

RESIDENTIAL END USES OF WATER

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Sponsored by:

AWWA Research Foundation
6666 West Quincy Avenue
Denver, CO 80235

Published by the
AWWA Research Foundation and
American Water Works Association

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EXECUTIVE SUMMARY

Where is water used in single-family homes? How much water is used for toilets, showers, clothes washers, faucets, dishwashers, and all other purposes? What component of total use can be attributed to each specific water using device and fixture? How does water use vary across single-family homes? What are the factors that influence single-family residential water use? How does water use differ in households equipped with conserving fixtures? *The Residential End Uses of Water Study* (REUWS) was designed to help answer these and other questions and to provide specific data on the end uses of water in single-family residential settings across North America.

The “end uses” of water include all the places where water is used in a single-family home such as toilets, showers, clothes washers, faucets, lawn watering, etc. Accurately measuring and modeling the residential end uses of water and the effectiveness of conservation efforts has been the Achilles heel of urban water planning for many years. Understanding where water is put to use by the consumer is critical information for utilities, planners, and conservation professionals. Empirical evidence of the effectiveness of specific conservation measures can be used to improve the design of conservation programs and can provide justification for continued support of conservation efforts.

RESEARCH OBJECTIVES

The American Water Works Association Research Foundation (AWWARF) and 22 municipalities, water utilities, water purveyors, water districts, and water providers funded this study. Goals of this research included:

- Providing specific data on the end uses of water in residential settings across the continent.
- Assembling data on disaggregated indoor and outdoor uses.
- Identifying variations in water used for each fixture or appliance according to a variety of factors.

- Developing predictive models to forecast residential water demand.

This report represents a time and place snapshot of how water is used in single-family homes in twelve North American locations. Similarities and differences among "end uses" were tabulated for each location, analyzed, and summarized. Great care was taken to create a statistically significant representative sample of customer for each of the twelve locations. However, these twelve locations *are not* statistically representative of all North American locations.

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

Analyses are presented for each of the participating cities individually and for the pooled sample of 1,188 households. Creating national water use "averages" was not an objective of this study. The pooled results are presented for summary and comparative purposes alone. Two major contributions of this study are demonstrating the feasibility of identifying and measuring the different ways households use water and describing and analyzing variations in water used for specific purposes between different households. Armed with this insight, individual water utilities interested in reducing water demands in single-family homes now have a better tool to assess their own conservation potential.

The diversity of the water use data found over the twelve locations illustrates the importance of utility specific information on how individual behavior influences home water use. However, a striking conclusion of this report is in the *similarities* between these twelve locations in the amount of water fixtures and appliances use. The range in the amount of water used by hardware such as toilets, washing machines, showerheads, dishwashers, faucets, and fixture leaks is now documented and surprisingly similar - suggesting that this portion of the data has significant "transfer" value across North America. The predictive models developed as part of this study to forecast indoor demand significantly increase the confidence in explaining the water use variations observed. The major benefit of modeling is to provide a predictive tool with a high transfer value for use by other utilities.

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APPROACH

The project team developed a multifaceted approach to accomplish the research objectives set out for this study. After invitations were sent to utilities and water providers across the United States and Canada, 12 study sites volunteered to participate and partially fund this research. These 12 study sites were: Boulder, Colorado; Denver, Colorado; Eugene, Oregon; Seattle, Washington; San Diego, California; Tampa, Florida; Phoenix, Arizona; Tempe and Scottsdale, Arizona; the Regional Municipality of Waterloo, Ontario; Walnut Valley Water District, California; Las Virgenes Municipal Water District, California; and Lompoc, California.

A detailed and rigorous workplan to obtain data from each study site was developed by the project team. Data collected from each study site included: historic billing records from a systematic random sample of 1,000 single-family detached residential accounts; household level information obtained through a detailed mail survey sent to each of the selected 1,000 households; approximately four weeks of specific data on the end uses of water collected from a total of 1,188 households (approximately 100 per study site), data collection was divided into two, two-week intervals spaced in time to attempt to capture summer (peak) and winter (off-peak mostly indoor water use) time frames; supplemental information including climate data and information specific to each participating utility.

In this study, water consumption for various end uses was measured from a significant sample of residential housing across North America using compact data loggers and a PC-based flow trace analysis software. A flow trace is a record of flow through a residential water meter recorded in 10 second intervals which provides sufficient resolution to identify the patterns of specific fixtures within the household. The flow trace analysis software disaggregates this virtually continuous flow trace into individual water use events such as a toilet flush or clothes washer cycle and then an analyst implements signal processing tools to assign fixture designations to each event.

The data assembled for this research effort include: A sizable residential water use database containing nearly one million individual water use "events" collected from 1,188 residences in the 12 study sites; extensive household level information obtained through the mail survey completed by approximately 6,000 households, and historic water billing records from 12,000 residences. All of this information was collected to provide answers to many long

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standing questions about how much and where water is used in the residential setting and to provide estimates of the savings available from various conservation measures.

