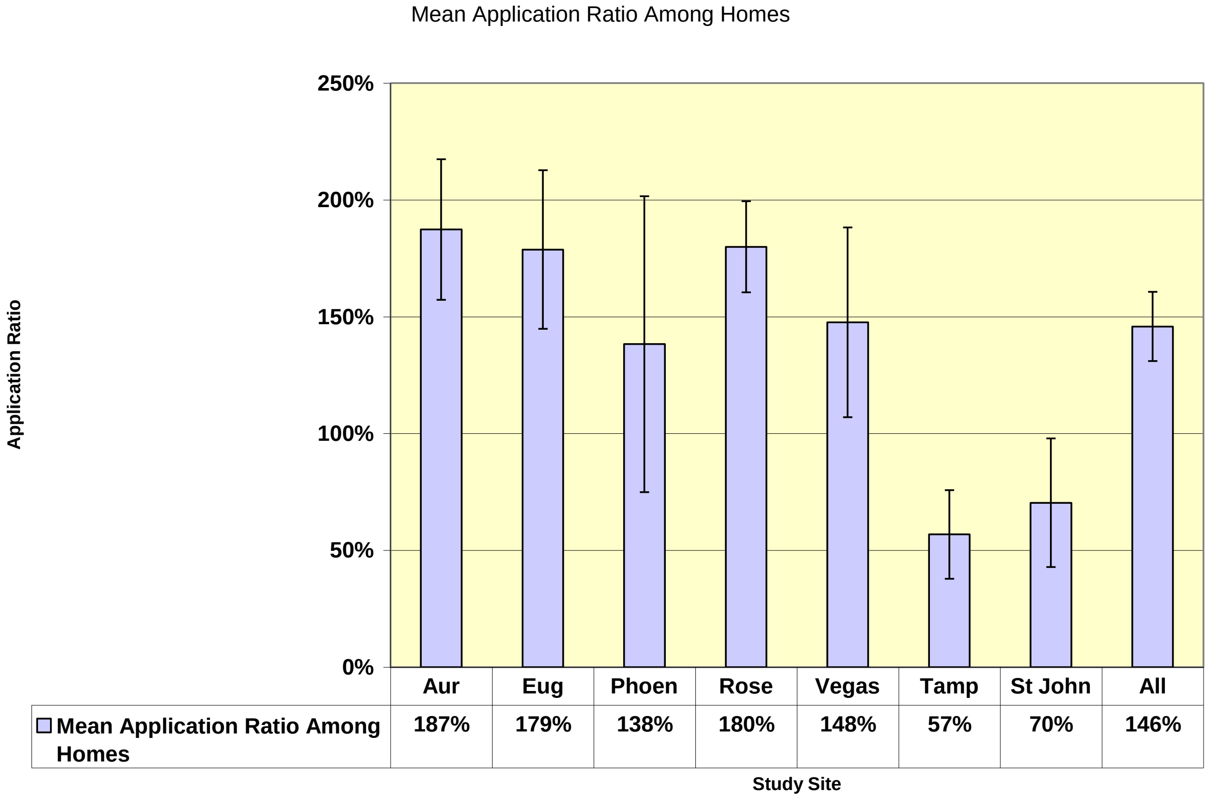
Figure 4-39: Irrigation applications (inches) versus net ET_o[62]

Irrigation Application Ratios

The ratio of the actual irrigation application to the theoretical irrigation requirement (TIR) is referred to as the application ratio. When this ratio is greater than 1 there is excess irrigation occurring, and when it is less than 1 there is deficit irrigation. As described in the following section, the theoretical irrigation requirement is developed from ET_o, the irrigated area, the crop coefficients of the plants, and the irrigation efficiencies. When all are considered the theoretical irrigation requirement for each lot can be estimated in either gallons or inches.

As shown in **Figure 4-40**, only Tampa Bay Water and St. John's River had an average application ratio less than 1 and the other sites had an average greater than one. Homes in the service areas of Tampa Bay Water and St. John's River were applying 57% and 70% of TIR respectively; homes in Roseville were applying 180%, of the theoretical irrigation requirement. The average actual irrigation application of all of the homes was 146%. These averages can be misleading, and should not be used to estimate the volume of excess water use since homes with large application ratios may have small irrigated areas and vice versa. The actual ratio of applied water to TIR for the group as a whole was 109%.

[62] Ibid



	Aur	Eug	Phoen	Rose	Vegas	Tamp	St John	All
Mean Application Ratio Among Homes	187%	179%	138%	180%	148%	57%	70%	146%

Figure 4-40: Application ratios of study sites

The application ratios are key parameters in assessing irrigation use because they indicate at a glance whether a given site is over or under irrigating. Figure 4-41 shows the distribution of application ratios in the study homes. This shows a typical log normal distribution with around 1% outliers at the top end. The fact that 37% of the homes are not over-irrigating is very important fact to keep in mind when designing irrigation conservation programs, such as weather based irrigation controllers, or improved irrigation scheduling. These under-irrigators will probably *increase* their water use in response to such programs. This makes it important to devise targeting strategies for outdoor conservation programs.

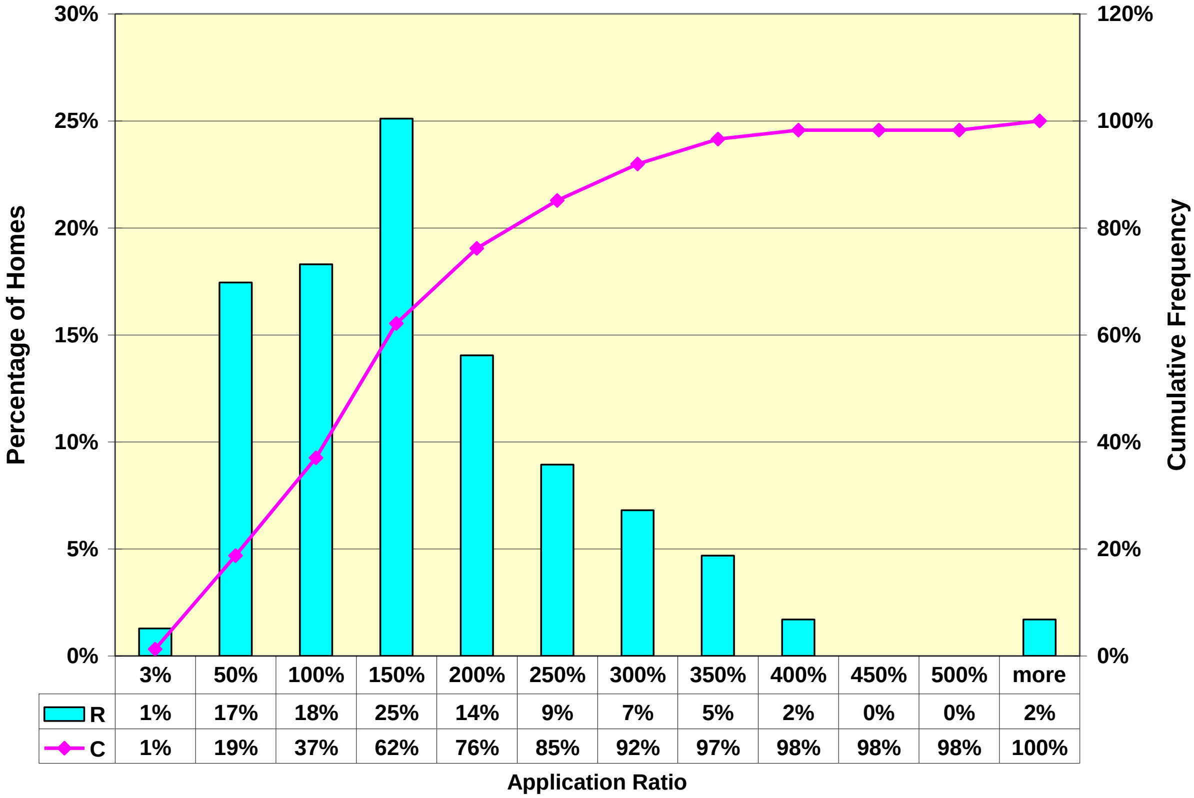


Figure 4-41: Distribution of application ratios in study homes

Excess Irrigation

The theoretical irrigation requirement (TIR) is the benchmark for outdoor irrigation use. Homes that use more than the TIR are over-irrigating; those that are using less are deficit irrigating. If we compare the average outdoor use of <u>all</u> of the irrigating homes to their average theoretical requirement we see that the two values are similar. The average annual outdoor use for the group as a whole is 90 kgal while the average theoretical irrigation requirement for the group is 83 kgal as shown in Table 4-37. Looking at the group as a whole the difference between the average irrigation usage and the average TIR is 7.3 kgal/year.

As a group the average excess use is only 7.3 kgal per household, but if one looks only at the homes that are over-irrigating this volume is much larger. Of the homes for which irrigation analyses were performed 86 or 37% were under-irrigating. The average volume of deficit irrigation, shown in Table 4-38 was 62 kgal and the median was 40 kgal. The minimum volume of under-irrigation was close to 0 and the maximum was 408 kgal.

Table 4-37: Theoretical irrigation requirement of the study sites

Parameter	Value
Number of lots analyzed from aerials	235
Average irrigation usage of all sites	90±9 kgal
Average theoretical irrigation requirement	83±8 kgal
Median irrigation usage	78 kgal
Minimum irrigation usage	4 kgal
Maximum irrigation usage	620 kgal

Table 4-38: Statistical information on sites that are deficit irrigating[63]

Parameter	Value
Number of sites deficit irrigating	86
Average volume of deficit irrigation	62±13 kgal
Median volume of deficit irrigation	40 kgal
Minimum volume of deficit irrigation	0 kgal
Maximum volume of deficit irrigation	408 kgal
Total volume of deficit irrigation	5351 kgal

Percent of Lots that are Over-Irrigating

Approximately 63% of the study homes were over-irrigating to some degree. However the percentage of homes that were over-irrigating were not evenly distributed among the study sites and ranged from a low in the Tampa Bay area to a high in Roseville as shown in Figure 4-42. The smaller the percentage of customers that are over-irrigating the harder it is to locate them by random selection, and the more important it is to target. In St. John's River and the Tampa Bay Water service area, where fewer than 25% of the home sites are over-irrigating, a random selection will give less than one in four customers that have potential outdoor savings; four out of five customers will not benefit. At the other extreme, in Aurora and Roseville a random selection will yield at least nine out of ten customers that would benefit from outdoor conservation measures.

[63] Ibid, !Excess Pivot

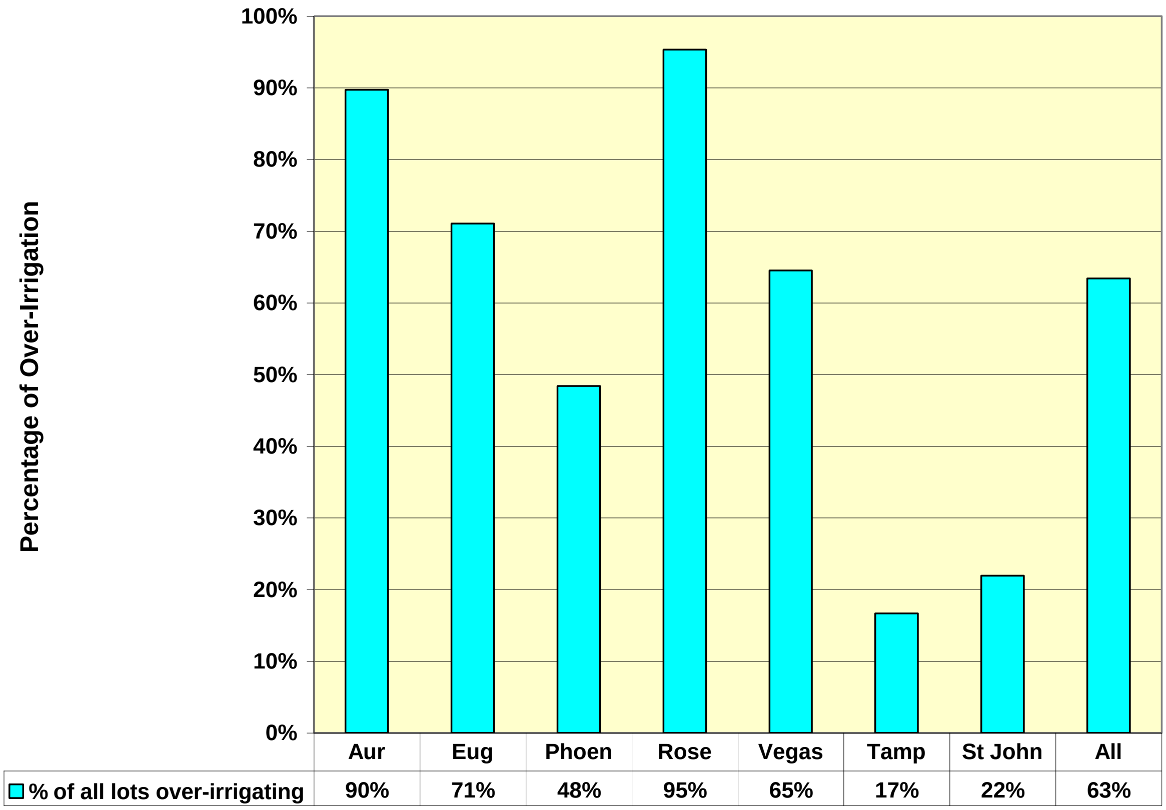


Figure 4-42: Percent of lots that were over-irrigating

While application ratios provide information on the percentage of homes that are over-irrigating and the extent to which they are over-irrigating they do not tell anything about *volumes* of excess use irrigation which depend instead on the irrigated areas and the volumes of the theoretical irrigation requirements.

