RESIDENTIAL END USES OF WATER

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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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FOREWORD

The AWWA Research Foundation is a nonprofit corporation that is dedicated to the implementation of a research effort to help utilities respond to regulatory requirements and traditional high-priority concerns of the industry. The research agenda is developed through a process of consultation with subscribers and drinking water professionals. Under the umbrella of a Strategic Research Plan, the Research Advisory Council prioritizes the suggested projects based upon current and future needs, applicability, and past work: the recommendations are forwarded to the Board of Trustees for final selection. The foundation also sponsors research projects through the unsolicited proposal process; the Collaborative Research, Research Applications, and Tailored Collaboration programs; and various joint research efforts with organizations such as the U.S. Environmental Protection Agency, the U.S. Bureau of Reclamation, and the Association of California Water Agencies.

This publication is a result of one of these sponsored studies, and it is hoped that its findings will be applied in communities throughout the world. The following report serves not only as a means of communicating the results of the water industry's centralized research program, but also as a tool to enlist the further support of the nonmember utilities and individuals.

Projects are managed closely from their inception to the final report by the foundation's staff and large cadre of volunteers who willingly contribute their time and expertise. The foundation serves a planning and management function and awards contracts to other institutions such as water utilities, universities, and engineering firms. The funding for this research effort comes primarily from the Subscription Program, through which water utilities subscribe to the research program and make an annual payment proportionate to the volume of water they deliver and consultants and manufacturers subscribe based on their annual billings. The program offers a cost effective and fair method for funding research in the public interest.

A broad spectrum of water supply issues is addressed by the foundation's research agenda: resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide the highest possible quality of water economically and reliably.

The "end uses" of water is a fundamental planning issue. Water conservation and resource planners need an accurate picture of how consumers use water. Engineers rely upon end use information to identify design capacity and other engineering parameters. Most existing end use information is extremely site specific and often of little value outside of a particular region. Unfortunately, engineers and planers are left to estimate end uses without the basis of sound analytical data. This project developed an extensive database of end use information. The database was developed using sophisticated data logging techniques and computer based analytical models. From the data and models, accurate end uses of water estimates were developed.

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ACKNOWLEDGMENTS

This research would never have been completed without the cooperation of more than 5,000 households across the continent who completed mail surveys and the 1,200 households that agreed to participate in the detailed end use study. Our heartfelt thanks to each and every one.

This research project was made possible by AWWARF and the following municipalities and water providers: City of Boulder Office of Water Conservation, Denver Water, Eugene Water and Electric Board, Seattle Public Utilities, Northshore Water District, Highline Water District, Bellevue Water Department, City of San Diego Water, Tampa Water Department, Phoenix Water Department, Tempe and Scottsdale Water Departments, Regional Municipality of Waterloo, Walnut Valley Water District, Las Virgenes Municipal Water District of Southern California, City of Lompoc, Metropolitan Water District of Southern California, Southwestern Florida Water Management District, Arizona Municipal Water Users Association, Santa Barbara County Flood Control and Water Conservation District and Water Agency, California Department of Water Resources, Sonoma County Water Agency, North Marin Water District.

The project team wishes express our sincere thanks to the following individuals and groups for their assistance on this project: David Lewis, Laurel Stadjuhar, Jeff Harpring, Beorn Courtney, Mark Alexander, Eric Loew, Paul Lander, Bob Harburg, Don Vetterling, Jim Heiser, Edward Pokorney, John Loughrey, David Allen, Steve West, Brenda Sirois, Richard Head, Al Dietemann, Tim Skeel, Fanny Yee, Patricia Burgess, Steve Wieneke, Judy Burdin, Jim Echert, Kim Drury, Marsi Steirer, Luis Generoso, Kathy Fry, Arnold Niemann, Robert Lauria, Phillip Elkins, Tom Babcock, Andy Terry, Lisa Helm, Vonnie Caraballo, Karen Warner, Oliver Ncube, Pete Smith, Ken Sharratt, Deborah Walker, Sean Smith, Derek Berkhout, Darcy Jones, James Robinson, Denis Hernandez, Scott Harris, Randall Orton, Lynn Anderson-Rodriguez, Charlie Pike, Gary Keefe, Susan Zavolta, Mario Villareal, Jim Heaney, Tony Gregg, Bill Hoffman, Dan Rodrigo, Cathy Pieroni, Barbara Nadon, Warren Teitz, Mike Hollis, Cliff Pugh, John Balliew, John Sweeten, Ed Craddock, Robert Almy, Chris DeGabriele, Bill Jacoby, George Martin, John Wiedmann, John Flowers, Randy Poole, Robert Allen, the AWWA Water Conservation Planning and Evaluation Committee and the AWWA Water Conservation Division Board.

