Residential End Uses of Water, Version 2 [Project #4309]

ORDER NUMBER: 4309B

DATE AVAILABLE: April 2016

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Water demands of single-family[1] homes are significant because they typically use the most water of any utility customer sector in North America. Water use in homes and buildings has been the subject of scientific research since the 1940s. Since 1994, interest in the specific "end uses" of water in homes has intensified, as the Energy Policy Act of 1992 (DOE 1992) and other codes and standards have mandated reductions in toilet flush volumes, clothes washer volumes, as well as shower and faucet flow rates. End uses of water are also of interest as urban water demand management programs have become a focus for many water utilities. A detailed understanding of how water is used in the residential setting is essential for water providers and the urban water supply industry. This fundamental information on water consumption is useful for water planning, demand forecasting, metering, efficiency and demand management programs, water loss control, plumbing product development, and many other core water industry purposes.

Single-family residential water use has declined across North America in recent years, posing new challenges (Maupin et al. 2014, Coomes et al. 2010). In 2015, water providers now confront a new paradigm, where increasing population does not necessarily result in a proportional increase in water use. Changes in residential demand have been observed and documented at an annual level, but little is known about what has driven these changes at the customer end use level.

The most significant residential end use study conducted in North America until now was the Water Research Foundation's 1999 *Residential End Uses of Water* (Mayer et al. 1999). This report (REU1999) provided detailed information on residential water use patterns and efficiency levels.

Residential End Uses of Water Study Update – Version 2 (REU2016) provides an updated and expanded assessment of water use in single-family households across North America, and presents detailed information and data about how water use has changed since REU1999.

[1] In this study, the focus was on single-family detached homes, not single family attached homes nor multi-unit housing.

RESEARCH OBJECTIVES

The objectives of REU2016 were to:

- Collect and analyze current data on the indoor end uses of water in single-family residential settings across North America.
- Collect and analyze current data on outdoor water use patterns and efficiency levels.
- Evaluate changes in water use patterns over a 15-year period.
- Identify variations in water used by each fixture or appliance.
- Evaluate conservation potential.
- Determine the factors influencing residential water use and evaluate their relative impact.
- Develop predictive models to assess and forecast residential demand.
- Prepare an end use database combining results from multiple studies including REU2016 for use by future researchers.

REU2016 includes some notable additions and amplifications over REU1999, including more varied site locations, collection of hot water end use data, more detailed landscape analysis, and expanded water rates analysis.

RESEARCH APPROACH

The REU2016 research approach centered on the selection of representative random samples of single-family customers, analysis of billed consumption in these samples, and obtaining highly detailed information on water use, demographics, attitudes, and the physical nature of the houses and landscapes. REU2016 investigated single-family household water use based on data collected from 2010 through 2013, and followed the same basic research approach as REU1999 with some notable additions. Water use data from historical billing records and a sub-sample of high-resolution flow monitoring were assembled into databases along with survey response data. From these databases, descriptive statistics were prepared, metrics examined against benchmarks, and models created to identify the most influential factors explaining water use. These data were then used to predict how residential water demands might change in the future.

Participating Utilities

Utilities from across the United States and Canada were invited to participate as study sites in REU2016, and ultimately, 26 utilities were involved and 23 utilities provided full data sets to be considered as Level 1 or 2 participants, see Table ES.1. Nine utilities (7 in the United States and 2 in Canada) joined the study as “Level 1” participants. Level 1 participation included contribution of billing data from approximately 1,000 homes, a mail survey sent to these 1,000 homes, end use monitoring of approximately 100 homes, and hot water end use monitoring of 10 homes. Fourteen utilities (13 in the United States and 1 in Canada) joined the study as “Level 2” participants, which included contribution of billing data from approximately 1,000 homes, analysis of billed consumption, and a mail survey sent to approximately 330 homes. All Level 1 and 2 participating water agencies also provided information on the overall metered consumption in their service area, water conservation programs, drought and conservation plans, budgets, staffing levels, water and wastewater rates, and other relevant information.

Sampling Approach

Each participating utility (Level 1 and Level 2) used a systematic random sampling approach developed by the research team to select a sample of 1,000 single-family homes from their population of active customer accounts. The historical annual water use characteristics of each 1,000-home sample was compared against the water use characteristics of the population from which it was drawn to ensure that the sample was representative at a 95% confidence level. Billed consumption data from 23,749 single-family homes (~1,000 per study site) were collected through this process. Each sample of 1,000 single-family customers (the "Q1000" data sets) were used to characterize annual and seasonal water use.

Customer Survey

Customer surveys were used to obtain information on a wide range of topics as described in Chapter 4 to accompany the water use data. After the Q1000 samples were selected, an extensive survey was mailed to 13,749 homes (~1,000 homes in each of the Level 1 sites for a total of 8,749 surveys and to 5,000 homes from the combined Q1000 samples from the Level 2 sites). Thirty-four percent of usable surveys were returned and coded (survey response group n=4,643). Survey response data were used as inputs for water use analyses and as part of the modelling process.

End Use Sample

After the surveys were tabulated, 900 homes were selected (approximately 100 homes per agency were selected from each of the nine Level 1 utilities), and these homes agreed to participate in the detailed flow monitoring portion of the project which involved recording flow through each customer's water meter every 10 seconds for a period of two weeks. This portion of the project took more than a year to complete, as the research team installed the flow monitoring equipment, collected the data, and moved the equipment from city to city. From this effort, high-quality flow data were successfully obtained from 762 homes spread across the nine Level 1 study sites, and comprised the flow monitoring group (end use analysis sample n=762).

Hot Water Investigation

Subsets of the end uses analysis sample groups were selected for hot water flow trace analysis. One hundred and ten homes (about 10 homes from each of the 9 Level 1 sites, plus an additional 27 homes in Tacoma, WA) were monitored for hot water use for approximately two weeks, and accurate and usable hot water data was obtained from 94 homes. Hot water monitoring was one of the new components of REU2016, and represents one of the largest efforts to date to collect and analyze hot water end use data in North America. In the subset of homes (hot water sample n=94) chosen for hot water monitoring, total water use into the home *and* hot water use were flow-monitored simultaneously from two separate water meters, thus enabling the hot water portion of each end use to be evaluated.

Outdoor Use Investigation

The primary goal of the outdoor water use analysis was explore the efficiency of irrigation practices through a comparison of the volume of irrigation water applied to the theoretical irrigation requirements of each residential lot. The sample group for outdoor water use analysis was based on the end use sample group, with 762 samples that successfully captured flow trace data plus 76 samples that were not successfully logged in the end use sample group. These 838 samples comprise the "landscape group".

Outdoor annual water use was estimated for each house using historical billing records, seasonal use analysis, and - where possible - the combination of measured indoor use from flow monitoring and historical billing records.[2] For the additional 76 homes, where flow trace monitoring was not successfully completed, the minimum month method was used to estimate seasonal and non-seasonal use. To explore landscape irrigation practices, pre-existing high-resolution aerial photographs were used to measure irrigable area and the landscape at each of the homes originally selected for end use monitoring was characterized. The research team's measurements of landscape area and plant coverage were used in combination with local weather and evapotranspiration (ET) data to estimate the annual irrigation requirement for each landscape. Where applicable, outdoor swimming pools were included as part of the landscape and outdoor water use requirement. The methodology used is described in full detail in Chapter 6 of the report.

Data Analysis and Modeling

Summaries of seasonal and non-seasonal water use were developed for each home for which billed consumption data were provided, and these data were analyzed in conjunction with survey responses and other data collected. Descriptive statistics and mathematical (regression) models were developed to investigate the factors that affect residential indoor and outdoor water use separately. Additional data from previous end use studies (REU1999 and others) conducted by the research team were employed to further describe water use patterns and to develop efficiency benchmarks based on established metrics, such as the *WaterSense New Home Specification* (EPA 2014).

A diagram summarizing the data collection activities and data sets of the research is shown in Figure ES.1.

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[2] Non-seasonal use was calculated as the water use during the period of minimum irrigation (usually the winter) pro-rated for the entire year. Seasonal use was calculated as the difference between the annual use and the non-seasonal use. For the Landscape Group sample (n=838), daily indoor water use was calculated from high-resolution flow data and then pro-rated across the year. Outdoor use was calculated by deducting pro-rated indoor use from metered annual use.

