Insights into declining single-family residential water demands

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Water use, especially indoor use, in single-family residences has declined since 1995 and is expected to continue to do so as new technologies enter the market. This conclusion is unavoidable when empirical data from residential end use studies dating back to 1995 are compared. Furthermore, the observed declines in indoor use are not related to economic conditions—the bulk of the data used for the analysis were taken before the 2008 recession. This article presents key data and findings from a 16-year data collection effort and closely examines changes in water use over that time as well as the potential for additional residential demand reductions in the future. The demand data presented here show patterns in single-family indoor and outdoor demands and provide a basis for future water supply planning and conservation program design.

KEYWORDS: *end uses, models of residential water demand, residential, trends in residential water demands, water demands, water use*

This article summarizes end-use data from a series of single-family residential studies over time and compares indoor and outdoor water use in order to demonstrate how water use is changing and what these trends suggest for water planning. Utilities need to know how low household and per capita water demands are likely to fall and what factors affect these demands. The data offer some reliable relationships on the question of future water demands.

Water use in single-family residences has declined since 1995, and this trend is expected to continue as new technologies enter the market. These declines are not a result of the 2008 recession—the majority of the data were collected before the last quarter of 2008 when the recession began. The data show clear decreases in household and per capita indoor water use over time, and additional indoor demand reductions are likely as high-efficiency fixtures and appliances further saturate the market. Key findings of the analysis are summarized here.

- Indoor water use for a family of three was observed to decrease from 187 gpd per household in the Residential End Uses of Water Study (REUWS; Mayer et al, 1999) to 162 gpd per household in the California Single-family Water Use Efficiency Study (CSFWUES; DeOreo et al, 2011) and to 132 gpd per household in the New Single Family Home Study (NSFHS) prepared for the US Environmental Protection Agency (USEPA; DeOreo, 2011a). The end-use data for these studies were collected in 1996, 2007, and 2006, respectively.
- Data collected in 2002 and 2006 reported indoor water use for a family of three in two sets of homes that were modified by retrofits or by design to use less water dropped to 117 and 107 gpd per household, respectively (DeOreo, 2011a; Aquacraft, 2005).
- In the above referenced studies, the greatest reductions at the end-use level were seen in the toilet and clothes washer categories. Water use in other indoor categories was more variable (DeOreo, 2011a; DeOreo et al, 2011).
- Water use in categories such as leakage and excess irrigation tend to be skewed by a small number of homes with large use in these categories. Skewed use raises the average for the group as a whole, whereas most households used significantly less than the average.
- Finding ways of targeting and reducing excess use in these skewed end-use categories remains an important challenge for demand-management efforts (Aquacraft, 2011a, 2011b).
- Trends observed in the data strongly suggest that typical indoor household water use will decrease further in the coming years barring wholesale abandonment of the efficiency improvements developed over the past decade (Aquacraft, 2011a, 2011b).

These findings have important implications for water supply planning. If future demands are based on historic consumption patterns rather than new lower-demand patterns, raw water requirements will be overestimated and expensive, and potentially environmentally damaging new supply projects could be developed needlessly. Reduced residential indoor and outdoor demand is the payoff for years of water conservation efforts made by water utilities, conservation professionals, policymakers, and others. Unless these water demand reductions are accepted as permanent by water planners, the reductions will not have the benefits intended by the programs from which they arose.

FOUR KEY END-USE STUDIES

Since 1995 a methodology developed by the authors—flow trace analysis—and the analytic software they created have been used in major residential end-use studies. Data for this article were drawn from four key end-use studies (REUWS, USEPA Combined Retrofit Report [Aquacraft, 2005], NSFHS, and CSFWUES) conducted by the authors. These four studies provide water use information from five groups of homes based on the period from which they were sampled or types of fixtures and appliances in the home.

REUWS. Conducted for the Water Research Foundation, this baseline study (Mayer et al, 1999) collected water use data from 1,188 single-family homes served by 12 water agencies in the United States and Canada. These served by provide information on water use patterns circa 1996–97. Most of the homes in this study were constructed before implementation of the Energy Policy Act of 1992 (USDOE, 1992) and relatively few had installed newer, more water-efficient fixtures and appliances.

USEPA Combined Retrofit Report. This report (Aquacraft, 2005) measured indoor water use in 100 homes spread across three utilities before and after a high-efficiency fixture and appliance retrofit. Before the retrofit, the water use in these homes was similar to what was found in the 1999 REUWS. After the retrofit, indoor water use in these homes was reduced by more than 30%. The data for this study were collected between 2000 and 2002.

NSFHS. DeOreo (2011a) measured water use patterns in two groups: a randomly selected sample of 240 "standard" new homes drawn from nine participating utilities and a group of 36 new homes built to the WaterSense new home specification. This study comprised the following two groups.

- Standard new home group: Approximately 240 homes built after Jan. 1, 2001, were selected at random from nine water agencies in Arizona, California, Colorado, Florida, Nevada, Oregon, and Utah. These homes represent water use in new homes built to Energy Policy Act of 1992 standards or better. The data for the standard new homes were collected between 2006 and 2008.
- High-efficiency new home group: Water use patterns at 36 new homes built to meet the WaterSense new home specification (as of 2009), with the addition of a high-efficiency Energy Star–rated clothes washer, were studied in 2008 and 2009 (DeOreo et al, 2011). This sample is the most water-efficient group of homes the authors have studied to date.

CSFWUES. For this study (DeOreo et al, 2011), 780 single-family homes were chosen at random from the general population in 10 water agencies throughout California. These homes represent a snapshot of water use in existing homes circa 2007, approximately 10 years after the REUWS.

RESEARCH APPROACH

Each of the four end-use studies in this article focused on different groups of single-family homes but used similar research methods. Readers wanting a more detailed description of the methodology are referred to the study reports themselves, which also include discussion of accuracy and verification of the flow trace analysis as a method of disaggregating single-family water use into end uses.

- Each participating water agency provided one year of historic monthly or bimonthly billed consumption data from a random sample of single-family customers in its service areas. The annual water use of each sample was compared against the average annual use of the population from which each sample was drawn to verify that the samples were representative of their respective populations.
- A detailed mail survey was sent to each household in every sample to collect demographic, physical, and economic data for modeling and statistical analysis.
- A sample of homes was drawn from the survey respondents for more detailed analysis including flow recording by data loggers, disaggregation of water use into end uses, and landscape analysis.
- A database was prepared that included the annual and disaggregated water use for each study home, survey information, and weather data.

In these studies, water use was disaggregated into the following end-use categories: toilets, clothes washers, dishwashers, showers, baths, miscellaneous faucets, irrigation, leaks, and special uses such as evaporative coolers, water treatment, and pools. The flow trace analysis technique used for the disaggregation has been described in detail in previous studies (Mayer et al, 1999; Lewis, 1998; DeOreo et al, 1996a, 1996b); a detailed explanation and validation of the technique is beyond the scope of this article.