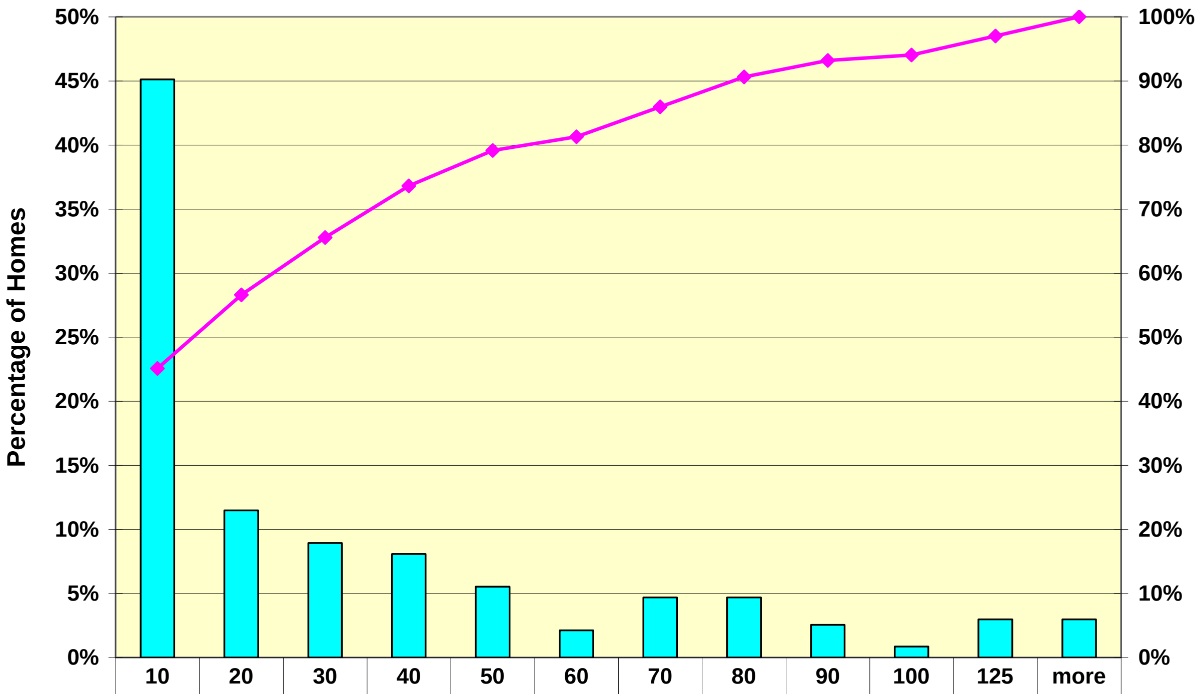
Excess Irrigation Volumes

From the perspective of water conservation, excess irrigation is the key parameter because it is a measure of potential actual volume of water savings from improved irrigation management, measured in acre feet or millions of gallons. The average excess use for the group as a whole was only 7 kgal, but on the homes that are over-irrigating it is nearly 47 kgal annually as shown in Table 4-39. This shows that if just the over-irrigators can be identified the potential water savings can be maximized.

Table 4-39: Excess use parameters

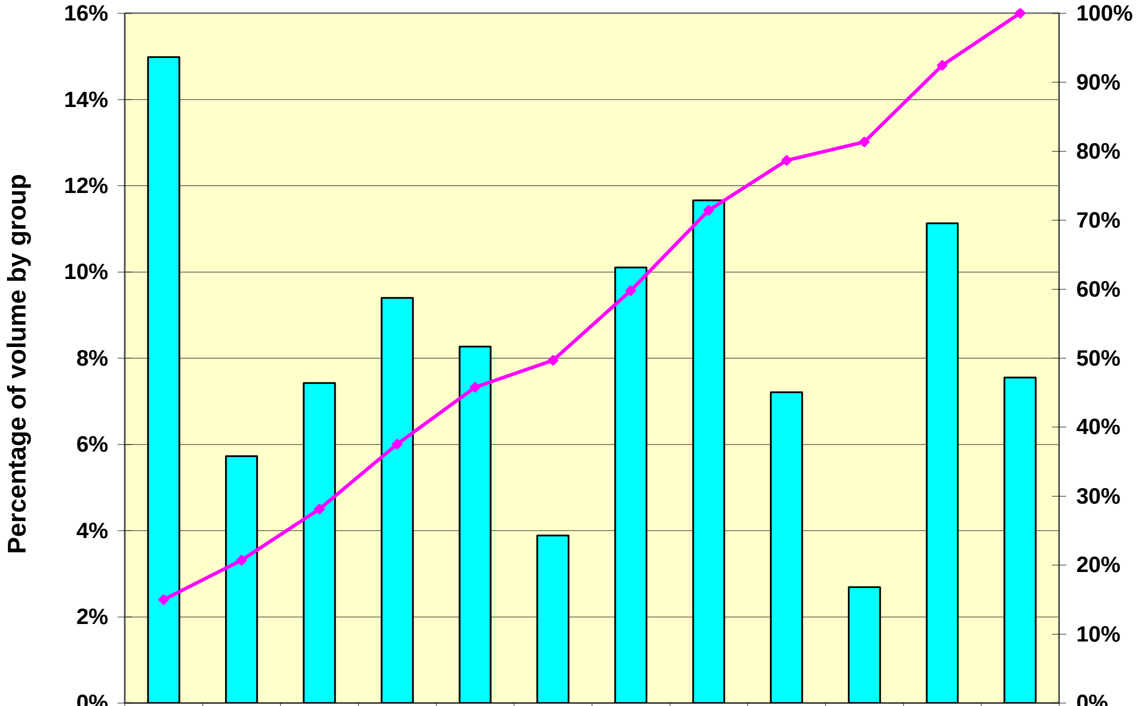
Irrigation Parameter	Value
Number of lots analyzed from aerials	235
Overall excess use per site, balanced by deficits	7 kgal
Average excess use on over-irrigating lots	47 kgal
Overall excess use in just over-irrigators	30 kgal

Figure 4-43 shows the distribution of the number of accounts in various excess use bins. As was the case with outdoor water use, based on the numbers of accounts, the heavy users seem relatively unimportant, but based on the percent of the total volume of excess irrigation the impact of the higher users becomes much more dramatic. For example Figure 4-43 shows that the 0-10 kgal group makes up 45% of all accounts, but we see in Figure 4-44 that this group accounts for only 15% of the total volume of excess use. The homes that are using more than 60 kgal of excess irrigation water make up only 19% of all irrigators, but they account for 50% of the total excess volume.



	10	20	30	40	50	60	70	80	90	100	125	more
R	45%	11%	9%	8%	6%	2%	5%	5%	3%	1%	3%	3%
C	45%	57%	66%	74%	79%	81%	86%	91%	93%	94%	97%	100%

Figure 4-43: Distribution of excess irrigation by number of accounts



	10	20	30	40	50	60	70	80	90	100	125	more
Volume R	15%	6%	7%	9%	8%	4%	10%	12%	7%	3%	11%	8%
Volume C	15%	21%	28%	38%	46%	50%	60%	71%	79%	81%	92%	100%

Figure 4-44: Percent of excess volume attributed to group

Modeling Results

The data from the survey responses were combined with the end use results to construct models of indoor and outdoor water use for the standard new homes. There were not enough data for the high-efficiency homes to generate useful models, so the reporting for these homes was limited to mean values. The modeling results provide a way to normalize the data for the impact of the variable, and make useful comparisons of results possible.

Indoor

Creating the model for indoor water use was a two step process. First a set of continuous variables were tested to see which combination gave the best fit to the data, and second a series of conditional (flag) variables were tested to see whether their presence had a significant impact on predicting the indoor water use. The conditional variables that reduced the overall model residuals, with a p value of <0.10, were selected for inclusion.

The only continuous variable that was found to be significant for predicting water use was the number of residents in the home. Indoor use was therefore first corrected to account for the number of residents in the home. The best relationship was a log-log regression with $r^2=0.128$. The residuals from that regression were then used to explore influential factors using ANOVA. For conditional (flag) factors, one-way ANOVA was used on log residuals. For these variables, the ANOVA is equivalent to a t-test on the mean of log residuals, and significance is shown based by the F-statistic. For continuous factors, Pearson's r is reported with one-tailed significance.

Table 4-40: Parameters tested for indoor model

					Mean Change		N		
Factor	sig	F-test	r	r²	pos	neg	pos	neg	tot
Average_clotheswasher_load_gal	0.000		0.26	0.07					287
CW_HE	0.000	22.02			94%	122%	113	174	287
Trace shows significant leak	0.000	21.21			202%	93%	26	270	296
outdoor spa	0.006	7.61			140%	94%	40	254	294
pool	0.011	6.48			134%	95%	45	250	295
Average_toilet_flush_volume	0.023		0.13	0.02					293
Bed Rooms	0.024		0.13	0.02					295
outdoor feature	0.049	3.91			125%	95%	45	234	279
Cost of water is important for indoor use	0.049	3.92			92%	112%	170	124	294
Treatment	0.050	3.87			119%	95%	69	226	295
Hot water remedy installed	0.080	3.08			129%	96%	30	247	277
Multi-showerheads	0.111	2.56			130%	98%	24	269	293
Environmental reasons	0.151	2.07			103%	86%	236	55	291
Youth	0.161	1.97			111%	96%	82	212	294
Front-loader	0.258	1.28			93%	104%	103	192	295
Bath Rooms	0.300		0.07	0.01					203
Know last billing total	0.397	0.72			102%	91%	235	58	293
indoor feature	0.402	0.70			126%	99%	9	286	295
Dishwasher	0.431	0.62			99%	146%	292	3	295
age_of_home	0.532		-0.04	0.00					295
Aware of leak	0.561	0.34			108%	99%	35	259	294
Know amount of water on last bill	0.597	0.28			102%	97%	155	137	292
indoor spa	0.598	0.28			125%	100%	4	291	295
pays bill	0.607	0.27			100%	64%	292	1	293
Toilt_HE	0.623	0.24			104%	108%	142	151	293
ULFT on survey or audit	0.630	0.23			100%	133%	287	2	289
Floor Area (sf)	0.631		0.03	0.00					271
survey_homies	0.633	0.23			98%	103%	189	103	292
survey_income	0.661		0.03	0.00					261
renter	0.671	0.18			118%	100%	5	287	292
CW	0.671	0.18			100%	77%	293	2	295
Evaporative/swamp cooler	0.868	0.03			105%	100%	8	287	295
Hot water wait is "very much"	0.986	0.01			101%	99%	72	213	285
garb	0.991	0.04			100%	105%	286	10	296

Factors with significance less than 0.10 were chosen for SPSS stepwise regression. Note that not all factors included in the stepwise regression test were found to improve the accuracy of the model. The following factors were shown to be significant for the regression equation:

Indoor Use = Indoor water use (gphd) (the dependent variable).