In addition to presenting the findings from the data collection effort, the project team also developed predictive models which incorporated the detailed end use information and household level socioeconomic data.

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

1. The accuracy of the billing consumption histories provided by participating utilities
2. The accuracy of mail survey responses
3. The timeframe of monitoring capturing "representative" indoor water use for each home
4. Capturing the precise weather related use within the monitoring timeframe needed to analyze the variables associated with outdoor use

RESEARCH FINDINGS

The primary goal of this study was to provide specific data on the end uses of water in residential settings across the continent. The accomplishment of this and the other stated goals of the REUWS are summarized in the findings below.

Annual Use

Average annual water use, based on historic billing records from approximately 1,000 accounts in each of the 12 study sites, ranged from 69,900 gallons per household per year in Waterloo and Cambridge, Ontario to 301,100 gallons per household per year in Las Virgenes MWD. The mean annual water use for the 12 combined sites was 146,100 gallons per household per year with a standard deviation of 103,500 gallons and a median of 123,200 gallons (n=12,075). Across all study sites 42 percent of annual water use was for indoor purposes and 58 percent for outdoor purposes. This mix of indoor and outdoor was strongly influenced by annual weather patterns and, as expected, sites in hot climates like Phoenix and Tempe and

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Scottsdale had a higher percentage of outdoor use (59 – 67 percent) while sites in cooler, wetter climates like Seattle and Tampa and Waterloo had much lower percentages of outdoor use (22 – 38 percent). The net annual ET requirement for turf grass ranged from 15.65 inches in Waterloo to 73.40 inches in Phoenix, Tempe, and Scottsdale.

Daily Per Capita Use

Per capita daily indoor water use was calculated for each study site and for the entire study using data logging results from 28,015 complete logged days to calculate water consumption and mail survey responses to count the number of people per household. Across all 1,188 study homes in the 12 study sites the mean per capita indoor daily water use was 69.3 gallons (including leakage). Results are shown in Figures ES.1. Toilet use was calculated at 18.5 gallons per capita per day (gpcd), clothes washer use was 15.0 gpcd, shower use was 11.6 gpcd, faucet use was 10.9 gpcd, leaks were 9.5 gpcd, baths were 1.2 gpcd, dishwasher use was 1.0 gpcd, and other domestic use was 1.6 gpcd. Mean indoor per capita use in each study site ranged from 57.1 gpcd in Seattle, Washington to 83.5 gpcd in Eugene, Oregon.

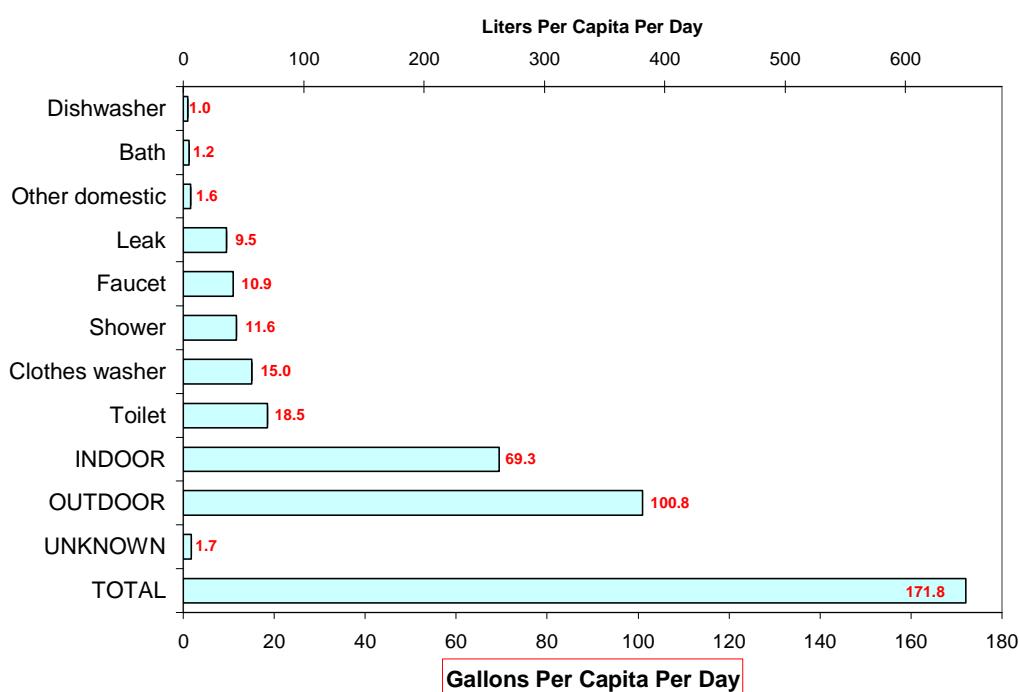


Figure ES.1 Mean daily per capita water use, 12 study sites

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The relative percent of per capita water used for indoor purposes across all twelve study sites is shown in Figure ES.2.