The analytic database developed for each study enabled a variety of computations and analyses to be completed. Water use event data can be summarized by any of the available parameters such as the average daily use by end-use category. The event data for individual fixtures were analyzed to determine number of uses, average volume per use, and percent of uses that are equal to or less than a specified benchmark value.

In these studies, flow trace data were typically limited to a single two-week period. Outdoor use from manual or automatic irrigation occurring during the logging period was identified and analyzed with respect to the use patterns during the logging period. Because of the high variability of outdoor use over the course of a year, a limited two-week snapshot cannot be used to estimate annual outdoor use. Therefore outdoor use was usually estimated for each household by taking the total annual water use from the billing data and subtracting the projected annual indoor use as determined from the two-week flow monitoring period. In some cases, billed consumption data were used to estimate indoor use using a minimum month or average winter consumption method, which was then subtracted from annual use to obtain an estimate for annual outdoor use.

By combining the datasets developed for each of these four end-use studies, the authors were afforded a unique and powerful tool for examining changes in both indoor and outdoor residential water use over the past 15 years. With these data, it was also possible to determine the percent of homes meeting specified efficiency benchmarks for end uses such as toilet flushing and automatic clothes washing. Outdoor use efficiency was characterized by comparing the depth of irrigation water applied to each landscape against the theoretical irrigation demands calculated for each landscape using locally obtained evapotranspiration (ET) and precipitation data. Outdoor use tends to be more variable and unpredictable, but there are good relationships between outdoor water use and a few key parameters that will allow conservation planners to design better programs for managing these demands and reducing excess irrigation.

INDOOR USE

The analyses of the end-use studies are provided in the study reports. The results from the studies are compared here to show how the study groups' water use has changed and which factors best explain their use. The analysis shows that indoor water use is measurably reduced on both a household and a per capita basis in the newer and more efficient homes. The results also show that older homes can be brought to a similar high-efficiency level through basic fixture and appliance retrofits and management of leaks.

Average daily indoor use. There have been significant reductions in residential indoor water use since the data for the 1999 REUWS were collected. The household data shown in Figure 1 indicate a trend in decreased household water use as consumption patterns from standard housing stock in the 1990s are compared with the standard new homes, retrofit homes, and the high-efficiency new homes. The household data from the CSFWUES, which shows a random sample of existing homes sampled around 2007, does not show a significant decrease in water use at the household level. However, as explained in subsequent sections and shown in Figure 2, when corrected for the number of occupants in the homes, there has been a significant reduction in per capita use.

Figure 2 shows the trend for reduced water use on both a household and per capita level by normalizing the water use in each study group for a family of three. In the REUWS (standard housing stock from the 1990s), a family of three used an average of 187 gpd per household for indoor purposes. A family of three in California in 2007 used an average of 162 gpd per household indoors—a 13.3% reduction from the use information reported in the REUWS. A family of three in a typical new home built after 2001 used an average of 132 gpd per household indoors—a 29.4% reduction from the data collected for the REUWS. A family of three in an older home that was retrofitted with water-efficient fixtures and appliances used an average of 117 gpd per household indoors—a 37.4% reduction from the REUWS. Most efficient of all, a family of three in a new home built to WaterSense specifications and with an Energy Star–rated clothes washer used an average of just 107 gpd per household indoors—a 42.7% reduction from the REUWS. This result shows the clear trend toward water efficiency in indoor use and suggests that further reductions in indoor use are likely as older toilets and clothes washers are replaced in the future.

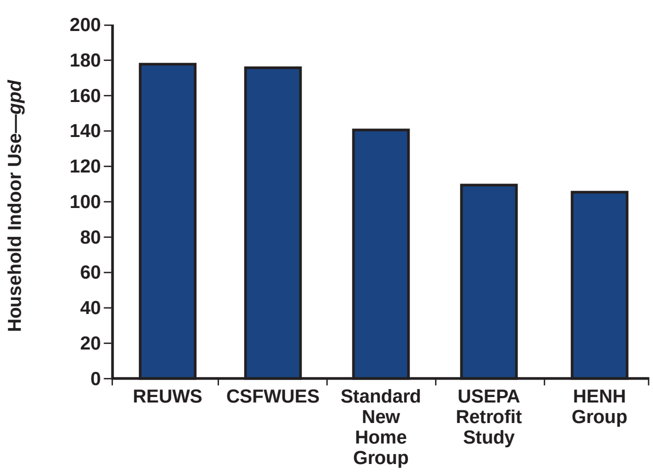
Comparison by end use. Indoor water use was disaggregated into individual categories and summarized by average daily gallons of use per household. The average daily per household water use from the four key studies is shown in Figure 3. These data show a dramatic reduction in household use in two major end-use categories: toilets and clothes washers.

Although the existing homes studied in the 1999 REUWS and the 2011 CSFWUES averaged more than 40 gpd for toilet flushing, retrofit homes equipped with a mixture of 1.6- and 1.28-gpf toilets averaged 20.3 gpd for flushing. The high-efficiency homes, built to the WaterSense new home specification and equipped exclusively with 1.28-gpf toilets, averaged 16.2 gpd for flushing.

The pattern for clothes washers was similar: the existing homes averaged around 35 gpd for clothes washing. The high-efficiency new homes used just under 12 gpd for clothes washing. These homes were equipped with clothes washers rated at tier 3 by the Consortium for Energy Efficiency.

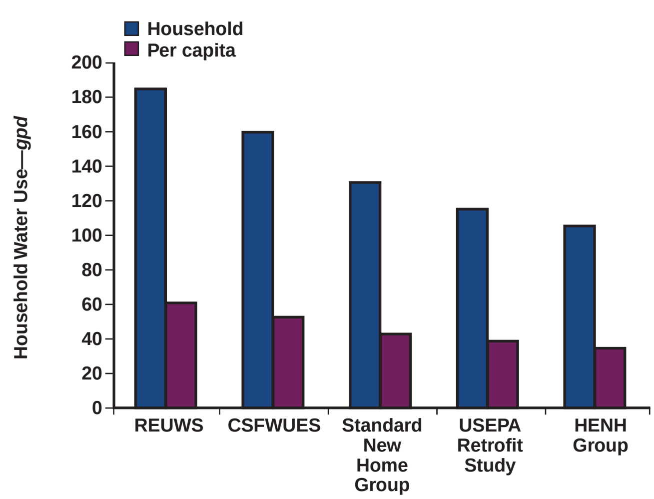
Water use for showers did not show a consistent decline. The existing homes from the REUWS and CSFWUES used an average of around 33 gpd for showering, whereas the two groups

FIGURE 1 Comparison of actual average daily per household indoor use from five groups of homes