Res_No = Number of residents in household, raised to the 0.63 power
Significant_leak = multiply by 191% if the household shows a leak over 50 GPD
CW_HE = multiply by 77% if the household has a clothes washer using less than 30 GPL
Softener = multiply by 112% if the household has a water softener

The coefficient of determination (r^2) for the selected model was 0.442, which implies that 44.2% of the variation in indoor use can be explained by the model. Other independent variables included in regression did not improve the model fit, which can happen if independent variables are very closely related (such as average flush volume and whether or not toilets are ULFTs). In these models the only significant continuous variable discovered in the analysis was the number of residents per household.

Equation 4-1: Indoor use regression equation

r^2=0.442

$$\text{Indooor GPHD} = 71.2 * \text{Res\_No}^{0.63} * \text{significant\_leak} * \text{CW\_HE} * \text{softener} + 11.8$$

$$\text{Indooor Kgal/year} = 26.0 * \text{Res\_No}^{0.63} * \text{significant\_leak} * \text{CW\_HE} * \text{softener} + 4.3$$

This equation fits observed indoor use for N=286 logged homes.
Overall, the mean of regression predictions equals the observed mean. The regression equation can be used to estimate average indoor use among a population, though regression does not always perform well against extreme cases. In fact, **Table 4-41** shows observed indoor use min and max are far wider than the regression predicted values. In one case, observed indoor use is 150 kgal/year higher than predicted.

Table 4-41: Indoor use predicted by regression

	N	Minimum	Maximum	Mean	Std. Deviation
Observed	286	6.4	252.6	52.0	30.3
Predicted	286	24.0	139.3	52.0	19.4
Residual	286	-51.9	150.4	0.0	22.8

These regression coefficients are shown in **Table 4-42** with the study average for each factor. Using the study average for each factor, the regression results in an estimated population average of 51.9 kgal/year. The observed average is 52.0 kgal/year. This difference emerges from log-log regression: the regression routine is fitting the mean of log-transformed data.

Table 4-42: Indoor use regression, r^2=0.442

TraceProjected (Kgal)	Coefficient	Overall Average	Model equation term
(Constant)	25.7		25.7
Res_No	0.63	2.73	1.88
significant_leak	191%	9%	1.1
CW_HE	77%	39%	0.9
Softener	112%	23%	1.0

TraceProjected (Kgal)	Coefficient	Overall Average	Model equation term
Bias correction	4.3		4.3
		Predicted Kgal:	51.9
		Predicted GPD:	142.2

Outdoor

As part of the preparation of the outdoor use models the estimated outdoor use for each home was used as the dependent variable in a multiple regression model to correct for physical characteristics of each site that can be expressed as continuous variables. This analysis took the form of a log-log regression, and the resulting model had a coefficient of determination (r^2) of 0.16 using income, number of residents (from survey responses), and total irrigated area (from aerial imagery). Other continuous variables were tested, as shown in **Table 4-43**, but did not help the regression achieve a better fit.

Table 4-43: Excluded variables

Excluded Variables	Coefficient	Significance
Lage_of_home	-0.013	0.799
Lsurvey_years_in_home	0.027	0.587
LRes_No	0.040	0.444
survey_outdoor_feature Do you have an outdoor water feature like a fountain or pond?	0.074	0.137
survey_pool_leak Leaks in your pool system	0.031	0.534
survey_know_cost_of_water	-0.070	0.137

The regression model initially included all of the available continuous variables. As part of the analysis factors with significance less than 0.10 were chosen for stepwise log regression analysis. When the conditional variables were added to the analysis the fit of the model improved significantly. The coefficient of determination for the final model was 0.56, which means that the model describes 56% of the variance in the observed data. The following variables were selected for inclusion into the final regression equation:

The final form of the outdoor use model derived from the study data are shown in Equation 4-2 This equation fits observed indoor use for N=202 logged homes. Overall, the mean of regression predictions equals the observed mean. The regression equation can be used to estimate average outdoor use among a population by assigning the best estimates for each of the parameters in the model.

Equation 4-2: Outdoor use regression equation

$$\text{Outdoor Kgal} = 2.02 * 10^{-4} * \text{Income}^{0.36} * \text{Net ET}^{0.85} * \text{Irr\_Area}^{0.61} * \text{LandscapeRatio}^{0.65} * \text{Excess} * \text{Person at home} - 15.20$$

Where:

Outdoor Kgal = dependent variable

Income = Household income, dollars
Net ET_o = Gross ET_o – effective precipitation
Total Irrigated Area = sq. ft. of irrigated area
Landscape Ratio = ratio of landscape coefficient to turf
Excess Irrigator = multiply by 323% times percent of homes that are irrigating above TIR
Person at Home = multiply by 115% times percent of homes with adult(s) not employed

These regression coefficients are shown in Table 4-44 with the study average for each factor. Using the study average for each factor, the regression results in an estimated population average of 93.1 kgal/year of outdoor use, while the observed average was 93.1 kgal/year.

Table 4-44: Outdoor use regression

Outdoor Factor	Model Coefficient	Ave value in sample	Factor for Parameter	Explanation
Constant	0.000202		0.0002020	constant factor
Excess (% of group)	3.23	0.64	2.44	= 3.23*0.64 + (1-0.64)
Irrigated Area (sf)	0.61	3749.08	155.53	= 3749.08 ^ 0.61
Net ET	0.85	34.68	20.54	= 34.68 ^ 0.85
Income	0.36	96385.66	63.54	= 96385 ^ 0.36
Landscape Ratio	0.65	0.98	0.99	= 0.98 ^ 0.65
Person at home	1.15	0.64	1.10	= 1.15 * .64 + (1-0.64)
Bias correction	-15.20			correction factor
		Product of terms:	93.12	= kgal/year, product + biac corr.

The outdoor use model provided results that make intuitive sense. The total outdoor water use for a given single family residence was found to be a factor of the irrigated area, the local ET_o, the household income and the nature of the landscape's water requirement relative to turf. The single most significant factor in predicting water use was whether or not the homeowners were over-irrigating their landscape. These results point out that the keys to outdoor water conservation in new single family homes is to prevent over-irrigation, to limit the size of the landscape, and to limit the water requirements of the plant materials used on the landscape.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

This study has been the result of nearly five years of data collection and analysis. Based on data from billing sources, surveys, aerial photography and flow trace analysis it has provided a picture of the water use patterns in both standard and high-efficiency new homes of a highly detailed and precise nature. The results of the study show that single family homes can be categorized according to their water use efficiency. Over time the trend has been towards greater water use efficiency at both the household and per-capita level. There are still challenges created by relatively small numbers of homes with high water use. Finding ways to address these customers is a challenge that must be met if overall household water use is to be optimized.

Among the key conclusions that can be drawn from the data are the following:

From the Survey Data

- The new homes and households in the study tended to be a little larger than the stock of existing homes with slightly more bedrooms and more children.
- The average number of residents in the new homes was 2.9 persons; compared to 2.5 in the existing homes.
- The residents of the new homes had a higher income level than the residents of existing homes.
- The estimated values of the new homes was higher than for the existing homes.
- The overall education level of the residents of the new and existing homes was very similar.
- The majority of the existing homes in the sample were built before 1980.
- The new homes tended to have more toilets (and bathrooms), and were much more likely to be equipped with ULF toilets.
- The percent of toilets in the new homes reported to be ULF or better models was over 90%, while in the older homes approximately 58% of the toilets were reported to be ULF.
- ULF retrofits are occurring at a relatively constant rate among older homes in this study group. The age of the home is not a significant factor in determining the likelihood of completing a ULF retrofit.
- New homes have slightly more shower fixtures than the existing homes and the respondents report approximately 76% of these are LF models.
- The existing homes report 60% of the showers as LF models.
- The vast majority of both existing and new homes are equipped with garbage disposals, dishwashers and clothes washers.
- High-efficiency clothes washers were reported in around 20% of the existing homes and 30% of the new homes.
- Outdoor irrigation of some form is practiced in over 93% of the existing and new homes, and the majority of irrigation is done with automatic sprinkler systems.
- More people report knowing how much they pay for water than how much water they use. Just over half of the respondents thought they knew how much water they typically use.

From Billing Data:

- Total annual billed water use of the new homes was not statistically different from the existing homes, however, new homes tend to use less water indoors, and more water outdoors.
- There is considerable variation in water use among the various study cities. Homes in warm dry areas use more water than homes in colder or wetter areas.
- Cities in warmer climates tended to have higher non-seasonal (indoor) water use. This is probably due to winter irrigation, not greater indoor use.

From Flow Trace Analysis (Standard New Homes):

- The average indoor water for the standard new homes was 140 gphd, compared to 177 gphd for the homes from the 1999 REUWS. This result indicates a sharp decrease in indoor use in new homes, even though the average number of residents increased from 2.7 in the REUWS to 2.9 in this study.
- The measured decrease in indoor use was not evident simply by comparing billed consumption because many of the study homes practiced winter irrigation which masked changes in indoor demand.
- The standard new homes showed major decreases in toilet and clothes washer use, while use in other categories was approximately the same as what was found in the 1999 REUWS.
- The average toilet flush volume in the standard new homes was 2.13 gpf, and nearly 90% of all flushes were less than 3 gpf.
- A small number of higher volume toilets appear to be grouped in a few homes in the standard new home sample. In the standard new home study sample, 1% of the homes that had average flush volumes greater than 4 gpf.
- The standard new homes were equipped with a mix of both standard and high-efficiency clothes washers. Approximately 60% of the homes had a standard washer and 40% had a high-efficiency washer.
- The average shower flow rate (2.0 gpm) and average gallons per shower (15.9 gal.) were slightly lower in the standard new homes compared to the REUWS results (2.2 gpm and 17.2 gal/shower).
- Leakage in the standard new homes was slightly lower than in the REUWS group. The standard new homes averaged 19.7 gpd for leakage and the REUWS homes averaged 21.9. As was the case in the REUWS most of the leak volume is accounted for by a few homes with high leakage rates.
- 39% of the standard new homes were equipped with a high-efficiency clothes washer (30 gallons per load or less)
- 89% of the standard new homes met the criteria for high-efficiency showers (average flow rate of 2.5 gpf or less)
- 48% of the standard new homes met the criteria for high-efficiency toilets (average flush volume for home of 2 gal or less).
- Less than half of the standard new homes averaged toilet flush volumes less than 2.0 gpf which indicates that there are many 1.6 gpf toilets are exceeding their design flush volumes.

From Flow Trace Analysis (High-efficiency New Homes)

- The average indoor use in the high-efficiency new homes was 105 gphd, and most of the high-efficiency new homes used less than 100 gphd.
- The water use for toilets, clothes washers and faucets in the high-efficiency new homes was significantly lower than in either the REUWS homes or the standard new homes. These end use categories accounted for the bulk of the reduction in water use.
- The average toilet flush in the high-efficiency new homes was 1.4 gpf.
- The toilet flush volumes in the high-efficiency new homes were consistent. All toilets installed in the high-efficiency new homes were WaterSense labeled. 92% were less than 1.8 gpf and no flushes were recorded at greater than 2.2 gpf.
- The average volume per load for the clothes washers in the high-efficiency new homes was 15.1 gpl, and 96% of the loads were washed using less than 20 gallons. While there is no official WaterSense specification for clothes washers, the machines in this study met Tier 3 requirements for the Consortium for Energy Efficiency (CEE), and had a water factor of 5 or less.
- The high-efficiency shower heads in the homes resulted in average shower flow rates of 1.64 gpm, but the average shower volume was about the same as in the standard new homes.
- A few of the high-efficiency new homes showed large volumes of water use that appeared to be leakage in the flow trace analysis. 84% of the high-efficiency new homes had leakage rates less than 10 gpd, but 4% of the homes leaked at 100 gpd or more, and these few homes accounted for 32% of the total leak volume among the high-efficiency home sample.
- The average faucet flow rate in the high-efficiency homes was less than 1 gpm. This, and a slightly lower faucet use duration resulted in a significant reduction in average household faucet use.
- The percentage of the high-efficiency homes that met the study criteria for high-efficiency was: 100% for clothes washers, 100% for showers, and 96% for toilets.