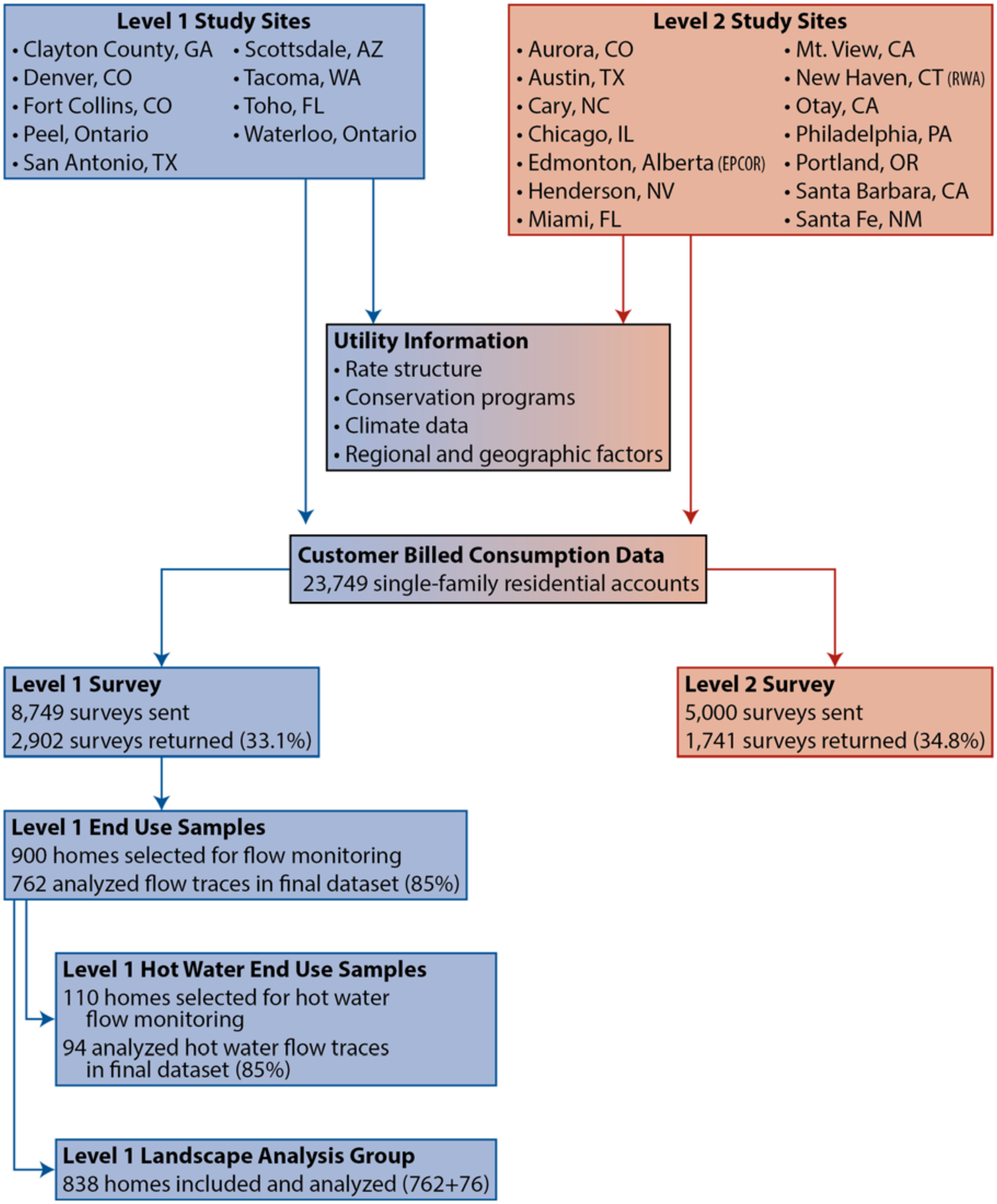


Figure ES.1: Data Sets in REU2016

RESEARCH CONSIDERATIONS

This project, like other research studies using similar methods, relied on a variety of assumptions (described below). Great care and effort was made to ensure the accuracy of the data and information presented in this report, but it is recognized that changes in any of the assumptions outlined below could impact the results.

1. The billing consumption data provided by participating water utilities were accurate.
2. The mail survey responses were accurate.
3. The timeframe for monitoring demand for two weeks (duration and timing) captured "representative" indoor water use from each home.
4. The time and date correspondence of measured consumption data and weather variables was accurate.
5. The end use disaggregation was accurate.

This report represents a time and place snapshot of how water is used in single-family homes in nine North American locations. Great care was taken to create a statistically significant representative sample of customers from each location. However, these nine locations alone are not statistically representative of all North American residential characteristics, and only two of the nine locations were part of both the REU1999 and REU2016 studies.

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

RESEARCH FINDINGS

The core objectives of REU2016 were to comprehensively update and expand REU1999, and to provide data and analysis on the end uses of water, both indoor and outdoor, in single-family residential settings across North America. The accomplishment of these and the other stated goals of REU2016 are summarized in the findings below.

Annual Use

The 23 participating agencies in the REU2016 come from across North America and encompass a tremendous climatic, geographic, and demographic diversity, see Table ES.1. The study sites included large cities like San Antonio, Chicago, Philadelphia, Miami, and Denver; Canadian regional municipalities Peel and Waterloo, Ontario and Edmonton, Alberta; and small to mid-sized communities such as Fort Collins, Colorado, Santa Fe, New Mexico, and Santa Barbara, California.

Average annual per household water use ranged from 44,000 gallons per household per year (gal/hh/year) in Santa Fe, NM to 175,000 gal/hh/year in Scottsdale, AZ, based on year 2010 billing records from approximately 1,000 single-family residential accounts randomly selected from each of the 24 study sites (n=23,749). The average annual water use for all study sites combined was 88,000 gal/hh/year with a standard deviation of 32,000 gal/hh/year and a median of 83,000 gal/hh/year (n=23,749). A listing of study sites' average annual and seasonal per household water use is shown in Table ES.1. In this table, non-seasonal use was calculated as the water use during the period of minimum irrigation (usually the winter) pro-rated to the entire year. Across all study sites in 2010 (n=23,749), 73 percent of annual water use was for non-seasonal purposes and 27 percent for seasonal purposes. In general, seasonal use was strongly influenced by climate and weather patterns, but there were exceptions.

Seasonal and non-seasonal use are often used as convenient proxies for outdoor and indoor use respectively, but there is potential for significant error in this technique because there is frequently some water used outdoors during winter months. Most of the detailed outdoor use analysis presented in this report was conducted on data collected from the “Landscape Group,” a sample of 838 homes selected from across the nine Level 1 participating water utilities. The Landscape Group includes the 762 homes that participated in the detailed end use monitoring portion of this study plus an additional 76 homes for which end use data were not successfully obtained. The Landscape Group averaged 101 kgal per year in 2010, and 50% of annual water use was for outdoor use. The outdoor water use patterns of the Landscape Group differed from the seasonal use patterns across all 24 study sites, in large part because the Landscape Group sample was selected to be representative of the subset of nine water providers that participated in the flow monitoring portion of REU2016.

Limits of Annual Consumption Data

Annual consumption data compiled from monthly or bi-monthly[3] billing records is useful, but has limitations. In analyzing consumption records from the 23 participating water utilities, the relative contribution of residential and non-residential sectors to the total consumption varied greatly by service area. Differing demand patterns as well as other site-specific factors that influence water consumption mean that few dependable benchmarks of water use can be developed from aggregate annual customer account data. Aggregate or uniform gross per capita use, which has come into use as a measure of water use efficiency, should be used with caution because of the utility-specific factors that influence demand.

Detailed water use data are important for understanding demand patterns and establishing end use benchmarks. Basic information can be obtained from annual data; more can be learned from seasonal and non-seasonal data, and so on. As data sets become more detailed, the information becomes more meaningful. Ultimately, the most detailed information can be obtained when household water use is disaggregated down to the end use level as was done in REU2016 and REU1999.

[3] Billing every 2 months.