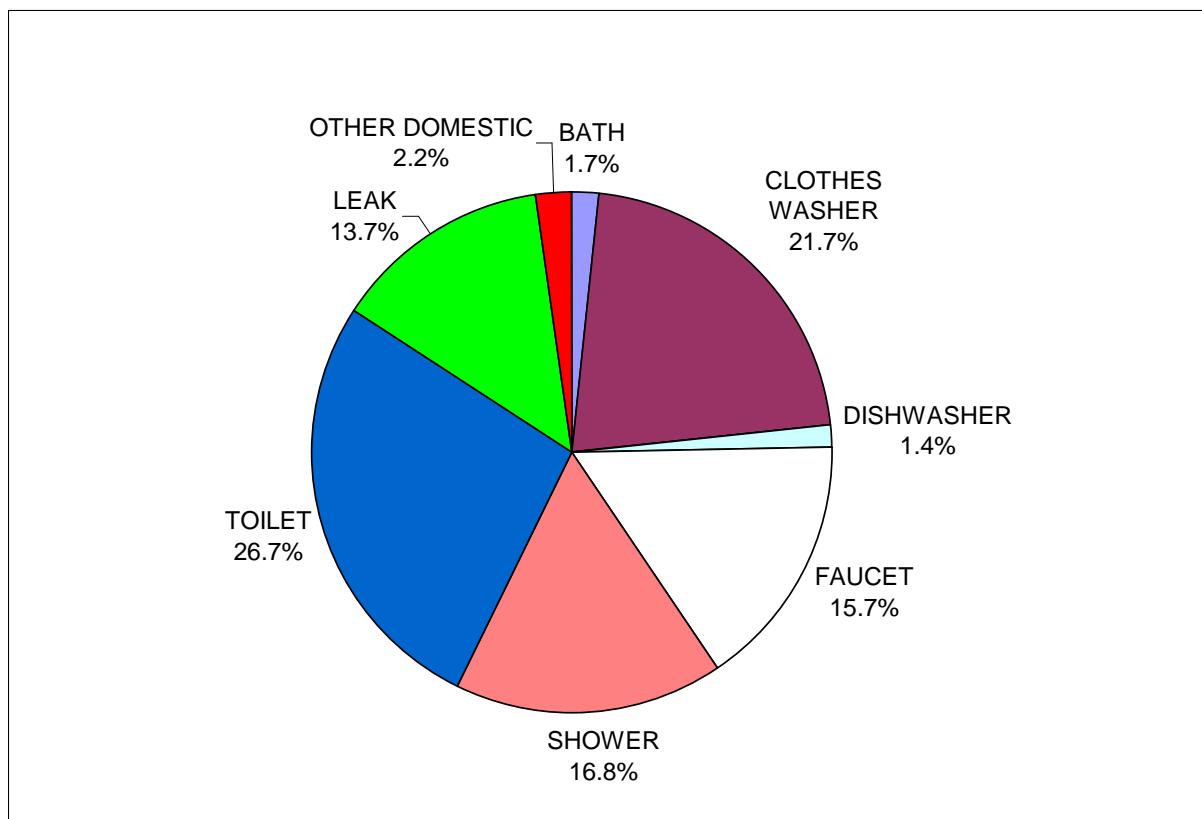


Figure ES.2 Indoor per capita use percent by fixture, 12 study sites

Leaks

In the REUWS it was found that a small number of homes were responsible for the majority of the leakage. While the average daily leakage was 21.9 gallons, the standard deviation was 54.1 indicating a wide spread in the data. The median leakage rate was only 4.2 gallons per household per day. Nearly 67 percent of the study homes leaked an average of 10 gallons per day or less, but 5.5 percent of the homes leaked an average of more than 100 gallons

per day. Saying it another way, 10% of the homes logged were responsible for 58% of the leaks found.

In the 100 data logged homes with the highest average daily indoor water use, leaks accounted for 24.5 percent of average daily use. These top 100 homes averaged 90.4 gallons per day (gpd) of leaks compared with 21.9 gpd for the entire 1,188 home data logged group.

Clothes Washers

A total of 26,981 loads of laundry were recorded over the 28,015 logged days during the study. Across all 1,188 logged households in the REUWS, the average loads of laundry per day was 0.96 (this includes the 26 logged homes which reported they did not have a clothes washer on the mail survey). The mean daily per capita clothes washer usage across all households was 15.0 gpcd.

The average volume per load of clothes was 40.9 gallons with a standard deviation of 12.2 and a median volume of 39.8 gallons. Seventy-five percent of the observed loads were between 25 and 50 gallons. The range in volumes indicates the variety of clothes washers in service which includes extra large top loading machines and low volume horizontal axis washers. Also influencing the distribution is the tremendous number of wash settings available on modern clothes washers. Users are often able to individually adjust the size of the load, the number of cycles, the water temperature, etc.