Per Capita Relationships

- The number of persons in the homes is the most important factor in determining household indoor water use.
- The relationship between household use and number of residents is non-linear.
- When household water use is modeled against the number of persons per household the high-efficiency new homes show up as the most efficient on a per capita basis, at 35.6 gpcd for a family of 3.
- High-efficiency homes showed a lower impact per capita than do the other homes. As new residents are added, household water use increases at a lower rate.
- The per capita relationship shows that the water savings in the new homes was due to actual higher efficiencies of use, and not a lower population in the homes.
- Standard new homes represent a water efficiency improvement over existing homes, but were not as efficient in their indoor use as are the high-efficiency new homes.
- The indoor use pattern of the high-efficiency new homes can be used as a benchmark for high-efficiency indoor single family water use. These homes met criteria from early

drafts of the WaterSense indoor specification and used 29% less water indoors than the standard new homes.

Indoor Model Results

The following factors were found to be significant in explaining indoor water use in the standard new homes[64]:

- Number of residents
- Presence of a leak of more than 100 gpd
- Presence of a high-efficiency clothes washer
- Presence of a home treatment system

In this group, indoor use was most heavily influenced by the number of persons in the home. Since these were all new homes with a preponderance of similar ULF toilets the type of toilet in the home was not significant predictor, but the presence of a high-efficiency clothes washer is. The presence of a home water treatment system was found to be significant in predicting indoor use in new homes. Home treatment systems consist of either water softeners, which use water for regeneration, or reverse osmosis systems, which use water whenever they are treating water, for concentrate waste. It is interesting that over 23% of the new homes in this group had some form of home water treatment.

Outdoor Model Results

The factors that best explain outdoor water use in standard new homes are:

- Irrigated area
- Number of person in home
- Household income,
- Whether landscape is being over-irrigated
- Landscape ratio
- Whether occupants reported having a leak in their swimming pool
- The presence of persons at home during the day
- The presence of a water feature or spa

Over-application of water for irrigation is an issue in new as well as in existing homes, with 62% of the homes applying more than the theoretical requirement for the landscape. The average over-irrigation among the standard new homes was just 6 kgal per home. This relatively low level of average over-irrigation indicates a balance between the many homes that tend to under-irrigate, which offsets the homes that tend to over-irrigate. This result indicates that if all members of the standard new home study group were to irrigate at exactly the level of the theoretical requirement then the average water savings would equal only 6 kgal per household.

The average excess use among sites that did over-irrigate was 27.7 kgal per household. This means that if the excess irrigators could be persuaded to reduce their use to the theoretical requirement, the savings would average 27.7 kgal per household for the entire 235 home sample.

[64] There was not enough homes built to create reliable models of water use for the high-efficiency new homes.

The model for outdoor water use prepared for the standard new home group shows few surprises. The irrigated area and the type of landscape relative to a pure turf landscape, measured by the landscape ratio, are key physical variables. The fact that ET does not show up on the list of explanatory variables is not surprising given the fact that many people are not aware of how to use ET to manage irrigation. The presence of over irrigation is a major determinant of outdoor water use, and a good indicator of conservation potential. Household income shows up as a factor for explaining outdoor use, but it was not a factor for indoor use. This implies that outdoor water use is more discretionary than indoor use and outdoor use will increase with income. The relationship between leaks in pools and the presence of water features and greater outdoor use is intuitive. The fact that having someone home during the day is a factor in increased outdoor use implies that having someone at home during the days to care for and enjoy the yard tends to lead to more water use.

General Conclusions

Largely due to changes in the plumbing codes over the past 20 years, people living in new homes are using less water than people living in older homes. However, these gains in indoor use efficiency are being offset by increases in outdoor use measured in new homes. On an annual basis water use in new and existing homes is statistically similar.

In this study the standard new homes used an average of 44 gallons per capita per day indoors while existing homes used an average of 62 gallons per capita per day. The high-efficiency new homes, which were generally built to the current WaterSense New Home specification showed even further improvements in indoor efficiency averaging 35.6 gpcd.

Water use reductions in the high-efficiency homes came mainly from toilets, clothes washers and faucet fixtures. Shower use stayed approximately the same. Average leakage rates in the new homes was essentially unchanged at around 20 gphd. The majority of leakage occurred in a small number of homes. The median household leakage rate was less than 3 gphd. Strategies and technologies to identify houses with significant leaks could be of great benefit to improving water use efficiency in the future.

These results show that there is no technical reason why household water use in single family homes can not be brought down to the range of 110 gphd for an average American family of 3. The homes in this study were not equipped with any highly specialized devices, rather they were equipped standard fixtures and appliances being manufactured to higher efficiency standards. Over time, it is only reasonable to expect that these devices will become the standard for both new construction and retrofits, making passive conservation savings inevitable and significant. For planning purposes use of 110 gphd for average indoor use for a family of 3 is supported by these data. Use of more sophisticated devices like smart meters and automatic leak detection devices can only enhance these trends toward lower household water use.

Outdoor water use efficiency levels are essential the same for new homes and existing homes, although factors such as irrigation method play an important role. Good strategies to conserve outdoor water use are to eliminate excess irrigation, prevent leaks, reduce the irrigated areas and use plant materials that require less irrigation water. Of these, the most important single factor is the presence of over-irrigation on the property. This is linked to an increase of 239% relative to the mean outdoor use in homes that over-irrigate. The key to converting this into water savings is to find ways to eliminate the over-irrigation without encouraging the under-irrigators to increase their use, which would eliminate most of the outdoor savings.

On a percent basis the data from this study suggest that a 40% reduction in indoor water use is a reasonable estimate of indoor savings by existing homes, which derives from a reduction in indoor use from 177 to 105 gphd. For outdoor use the savings potential appear to be around 35%, which is derived from reducing the average over-irrigation of 27 kgal per year relative to the baseline use of 78 kgal per year. On a volumetric basis these saving equate to approximately 26 kgal per year indoor use (365 x 72 gphd) and 27 kgal per year outdoor, or 53 kgal per year per home.

Perhaps the key conclusion of the report is that there are reasonable efficiency benchmarks for both indoor and outdoor water use in single family homes, which are supported by empirical data. For indoor use the data suggest three efficiency levels shown in Table 5-1. These values were projected from the relationships shown in Table 4-33, rounded to the nearest 10 gphd.

Table 5-1: Efficiency benchmarks for indoor water use

Category	**Household Efficiency Benchmark for Family of 3**	Description
Baseline	190 gphd	**Existing homes in the general population**
Standard New Home Efficiency	130 gphd	**Homes complying with NEPA plus 40% HE clothes washers**
High-efficiency New Homes	110 gphd	**Homes closely matching WaterSense New Home specification and matching end use pattern from Figure 4-19.**
Estimated water savings going from baseline to high-efficiency homes	**26 kgal/yr indoor 27 kgal/yr outdoor 53 kgal/yr total household**	**These are average savings, but are accounted for by a small group of high-users.**

The high-efficiency homes need to achieve two major goals: the use of indoor fixtures and appliances that meet or exceed the criteria similar to the WaterSense New Home specification, and the limitation of leakage to 20 gpd or less per household.

For outdoor use the efficiency benchmarks are not as clear cut, since there is so much variability among residential landscapes that affect their outdoor use. The study data, however, clearly suggest a range of outdoor use and what changes would be needed in the standard new homes in order to improve their efficiencies.

Table 5-2 and Table 5-3 use the regression models developed from the data (from Chapter 4) to predict outdoor water use from the study data set. If we assume a constant income, number of residents and irrigated area and allow the other parameters to vary, we can see that the current new home landscapes will have water requirements close to those of turf (as shown by the landscape ratio of 0.98), and the majority will be applying more than the theoretical requirements to the landscape. The average outdoor use for these homes is estimated at 93 kgal/year.

Table 5-2: Model predictions for current efficiency landscapes

Current Efficiency Landscapes				
Outdoor Factor	**Model Coefficient**	**Average value in sample**	**Model Factor**	**Explanation**
Constant	0.000202		0.0002020	constant factor
Excess (% of group)	3.23	64.4%	2.44	= 3.23*0.64 + (1-0.64)
Irrigated Area (sf)	0.61	3749.08	155.53	= 3749.08 ^ 0.61
Net ET	0.85	34.68	20.54	= 34.68 ^ 0.85
Income	0.36	$ 96,386	63.54	= 96385 ^ 0.36
Landscape Ratio	0.65	0.981	0.99	= .981 ^ 0.65
Person at home in day	1.15	0.64	1.10	= 1.15 * .64 + (1-0.64)
Bias correction	-15.20			correction factor
Predicted Annual use (kgal)			93.12	= product of 7 factors + bias correction

In order to improve the outdoor use efficiency of the homes by 27 kgal per year **Table 5-3** shows that it would be necessary to reduce the percent of homes that are over irrigating from 64% to 50% of the population and reduce the landscape ratio from 0.98 to 0.78. Both of these changes seem easily achievable.

Table 5-3: Predictions for improved efficiency landscapes

Imporved Efficiency Landscapes				
Outdoor Factor	**Model Coefficient**	**Average value in sample**	**Model Factor**	**Explanation**
Constant	0.000202		0.0002020	constant factor
Excess (% of group)	3.23	50%	2.12	= 3.23*0.5 + (1-0.5)
Irrigated Area (sf)	0.61	3749.08	155.53	= 3749.08 ^ 0.61
Net ET	0.85	34.68	20.54	= 34.68 ^ 0.85
Income	0.36	$ 96,386	63.54	= 96385 ^ 0.36
Landscape Ratio	0.65	0.78	0.85	= 0.78 ^ 0.65
Person at home in day	1.15	0.64	1.10	= 1.15 * .64 + (1-0.64)
Bias correction	-15.20			correction factor
Predicted Annual use (kgal)			65.93	= product of 7 factors + bias correction

Both of the outdoor use examples illustrate the factors that are important in varying outdoor water use. A well designed and maintained landscape could easily employ pools and water features while achieving a higher efficiency level provided leakage and excess irrigation were minimized and overall landscape water requirement (measured as a percentage of turf) was kept low. It is also important to keep in mind that of all of the factors, the most important with respect to conservative irrigation practice is the avoidance of excess irrigation (including leakage). Consider the data shown in Figure 4-41, which shows that 43% of the homes are applying more than 150% of their theoretical irrigation requirement. If the excess irrigation use on these homes was eliminated it would decrease the average outdoor use significantly without affecting the majority of the customers at all.

This report focused on analysis of water use patterns and efficiency benchmarks. Analysis of policies and practices needed to achieve these efficiencies is a subject for another study. The data from this study do suggest the key factors to consider in moving towards more effective water demand management programs. These include recognizing that water use is a highly skewed phenomenon, with a small number of large users influencing the mean use out of proportion to their numbers. Thus programs that are aimed at average users, may work well for mechanical devices like toilets and clothes washers, but they may not be applicable for excess irrigation and leakage. Water budgets, driven by marginal cost or penalty rate pricing or targeted interventions may work better for these cases.

Overall, this study shows a highly encouraging set of results. It demonstrates that by use of the current (as of 2010) best available technologies for toilets, clothes washers, showers and faucets real reductions in indoor water use can be achieved. The indoor use results showed a steady reduction in household and per capita use going from the 1999 REUWS homes to the Standard New Homes and then to the High-efficiency New Homes. This last group represents the current benchmark for high-efficiency indoor use in single family homes. It seems highly possible for homes with average number of residents to use less than 100 gpd for indoor purposes if better ways could be found to control high volume leaks resulting from long duration leak events.

The results also show that significant savings in outdoor use can be achieved by reducing the percent of customers who are over-irrigating, switching to lower water demand plant material and modest reductions in irrigated areas.

All of these efforts, both indoor and outdoor, would be enhanced with better real time data on water use reported to the occupants through easily accessible in-home reader. Such a device, when combined with reasonable water budgets would provide the customers with the information they need to be partners in the overall water management effort.

APPENDIX A – MEMO ON SELECTION OF STUDY GROUPS

From: Peter Mayer, Bill DeOreo, and Matt Hayden

Re: Clarification on Task 3: Selection of Study Groups: $Q_{1000pre}$, $Q_{1000post}$

There are two acceptable ways to select the sample groups. While we recommend the systematic random sample both were successfully used in the REUWS. The detailed procedure for selection of the survey study group follows. Please read through the procedures section of this memo and contact us at Aquacraft if you have any questions.

The preferred method of sample selection is called the systematic random sample approach (step 4a). In a systematic random sample the customer data are first sorted by their annual water use and then divided into strata. This helps insure that the sample matches the water use characteristic of the populations, especially if the consumption patterns are unevenly distributed. An alternate is to simply select a random sample from the pre and post 2001 groups (step 4b), which is undesirable at lower sample sizes.