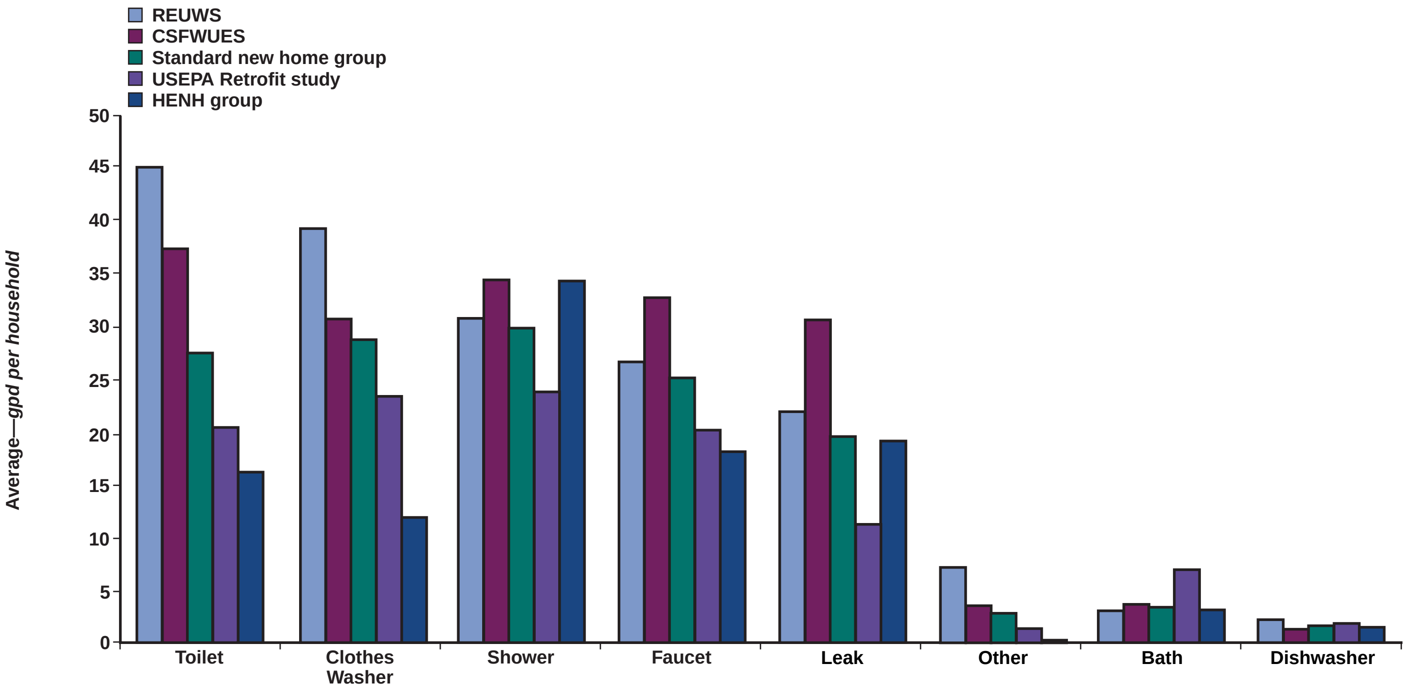
CSFWUES—California Single-family Water Use Efficiency Study, HENH group—high-efficiency new home group, REUWS—Residential End Uses of Water Study, USEPA—US Environmental Protection Agency

FIGURE 2 Comparison of per household and per capita water use normalized for a family of three



CSFWUES—California Single-family Water Use Efficiency Study, HENH group—high-efficiency new home group, REUWS—Residential End Uses of Water Study, USEPA—US Environmental Protection Agency

FIGURE 3 Comparison of end uses of water by study group



CSFWUES—California Single-family Water Use Efficiency Study, HENH group—high-efficiency new home group, REUWS—Residential End Uses of Water Study, USEPA—US Environmental Protection Agency

of high-efficiency homes from the USEPA Combined Retrofit Report and the NSFHS averaged 29 gpd. The lowest shower use was seen in the USEPA Retrofit Study homes, which averaged 24 gpd. Ironically, the high-efficiency new homes used more than 34 gpd, which spoiled the downward trend. Even though the shower flow rates in the new high-efficiency homes were lower than the other groups, the homes had more showers per day and longer shower durations, which masked the effects of the lower flow rates. Essentially, shower use was considered to remain flat across the study groups, even though the data from the USEPA Combined Retrofit Report suggest that lower shower use is possible.

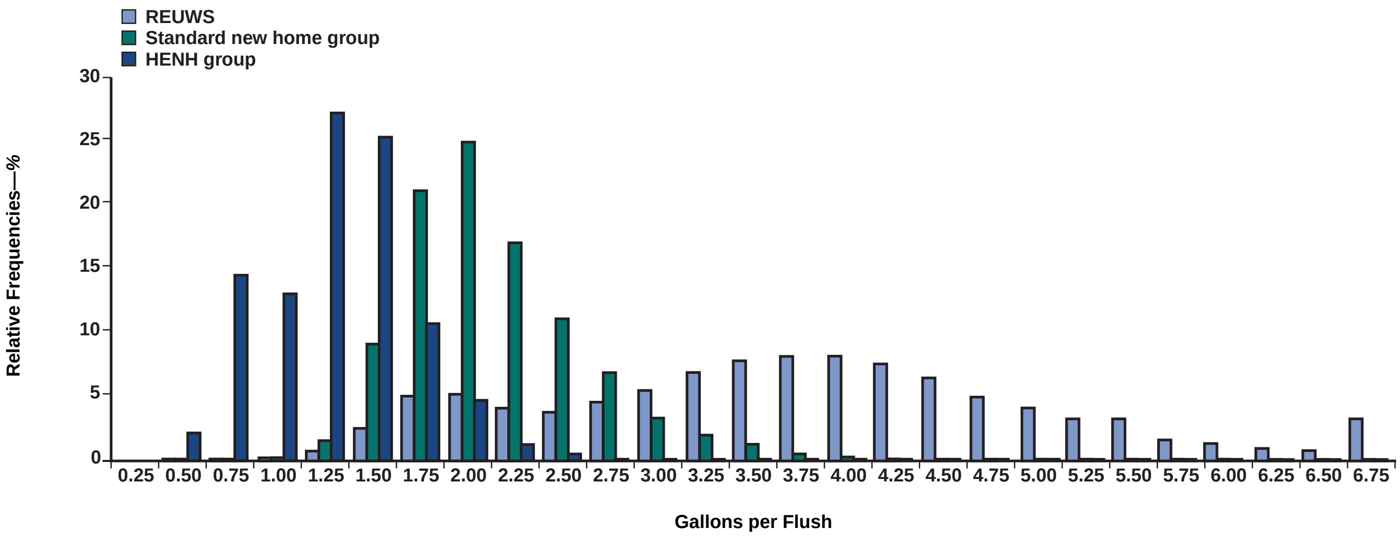
Faucet use did appear to decrease. The existing homes averaged 30 gpd, whereas faucet use in the high-efficiency homes averaged 19 gpd. Leakage volumes also dropped. The existing homes averaged 26 gpd for events that were classified as leaks, whereas the high-efficiency homes averaged 15 gpd. Events classified under the "other" category were also lower in the high-efficiency homes, whereas bathtub and dishwasher use remained essentially unchanged. Additional details of interest on individual end uses are given in the following section.