Fixture Utilization

The data collection technique employed in the REUWS made it possible to calculate mean daily fixture usage for toilets, showers, clothes washers, dishwashers, baths, faucets, etc. Study participants across all 12 study sites flushed the toilet an average of 5.05 times per person per day. The participants took an average of 0.75 showers and baths combined per person per day. Clothes washers were run an average of 0.37 times per person per day and dishwashers were run an average of 0.1 times per person per day. Faucet utilization was calculated in terms of minutes per capita per day rather than as a count of faucet uses per day. Study residents ran their faucets an average of 8.1 minutes per capita per day.

ULF Toilet Savings

Of the over 289,000 toilet flushes recorded during the two year end use monitoring portion of the REUWS, 14.5 percent of the flushes were less than 2.0 gpf, 34.7 percent of the flushes were between 2 and 3.5 gpf, and 50.8 percent were greater than 4 gpf.

Of the 1188 data logged homes in the REUWS, 101 (8.5 percent) used ULF toilets almost exclusively. This number was determined by first calculating the average flush volume for each study residence. Homes with an average volume per flush of less than 2.0 gallons over the 4 week data logging period were classified as "ULF only" homes meaning that while they may have other units, they use ULF units almost exclusively. The 101 "ULF only" homes used an average of 24.1 gallons per household per day (gpd) for toilet purposes. The residents of these homes flushed the toilet an average of 5.04 times per person per day and used an average of 9.5 gpcd for toilet purposes.

Another 311 study homes (26.2 percent) were found to have a mixture of ULF and non-ULF toilets. These homes were distinguished by counting the number of toilet flushes which used less than 2.0 gallons per flush. Homes that had six or more ULF flushes (and who were not part of the "ULF only" group were placed in the "mixed" toilet group. Homes with a mixture of ULF and non-ULF toilets used an average of 45.4 gpd for toilet purposes. The residents of these homes flushed the toilet an average of 5.39 times per person per day and used an average of 17.6 gpcd for toilet purposes. The remaining 776 study homes we placed in the "non-ULF" group. The "non-ULF" study homes averaged 47.9 gpd for toilets. Residents in these homes flushed an average of 4.92 times per person per day and used an average of 20.1 gpcd. The net potential savings when comparing "ULF only" homes from this study to the "non-ULF" homes is therefore is 10.5 gpcd.

LF Shower Savings

So called "Low Flow" shower heads are designed to restrict flow to a rate of 2.5 gpm or less. By calculating the modal shower flow rate for each shower at each study residence it was possible to separate homes which always showered in the low-flow range (LF houses), homes which occasionally showered in the low flow range (Mixed houses), or homes which showered

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exclusively above the low flow range (Non-LF houses). About 15 percent of the study homes showered in the low flow range exclusively, 60.4 percent occasionally showered in the low flow range, and 24.5 percent showered exclusively above the low flow range.

The LF shower homes used an average of 20.7 gpd and 8.8 gpcd for showering, while the non-LF shower homes used an average of 34.8 gpd and 13.3 gpcd. However, the duration of the average shower in the LF shower homes was 8 minutes and 30 seconds, 1 minute and 48 seconds longer than the average shower duration in the non-LF homes which was 6 minutes and 48 seconds.

Peak Use

At the end of the data collection effort of the REUWS, 28,015 complete days of data (also called “logged days”) were collected from the 1,188 participating study homes. Frequency distributions of the peak instantaneous flow rate observed during each of the logged days for each study house were developed. The frequency distribution, shown in Figure E.S.3 shows the observed peak instantaneous flow irrespective of water use category (indoor and outdoor). Typically the highest flows in the single-family setting occur during irrigation and lawn watering or when re-filling a swimming pool. The peak flow need only have been observed for a single 10-second interval to be included in these analyses.

The majority (more than 85%) of water meters used in this study were 5/8 inch or ¾ inch in size. The peak flow capacity of a 5/8 inch meter is approximately 25 gpm and the peak flow capacity of a ¾ inch meter is approximately 35 gpm. The largest water size meter used in this study was a 1 ½ inch meter (quite unusual in the single-family sector). This size of meter has an approximate peak flow capacity of 100 gpm. Because days without any water use were excluded from this analysis, a total of 27,579 logged days are included in this distribution. The highest peak flow recorded in this study was 64.63 gpm. The mean peak flow was 8.23 gpm, the standard deviation was 5.02 gpm, and the median peak flow was 6.71 gpm. More than 90% of the recorded peak instantaneous flows were less than or equal to 15 gpm.