Step 1 – Provide Aquacraft Information about Your Water Billing Database

Prior to sampling from your water billing data base, we would like to know specific "fields" of information that you maintain. Often, fields will have strange names, so please include descriptive definition. Please fax or e-mail us the complete list of available fields in your customer information and billing databases with definitions of each field. Also, if you re-use customer ID numbers, please describe how to uniquely identify individual accounts.

Step 2: Database Preparation – Screening and Sorting

Our goal is to retrieve a sample of 1,000 single-family (detached) accounts from both the pre and post 2001 population of single family homes. In the above survey, we ask if you have access to the year each customer's house was built. This is vital because the first step in this task is forming two exclusive sample sets from each participating utility: houses built prior to Jan 1, 2001, and houses built after Jan 1, 2001. Depending on your billing database, or the source of year-built information, some sites may not have this data. Hopefully these are rare exceptions, because we must exclude them from analysis.

These samples need to be representative of their respective populations. For the purposes of our study we need only look at consumption during 2005.

Working with a database of all single-family residential accounts the following tasks must be accomplished:

1) First separate out all the currently active single-family detached home account records in your database
2) Second, filter out accounts that do not have a complete year of data. (i.e. accounts that either opened or closed during 2005 and accounts that had no consumption in 2005)
3) Eliminate accounts that do not have a magnetic drive water meter

4) Select accounts for single-family (detached) homes for which you know the year built or the date on which the service was first initiated to the address. You may have this data for all houses in the database.

You'll end up doing the following steps twice:

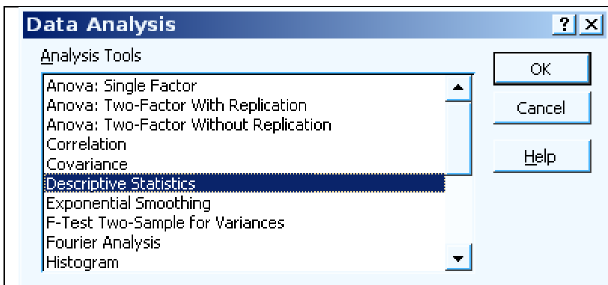
5) 9) Apply a filter within the database to export account records for homes built pre-2001, or apply a similar filter for those built 2001-on. Alternatively, you can accomplish this if you're willing to export your billing database into an external application, like MS Access.
6) 10) Separate the customers into pre and post 1/1/2001 groups.
7) 11) Count the number of accounts in each group.
8) 12) Number the accounts in each group sequentially.

Step 3: Calculating Summary Statistics

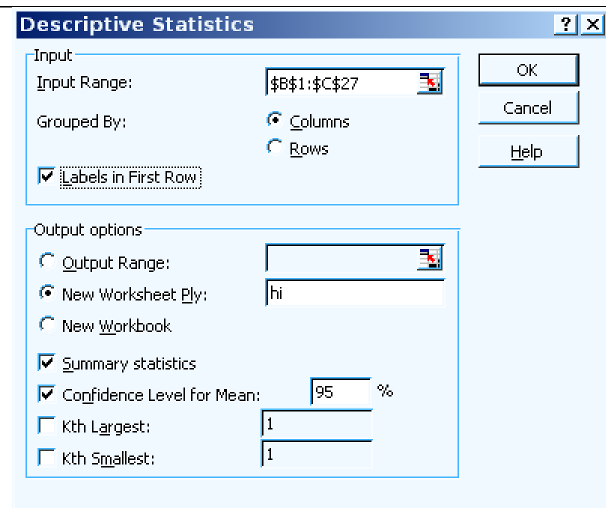
In order to evaluate the representativeness of the pre and post Q_{1000} samples we will need some summary statistics about each sample. These statistics will be used to compare a sample set against your entire database, thus ensuring you the chance to inspect it's randomness. The following statistics should be determined for the 2005 consumptions data for the pre and post 2001 groups:

- Count of accounts
- Total deliveries to all account in the group
- Mean annual delivery per account
- Median annual delivery per account
- Standard Deviation of the annual deliveries
- 10 through 90 percentiles

1) If you're familiar with the Analysis Toolkit optional add-in to Microsoft Excel, these numbers can be extracted quite easily using Descriptive Statistics.



1) After clicking Tools-> Data Analysis



2) After clicking Descriptive Statistics. The only required option is Summary statistics.

-or-

2) Alternatively, it's quite easy to extract Count, Total, and Mean using Microsoft Access. However, if you're interested in using Access to calculate the *Median* function, it gets complicated--contact me at Aquacraft.

For many, standard deviation and histograms on 1000 records are actually easier in Excel.

SELECT EITHER STEP 4A OR 4B:

Step 4a: Systematic Random Sample Option

In order to select the random sample perform the following steps:

1) Divide the accounts into pre and post 1/1/2001 start dates.
2) Sort the accounts in each group by annual water use, from lowest to highest.
3) Divide the total number of accounts in the, sorted database by 1,000 to generate a sampling interval. For example, if you have 35,000 accounts, the sampling interval would be 35.
4) If you have fewer than 1000 post 2001 accounts (i.e. your sampling interval is 1 or less) skip the selection process and simply send the data for all of the new accounts.
5) If you have more than 1000, select a random number between 1 and 35 (or whatever your sampling interval happens to be).
6) The random number will be the first member of the sample. Assuming that the random number is 6, the utility should select the 6th account from the screened and sorted data base, and then select every 35th (use your own sampling interval) thereafter, until the complete list of single-family accounts (i.e., all 35,000) is exhausted. This procedure will roughly provide a list of ~1,000 single-family accounts.
7) Check that the mean of the Q1000 you select lies within the 95% confidence interval around the mean use for the population. If it doesn't, pick another random number for starting your selection and re-check. Often a very few outliers can affect the mean of the sample, so this iterative process may be needed. We need to have the mean of the sample within the 95% confidence interval for the population of all single family homes in your sample frame.

Step 4b: Simple Random Sample Alternative

In some cases, such as when you are dealing with multi-jurisdictional samples, or very large customer databases[65], it may prove simpler to choose a sample using the following approach.

1) Screen out the customers with incomplete data for 2005 or those who do not have a magnetically-driven water meter, as was done above
2) Sort the list into pre and post 1/1/2001
3) Keep the customer list in a random order; not sorted by any particular parameter
4) Generate a list of *n* random numbers between 1 and the total number of accounts in your screened database where *n* equals the number you wish to have in your sample
5) Extract those records to a separate table
6) Check the annual water use statistics of the selected sample (using the same process as Step 3, like Descriptive Statistics in Excel) against those of the entire screened database. The mean of the sample should lie within the 95% confidence intervals of the mean of the population. If the sample mean does not lie within the 95% confidence interval; resample and check again.

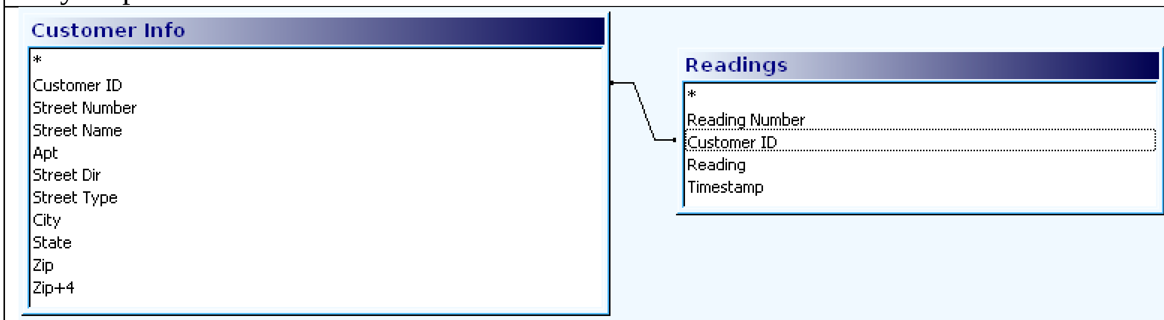
Step 5: Export Q1000Pre and Q1000Post databases

[65] Larger than 65535 records

Once selected, the 1000-member Q_{1000}Pre and Q_{1000}Post groups should be saved to separate files. A common way to do this would be to provide one table with all of the customer information for each account (for example, the year their house was built) and separate files with the consumption information for 2005. Please call to discuss the exact format once we get to this step. Once the Q_{1000} databases are delivered they will be used to mail out the surveys and to select the 40 new homes for logging.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	CUSTID	NO	NO-EXT	DIR	STREET	TYPE	CITY	STATE	ZIP	ZIP-4	Jan-Feb 04	Mar-Apr 04	May-Jun 04	Jul-Aug 04	Sep-Oct 04	Nov-Dec 04
2	0001	1234			YOSEMITE	ST	DENVER	CO	80220	3611	2	1	5	10	3	1
3	0002	1235		S	SPOTSWOOD	ST	LITTLETON	CO	80120		4	2	6	13	14	13
4	0003	1236		S	CHEROKEE	ST	LITTLETON	CO	80120	2341	10	3	3	5	4	5
5	0004	1237			ZENOBIA	ST	DENVER	CO	80212		8	9	12	17	13	4
6	0005	1238		W	BEEKMAN	PL	DENVER	CO	80221	1585	10	10	6	10	16	7
7	0006	1239		S	RALEIGH	ST	DENVER	CO	80219		16	13	7	13	13	11
8	0007	1240		S	EMPORIA	CIR	ENGLEWOOD	CO	80111		0	23	77	85	96	10
9	0008	1241		W	KENYON	AVE	DENVER	CO	80235		11	9	12	23	25	17
10	0009	1242		S	PATTON	CT	DENVER	CO	80236		16	9	16	30	34	23
11	0010	1243		S	HONEY LOCUST	CIR	ENGLEWOOD	CO	80121	2136	9	108	86	130	66	13
12	0011	1244		S	MARSHALL	CT	LITTLETON	CO	80123		12	10	12	14	12	11
13	0012	1245		S	KIPLING	CT	LITTLETON	CO	80127	2571	21	11	10	15	12	12
14	0013	1246		S	ALBION	ST	DENVER	CO	80222		11	13	20	23	14	11

A flat file in MS Excel will appear like this. Note that each row indicates a single customer's usage data. When possible, a header row and an explanation of the units is very helpful.



Obtaining the same format in MS Access, however, will start with a screen like this. Both of these formats are convenient. The Excel format above is easier for human interpretation, but the Access version below is much easier for computerized analysis. For example, over many billing cycles, the Excel format will have an unwieldy number of columns.

The above data sample from a previous study should illustrate the ideal format for the consumption data. Below we list the precise fields we would like to obtain for both groups of 1000.

Database Fields of Interest - We are interested in the following fields for the purpose of surveying customers, analyzing historic water use patterns, and collecting detailed end use data from a sub-set of customers. Items in red are mandatory fields that we must have to conduct the study.

- Account Number (number which remains with the ***service address***)
- Customer name (for addressing surveys)
- Service Address (the following is often is separate data field)
    - Street Number
    - Street Name

    - Suffix (Rd ., St., Lane, etc.)
- Service city
- Service state
- Service zip code
- Home telephone number (if available)
- Status (when doing the selection; you may have to screen on a field that denotes "active" accounts)
- Date of account initiation (i.e., when the account was started)
- Water meter information (these data are important for the data logging effort)
    - Meter make
    - Meter model
    - Meter size
    - Meter ID number
    - Meter location
- Lot size/landscape area
- Individual periodic consumption data and the read date for each account in addition to the annual summary. This data should include the most recent 13 months (13 meter read dates and consumption on a monthly cycle or 7 meter read dates and consumption if on a bimonthly billing cycle)
- Days of each billing period. The number of days covered in a given billing period. Meter read dates are also acceptable.
- Other customer information (# of bedrooms, bathrooms, building footprint, impervious area, etc.

Example: The customer billing data base for Watertown, USA includes the following fields:

1) ACCTNO -- Individual number which remains with service address.
2) NAME -- Name of the account holder.
3) ST_NO -- Service address number
4) ST_NAME -- Name of Service Street
5) ST_TYPE -- Type of Service Street (Ave., Blvd. etc.)
6) CITY -- Service City name
7) ZIP -- Service Zip code
8) ACCT_TYPE -- Type of account (single-family, commercial, industrial, etc.)
9) METER_SIZE
10) JAN06 -- Water consumption for January 2006
11) JANDATE -- Read date for January 2006 consumption
12) JANDAYS -- Number of days in the January 2006 consumption period
13) DEC05 -- Water consumption for December 2005
14) DECDATE -- Read date for December 2005
15) .... You get the idea.