Changes in toilet flush volume. The volume of water used to flush a toilet has been reduced significantly over the past 15 years and is likely to decrease further as more 1.28-gpf high-efficiency toilets (HETs) are installed. In 1999, the average flush volume was measured to be 3.48 gpf in the REUWS (Mayer et al, 1999). In the 2011 CSF study, the average flush volume was measured to be 2.8 gpf. Standard new homes in the 2011 NSFHS had an average flush volume of 2.1 gpf. The group of homes built to meet the WaterSense new home specification (high-efficiency new home group) had an average flush volume of just 1.4 gpf.

One of the most interesting results from the data analysis was the shift in the distribution of toilet flush volumes. Figure 4 shows the relative frequencies of all the toilet flushes recorded in the REUWS, the standard new home group, and the combined high-efficiency new home group homes from the USEPA Retrofit and USEPA Combined Retrofit Report studies. The volume pattern is broadly distributed around 3.5 gpf in the REUWS group and contains a significant number of flushes at 6.75 gpf or more. In the standard new home group, the mean has shifted downward to less than 2 gpf and the distribution is much more tightly grouped, but there are still flushes at 3.5 gpf or more, which is somewhat surprising because these were all homes in which the expectation was to find 1.6-gpf or better toilets. Finally, the high-efficiency homes, in which only HET models were installed, had flushes grouped around 1.25 gpf and had relatively few flushes at more than 2 gpf.

Changes in clothes washer use. Clothes washers have become dramatically more efficient over the past 15 years. In the REUWS, the average clothes washer load consumed 41 gal per load (gpl). In the high-efficiency homes, this had dropped by 63% to 15 gpl. At the same time, the number of loads per day dropped by 20%,

FIGURE 4 Changes in distributions of toilet flush volume



HENH group—high-efficiency new home group, REUWS—Residential End Uses of Water Study

resulting in the decrease in household use for clothes washing shown in Figure 3.

Shower use comparison. Shower use has tended to remain relatively stable over time. Shower use comparisons are shown in Table 1. The number of showers per household per day has stayed between 1.9 and 2.1; the shower duration is between 8.2 and 9.6 minutes in all four studies. Although shower flow rates were reduced in the new high-efficiency homes, significant reductions in shower volumes were not observed because the average duration increased enough to maintain the average shower volume of around 16 gal. This explains why there is no clear downward trend in shower use. It appears that, at least in these samples, simply reducing the flow rate in showerheads is not sufficient by itself to cause a reduction in shower volume.

Faucet use comparison. Faucet use has decreased in both the new and the high-efficiency homes (Table 2), but research results indicate that this is primarily because people in the high-efficiency homes used the faucet less frequently. Many of the faucet parameters shown in Table 2 were similar across the four studies. Of interest was that in the CSF study statistical analysis showed that the presence of both dishwashers and garbage disposals was associated with lower faucet use.

Leak effects. Leakage data can be misleading. Leakage is one of several categories of water use that tend to be skewed by a relatively small number of homes with high leakage rates. These high-leakage accounts, although small in number, have a disproportionate effect on the average of the group as a whole. For example, the leakage data from the CSFWUES group were used to create Figures 5 and 6. Figure 5 shows the percentage of the study homes that fall into the various daily leakage bins ranging from 10 to > 200 gpd per household. From this figure, the homes in the upper bins appear fairly insignificant with only 7% of the houses leaking at greater than 100 gpd and only 4% leaking at more than 150 gpd.

If the data are expressed in terms of the percentage of the total leakage volume accounted for by the houses in each bin, a different picture emerges. Figure 6 shows that the 7% of homes with leakage greater than 100 gpd actually account for 44% of the

TABLE 1 Shower data comparisons

Parameter	REUWS	CSFWUES	Standard New Home Group	HENH Group
Average minutes	8.2	8.7	8.2	9.6
Average showers/day	2.1	2.0	1.9	2.1
Average flow	2.2	2.2	2.0	1.6
Average volume	17.2	18.2	15.9	15.9

CSFWUES—California Single-family Water Use Efficiency Study, HENH—high-efficiency new home group, REUWS—Residential End Uses of Water Study

TABLE 2 Faucet data

Parameter	REUWS	CSFWUES	Standard New Home Group	HENH Group
Average uses per day	41	57	48	33
Average gallons per use	0.65	0.60	0.53	0.60
Average peak flow—*gpm*	1.28	1.1	1.1	1.0
Average duration—*min*	0.59	0.62	0.58	0.68

CSFWUES—California Single-family Water Use Efficiency Study, HENH—high-efficiency new home group, REUWS—Residential End Uses of Water Study

FIGURE 5 Distribution of percentage of California Single-family Water Use Efficiency Study houses into leakage bins