Table ES.1 Average annual and seasonal per household water use, all REU2016 study sites

Participating Agency	Part. Level	Single-Family Residential Connections 2010	Avg. Annual per Household Use - 2010* (kgal)			% Seasonal
			Total	Seasonal	Non-Seasonal	
City of Fort Collins Water Dept., CO	1	27,867	105	52	53	44%
City of Scottsdale, AZ	1	146,138	175	46	129	23%
Clayton County Water Authority, GA	1	70,421	58	6	52	9%
Denver Water, CO	1	195,487	118	63	56	46%
Region of Peel Public Works, Ontario, Canada	1	273,989	82	11	72	12%
Region of Waterloo, Ontario, Canada	1	55,733	55	19	47	27%
San Antonio Water System, TX	1	331,853	106	43	63	37%
Tacoma Water, WA	1	85,288	69	17	52	20%
Toho Water Authority, FL	1	68,021	88	31	57	26%
Aurora Water, CO	2	70,608	98	39	59	35%
Austin Water, TX	2	189,038	93	51	42	50%
City of Chicago, IL	2	269,698	91	12	78	12%
City of Henderson, NV	2	80,352	141	83	59	54%
City of Mountain View, CA	2	11,802	83	37	46	40%
City of Santa Barbara, CA	2	16,919	96	51	44	52%
City of Santa Fe, NM	2	26,871	44	10	34	21%
EPCOR (Edmonton), Alberta, Canada	2	220,090	54	5	49	9%
Miami-Dade Water and Sewer, FL	2	377,846	83	7	76	8%
Otay Water District, CA	2	40,994	127	68	59	51%
Philadelphia Water Department, PA	2	392,639	57	4	53	6%
Portland Water Bureau, OR	2	153,500	53	10	43	16%
South Central Connecticut Regional Water Authority (RWA), CT	2	107,141	67	10	58	11%
Town of Cary, NC	2	45,120	70	18	52	18%
Average (Level 1 and 2: 23 sites) (n=23,749)		141,627	88	30	58	27%
Average (Level 1: 9 sites) (n=8,749)			96	32	64	27%

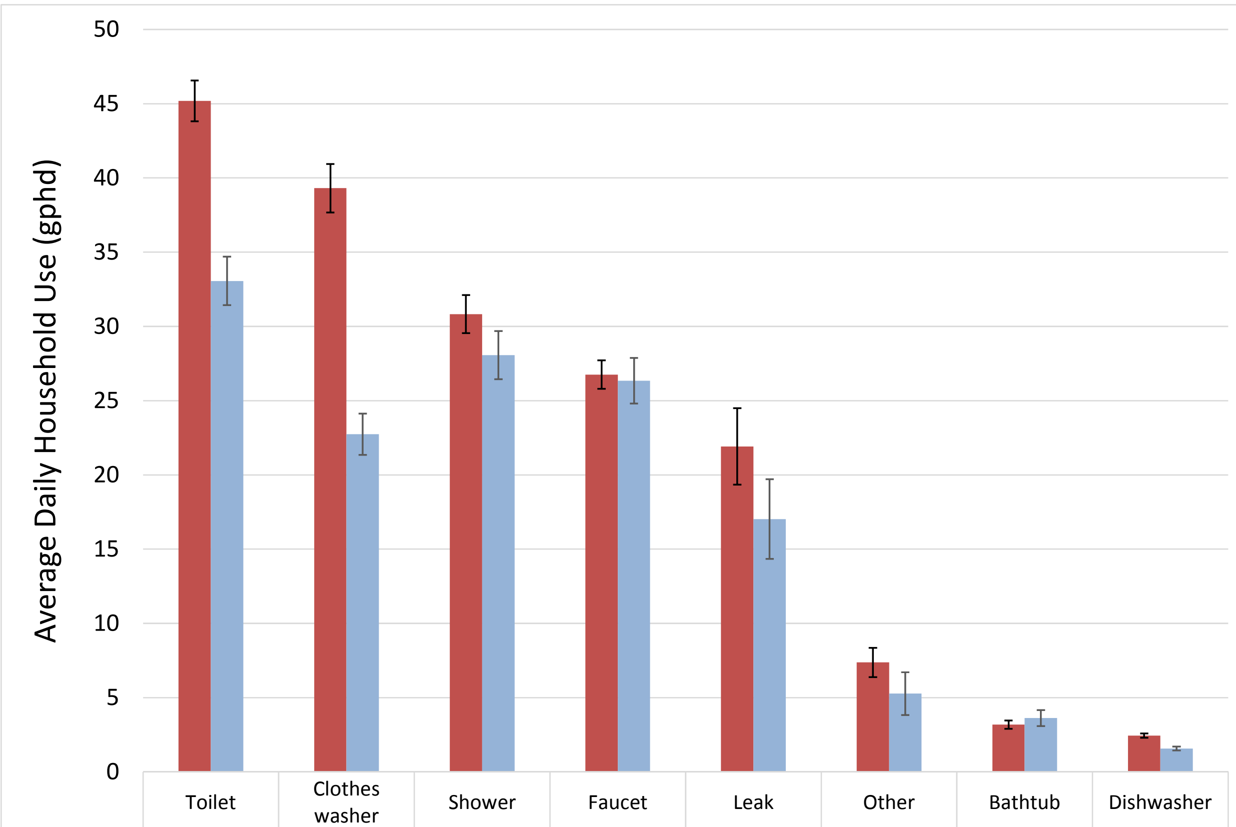
*Data from San Antonio came from 2008.

Indoor Use

Quantifying how much water is used indoors was a fundamental goal of REU2016. Indoor water use is presented on both a per household and per capita basis. Both metrics are valuable for understanding water use patterns, establishing efficiency levels, and developing predictive models of future demand.

Indoor Daily Per Household Use

A comparison of the average daily end uses between REU 1999 and REU 2015 is shown in Figure ES.2, which shows the average daily use and the margin of error at the 95% confidence level. In REU1999 the indoor average per household water use was 177 gphd and in the REU2016 the indoor average per household water use was 138 gphd. Changes in water use between REU1999 (n=1,187) and REU2016 (n=762) were found in the following categories: toilets, clothes washers, showers, leaks, dishwashers, and other. Faucets and bathtubs did not show a statistically significant difference in usage. There were average of 2.65 people per household in REU2016 end use study group and an average of 2.77 per household in REU1999. Additional information on per household water use can be found in Chapter 6.

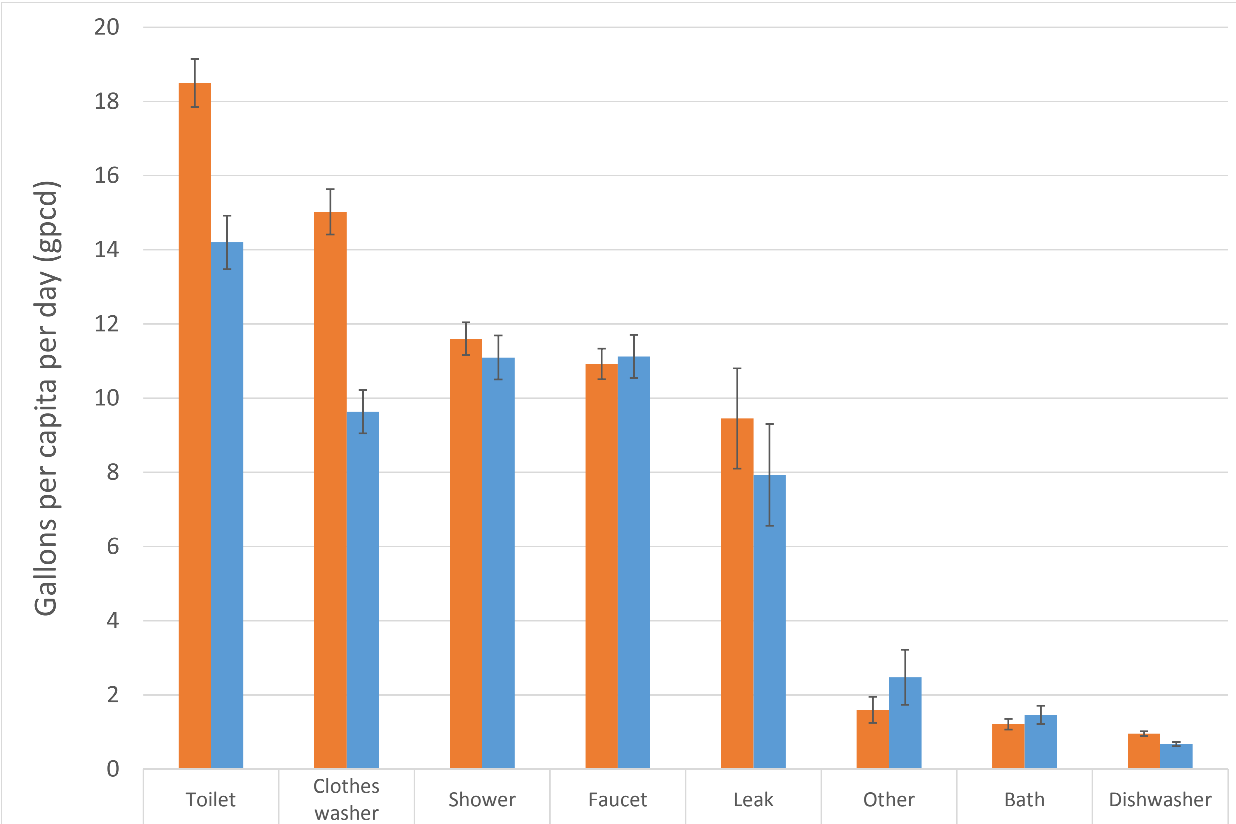


	Toilet	Clothes washer	Shower	Faucet	Leak	Other	Bathtub	Dishwasher
REU1999	45.2	39.3	30.8	26.7	21.9	7.4	3.2	2.4
REU2016	33.1	22.7	28.1	26.3	17.0	5.3	3.6	1.6

Figure ES.2 Indoor per household water use – REU1999 and REU2016

Indoor Daily Per Capita Use

Per capita daily indoor water use was calculated for the entire study using flow monitoring results from 737 homes and corresponding mail survey responses to assess the number of people in each household. The sample size for the per capita analysis was smaller than the household analysis because not everyone responded fully to the survey. Across the 737 study homes in the nine Level 1 study sites, the average per capita indoor daily water use was 58.6 gallons per capita per day (gpcd). In REU1999, the average per capita indoor daily water use was 69.3 gpcd. This indicates an overall 15.4% reduction in indoor per capita usage between the two studies. This change was found to be statistically significant at the 95% confidence level. Results are shown in Figure ES.3.