The Watertown water meters are read on a monthly basis.
The units of water consumption for the Watertown utility are: Kgal

Thank you for giving this matter your attention.

APPENDIX B – HOUSEHOLD WATER USE SURVEY

Household Water Use Survey

Indoor Water Fixtures

1. Please indicate how many of each of the following types of water-using appliances or fixtures you have in your home. Please circle the appropriate number for each.

	None	One	Two	Three	Four	Five	Six	Seven or more
Toilets	0	1	2	3	4	5	6	7+
Bathtub with shower	0	1	2	3	4	5	6	7+
Bathtub only	0	1	2	3	4	5	6	7+
Shower only (no bathtub)	0	1	2	3	4	5	6	7+
Indoor utility/garage sink	0	1	2	3	4	5	6	7+

2. Please indicate whether you have any of the following in your home.
Please check the appropriate box for each.

	Yes	No
Garbage disposal	❑	❑
Top-loading clothes washing machine	❑	❑
Front-loading clothes washing machine	❑	❑
Dishwashing machine	❑	❑
Whirlpool bathtub with jets	❑	❑
Indoor spa or hot tub with jets (if hot tub is NOT usually filled with water, indicate "no")	❑	❑
Evaporative/swamp cooler	❑	❑
A built-in indoor water feature (like a water fountain or water pond)	❑	❑
A "whole house" water treatment system (like a water softener or a filter system) which is attached to water system, not just to a faucet	❑	❑

	None	One	Two	Three	Four or more	Don't Know
3. How many of the toilets in your home are ultra-low-flush toilets (1.6 gallons per flush)? *(If your home was built in 1994 or later, the toilets are probably ultra-low flush)*	❑	❑	❑	❑	❑	❑
4. How many of the showers in your home have low-flow (water conserving*) showerheads? **2.5 gallons per minute (gpm) or less, usually stamped on the showerhead*	❑	❑	❑	❑	❑	❑
5. How many of the showers in your home have a hand-held sprayer?	❑	❑	❑	❑	❑	❑

6. Do any of the showers in your home have multiple showerheads?
   - ❑ Yes → How many showerheads per shower? ❑ 2 ❑ 3 ❑ 4 or more
   - ❑ No

7. Please indicate whether you have renovated or replaced any of the following since 1995.
Please check the appropriate box for each.

	Yes	No
Plumbing pipes (inside the house)	❑	❑
Bathroom fixtures	❑	❑
Kitchen fixtures	❑	❑

8. Please indicate whether you have any of the following.
Please check the appropriate box for each.

	Yes	No
Leaking toilet (you can hear it running when not in use)	❑	❑
Dripping faucet	❑	❑
Leaks in your pool system	❑	❑
Leaks in your irrigation system	❑	❑
Other leaks in the water system	❑	❑

Household Water Use Survey (version 2006-11-01) *Page 1 of 5*

Hot Water

9. What type is your water heater?
(Please check all that apply.)
   - ❑ Gas
   - ❑ Electric
   - ❑ Propane
   - ❑ Solar
   - ❑ Other ________________
   - ❑ Don't know

10. Do you have or have you installed a remedy to eliminate or reduce "waiting for hot water"?
   - ❑ Yes
   - ❑ No → *go to question #12*
   - ❑ Don't Know → *go to question #12*

11. What remedies are installed?
(Please check all that apply.)
   - ❑ Tankless water heater
   - ❑ On-demand system (recirculating pump that goes on when I push a button)
   - ❑ Other __________________________
   - ❑ Recirculating pump installed on hot water system → How does it work?
     - ❑ It runs all the time
     - ❑ It is controlled by a timer clock
     - ❑ Don't know
     - ❑ Other _________________

12. Does hot water take longer to reach some places in your house than others?
   - ❑ No, hot water reaches all fixtures in about the same amount of time
   - ❑ Yes, some places take longer than others for hot water to reach → Which rooms? (Check all that apply.)
     - ❑ kitchen
     - ❑ master bathroom
     - ❑ other bathroom
     - ❑ other room ________________

13. Thinking of the place in the house where it takes hot water the longest to reach, how long would you say you have to wait for hot water?
   - ❑ Almost no time at all
   - ❑ Not very long, we just have to let the water run for a few seconds
   - ❑ Pretty long, we have to let the water run a while before it runs hot
   - ❑ Very long, we have to let the water run a long time before it runs hot

14. Does the wait for hot water bother you?
   - ❑ Yes, very much
   - ❑ Yes, a little bit
   - ❑ No, not really

Outdoor Landscape

15. Do you water your outside landscape?
(Include everything you apply water to, either by hand, or via an irrigation system or other method.)
   ❑ Yes ❑ No → *go to question #36*

16. Do you use a contractor for any part of your outdoor landscape maintenance?
   ❑ Yes ❑ No → *go to question #19*

17. Is your contractor responsible for watering (irrigating) your outdoor landscape?
   ❑ Yes ❑ No

18. About how much of your outdoor landscape is <u>turf (lawn or grass)</u>?
   - ❑ All of it (100%)
   - ❑ Half or more
   - ❑ About 20% to 50%
   - ❑ About 10% to 20%
   - ❑ About 5% to 10%
   - ❑ Less than 5%
   - ❑ None of it → *go to question #21*

19. During the winter months of the year (generally December - February), how often do you usually water your turf?
   - ❑ Never
   - ❑ Twice a month or less
   - ❑ A few times per month
   - ❑ 1 day a week
   - ❑ 2 days a week
   - ❑ 3 days a week
   - ❑ 4 days a week
   - ❑ 5 days a week
   - ❑ 6 days a week
   - ❑ 7 days a week
   - ❑ Not sure

20. During the summer months of the year (generally June - August), how often do you usually water your turf?
   - ❑ Never
   - ❑ Twice a month or less
   - ❑ A few times per month
   - ❑ 1 day a week
   - ❑ 2 days a week
   - ❑ 3 days a week
   - ❑ 4 days a week
   - ❑ 5 days a week
   - ❑ 6 days a week
   - ❑ 7 days a week
   - ❑ Not sure

Household Water Use Survey (version 2006-11-01) *Page 2 of 5*

21. About how much of your outdoor landscape is garden (flower or vegetables)?
    - ❑ All of it (100%)
    - ❑ Half or more
    - ❑ About 20% to 50%
    - ❑ About 10% to 20%
    - ❑ About 5% to 10%
    - ❑ Less than 5%
    - ❑ None of it → *go to question #24*

22. During the winter months of the year (generally December - February), how often do you usually water your garden(s)?
    - ❑ Never
    - ❑ Twice a month or less
    - ❑ A few times per month
    - ❑ 1 day a week
    - ❑ 2 days a week
    - ❑ 3 days a week
    - ❑ 4 days a week
    - ❑ 5 days a week
    - ❑ 6 days a week
    - ❑ 7 days a week
    - ❑ Not sure

23. During the summer months of the year (generally June - August), how often do you usually water your garden(s)?
    - ❑ Never
    - ❑ Twice a month or less
    - ❑ A few times per month
    - ❑ 1 day a week
    - ❑ 2 days a week
    - ❑ 3 days a week
    - ❑ 4 days a week
    - ❑ 5 days a week
    - ❑ 6 days a week
    - ❑ 7 days a week
    - ❑ Not sure

24. About how much of your outdoor landscape is other landscape plants (e.g., trees, shrubs, vines, ground covers, etc.)?
    - ❑ All of it (100%)
    - ❑ Half or more
    - ❑ About 20% to 50%
    - ❑ About 10% to 20%
    - ❑ About 5% to 10%
    - ❑ Less than 5%
    - ❑ None of it → *go to question #27*

25. During the winter months of the year (generally December - February), how often do you usually water your other landscape plants?
    - ❑ Never
    - ❑ Twice a month or less
    - ❑ A few times per month
    - ❑ 1 day a week
    - ❑ 2 days a week
    - ❑ 3 days a week
    - ❑ 4 days a week
    - ❑ 5 days a week
    - ❑ 6 days a week
    - ❑ 7 days a week
    - ❑ Not sure

26. During the summer months of the year (generally June - August), how often do you usually water your other landscape plants?
    - ❑ Never
    - ❑ Twice a month or less
    - ❑ A few times per month
    - ❑ 1 day a week
    - ❑ 2 days a week
    - ❑ 3 days a week
    - ❑ 4 days a week
    - ❑ 5 days a week
    - ❑ 6 days a week
    - ❑ 7 days a week
    - ❑ Not sure

27. 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?
    - ❑ No additional sources of water used
    - ❑ Well water
    - ❑ Canal/ditch
    - ❑ Stream/river
    - ❑ Cistern (rainwater harvesting)
    - ❑ Landscaping or device which directs roof water toward plants in the yard
    - ❑ Other: ______________________________

28. Is any part of your outdoor landscape watered manually?
    - ❑ Yes   ❑ No → *go to question #31*

29. In what ways is the outdoor landscape watered manually? (Please check all that apply.)
    - ❑ Hand-held garden hose (with or without a nozzle)
    - ❑ Garden hose with sprinkler attached
    - ❑ Soaker hose
    - ❑ Drip irrigation or bubbler system
    - ❑ In-ground sprinkler system without a timer

30. About how much of your outdoor landscape is watered manually?
    - ❑ All of it (100%)
    - ❑ Half or more
    - ❑ About 20% to 50%
    - ❑ About 10% to 20%
    - ❑ About 5% to 10%
    - ❑ Less than 5%

Household Water Use Survey (version 2006-11-01) *Page 3 of 5*

31. Do you have an in-ground watering (irrigation) system?
    - ❑ Yes
    - ❑ No → *go to question #36*

32. Does your outdoor water system have any broken sprinkler heads?
    - ❑ Yes
    - ❑ No
    - ❑ Don't know

33. Does your in-ground irrigation system have an automatic timer?
    - ❑ Yes
    - ❑ No

34. Does your automatic irrigation system have an override shut-off device such as a soil moisture sensor or rain sensor? (Please check all that apply.)
    - ❑ No override shut-off device
    - ❑ Yes, soil moisture sensor installed
    - ❑ Yes, rain sensor installed
    - ❑ Other ______________________
    - ❑ Don't know

35. Does your automatic irrigation system have a weather-based irrigation controller (WBIC) or "smart" controller?
    - ❑ No
    - ❑ Yes
    - ❑ Don't know

Outdoor Water Fixtures

36. Does your home have an outdoor spa or hot tub?
    - ❑ Yes
    - ❑ No → *go to question #38*

37. Is the outdoor spa or hot tub usually filled?
    - ❑ Yes, all year round
    - ❑ Yes, in the winter
    - ❑ No, but it is sometimes filled
    - ❑ No, it is never filled

38. Do you have an outdoor water feature like a fountain or pond? *(Note: do not include bird baths; only features that use a significant amount of water.)*
    - ❑ Yes
    - ❑ No

Swimming Pools

39. Does your home have a swimming pool?
    - ❑ No → *go to question #44*
    - ❑ Yes, outdoor pool only → *go to question #41*
    - ❑ Yes, indoor pool only
    - ❑ Yes, indoor AND outdoor pool

40. What type of filling system does the indoor swimming pool have? (If your home ONLY has an indoor swimming pool, please check the appropriate box and then go to question #44.)
    - ❑ Manual
    - ❑ Automatic

41. What type of filling system does the outdoor swimming pool have?
    - ❑ Manual
    - ❑ Automatic

42. Do you have a swimming pool cover that you use when the outdoor pool is not in use?
    - ❑ Yes
    - ❑ No → *go to question #44*

43. What months of the year do you typically use the pool cover? (Please check all that apply.)
    - ❑ January
    - ❑ February
    - ❑ March
    - ❑ April
    - ❑ May
    - ❑ June
    - ❑ July
    - ❑ August
    - ❑ September
    - ❑ October
    - ❑ November
    - ❑ December

44. How do you feel about enforcement of local water waste ordinances?
    - ❑ It is too lax
    - ❑ It is too stringent
    - ❑ Don't Know

45. 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
Without looking at past bills, I know about how much my average (typical) household water bill was (in dollars) last year	❑	❑	❑	❑	❑
Without looking at past bills, I know about how much water my household used in an average (typical) billing period last year	❑	❑	❑	❑	❑
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.)	❑	❑	❑	❑	❑
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.)	❑	❑	❑	❑	❑
I conserve water mainly for environmental reasons	❑	❑	❑	❑	❑
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."*

Household Water Use Survey (version 2006-11-01) Page 4 of 5

These last few questions are about your house and your household. This information will only be used to group responses.