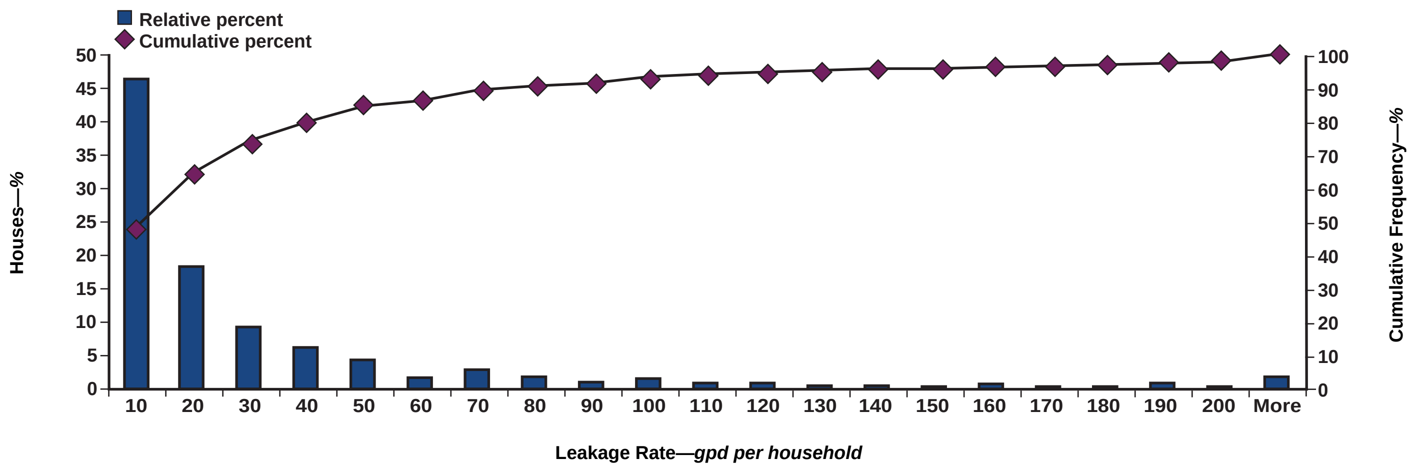
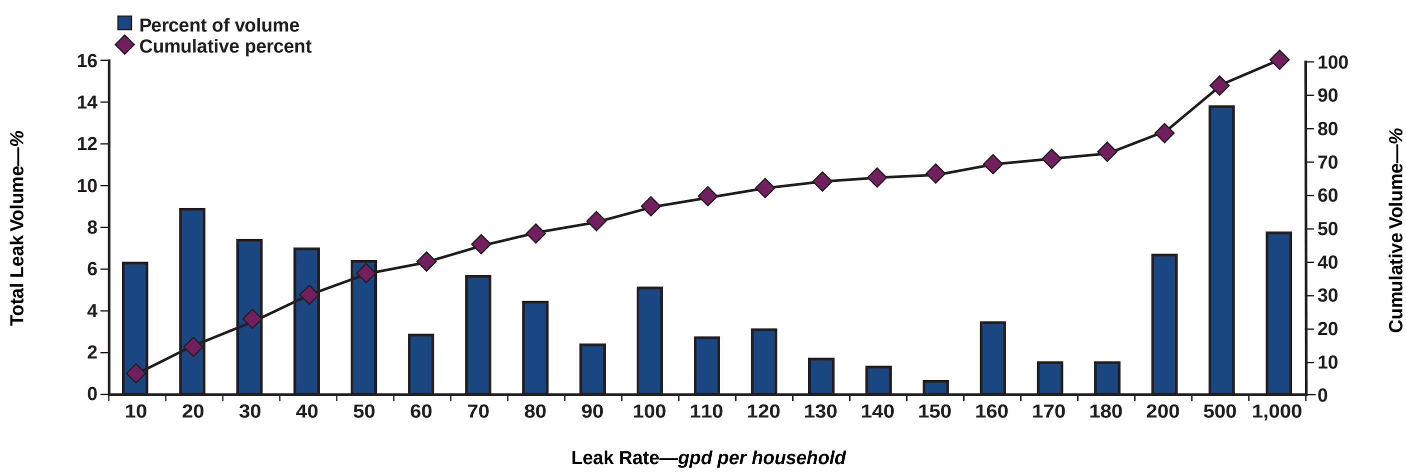


FIGURE 6 Distribution of percent of total leakage by leak bins for California Single-family Water Use Efficiency Study



total leakage volume of the entire group. Likewise, the 4% of homes that have leakage greater than 150 gpd account for 35% of the total leakage of the group. This result is not unusual. The average leakage for the CSFWUES group was approximately 30 gpd per household, but the median rate was only 11 gpd per household. Most of the houses had leakage of 10 gpd per household or less, and the few houses with very large leaks almost tripled the overall average.

This result suggests that leakage-reduction efforts should not be targeted at the general population but at the houses in the top 10% of the group, which in this case would be houses with leakage rates of 80 gpd or more. These top 10% of the houses account for 50% of the total leakage.

Household efficiency criteria. To judge the relative water efficiency level of the homes in these studies, the authors determined the percentage of homes in each study that met specific criteria for average toilet flush volume and average clothes washer load volume that indicate whether the house was equipped with high-efficiency devices. The criterion used for toilets was that the house had to have an average flush volume of 2.0 gpf or less to be considered meeting the high-efficiency criteria for toilet flushing. The value used for clothes washers was that the average gallons per load for the house had to be less than 30 gpl, which constituted a high-efficiency machine for the study period. Figure 7 shows the progression of homes meeting the toilet and clothes washer criteria. In the REUWS, only 10% of the homes met the 2.0-gpf toilet criteria and only 3% met the 30-gpl clothes washer criteria. Ten years later, 30% of homes in the CSFWUES met the toilet and clothes washer criteria. Not surprisingly, virtually all of the retrofit homes and new homes built to the WaterSense specification, here combined for convenience, met the toilet and clothes washer efficiency criteria. In addition, fewer than half of the standard new homes met thses criteria.

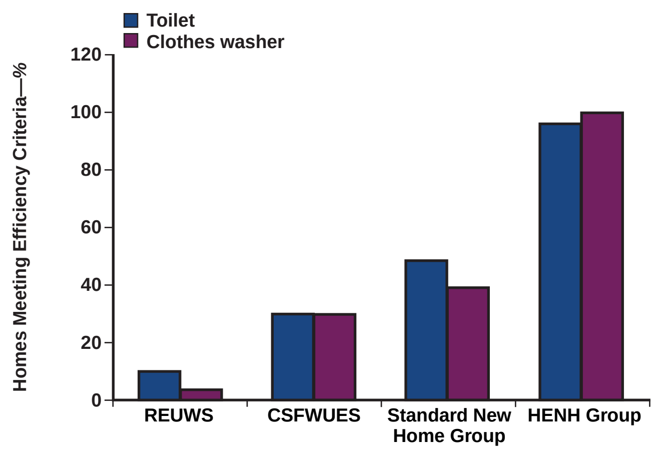
Unexpectedly high flush volumes in some new homes. An unexpected finding from the NSFHS houses built since 2001 was that a number of these new homes had toilet flush volumes that exceeded 1.6 gpf. In some cases, the flush volume in these homes was substantially higher than 1.6 gpf. Because of the provision of the Energy Policy Act of 1992, standard new homes built after 2001 should all have been equipped with 1.6-gpf toilets or better, yet the data showed that fewer than half of the homes had average flush volumes of 2 gpf or less.

During the data logging study of the NSFHS group, 41,957 flushes were recorded. The distribution of the flush volumes for the new homes is shown in Figure 8. Approximately 40% of the flushes are ≤ 1.6 gpf, and 60% of the flushes are > 1.6 gpf. Flush volumes were recorded at up to 6 gpf because some homes were equipped with non–ultra-low-flush (ULF) toilets and many ULF design toilets installed in the homes are actually flushing at volumes greater than 1.6 gal. The researchers were not able to inspect the individual toilets to determine the cause of the overflushing, but it is likely that this is the result of both poor adjustments by the installers and toilets that do not meet the 1.6-gpf specification.

Per capita use relationships. As part of the modeling effort, total household water use (in gallons per day per household) was generally used as the dependent variable; a range of variables were tested for their ability to predict indoor use. In many cases, the number of people in the house was the only continuous independent variable that proved significant in predicting indoor water use. In all four end-use studies discussed here, the relationship between household use and number of residents was nonlinear and followed a power curve relationship. The other relationship that was observed was that the newer and more-efficient homes had curves that were generally below the curves of the older and less-efficient homes.