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.

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 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

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.

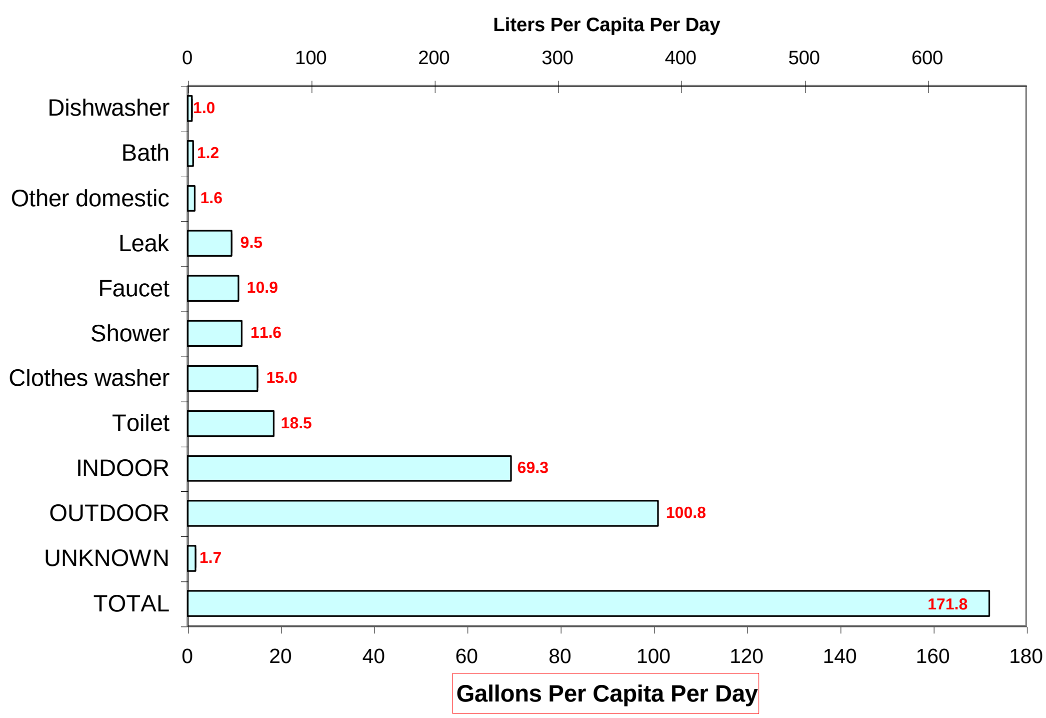

Figure ES.1 Mean daily per capita water use, 12 study sites

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

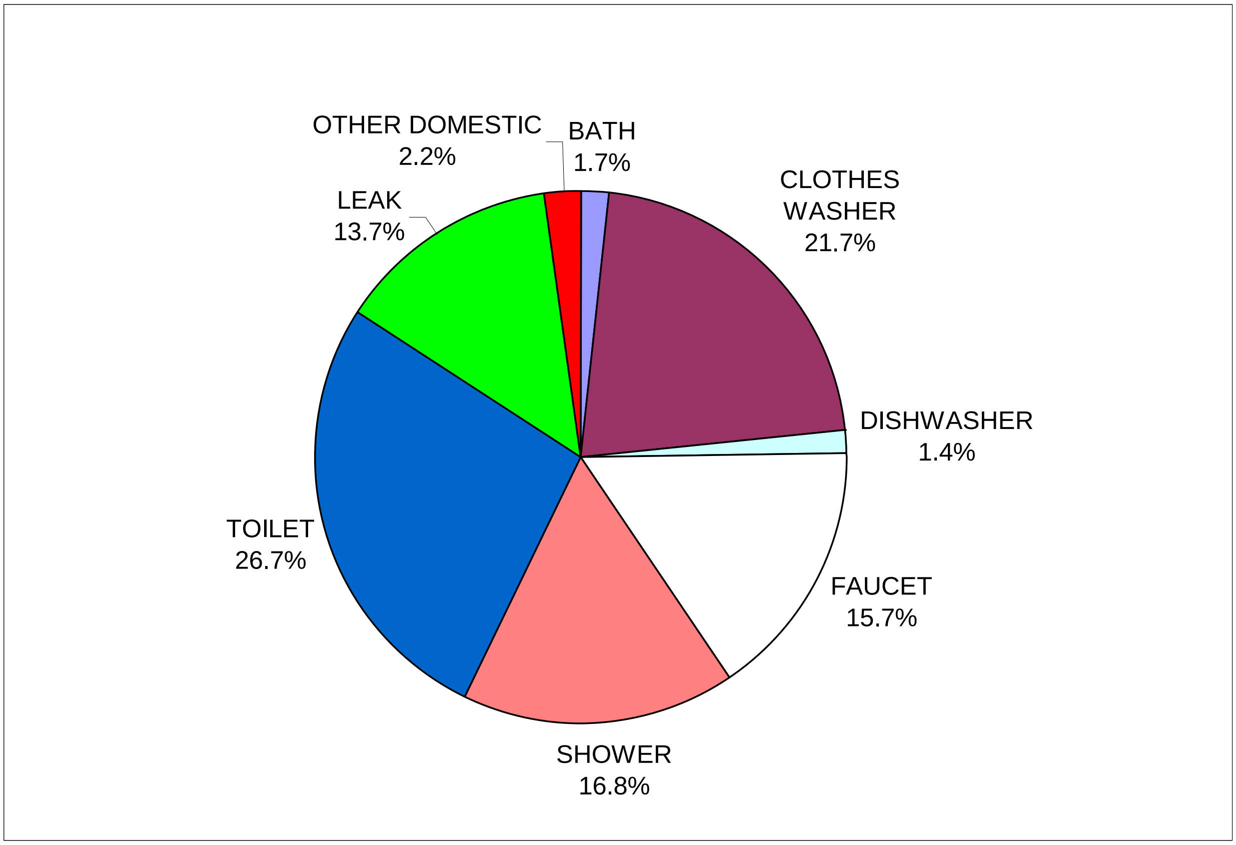

Figure ES.2 Indoor per capita use percent by fixture, 12 study sites

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 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.