46. Is your house on a septic system?
 ❑ Yes ❑ No ❑ Don't Know

47. Is your household responsible for paying the water bill, or is it paid by a landlord or homeowners' association?
 ❑ Household pays
 ❑ Landlord or a homeowner's association → *go to question #49*
 ❑ Don't know → *go to question #49*

48. Are wastewater (sewer) charges included on the bill you receive for water service?
 ❑ Yes ❑ No ❑ Don't Know

49. About when was your home built?
 ❑ Before 1940 ❑ 2001
 ❑ In the 1940s ❑ 2002
 ❑ In the 1950s ❑ 2003
 ❑ In the 1960s ❑ 2004
 ❑ In the 1970s ❑ 2005
 ❑ In the 1980s ❑ 2006
 ❑ Between 1990 and 1994
 ❑ Between 1995 and 2000

50. In what year did you move to this home? .... ___________*year*

51. How many bedrooms does this house have?
 ❑ 1 ❑ 3 ❑ 5
 ❑ 2 ❑ 4 ❑ 6 or more

52. Do you have a garage?
 ❑ No
 ❑ Yes, attached to the house
 ❑ Yes, detached from the house

53. How many people, including yourself, live full-time at this address?
 ______ Adults, including yourself (age 18+)
 ______ Teenagers (age 13-17)
 ______ Older Children (age 6-12)
 ______ Younger Children (age 3-5)
 ______ Infants or Toddlers (under age 3)

54. What number of adults living at this address are employed full-time OUTSIDE the home?
 ❑ None (0) ❑ 2 ❑ 4
 ❑ 1 ❑ 3 ❑ 5 or more

55. Do you rent or own your residence?
 ❑ Rent →
 About what is your monthly rent payment?
 ❑ Less than $300 per month
 ❑ $300 to $449 per month
 ❑ $450 to $600 per month
 ❑ $600 to $799 per month
 ❑ $800 to $999 per month
 ❑ $1,000 to $1,249 per month
 ❑ $1,250 to $1,499 per month
 ❑ $1,500 to $1,749 per month
 ❑ $1,750 to $2,000 per month
 ❑ $2,000 to $2,249 per month
 ❑ $2,250 to $2,499 per month
 ❑ $2,500 or more per month
 ❑ Own →
 About what is the market value of your home?
 ❑ $Less than $100,000 ❑ $400,000 to $449,999
 ❑ $100,000 to $149,999 ❑ $450,000 to $499,999
 ❑ $150,000 to $199,999 ❑ $500,000 to $599,999
 ❑ $200,000 to $249,999 ❑ $600,000 to $699,999
 ❑ $250,000 to $299,999 ❑ $700,000 to $799,999
 ❑ $300,000 to $349,999 ❑ $800,000 to $899,999
 ❑ $350,000 to $399,999 ❑ $900,000 to $999,999
 ❑ $1,000,000 to $1,249,999
 ❑ $1,250,000 to $1,499,999
 ❑ $1,500,000 or more

56. What is the last grade of formal education the primary wage earner has completed?
 ❑ Less than High School
 ❑ High School degree
 ❑ Some College or Associate's degree
 ❑ Bachelor's degree
 ❑ Master's degree
 ❑ Doctoral degree

57. About how much do you estimate your household's total income before taxes was last year? Please check the appropriate box below.
 ❑ Less than $30,000 ❑ $120,000 to $139,999
 ❑ $30,000 to $39,999 ❑ $140,000 to $159,999
 ❑ $40,000 to $49,999 ❑ $160,000 to $179,999
 ❑ $50,000 to $59,999 ❑ $180,000 to $199,999
 ❑ $60,000 to $69,999 ❑ $200,000 to $224,999
 ❑ $70,000 to $79,999 ❑ $225,000 to $249,999
 ❑ $80,000 to $89,999 ❑ $250,000 to $274,999
 ❑ $90,000 to $99,999 ❑ $275,000 to $299,999
 ❑ $100,000 to $119,999 ❑ $300,000 or more

58. If you have any comments about how your household uses water, or about your water service, please write them in the space below or include them on your own paper.

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APPENDIX C – HIGH-EFFICIENCY NEW HOME SPECIFICATION

Beginning in the spring of 2006, Salt Lake City and a number of other municipal water providers across the United States began a systematic study of water use in new homes. This study, funded by the US EPA and a consortium of nine participating water providers, is seen as an important component of EPA's WaterSense water efficiency program. The research team was led by Aquacraft, Inc. and includes 3D Building Solutions, and the National Research Center.

The goal of this study was to examine water use in new homes built across the United States. Water use in new homes were compared to use in existing homes to see if new homes use more or less water than existing homes (after normalizing on factors such as number or residents, size of home, size of landscape etc). The study also aimed to determine if a group of high-efficiency homes, using the best available technologies on the market, could make significant and cost-effective water use reductions beyond those derived from use of standard technology.

This raised the question as to what constitutes a high-efficiency (HE) new home. The researchers recognized that there are many definitions for the term "high-efficiency". Aggressive application of technology combined with proper training and education of residents could reduce water use in single-family homes significantly. For example, at one extreme one could simply apply more advanced fixtures and appliances to reduce indoor use, or at the other, one might use advanced recycling systems to recapture and reuse indoor use so that only makeup water would be needed. The decision was up to the builder and homeowner.

For this project, the researchers proposed a set of minimum criteria for qualification as a "high-efficiency" water use home. Homes participating in the "best available technology" portion of this study must have met as many these minimum qualification requirements as possible. It was left to the discretion of the builders and the local water providers to go beyond the minimum based on their level of experience, local situation, and commitment to water conservation.

Table C-1 contains the researchers' recommendations for minimum performance specifications for homes to be included in the high-efficiency group. These performance specifications represented the target minima, and we recognized that it may not be possible to include all of the water efficiency features in every home. In particular, landscape installation may have been beyond the builder's control. The goal of the research team was to encourage inclusion of all features at the minimum performance specification, but the team was willing to include homes with only some of the features if necessary. Some features such as toilets, showerheads, clothes washers, and faucet aerators were required to meet the minimum specification for inclusion in the study.

Table C-1: Suggested "minimum" specifications for high-efficiency homes

Feature	Performance Requirement	Performance Specification and/or Reference
High-efficiency Toilet (HET)*	1.28 gallons per flush (average)	EPA WaterSense draft HET spec (http://www2.ergweb.com/projects/conferences/water/het-docs/Specification_7-April-2006.pdf)
Faucet aerators*	Bath: 1.5 gpm @ 60 psi Kitchen: 2.2 gpm @ 60 psi	Builder option
Low-flow showerheads*	Single head using 1.6 gpm or less with "satisfactory" wetting performance	Builder option (e.g. Delta H2O Kinetics, Bricor, Niagara)
h-axis clothes washers*	Water Factor (WF) 7.5 or less	Consortium for Energy Efficiency rating Tier 3A (http://www.cee1.org/resid/seha/rwsh/reswash_specs.pdf)
Energy Star dishwashers*	6.5 gal/cycle or less	Energy Star rating. See State of Oregon listings: http://oregon.gov/ENERGY/CONS/RES/tax/appdish.shtml
Water-wise landscape design and installation	Landscaped designed to require < 60% ETo overall	See landscape budget worksheet on www.aquacraft.com or use the GreenCo water budget calculator at www.greenco.org. Use budget tools to develop water budget for design landscape and compare this to budget for a reference landscape of cool season grass.
Smart irrigation controllers *Controller utilizes local data to adjust irrigation schedule automatically.*	Devices with published SWAT testing results presumed acceptable; others on a case by case basis.	Based on SWAT performance criteria. http://www.irrigation.org/gov/default.aspx?pg=swat_intro.htm&id=105 This site lists testing criteria for both controllers and sensor based systems and provides performance reports for controllers that have passed the tests. Individuals may sign up for notices as new controller/sensor results are released.
Inspection of landscape and irrigation system by certified professional.	3rd-party field inspection/testing of landscape & irrigation system performance.	Independent party must verify that landscape was installed as designed, and that the irrigation system meets minimum performance standards based on IA BMP's. http://www.irrigation.org/gov/default.aspx?pg=BMPs.htm&id=104 Inspector should be IA certified (or hold a comparable certification).

*Minimum specification must be achieved for inclusion in study.

Other Recommendations for High-efficiency Homes

- Install devices that provide real time feedback to the homeowners on their water use.. These devices give the homeowners immediate and easy to access information on their current and cumulative water use and costs for water, and alert them to leaks. Water use should be compared to a water budget established for the home. Having this in the kitchen is ideal. System could also turn water off in case of leaks or burst pipes.
- Install hand sprayers (with on-off buttons) on all bathtubs so that people can wash with the sprayer instead of filling up the tub.
- Install aerators with on/off switches on all sinks so people can avoid running water unnecessarily.
- Install showerheads with on/off switches
- Install hands free faucet controllers
- Install faucets that utilize flow control technology (currently available in Europe)
- Plumbing systems that allow gray water reuse for toilet flushing or irrigation.
- Structured hot water plumbing designs to eliminate wait time for hot water
- Provide a clear set of instructions to the homeowners on how to use and take full advantage of the water efficiency features of the house.

APPENDIX D - FLOW TRACE ANALYSIS DESCRIPTION[66]

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

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

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

Data Logging Equipment

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

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

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

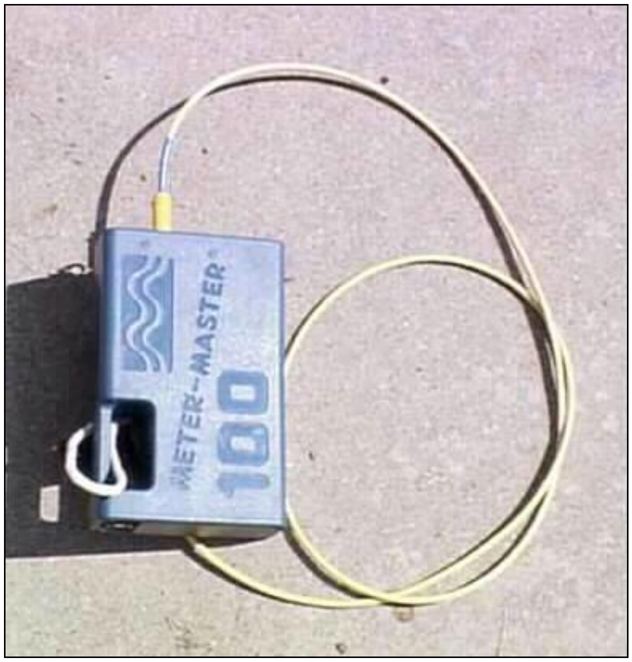

Figure D.1 One of the data loggers used in the study

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

End Use Data Analysis

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

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

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

Trace Wizard

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

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

Once all the water use events have been isolated and quantified and statistics generated, Trace Wizard implements a user defined set of parameters developed for each individual study residence to categorize the water use events and assign a specific fixture designation to each event. These parameters can include the volume, duration, peak flow rate, and mode flow rate of each specific fixture. For example, a toilet may be defined as using between 3.25 and 3.75 gallons per flush, the peak re-fill flow rate is between 4.2 and 4.6 gpm, the duration of flush event is between 30 and 50 seconds, and the mode flow rate is between 4 and 4.5 gpm. Similar parameters are established for each of the fixtures found in the household. This simple signal processing routine runs quickly and assigns a fixture category (toilet, shower, clothes washer, etc.) to each water use event. The routine is re-run by the analyst frequently during the analysis process as the parameters are "fine tuned" to fit the fixtures in each specific house. The analyst uses the survey response data detailing the specific water-using appliances and fixtures in the house to build the parameter file which assigns fixtures to water use events. The graphical interface of Trace Wizard allows the analyst to visually inspect water use events and build the parameter file so that it correctly identifies as many of the water use events as possible. When working for the first time with data from a residence it takes a trained analyst approximately one hour per week of data to complete flow trace analysis using Trace Wizard. Once an accurate parameter file has been created for that specific residence, the analysis time can be reduced significantly.