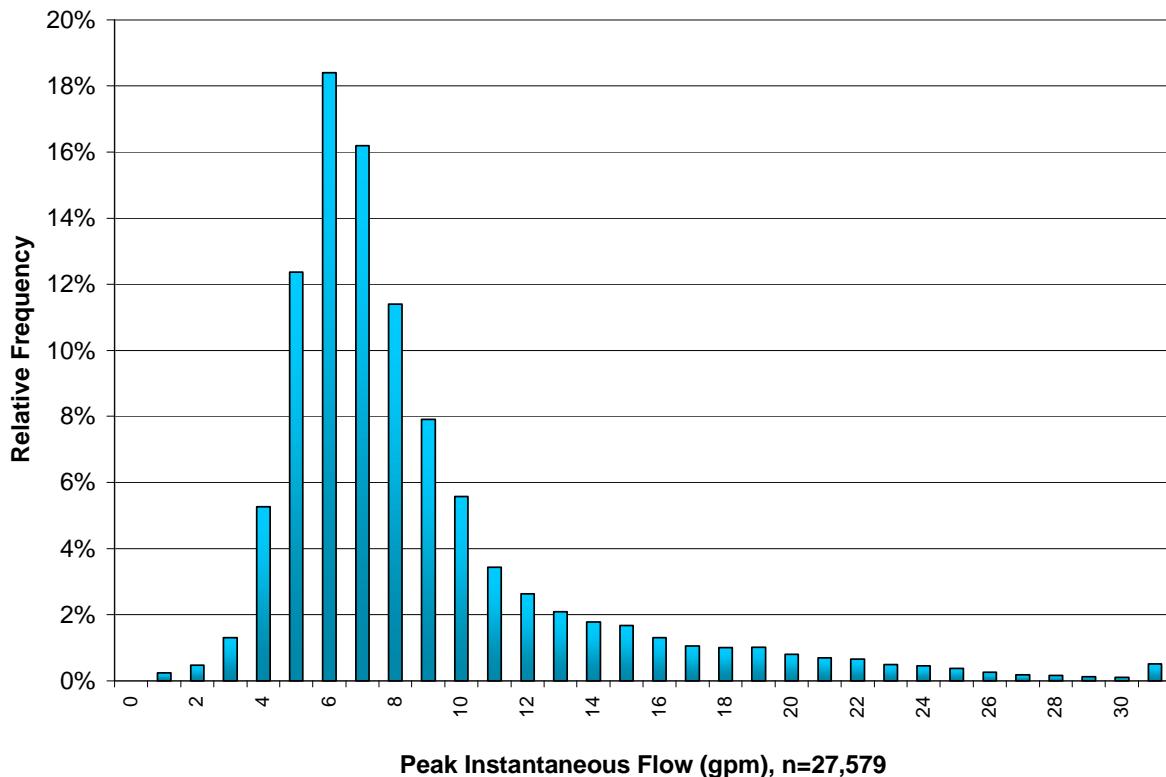


Figure ES.3 Daily peak instantaneous flow rates, 12 study sites

Hourly Use

In the REUWS, because the start time of each water use event was stored along with the volume, duration, flow rate, etc. it was possible to sum the volume of water used during each hour of the day and develop figures showing hourly water use patterns. The time pattern of overall residential water use followed a classic diurnal pattern shown in Figure ES.4 with four distinct typical characteristics:

- Lowest usage during the night (11 p.m. to 5 a.m.)
- Highest usage in the morning (5 a.m. to 11 a.m.)
- Moderate usage during the midday (11 a.m. to 6 p.m.)
- High evening usage (6 p.m. to 11 p.m.)

This same diurnal pattern in overall water use was observed in all 12 study sites.