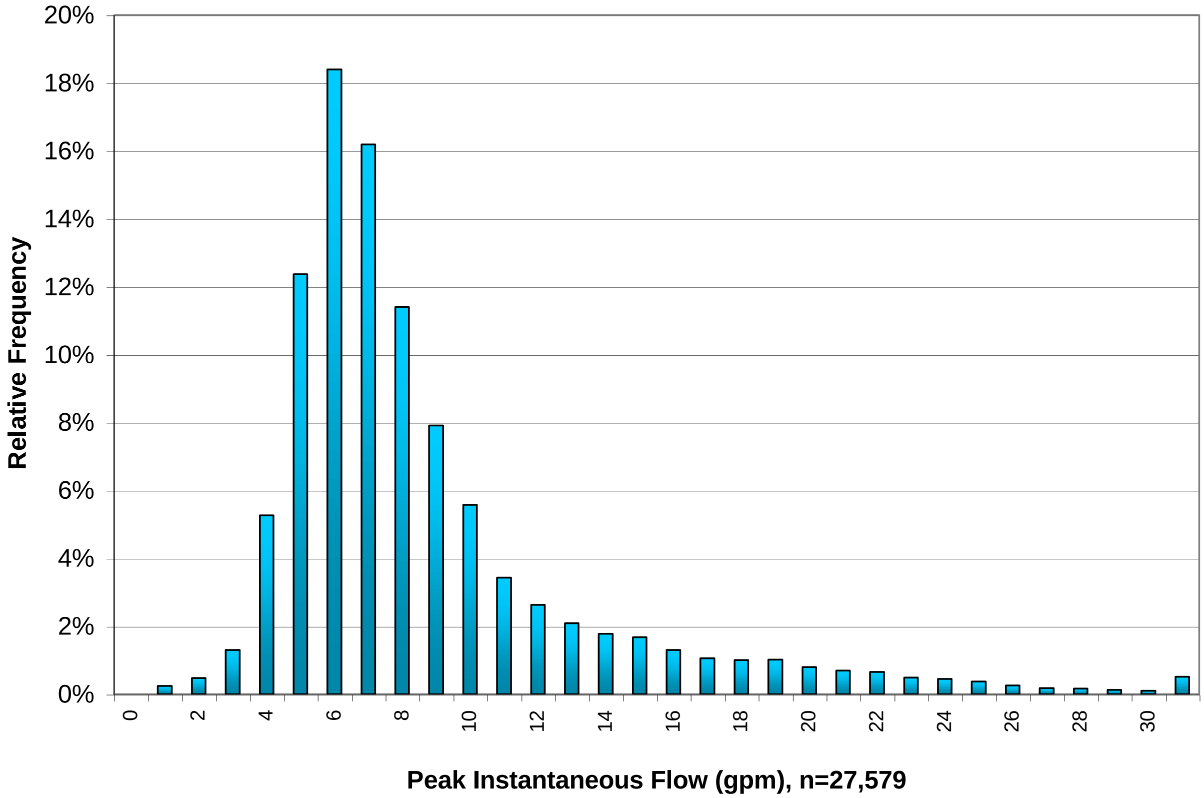

Figure ES.3 Daily peak instantaneous flow rates, 12 study sites

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:

a. Lowest usage during the night (11 p.m. to 5 a.m.)
b. Highest usage in the morning (5 a.m. to 11 a.m.)