	Toilet	Clothes washer	Shower	Faucet	Leak	Other	Bath	Dishwasher
REU1999	18.5	15.0	11.6	10.9	9.5	1.6	1.2	1.0
REU2016	14.2	9.6	11.1	11.1	7.9	2.5	1.5	0.7

Figure ES.3 Indoor per capita water use - REU1999 and REU2016

The biggest reduction in per capita water use between the two studies was measured in the clothes washer category, which fell by 36%, from 15.0 gpcd in REU1999 to 9.6 gpcd in REU2016. Toilet use fell by 23.2% from 18.5 gpcd (REU1999) to 14.2 gpcd (REU2016). Dishwasher use fell by 30% from 1.0 gpcd (REU1999) to 0.7 gpcd (REU2016). All of these reductions were statistically significant at a 95% confidence level.

Leakage was reduced by 16.8% from 9.5 gpcd (REU1999) to 7.9 gpcd (REU2016), but because of the high variability in this category, this change was not found to be statistically significant. Similarly, per capita shower use was reduced by 4.3% from 11.6 gpcd (REU1999) to 11.1 gpcd (REU2016), but the change was not statistically significant.

In three categories, per capita water use increased between the two studies, but none of these increases was statistically significant at the 95% confidence level. Faucet use was almost unchanged, and increased by just 1.8% from 10.9 gpcd (REU1999) to 11.1 gpcd (REU2016). Miscellaneous/other water use (evaporative cooling, humidification, water softening, and other uncategorized indoor uses) increased by 56.3% from 1.6 gpcd (REU1999) to 2.5 gpcd (REU2016). The bathtub category increased by 25% from 1.2 gpcd (REU1999) to 1.5 gpcd (REU2016).

The relative percent of indoor per capita water use across all nine Level 1 study sites is shown in Figure ES.4. In REU 2016, toilet flushing was the largest indoor use of water per person on average (14.2 gpcd, 24%) followed by showers (11.1 gpcd, 19%), kitchen and bathroom faucets (11.1 gpcd, 19%), clothes washers (9.6 gpcd, 16%), leaks (7.9 gpcd, 14%), other/miscellaneous (2.5 gpcd, 4%), bathtub (1.5, gpcd, 3%) and dishwashers (0.7, gpcd, 1%).

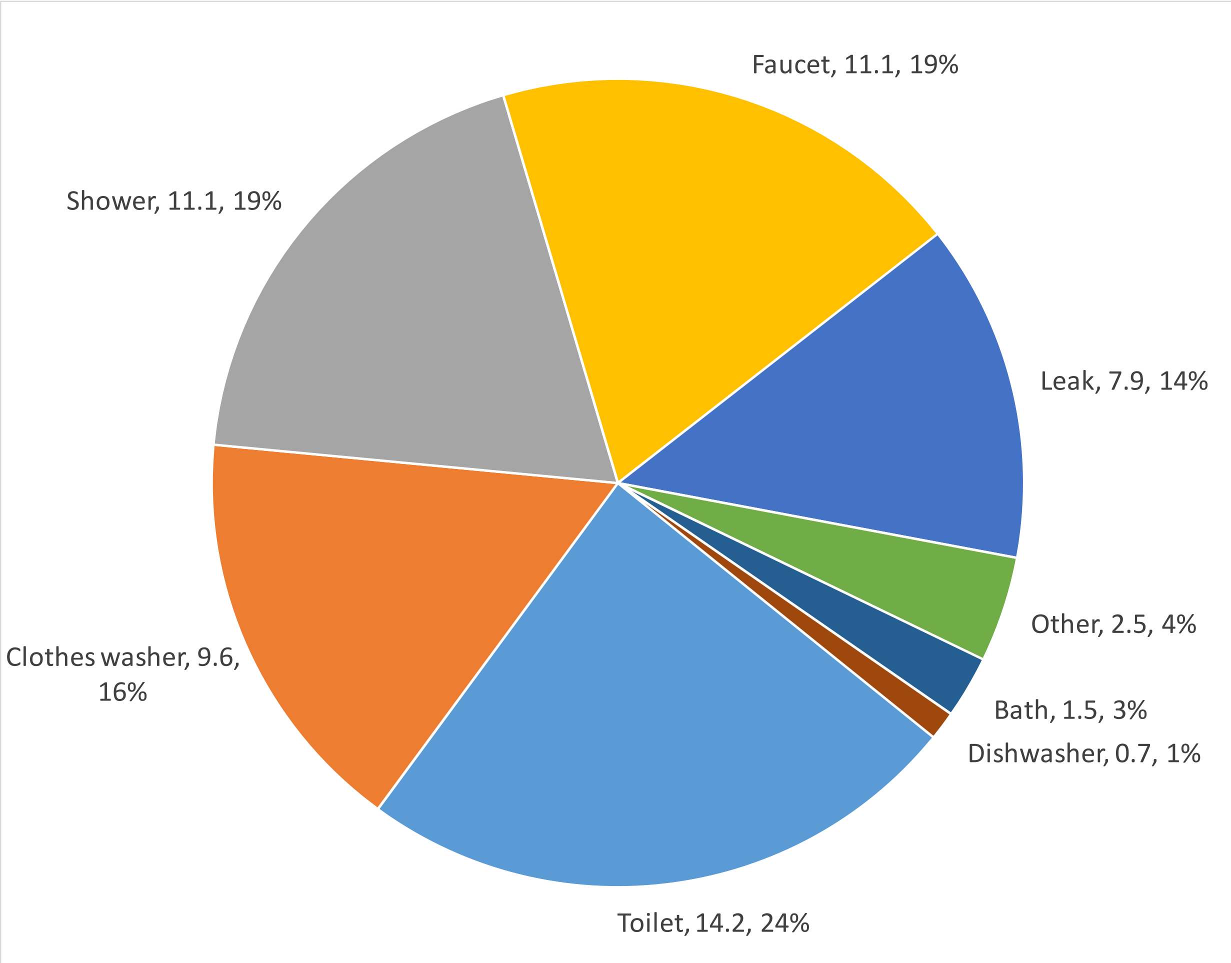


Figure ES.4 Indoor per capita use (gpcd and percent of indoor use) by fixture, 9 study sites, n=737

Hot Water Use

Among the subset of 94 homes where both total household water and hot water use was successfully simultaneously metered, flow monitored, and disaggregated, 66.8% of the indoor per household use was for cold water and 33.2% was for hot water. The percent of per household hot water used varied from a high of 40.2% in Tacoma, WA to a low of 20.3% in Scottsdale, AZ.

Showers and faucets are the end uses that consume the most hot water by volume on average, even though they use a mix of hot and cold water. The majority of hot water is used for showering (17.8 gphd or 39%) and faucet use (15.4 gphd or 34%) and both consumed substantially more hot water than all other end uses combined (27%). Clothes washers are the third largest user of hot water with 4.4 gphd. Table ES.2 shows the hot and cold water use by end use in the homes.

Most (66.2%) of the water used for showering was hot and 33.8% was cold. Faucet use consisted of 57.0% hot water and 43.0% cold water.