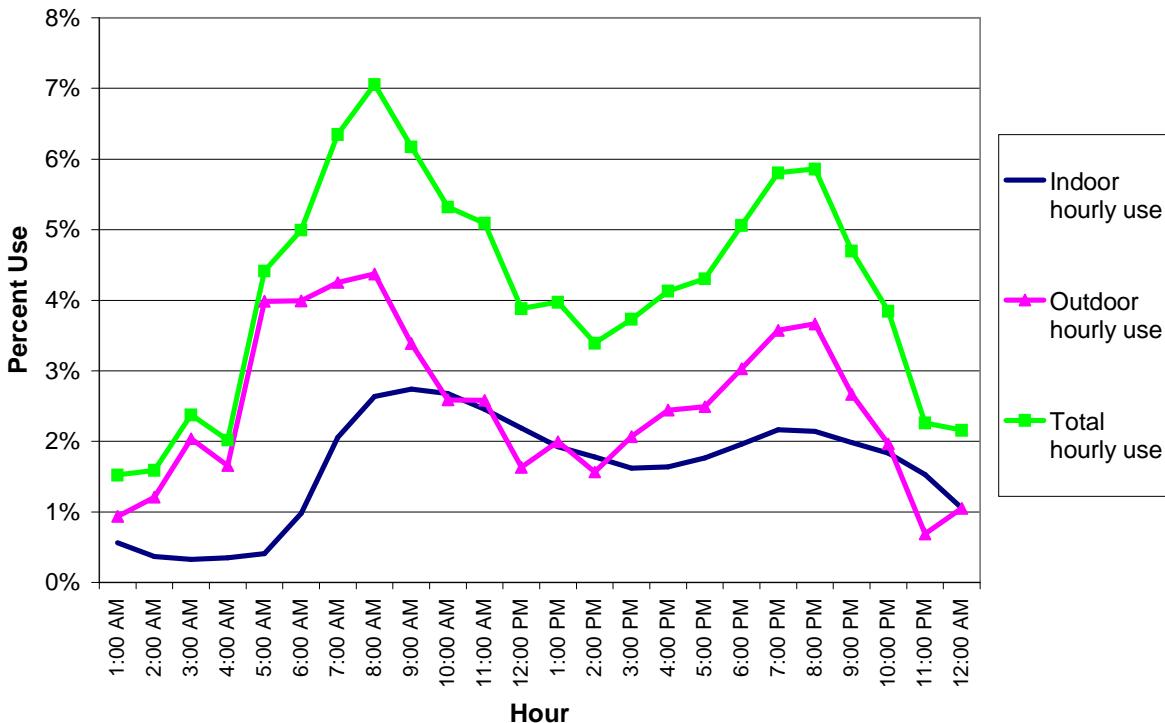


Figure ES.4 Hourly use patterns, 12 study sites

Indoor and outdoor use both followed diurnal patterns similar to the overall pattern, but with some important differences. Outdoor use ramped up steeply at 5 a.m., several hours earlier than the morning increase for indoor use which increased at 7 a.m. Outdoor use decreased significantly from 10 a.m. until 5 p.m. while indoor use reached a peak a 9 a.m. and decreased slowly until 4 p.m. Outdoor use achieved a secondary peak in the early evening from 6 p.m. to 9 p.m. Indoor use increased slightly from 6 p.m. to 10 p.m. before decreasing for the night. Indoor use was extremely low from 1 a.m. to 5 a.m.

When divided into component end uses, the hourly pattern of indoor use presents a set of separate curves of usage as shown in Figure ES.5. The largest component piece of indoor use, toilets, follow a diurnal pattern a morning peak between 7 a.m. and 10 a.m., moderately high use from 10 a.m. to 5 p.m., an evening peak from 5 p.m. to 11 p.m. and lowest usage from 11 p.m. to

5 a.m. Clothes washer usage peaks a little later than toilet usage, from 9 a.m. to 1 p.m. Washer use remains high from 1 p.m. to 9 p.m. and then declines steeply overnight when it is virtually non-existent until 8 a.m. when it ramps up towards the morning peak. Shower usage has a very high peak in the morning from 6 a.m. to 11 a.m. and then decreases significantly during the day until 6 p.m. when there is a smaller peak which continues until 11 p.m. Faucet usage is the only large indoor use which peaks in the evening from 5 p.m. to 10 p.m. Faucet use during the day is fairly consistent after a morning peak from 7 a.m. to 11 a.m.