The actual relationships between household indoor use and number of residents for the five study groups are shown in Table 3 and Figure 9. As household populations increase, water use does not increase in direct proportion but follows a power curve relationship that has an exponent < 1.0. The data group themselves as a family of curves, with the REUWS homes having the highest daily use, followed by those in the CSFWUES, the standard new home group, the USEPA Combined Retrofit Report, and the high-efficiency new home group.

FIGURE 7 Comparison of percentages of households meeting toilet and clothes washer efficiency criteria



CSFWUES—California Single-family Water Use Efficiency Study, HENH group—high-efficiency new home group, REUWS—Residential End Uses of Water Study

The implication of the nonlinear relationship between household use and the number of residents is that water planners should use caution when using per capita demand values for planning. Also, when setting water budgets, the temptation to increase budgets directly in proportion to the number of residents should be resisted because doing so could create excessive budgets for larger households.

Factors that affect indoor water use. A wide range of continuous and conditional variables were tested with respect to their

FIGURE 8 Distribution of toilet flush volumes in standard new homes built after 2001

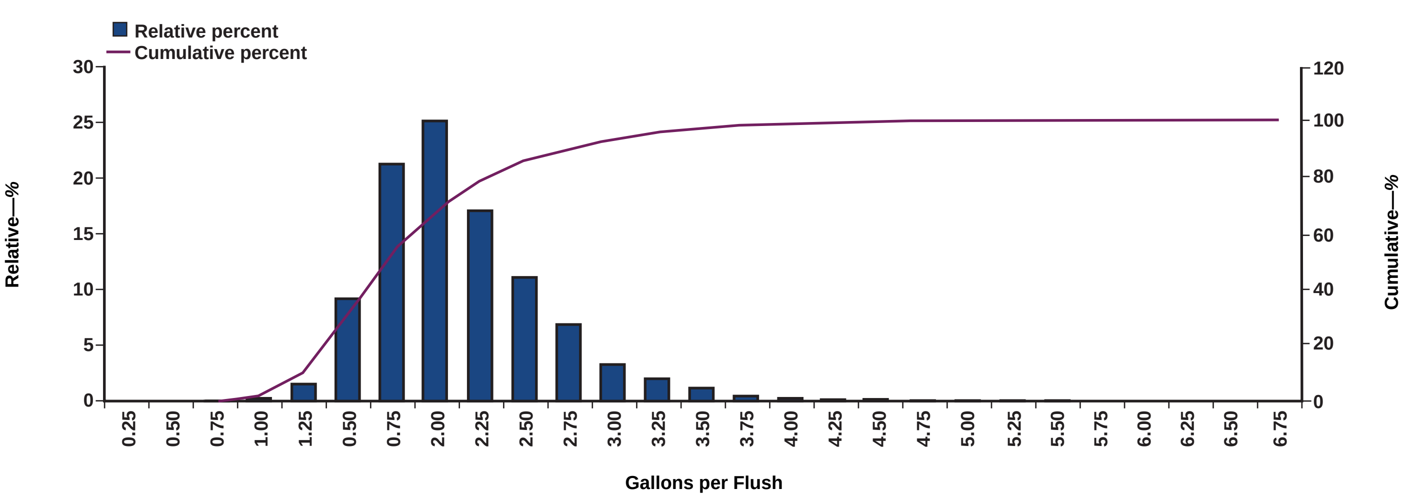


TABLE 3 Indoor household demands normalized for a family of three people

Parameter	REUWS (Built < 1995)	CSFWUES	Standard New Home Group (Built > 2001)	USEPA Retrofit Study	HENH Group
Number of households	1,188	728	302	96	25
Mean±95% CI—*gpd per household*	177±5.5	186±10.2	140±10.0	107±10.3	105±28
Median—*gpd per household*	160	165	125	100	90
Per capita relationship—*gpd per household*	87.41 × 0.69%	72.67 × 0.73%	66.30 × 0.63%	50.21 × 0.77%	59.58 × 0.53%
Household use for family of three people—*gpd per household*	187	162	132	117	107
Projected per capita use for family of three people—*gpcd*	62.18	53.9	44.15	39.0	35.6

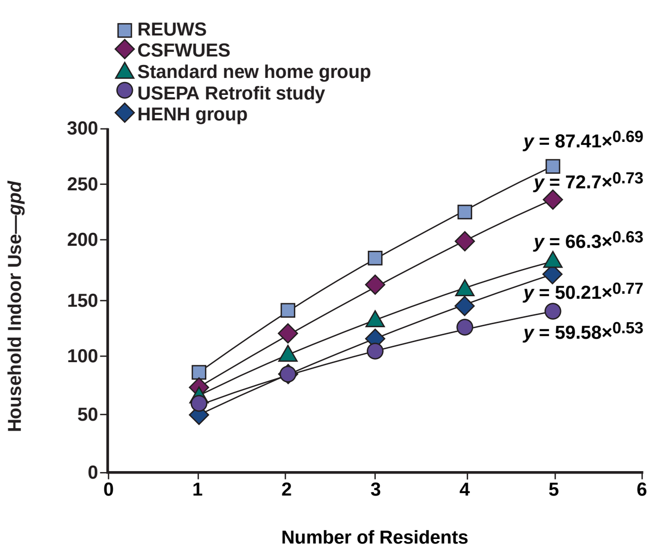
CI—confidence interval, CSFWUES—California Single-family Water Use Efficiency Study, HENH—high-efficiency new home group, REUWS—Residential End Uses of Water Study, USEPA—US Environmental Protection Agency

value for predicting indoor water use. The only continuous variable that was found to be statistically significant across all studies was the number of people in the home. These relationships are shown in Table 3. Others, such as the household income, age of the home, value of the home, number of bedrooms, or number of bathrooms, were not found to be significant. The living area of the home was found to be significant for some data sets, but to a smaller extent than the number of residents.

Analysis of variance was conducted on a range of conditional variables to see whether they affected the household water use. Several of these proved to be significant.

- The presence of a leak of more than 100 gpd on the flow trace was positively correlated with household use and increased the average daily indoor use by 223 gpd.
- The presence of a nonadult living in the home was negatively correlated with water use and decreased household water use by 42 gpd.
- The presence of high-efficiency (ULF or HET) toilets in the home was negatively correlated and reduced household water use by 22 gpd.
- The presence of a high-efficiency clothes washer was negatively correlated and reduced average indoor water use by 17 gpd.
- The presence of a dishwasher and a garbage disposal was linked to decreased faucet use.

FIGURE 9 Per capita use relationships in five study groups



CSFWUES—California Single-family Water Use Efficiency Study, HENH group—high-efficiency new home group, REUWS—Residential End Uses of Water Study, USEPA—US Environmental Protection Agency

OUTDOOR USE

It was not possible to demonstrate clear trends in outdoor water use from the four studies used for this analysis. The quality of the data for the analyses varied, and the only study groups that the authors felt to be comparable were the CSFWUES and the standard new home group. These two study groups provide a contemporaneous comparison for the period around 2007 of existing and new homes. In addition, the data from these studies showed consistent relationships between key parameters and outdoor use that can be used to make models of outdoor use from which projections can be made on how varying these parameters might affect outdoor use.