Table ES.2 Average daily hot and cold water use per household (n=92)

	Avg. Daily Hot Water Use (gphd)	Avg. Daily Cold water Use (gphd)	Indoor Total (gphd)	% Hot	% Cold
Toilet	0.0	32.6	32.6	0.0%	100%
Clothes washer	4.4	17.6	22.0	20.0%	80.0%
Shower	17.8	9.1	26.9	66.2%	33.8%
Faucet	15.4	11.6	27.0	57.0%	43.0%
Leak	2.1	15.7	17.8	11.8%	88.2%
Other	0.9	3.1	4.0	22.5%	77.5%
Bath	2.6	1.8	4.4	59.1%	40.9%
Dishwasher	2.2	0.0	2.2	100.0%	0.0%
Indoor Total	**45.5**	**91.5**	**137.0**	**33.2%**	**66.8%**

Per capita hot water use was calculated from 92 of the monitored homes that provided occupancy data. Total average per capita hot water use was 20.9 gpcd. Hot water use per fixture with 95% confidence boundaries is shown in Figure ES.5.

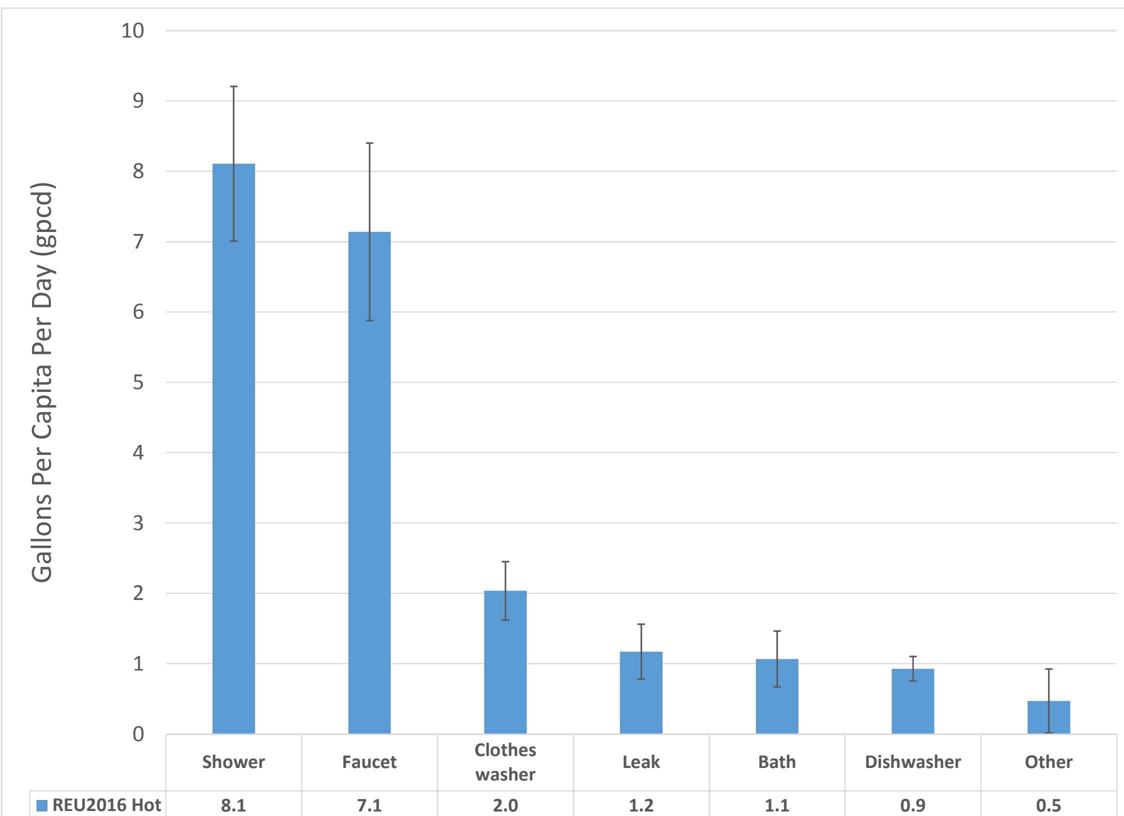


Figure ES.5 Hot water per capita use (n=92)

Indoor Use Comparison REU2016 and REU1999

The following sections compare findings on indoor fixture and appliance usage from REU2016 and REU1999.

Toilets

A comparison of toilet flushing statistics from REU1999 and REU2016 is shown in Table ES.3. Average daily per capita toilet use was 23.2% lower, falling from 18.5 gpcd (REU1999) to 14.2 gpcd (REU2016). This change was brought about by a 28.8% reduction in the average flush volume of toilets from 3.65 gal/flush to 2.6 gal/flush. Flushing frequency was unchanged at 5.0 flushes per person per day.

In REU1999, just 8.5% of the homes had an average toilet flush volume of less than 2.0 gal/flush.[4] In REU2016, 37% of the homes had an average toilet flush volume less than 2.0 gal/flush. Significant efficiency potential still exists in the toilet category as older, less efficient toilets are replaced by high-efficiency fixtures mandated by federal and state law, and market influence.

Table ES.3 Toilet flush statistical comparison, REU1999 and REU2016

	REU1999	REU2016
Sample size (houses)	1187	762
Average flushes per household per day	12.4	13
Average flushes per person per day	5.05	5.0
Average per capita toilet use (gpcd)*	18.5	14.2
Average toilet flush volume (gal.)	3.65 ± 0.06	2.6 ± 0.01
Average daily household toilet use (gphd)	45.2	33.1
Median daily household toilet use (gphd)	43	29

*Based on 737 houses for REU2016

Showers

Showering patterns have changed slightly over the past 15 years as shown in Table ES.4. The average shower duration remained unchanged at 7.8 minutes per shower and the average shower flow rate was reduced by 0.1 gpm. Showering frequency has not changed with an average of 1.8 showers per household per day in each study. There was a small, but statistically significant, reduction in average daily per household use in showering of 3 gphd. This was due to a reduction in persons per household and to reduced shower volume. The average shower volume was reduced from 16.7 gallons (REU1999) to 15.8 gallons (REU2016). In REU2016, it was found that 97% of the measured showers were less than 14 minutes in length, while in REU1999, 90.5% of the showers met this criteria.

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[4] Selected as an efficiency bench mark in REU1999 and used again in RUE2016 to allow an "apples to apples" comparison. This benchmark incorporates most low volume toilets manufactured from the late 1980s on.

Table ES.4 Shower statistical comparison, REU1999 and REU2016

	REU1999	REU2016
Sample size (houses)	1187	762
Average people per household	2.8	2.7
Average showers per household per day	1.8	1.8
Average showers per person per day*	0.66	0.69
Average shower volume (gal.)	16.7 ± 0.3	15.8 ± 0.5
Average shower duration (min.)	7.8 ± 0.14	7.8 ± 0.02
Average per capita shower use (gpcd)*	11.6	11.1
Average daily household shower use (gphd)	30.8 ± 1	28.1 ± 2
Median daily household shower use (gphd)	26	22
Average flow rate for showers (gpm)	2.2 ± 0.04	2.1 ± 0 .04

*Based on 737 houses for REU2016

Faucets

The faucet use category includes both kitchen and bathroom faucet use, hose bibs, utility sinks and other low volume water use events that did not fit into a recognizable category, but appear to be faucet events. Average faucet use per household and per capita level did not change significantly from REU1999 to REU2016 as shown in Table ES.5. The number of faucet uses per household increased in REU2016, but the average volume per use was lower.

Table ES.5 Faucet statistical comparison, REU1999 and REU2016

	REU1999	REU2016
Sample size (houses)	1187	762
Average faucet uses per household per day	41	51
Average faucet uses per person per day*	15	20
Average faucet use volume (gal/use)	0.7	0.5
Average faucet duration (seconds)	30	30
Average per capita faucet use (gpcd)*	10.9	11.1
Average daily household faucet use (gphd)	26.7 ± 1	26.3 ± 1.5
Median daily household faucet use (gphd)	23	22.5

*Based on 737 houses for REU2016

Clothes Washers

Starting in the mid-1990s, efficiency improvements have dramatically reduced clothes washer water use. The amount of water used to wash a typical load of clothes declined from 41 gallons (REU1999) to 31 gallons (REU2016), but the average number of loads per household and per person did not increase, as shown in Table ES.6. Average daily per capita water use for clothes washers declined by 36% from 15.0 gpcd (REU1999) to 9.6 gpcd (REU2016), which is the largest per capita use reduction measured in any indoor end use category. The improved water efficiency of clothes washers and toilets accounts for most of the changes in indoor use measured between REU1999 and REU2016.