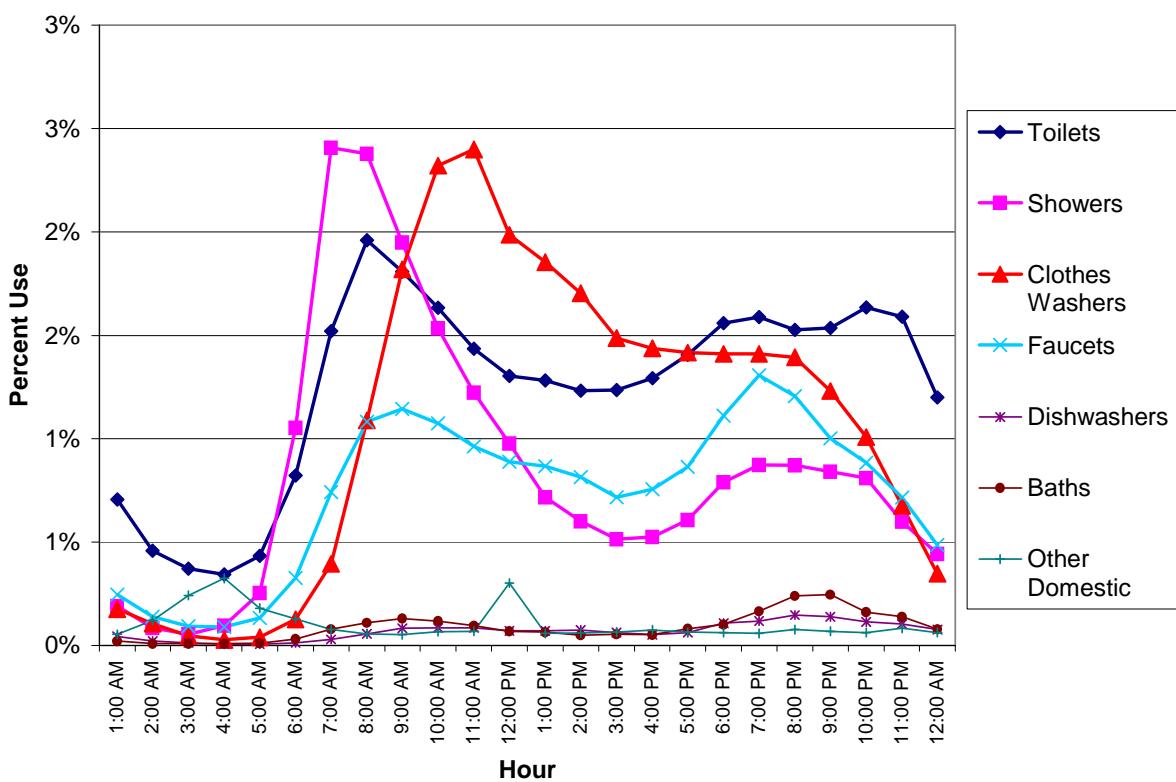


Figure ES.5 Indoor hourly use patterns, 12 study sites

End Use Models

The end use models developed for this study confirm some previous beliefs and offer additional insights about the time-series and cross-sectional phenomena that affect water use. These models also point out important relationships between specific end uses and

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socioeconomic factors obtained through the mail survey. This represents the first time that differences in water use at the end use level have been attributed to causal factors related to weather, climate, price, and socioeconomic characteristics.

Interpretation of the modeling effort include the following relationships between the end uses of water and various socioeconomic factors:

Toilet Use

The model estimation results for toilet flushing found household size to be an important indicator of water use for toilet flushing. The modeling result suggests that a one percent increase in household size would be expected to bring about a seven-tenths of one percent increase in water use for toilet flushing. Since an addition to household size would typically be much larger in percentage terms (e.g., an addition of one more person to a two person household is a 50 percent increase), the marginal impact of adding another person is quite large. However, the model estimates suggest that the impact on water use for toilet flushing depends on the age group of the new addition. The results imply that the addition of non-adults increases use for toilet flushing at a lower rate than the addition of an adult. The amount of water used for toilet flushing is negatively related to the number of persons employed full-time outside of the home. For those employed outside the home, some flushing at home is replaced by flushing at work.

The size of the house in square feet can be interpreted as a surrogate for standard of living and may also be indicative of the number of toilets at a residence. Results indicated that water use for toilet flushing increases with the size of the house. On average as a group, renters were shown to use about 10 percent more water for toilet flushing. Those who irrigate and those who have swimming pools were shown to use more water on average for toilet flushing.

The toilet use model showed a statistically significant, yet *inelastic* price effect. A one-percent increase in marginal price was estimated to lead to a 0.15 percent decrease in water use. The model estimates indicated that the amount of water used for toilet flushing depends on the time of year. For instance, households logged from September to November systematically used about 12 percent more water than those who were logged in the winter.

The set of binary variables for the decade in which the home was built showed an interesting pattern. Results suggest that homes built in the 1950s and 1960s were more likely to

have been retrofitted with new, more efficient, toilets and that homes built in the 1990s were installed with efficient toilets. One may deduce from these findings that homes built in the 1970s and 1980s may be better targets for retrofit and ultra-low-flow toilet (ULFT) rebate programs.

The model verified that ULFTs reduce water usage. Households for which logging traces indicated all ultra-low-flow events used 40 percent less water for flushing than other sample households. Evaluated at the mean usage for household that are not completely retrofitted (47.9 gallons per household per day allocated to toilets), this implies an average water savings of 19.2 gallons per household per day for the completely retrofitted group, given the effects of the other variables in the model. In per capita terms, this translates to a water savings of 7 gallons per person per day. Consistent with this finding, water use for toilet flushing is shown to decrease with the survey-reported fraction of toilets that are of the ultra-low-flow variety. The coefficient of this variable suggests that fully retrofitted households on average use about 10 percent less water for toilet flushing than households that have all non-conserving devices, everything else held constant. Adding this measurement to the savings implied by the ULT-only coefficient suggests total average savings from complete toilet retrofit of about 9 gallons per capita per day.

Shower and Bath Use

The number of persons per household was a significant factor in determining the amount of water used for showers and baths. Water use for showers and baths increased with household size and children and teens used incrementally more water for showers and baths than did adults. In addition, shower and bath use increased with the number of persons employed outside the home, suggesting a higher frequency of use for those who must prepare for work. Shower and bath use was positively related to household income, though the response to changes in income was estimated to be small.