Comparison of outdoor parameters. The most important outdoor parameters for the study groups are shown in Table 4. These results show a relatively high degree of consistency between the existing and new homes for the key parameters shown. All of the variations between the new and existing homes are 15% or less—and most of them are less than 10%.

Lot sizes and irrigated areas in the new home sample are approximately 10% larger, but the outdoor use was 15% less in the new homes. The average application for both groups was close to 57 in. compared with similar reference ET values of 43 in. Both groups of homes were applying, on average, 30–36% more than the ET requirement. When the excess use was determined for the lots that were overirrigating, this value averaged close to 30,000 gal/year/lot for the entire group and approximately twice this amount on the overirrigating lots. At the same time, if the algebraic average of excess and deficit irrigation

TABLE 4 Comparison of outdoor use parameters

Parameter	CSFWUES	Standard New Home Group	Ratio of Standard New Home Group to CSFWUES
Average lot size—*sq ft*	9,179	10,146	1.11
Irrigated area—*sq ft*	3,387	3,714	1.10
Outdoor use—*gal/year*	93,400	78,000	0.85
Average application—*in.*	57	56	0.98
Average reference evapotranspiration	42	43	1.02
Average application ratio	1.36	1.30	0.96
Average excess application—*gal/year for overirrigators*	29,400	30,000	1.02
Net application for all homes—*gal/year*	6,500	7,300	1.12

CSFWUES—California Single-family Water Use Efficiency Study

applications was calculated, this averaged between 6,500 and 7,300 gal/lot. The value of 30,000 gal/year represents the amount of water that could be saved if all of the excess irrigation could be eliminated on the lots where it was occurring, while leaving the deficit irrigators alone. The values between 6,500 and 7,300 gal/lot represent the amount of water that could be saved if everyone's irrigation were brought precisely to the ET-based theoretical irrigation requirement.

Outdoor water use relationships. The models of outdoor use were similar for both the standard new home and high-efficiency new home groups. For illustration purposes, the analysis of the outdoor use data for the CSFWUES sample is shown in Eq 1, which provided the best fit for predicting outdoor water use in the CSF study.

$$\text{Outdoor Water Use} = 1.6207 \times 10^{-4} \times \text{NetET}_o^{1.66} \times \text{IrrArea}^{0.682} \times \text{Inc}^{0.125} \times \text{LRatio}^{0.506} \times \text{Pool} \times \text{Excess} \times \text{Sprinkler} + C_f \quad (1)$$

See Table 5 for definitions of all factors in Eq 1.

Outdoor use is most strongly affected by ET, irrigated area, and the water use intensity of the landscape as measured by the landscape ratio—which is the ratio of the actual irrigation requirement of the lot to the requirement based on a total turf landscape, whether a pool is present on the landscape, whether excess irrigation is occurring on the lot, and whether there is an automatic irrigation system present.

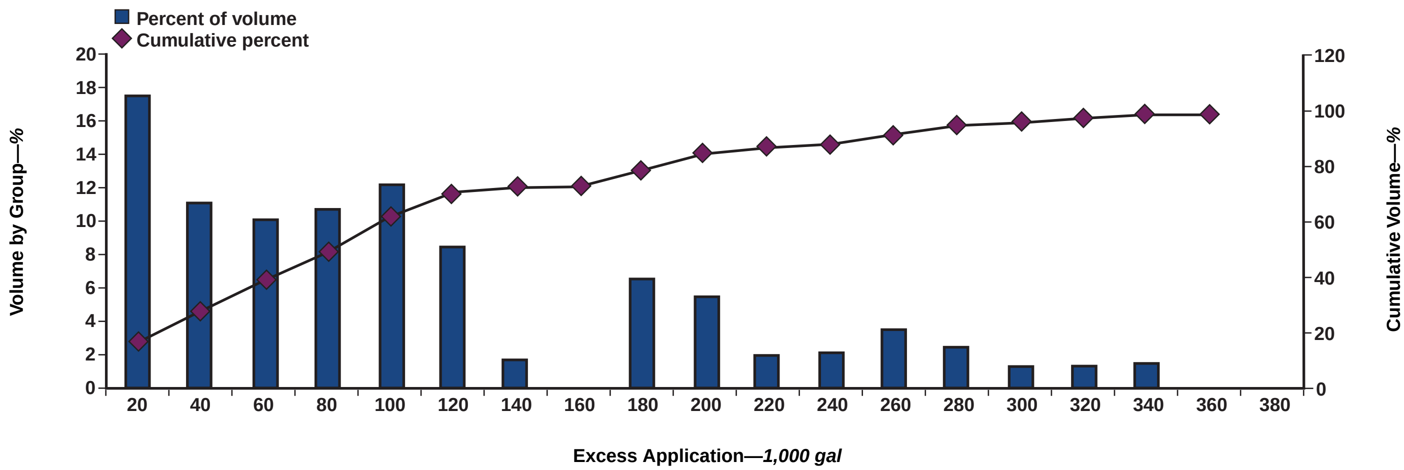
One of the key factors for predicting outdoor water use is whether the customer is overirrigating. Homes that overirrigate tend to have much larger outdoor use volumes. The situation with overirrigation is similar to that of leakage—a small number of homes influence the overall average far out of proportion to their numbers. Only a small number of homes were applying large volumes of excess irrigation: > 60% of the homes were applying 20,000 gal or less of excess water and only 8% of the homes were applying more than 100,000 gal of excess irrigation water (DeOreo et al, 2011). If, however, the percentage of excess irrigation water associated with the various bins of excess use (Figure 10) is investigated, this 8% accounts for 38% of the total excess irrigation (DeOreo et al, 2011).

The outdoor use model suggests that if the rate of overirrigation could be reduced from 50 to 25% of the households in California, the average outdoor use for all irrigating homes would decrease by approximately 25,000 gal/year, a savings of 29% in outdoor use. This would represent a total savings for the state of more than 630,000 acre-feet of raw water from simply reducing the percentage of homes that are overirrigating.

TABLE 5 Factors of interest for outdoor water use

Parameter	Description
Outdoor water use	The dependent variable (per 1,000 gal)
Net evapotranspiration (NetET_o)	Reference evapotranspiration—effective precipitation (in.)
Irrigated area (IrrArea)	Total irrigated area on lot (sq ft)
Income (Inc)	Household income (in $1,000s)
Landscape ratio (LRatio)	The ratio of the theoretical irrigation requirement to the reference requirement for the lot. This is a measure of the water requirements of the landscape relative to cool season turf (the reference crop).
Pool	Correction factor pool; multiply by 1.38 × percent of population with pools + percent without pools
Excess irrigation (Excess)	Correction factor for overirrigation; multiply by 3.13 × percent of homes that are overirrigating + percent that are not
Sprinkler	Correction factor for automatic sprinkler system; multiply by 1.21 × percent of homes with automatic sprinkler systems + percent without
C_f	Correction factor = –9,100 gal

FIGURE 10 Percent of volume of total excess use from California Single Family Water Use Efficiency Study homes



Additional outdoor savings can be achieved by reducing the irrigated areas and water requirements of the selected plant material or by prohibiting swimming pools, but all of these measures have effects on the quality of life. By comparison, the elimination of excess application seems like a fairly nonintrusive measure.