Table ES.6 Clothes washer statistical comparison, REU1999 and REU2016

	REU1999	REU2016
Sample size (houses)	1187	762
Average loads per household per day	0.81	0.78
Average loads uses per person per day*	0.3	0.3
Average gallons per load	41	31
Median gallons per load	40	31
Per capita clothes washer use (gpcd)*	15.0	9.6
Average daily household clothes washer use (gphd)	39.3 ± 1.6	22.7 ± 1.4
Median daily household clothes washer use (gphd)	32.8	17.8

*Based on 737 houses for REU2016

Leakage

Leakage rates declined between 1999 and 2015. Methodological differences in the two studies prohibit comparison of some statistical measures as shown in Table ES.7. Daily per capita leakage fell by 16.8%, from 9.5 gpcd (REU1999) to 7.9 gpcd (REU2016). Similar reductions in daily per household use were also observed. Leakage rates in both studies were highly skewed towards a low level of leakage. About 5% of the study homes had no leakage at all during the data collection period, and about 63% of the homes leaked some amount, but less than 10 gphd. The other 32% of homes had higher leakage rates, as high as 600 gphd.

Table ES.7 Leakage statistical comparison, REU1999 and REU2016

	REU1999	REU2016
Sample size (houses)	1187	762
Average Gal/leak event	NA	0.15
Average leak events/household per day	NA	117
Average leak events per person per day*	NA	43.3
Average per capita leakage (gpcd)*	9.5	7.9
Average daily household leakage (gphd)	21.9 ± 2.59	17.0 ± 2.69
Median daily household leakage (gphd)	5.9	4.3

*Based on 737 houses for REU2016

Bathtubs

Bathtub water use did not change significantly from REU1999 to REU2016, as shown in Table ES.8. The number of baths per household and per capita per day was a little higher in REU2016, but the average volume per bath event was a little lower. In both studies, the presence of children age 12 and under increased bathtub use.

Table ES.8 Bathtub statistical comparison, REU1999 and REU2016

	REU1999	REU2016
Sample size (houses)	1187	762
Average volume per bath (gal)	21.9	20.2
Average bathtub uses per household per day	0.15	0.18
Average bathtub uses per person per day*	0.05	0.07
Average per capita bath use (gpcd)*	1.2	1.5
Average daily household bathtub use (gphd)	3.2 ± 0.3	3.6 ± 0.5
Median daily bathtub use (gphd)	1.0	1.0

*Based on 737 houses for REU2016

Dishwashers

An automatic dishwasher was present in 84% of the end use study homes in REU2016 based on survey responses, and 68% of the study homes used a dishwasher during the two week flow data collection period. A comparison of dishwasher usage statistics is shown in Table ES.9. The average volume per load of dishes decreased 39% from an average of 10.0 gallons/load (REU1999) to an average of 6.1 gallons/load (REU2016). The frequency of dishwasher use was essentially unchanged from study to study, but because of the decreased average load volume, the average per capita and per household use for dishwashers decreased significantly.

Table ES.9 Dishwasher statistical comparison, REU1999 and REU2016

	REU1999	REU2016
Sample size (houses)	1187	762
Average dishwasher uses per household per day	0.24	0.26
Average dishwasher uses per person per day*	0.09	0.10
Average dishwasher load volume (gal)	10.0	6.1
Average per capita dishwasher use (gpcd)*	1.0	0.7
Average daily household dishwasher use (gphd)	2.4 ± 0.2	1.6 ± 0.13
Median daily household dishwasher use (gphd)	2.0	0.99

*Based on 737 houses for REU2016

REU2016 found use of a dishwasher did not result in less faucet use, which normally would be supposed. The 520 households in REU2016 that used dishwashers had an average faucet use of 26.3 gphd and the 241 homes that did not use dishwashers used an average of 26.4 gphd for faucets. These two values are not statistically different, which suggests that in this group, the use of dishwashers was not associated with less faucet use.

Indoor Conservation Potential

On a per capita basis, average indoor water use decreased by 15.4% from 69.3 gpcd to 58.6 gpcd from REU1999 to REU2016, as shown in Figure ES.6. A sample of new homes built according to the EPA's WaterSense New Home Specification (Version 1.0) with high efficiency fixtures and appliances had an average daily per capita water use of 36.7 gphd, measured in research using similar methods (DeOreo et al. 2011).[5] An average indoor per household usage level of 37 gpcd appears achievable with full saturation of high-efficiency fixtures and appliances.

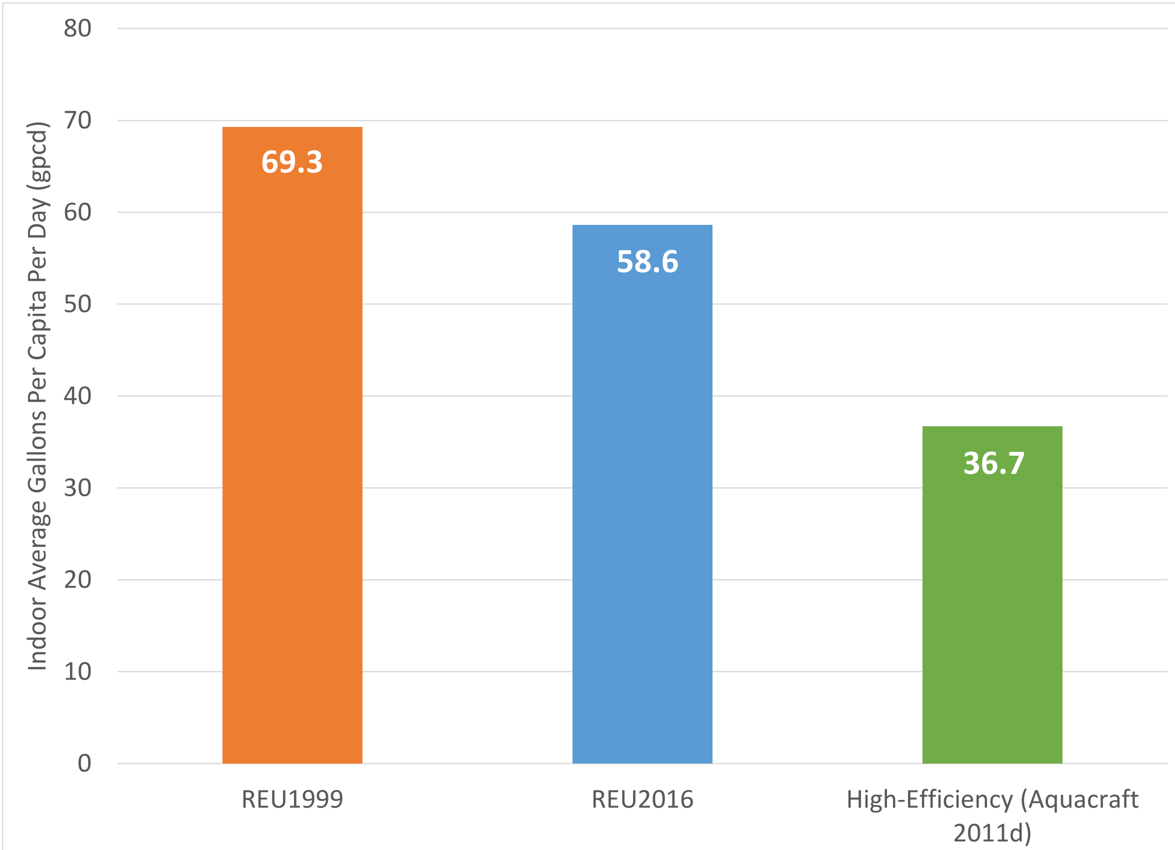


Figure ES.6 Indoor average gallons per capita per day, REU1999, REU2016, High Efficiency Studies

Additional indoor conservation potential may exist beyond the 37 gpcd level through new technologies, leak detection, or on-site reuse. There are many variables that contribute to indoor water use patterns, and utilities should determine appropriate efficiency targets for their own service area based on local factors. More discussion of conservation potential using a variety of methods is presented in Chapter 8.