Those who rent, on average used more water for showers and baths. Irrigators also displayed more water use for showers and baths than did non-irrigators. The estimated price elasticity of shower and bath use was greater than the price elasticity for toilets and suggests that a one percent increase in price will bring about a 0.35 percent decrease in water use.

Households that reported having all low-flow showerheads on average used about 9 percent less water for showers than households that are not completely retrofitted (everything else held constant).

Faucet and Water Treatment System Use

Faucet use is strongly and positively related to household size. The model suggests that small children add less to total faucet use than do teens and adults. Similar to the toilet model, faucet use is negatively related to the number of persons working outside the home. Faucet use is positively related to household square footage, which may act as a surrogate for the number of faucets in the home. Marginal price is positively related to faucet use, though the marginal price coefficient is not significant from a statistical perspective. As might be expected, faucet use is lower for those who have an automatic dishwasher. Faucet use displays a negative relationship with the reported fraction of showerheads that are of the low-flow variety. This may imply a tendency for households to install faucet aerators when they retrofit their showerheads.

Dishwasher Use

Household size is a prominent variable for explaining dishwasher use. Unlike the other indoor models, no distinct effects were detected for the number of teens or children. However, dishwasher use is negatively related to the number of persons employed full-time outside the home. Dishwasher use is shown to be responsive to marginal price, with an estimated price elasticity of -0.27. Dishwasher use is also slightly responsive to household income, with an estimated income elasticity of 0.11. Finally, households that reported conserving behavior related to indoor use (such as washing fuller dishwasher loads) used about 7 percent less water for dishwashing.

Clothes Washer Use

Consistent with the other models for indoor end uses, household size has a strong and positive influence on the amount of water used for clothes washing. Clothes washer use increases incrementally with the number of teens living in the household and the number of

persons working full-time outside the home. The coefficient of the marginal price variable retains a positive sign, but is not statistically significant. Clothes washer use is positively related to income, however the coefficient on income also shows relatively low statistical significance.

Outdoor Use

Outdoor use is taken as the sum of logged use allocated to irrigation and swimming pools. Since nearly all sample households reported to be irrigators, while only a small number had swimming pools, the impact of pool use was measured using a binary (0/1) variable in the outdoor model for presence of a pool. On average, homes with swimming pools are estimated to use more than twice as much water outdoors than homes without swimming pools, everything else held constant.

Outdoor use displays a relatively strong and positive relationship with home square footage. Inasmuch as this variable acts as a surrogate for standard of living, this is consistent with the notion of a higher ability to pay for this more discretionary use. As expected, the amount of water used for outdoor purposes (primarily irrigation) is positively related to the size of the lot (another potential proxy for standard of living) and the percentage of the lot that is irrigable landscape.

The following are other specific interpretations of the results of the outdoor end use model:

- Homes with in-ground sprinkler systems use 35 percent more water outdoors than those who do not have an in-ground system
- Households that employ an automatic timer to control their irrigation systems used 47 percent more water outdoors than those that do not
- Households with drip irrigation systems use 16 percent more water outdoors than those without drip irrigation systems
- Households who water with a hand-held hose use 33 percent less water outdoors than other households
- Households who maintain a garden use 30 percent more water outdoors than those without a garden

- Households with access to another, non-utility, water source displayed 25 percent lower outdoor use than those who used only utility-supplied water

Finally, outdoor use is found to be relatively sensitive to the marginal price of water. The estimated price elasticity of -0.82 for outdoor use is larger in magnitude than the price elasticities that have been estimated for other end uses. This finding is consistent with the belief that outdoor use is more discretionary and therefore more price elastic than indoor water uses.

Leaks

Many variables were found to explain the variance in leakage rates. The quantity of water attributable to leaks increased with temperatures and decreases with precipitation. Accounting for the effects of the other variables in the model, higher leakage was registered for households logged during the winter months.

The quantity of water leaks showed a statistically significant relationship with both the marginal price for water and the marginal price for sewer. Results imply that a one-percent increase in the marginal price of water will lead to a 0.49 percent decrease in the amount of leakage, while a one-percent increase in the marginal price of sewer will lead to a 0.12 percent decrease in the amount of leakage. These findings seem to verify that higher prices lead to some degree of voluntary leak detection and correction. With regard to correcting leaks, renters as group had a lower amount of leakage than non-renters. This may confirm the expectation that landlords seek to minimizing costs.

Following a pattern consistent with the indoor end uses, the amount of leakage was positively related to the number of persons in a household, but negatively related to the number of people working full-time outside the home. The amount of leaks were shown to increase with the number of toilets in the home.

Leakage was found to be higher in homes that were built in the 1970s and in households that use a sprinkler system that is attached to the garden hose. Leakage is found to be generally *lower* for households that use drip irrigation systems or use a hand-held hose for watering and for those who have reported taking behavioral and technological actions to save conserve water outdoors.