Although indoor use has been shown to be unaffected by household income, outdoor use is related to income. Consequently, it could be expected that during an economic downturn there would be a reduction in outdoor water use, which would add to declines in single-family water use from indoor efficiencies during times of economic downturn.

CONCLUSIONS

The results from four residential water use studies and five study groups summarized in this report lead to several important conclusions. There is a clear trend toward lower single-family indoor water use from both the household and the per capita perspective. Results from the CSFWUES show that existing homes sampled 10 years after the REUWS are using less indoor water. This demonstrates that water conservation efforts are bearing fruit and demand reductions are occurring. As time goes on, it is safe to assume that more homes will be retrofit with high-efficiency fixtures and appliances and that household water use in the existing customer pool will continue to decrease both on a per capita and a household basis. Water efficiency provisions are built into national building codes and the national Energy Policy Act of 1992. The effect of these provisions is measurable, as shown by the results of this analysis. Water planners should incorporate these changes in demand into future demand projections or run the risk of significantly overestimating future residential demands.

At the same time, the data from the two comparable outdoor studies show a remarkable degree of similarity in outdoor use between existing California homes and new homes across the country. They also show a similar set of factors affecting outdoor use and that the key of these is whether the home is overirrigating. Elimination of excess irrigation where it is occurring (while allowing the deficit irrigators to continue their practice) is the key to achieving outdoor water conservation that has minimal effects on quality of life.

The indoor end uses where the greatest decrease has been measured are toilets and clothes washers. This makes sense because toilets and clothes washers have been the target of the most intense design and manufacturing upgrades for the past 15 years. What were once specialized "water-conserving" devices are now common to the market. In contrast to toilets and clothes washers, water use for showering has stayed relatively constant in spite of concerted efforts to reduce shower flow rates.

Beyond fixture and appliance efficiency improvements, a key objective for future water conservation efforts should be to decrease the number of homes with significant leaks. Most large-volume leaks are caused by constant flows. These types of flows can be detected with smart water meters or automatic meter infrastructure (AMI) capable of detecting constant flows. Utilities equipped with AMI and automatic meter reading systems have used this capability to issue leak alerts to customers with ongoing continuous flows. This is a powerful targeting tool. If AMI is not a viable option, there are devices on the market that can detect constant flows, turn off the water, and alert the homeowner of the situation. These are the types of devices that could help reduce leakage and could be included in specifications for building codes or voluntary "green" building standards.

Dealing with leaks is important if the savings from future retrofits are to be fully realized. For example, as shown in Figure 3, the savings in water use associated with toilets and clothes washers in the California homes was approximately 17 gpd per household, but there also was a 9-gpd per household increase (from REUWS) in leakage that prevented the savings from fully showing on the bottom line of total daily indoor use.

The data on toilet flush volumes, shown in Figures 4 and 8, indicate that there may be problems with some off-the-shelf ULF design toilets that cause their flush volume to exceed the 1.6-gpf design. This could be the result of problems with installation or manufacturing. The 1.28-gpf HETs show a much closer flush volume distribution and much less excess flush volume than their 1.6-gpf counterparts. This is likely the result of increased third-party testing of toilets required by the WaterSense program.

Over time, the percent of households that can be classified as "high efficiency" with respect to toilet and clothes washer use has increased significantly. During the 10 years between the REUWS and the CSFWUES, the household efficiency rates for these devices have increased by a factor of 3 for toilets and a factor of 10 for clothes washers. However, the data for the standard new homes suggest a decrease in these rates of penetration because only about half of the new homes met the study criteria of 2.0-gpf average flush volume and a third met the 30-gpl clothes washer criteria. If a utility wants all new homes to meet these basic efficiency criteria, it is probably necessary to specify HETs (or WaterSense–labeled toilets) and Consortium for Energy Efficiency tier 3 clothes washers as the standards for new construction.

This research has found a nonlinear relationship between household domestic water use and the number of residents in the home. As the number of people in a home increases, water use does not increase proportionally. There are efficiencies associated with living in larger groups—each additional person in a home has a smaller effect on household water use. Because of this finding, water planners must use discretion when applying per capita demands to estimate household or population demands.

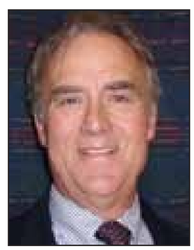
The relationships developed in these studies show that there are clear distinctions in household water use versus residents for the various groups. When these relationships are used to normalize the demands on the basis of the same number of residents, the demand patterns can be compared properly. Figures 2 and 9 show this dramatically and represent the key result for indoor use—agencies should be planning for per capita demands of around 40 gpcd or less for a family of three and household uses of 120 gphd or 44,000 gal/year or less for indoor use by the average home. Just as the mileage standards for automobiles are increasing in response to higher gas prices and oil shortages, the water use standards for households are, or should be, increasing as well.

The declines in indoor water use identified in this article were not an artifact of the economic recession of 2008–10. Most of the data on which these studies have been based were collected before the start of the recession. Outdoor water use, however, would be expected to decline during recessions as incomes fall because outdoor use is dependent on household income.

The results on outdoor use show that a key to outdoor water conservation is preventing excess irrigation. The results show that the majority of homes are irrigating at or below what appears to be a reasonable amount for their landscape and area, but the small number of homes that overirrigate raise the average for the group. The small numbers of homes that grossly overirrigate have a disproportionate effect on outdoor use, raising the averages further. Finding ways to target the water use in these homes, perhaps by use of water budgets linked to steeply inclining block rates, is an important goal of demand management efforts. Once excess irrigation is eliminated, then modest decreases in irrigated areas and shifting to less water-intensive plant materials can optimize outdoor use.

Overall, the results from the studies of single-family water use discussed in this article show that great strides have been made in reducing residential water demands and that there are also substantial opportunities for water savings remaining. The improved designs of household fixtures and appliances have made it possible to consider household demands of 40 gpcd (or 120 gphd for a family of three) a reasonable target. Better technologies for identifying leaks and preventing overirrigation of landscapes make it possible to envision significant demand reductions in these difficult categories. Finding better ways of providing customers with real-time information on their water use, along with reasonable budgets, can make allies of customers in a community-based effort of water conservation. Reduced residential demand is a cornerstone of future urban water resource management. Great progress has been made in the past 15 years, and the industry appears poised to realize further demand reductions in the future.

ABOUT THE AUTHORS



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PEER REVIEW

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