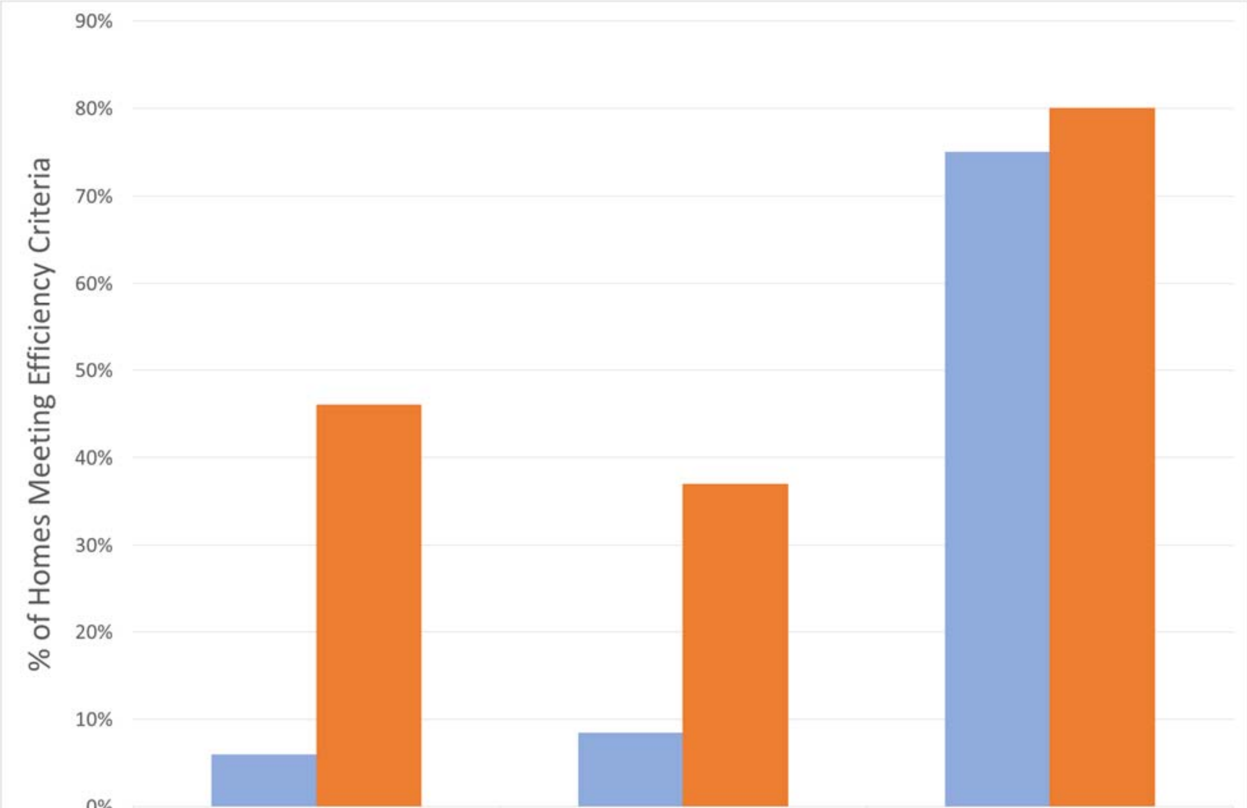
Saturation Rate of Efficient Fixtures and Appliances

An analysis of the saturation rate of water efficiency fixtures and appliances found in REU2016 shows many more households are using water efficient showerheads, toilets, and clothes washers than in REU1999, as shown in Figure ES.7. The minimum household efficiency criteria used in these studies were:

- Average clothes washer load < 30 gallons

[5] Nearly 100% of the 25 new homes studied in DeOreo et al. (2011) met the following efficiency criteria: clothes washers with capacities of ≤ 30 gpl, shower flow rates of ≤ 2.5 gpm and toilet flushes of ≤ 2.0 gpf.

- Average toilet flush < 2.0 gallons
- Average shower flow rate < 2.5 gallons per minute



	Clothes Washer	Toilet	Shower
REU1999	6%	8.5%	75%
REU2016	46%	37%	80%

Figure ES.7 Percent of homes meeting efficiency criteria, REU1999 and REU2016

Outdoor Use and Landscape Irrigation

The outdoor use category in this study is one category of end use and may include water used for landscape irrigation, as well as water used through hose bibs, water for filling and backwashing swimming pools, pavement and auto cleaning, etc. Outdoor water use was calculated for the Landscape Group (n=838) as the total annual water use for each home minus the best available estimate of indoor use in the home, primarily from the end use analysis and when not possible, from estimates of indoor use from models. The average outdoor water use for the Landscape Group was 50.5 kgal/year, representing approximately 50% of the total annual water use for this group. A little over 60% of the lot areas in this study group were devoted to landscape.

Local weather conditions, the size of the irrigated area, the type of plant materials, and the cost of water are major drivers of outdoor use. A summary of the annual water use and the outdoor use for the REU2016 landscape analysis sites is shown in Table ES.10.

Table ES.10 Summary of annual and outdoor water use for landscape group (n=838)

Site	Sample Size (n)	Average Annual Use (kgal)	Average Outdoor Use (kgal)	% Outdoor
Clayton County	103	62	19.2	31%
Denver Water	95	125	77.0	62%
Ft. Collins	88	111	55.9	50%
Peel	69	87	24.1	28%
San Antonio	98	112	62.0	55%
Scottsdale	111	186	120.4	65%
Tacoma Water	107	73	27.0	37%
Toho	95	93	33.1	36%
Waterloo	72	58	13.0	22%
Total (9 sites)	838	100.8	50.5	50 %

To evaluate the efficiency of landscape irrigation in the Landscape Group, theoretical landscape irrigation water budgets were constructed for each of the 838 properties using a method developed from agricultural crop research. This analysis utilized aerial photographs to determine the irrigated area and to estimate ground cover in seven classifications: cool-season grass, warm-season grass, non-turf plants, vegetable garden, Xeriscape, swimming pools, and non-irrigated vegetation. Each groundcover was assigned a species coefficient, irrigation type, and irrigation efficiency allowance (for drip and spray irrigation). The irrigation water requirement was calculated using multiple factors including species coefficient, the area of coverage, irrigation efficiency allowance, and the local irrigation season evapotranspiration (ET) data obtained from the best available weather stations at each study site. The result of this effort was an estimate of the annual theoretical irrigation requirement (TIR) in gallons per year, customized for each of the 838 homes in the Landscape Group. The TIR for each home was compared against the estimated outdoor use at each site, and the results are summarized in Figure ES.8.

The detailed analysis of outdoor water use summarized in Figure ES.8 shows that excess irrigation is an issue for a relatively small number of study participants. The majority of study participants (72%) applied considerably less water to their landscapes than was theoretically required based on averages of climate and plant science. Another 16% of participants applied an amount of water to their landscape over the year that was close to the theoretical requirement (between 70% and 130% of TIR). About 13% of participants applied an amount of water in gross excess of the estimated theoretical requirement to the landscape. This analysis suggests that excess irrigation is only practiced by a relatively small number of households and that a substantial majority of households under-irrigate, or deficit irrigate, compared to the theoretical requirement.

This analysis does not incorporate landscape appearance or health in any way. Deficit irrigation does not necessarily mean a dead, unhealthy, or unattractive landscape. Many landscapes thrive on less water than may be theoretically required due to lack of plant species specific water use requirements and factors such as shading and soil quality that can have a significant impact on landscape irrigation requirements.

Excess irrigation is a significant issue that can be addressed through water demand management programs, but outdoor demand management efforts should be targeted at excess irrigators to achieve water savings. There were 838 homes in the landscape analysis group, and the total annual excess irrigation for the group was 6,884 kgal. This volume was based on the sum of all of the excess irrigation occurring, while ignoring the volumes of deficit irrigation. If, however, the deficit irrigation values were added into the sum algebraically, then the total net irrigation dropped to a negative value of -50,440 kgal. In other words, if just the excess irrigation could be eliminated without changing irrigation in the rest of the group, then 6,884 kgal of water could be saved by the group, but if the entire group irrigated at precisely the theoretical requirement level, then the total outdoor use would increase by 50,440 kgal.