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

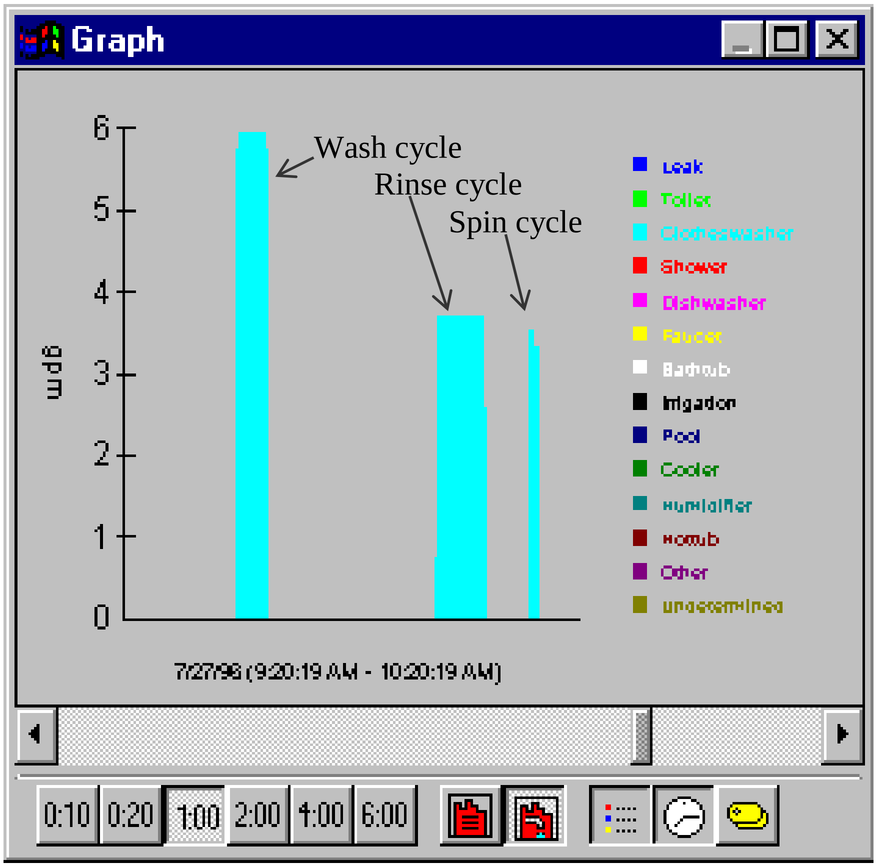

Figure D.2 Sample flow trace from Trace Wizard showing a one hour view. Water events depicted include a three cycle clothes washer.

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

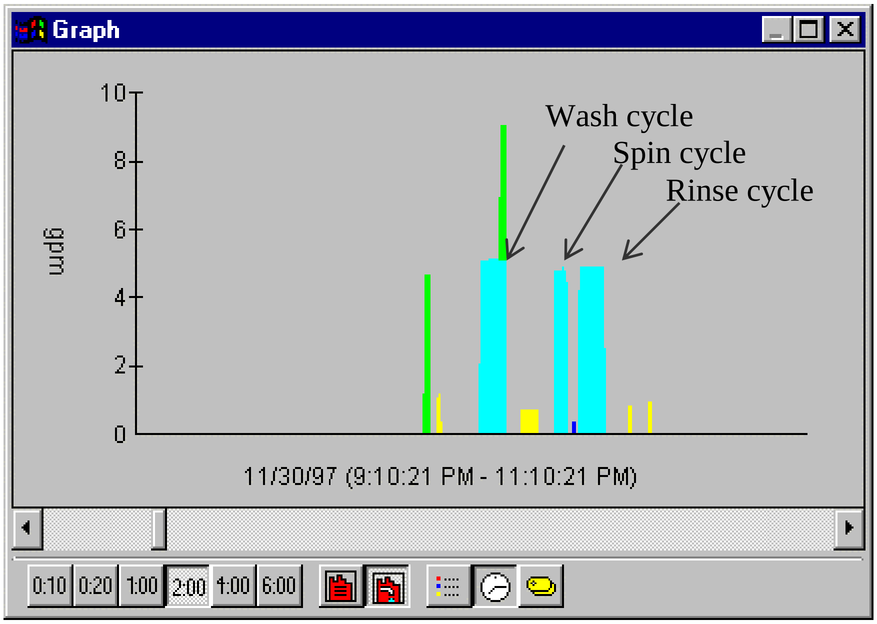

Figure D.3 Sample flow trace from Trace Wizard showing a two hour view. Water events depicted include two toilet flushes, a three cycle clothes washer, and several faucets.

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

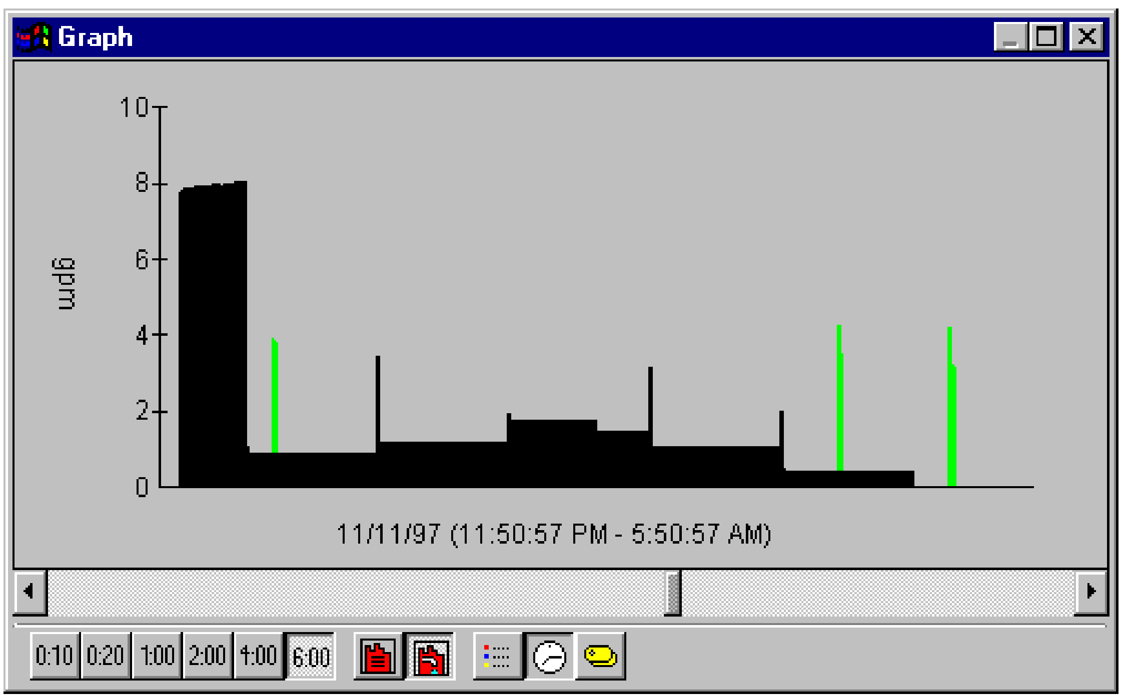

Figure D.4 Sample flow trace from Trace Wizard showing a six hour view. Water events depicted include a multi-zone automatic irrigation system and three toilet flushes.

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

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

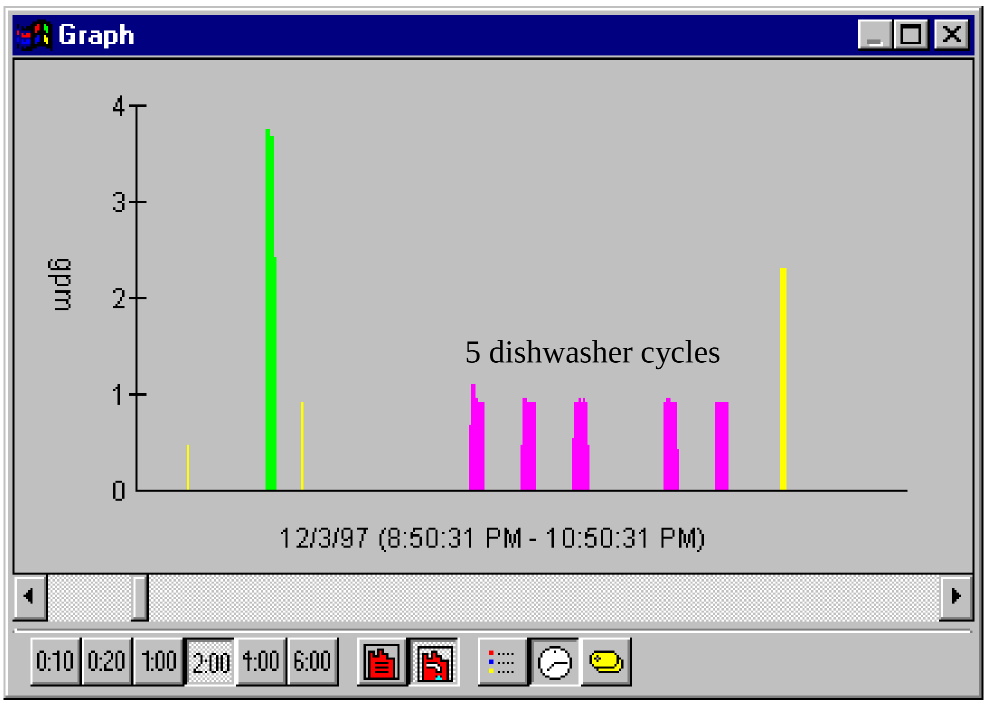

Figure D.5 Sample flow trace from Trace Wizard showing a two hour view. Water events depicted include a toilet flush, a five cycle dishwasher, and various faucet uses.

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

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

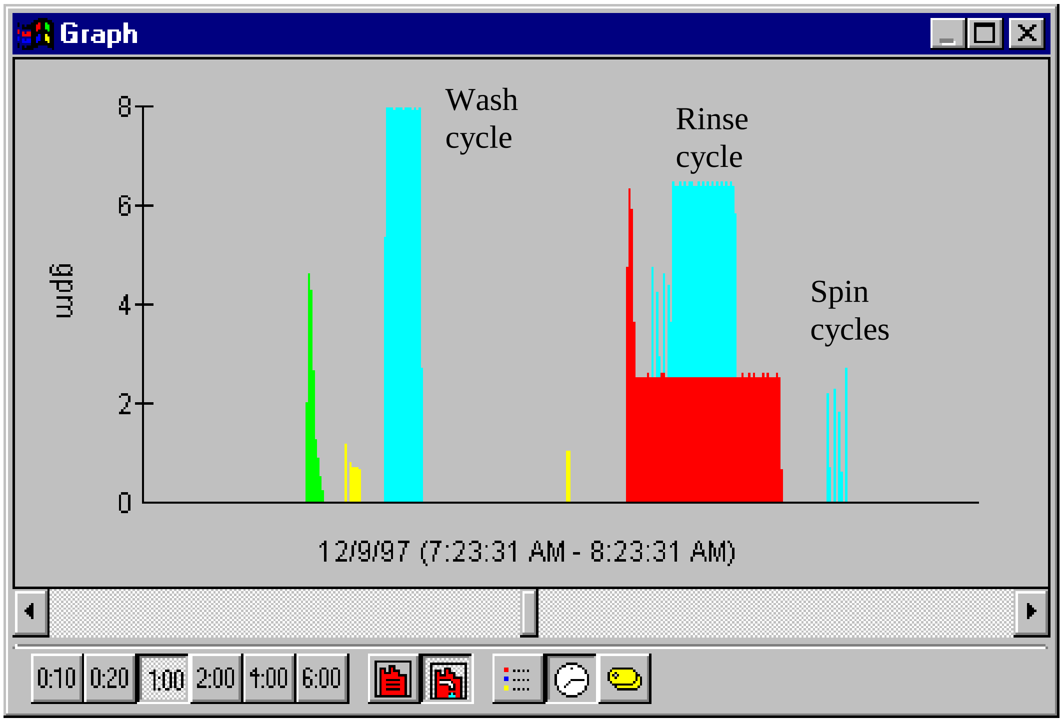

Figure D.6 Sample flow trace showing a one hour view. Water events depicted include a toilet flush, multi-cycle clothes washer, and shower.