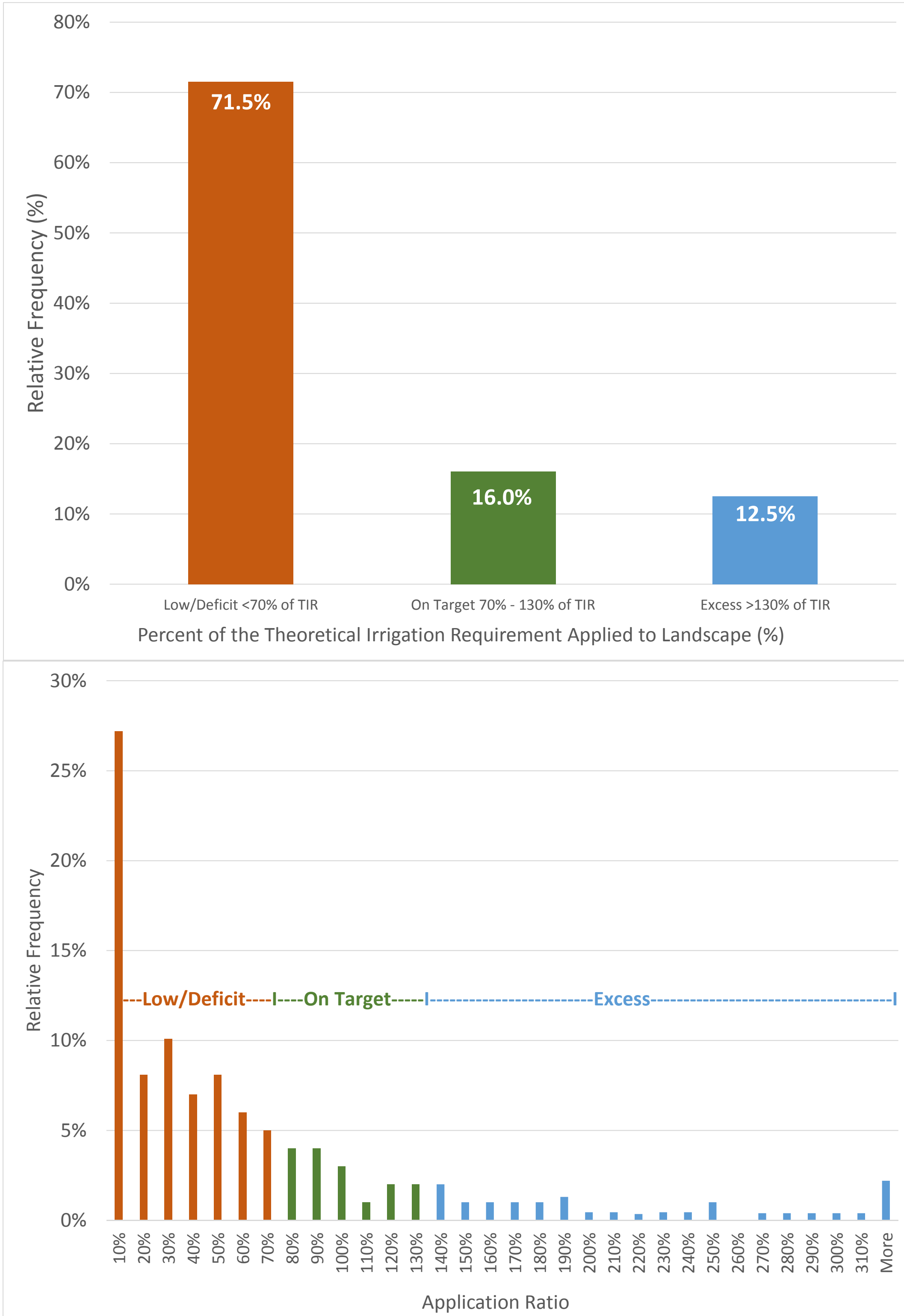


Figure ES.8 Distribution of application ratios, Landscape Group (n=838)

Factors that Influence Water Use

Creation of predictive mathematical models of indoor and landscape water use in single family households can show how variation in one set of parameters (called explanatory variables) is likely to impact the average daily household water use, for indoor purposes, and the average annual irrigation use, for landscape uses. Models are useful to the extent that they explain the variability in water use better than simple use of average values.

A model was created to evaluate the impacts of specific factors on indoor water use (Table 7.1). Some of the factors that have significant influence on increasing indoor water use are number of people residing in the home (large impact), presence of a home water treatment system, parcel size (proxy for income) and presence of a swimming pool. Some of the factors that have significant influence on decreasing indoor water use were the presence of efficient toilets (large impact), increased sewer rates, presence of a hot water recirculating system, and presence of efficient clothes washer. Additional models were created to examine individual end uses and conservation (see Tables 7.2 to Table 7.10).

Factors that were found to have significant influence on increasing outdoor water use in REU2016 were occurrence of excess irrigation (large impact), net ET (large impact), presence of an in-ground sprinkler system (large impact), irrigated area, and presence of a swimming pool. Factors that were found to have significant influence on decreasing outdoor water use was the cost of water. Additional models were created to examine conservation, see Table 7.14 and 7.15.

CONCLUSIONS AND APPLICATION OF THE RESEARCH

Key conclusions drawn from REU2016 include:

Residential Water Use Across North America is Variable

- Average annual per household water use across the 23 participating study sites in the REU2016 combined was 88,000 gal/hh/year with a standard deviation of 32,000 gal/hh/year and a median of 83,000 gal/hh/year (n=23,749). In REU1999 it was an average of 146,100 gal/hh/year (n=12,055) and median of 123,300 gal/hh/year.
- Local weather conditions, the size of the irrigated area, the cost of water, and the type of plant materials are major drivers of outdoor use.
- Indoor use was less variable between participating study sites than outdoor use.

Residential Indoor Water Use Has Decreased

- Average indoor per capita water use in single-family residences has decreased 15.4% from 69.3 gpcd (REU1999) to 58.6 gpcd (REU2016).
- Average indoor per household water use in single-family residences has decreased 22% from 177 gphd (REU1999) to 138 gphd (REU2016).
- The observed reductions in household use are largely due to more efficient fixtures and appliances, and are not the result of changes in either occupancy or behavior.

- The primary technologies that have contributed to the reductions in indoor water use are high efficiency clothes washers and toilets. However, high efficiency showerheads, dishwashers, and hot water recirculation systems have also contributed to reductions.
- The average toilet flush volume decreased from 3.65 gal/flush (REU1999) to 2.6 gal/flush (REU2016). Flushing frequency was unchanged at 5.0 flushes per person per day.
- Showering patterns have changed only slightly over the past 15 years, with average duration holding steady at 7.8 minutes/shower and a reduction in average shower flow rate of just 0.1 gpm.
- Average faucet use per household and per capita did not change at a statistically significant level from REU1999 to REU2016.
- Efficiency improvements in clothes washers have substantially reduced water use over the past 15 years from an average volume of 41 gal/load (REU1999) to 31 gal/load (REU2016).
- Average daily per capita use for clothes washing decreased 36% from 15.0 gpcd (REU1999) to 9.6 gpcd (REU2016).
- Average daily per capita leakage decreased 16.8% from 9.5 gpcd (REU1999) to 7.9 gpcd (REU2016)
- The average volume per load of dishes washed in an automatic dishwasher decreased 39% from 10.0 gallons/load (REU1999) to 6.1 gallons/load (REU2016).

Largest Water Uses Inside Homes

- Toilet flushing (24%) is the largest indoor end use of water in single-family homes followed by showers (19%), faucets (19%), clothes washers (16%), and leaks (14%).
- In a sub-sample of 94 homes, hot water accounted for 33% of indoor water use.
- The majority of hot water is used for showering (39%) and faucet use (34%) and both consumed substantially more hot water than all other end uses combined (27%).

Indoor Water Use Will Continue to Decline in the Future

- Substantial additional indoor conservation potential exists in the single-family sector. Current average daily indoor per household use of 138 gphd and per capita use of 58.6 gpcd are expected to reduce to 110 gphd and 36.7 gpcd in the coming years through replacement of old toilets and clothes washers. Additional indoor reductions below these levels can be expected as future fixtures and appliances become even more efficient than today's models and are widely installed and customer side leakage is reduced through automated metering and leak alert programs.
- The percentage of homes that have efficient toilets and clothes washers has increased substantially. In REU1999, only 6% of homes had average clothes washer loads of less than 30 gallons and in REU2016, this increased to 46%. In REU1999, only 8.5% of homes had average toilet flushes less than 2.0 gallons, and in REU2016 this increased to 37%.

Outdoor Use is Variable

- Water use for landscape irrigation is highly variable in terms of the volumes of use, but follows a consistent pattern where the majority of homes applied at or below the theoretical irrigation requirement while a small group of over-irrigators accounted for the most of the excess irrigation. The majority of study participants in the Landscape Group (72%) applied considerably less water to their landscapes than was theoretically required for optimal plant growth. Another 16% of participants applied an amount of water to their landscape over the year that was close to the theoretical requirement. About 13% of participants applied an amount of water in excess of the estimated theoretical requirement to the landscape.
- A little over 60% of the individual lot areas in this study group (n=838) were devoted to landscape.

Target Excess Irrigators to Achieve Outdoor Demand Reductions

- Outdoor efficiency can be maximized by targeting efforts at customers that are over-irrigating rather than on general programs aimed at all customers.
- Prevent deficit irrigators from increasing their irrigation in the future to help maintain demand reductions.
- Pricing programs and reduction in planting areas may achieve outdoor demand reductions beyond efficiency measures.
- Savings estimates for landscape conservation programs range from 20% reduction for mild programs to 50% for more aggressive programs that include price increases and reductions in areas requiring irrigation.