c. Moderate usage during the midday (11 a.m. to 6 p.m.)
d. 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.

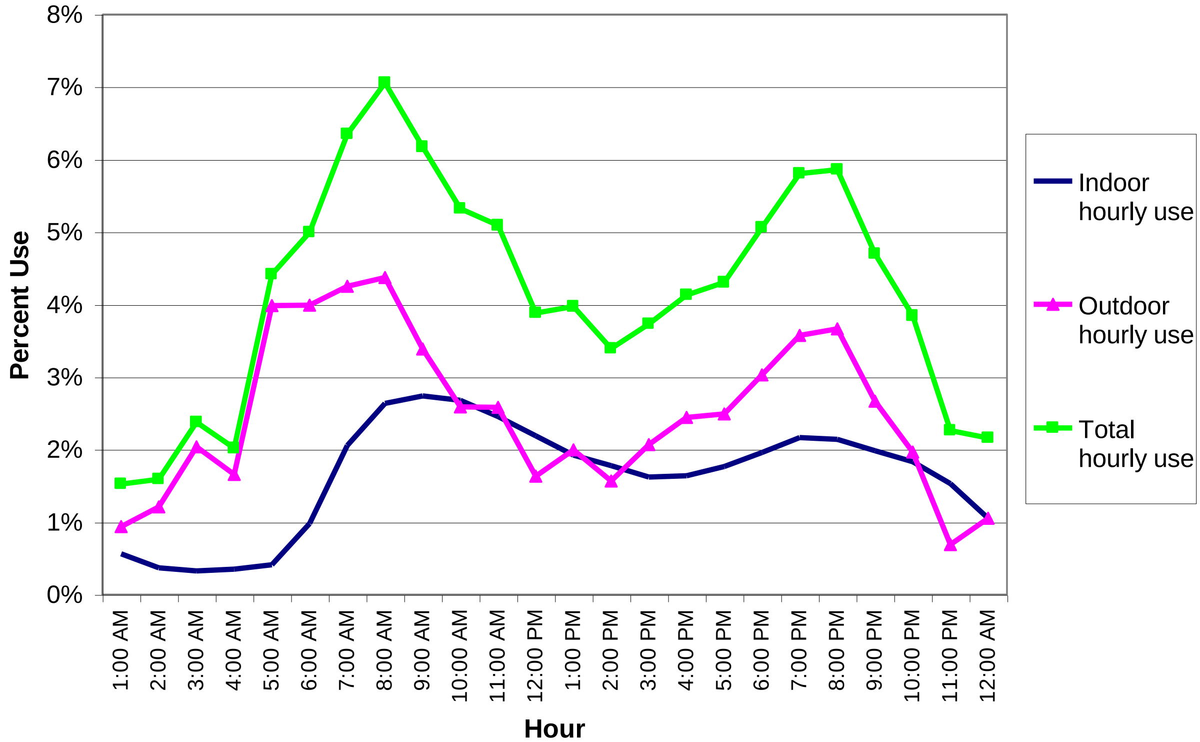

Figure ES.4 Hourly use patterns, 12 study sites

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.

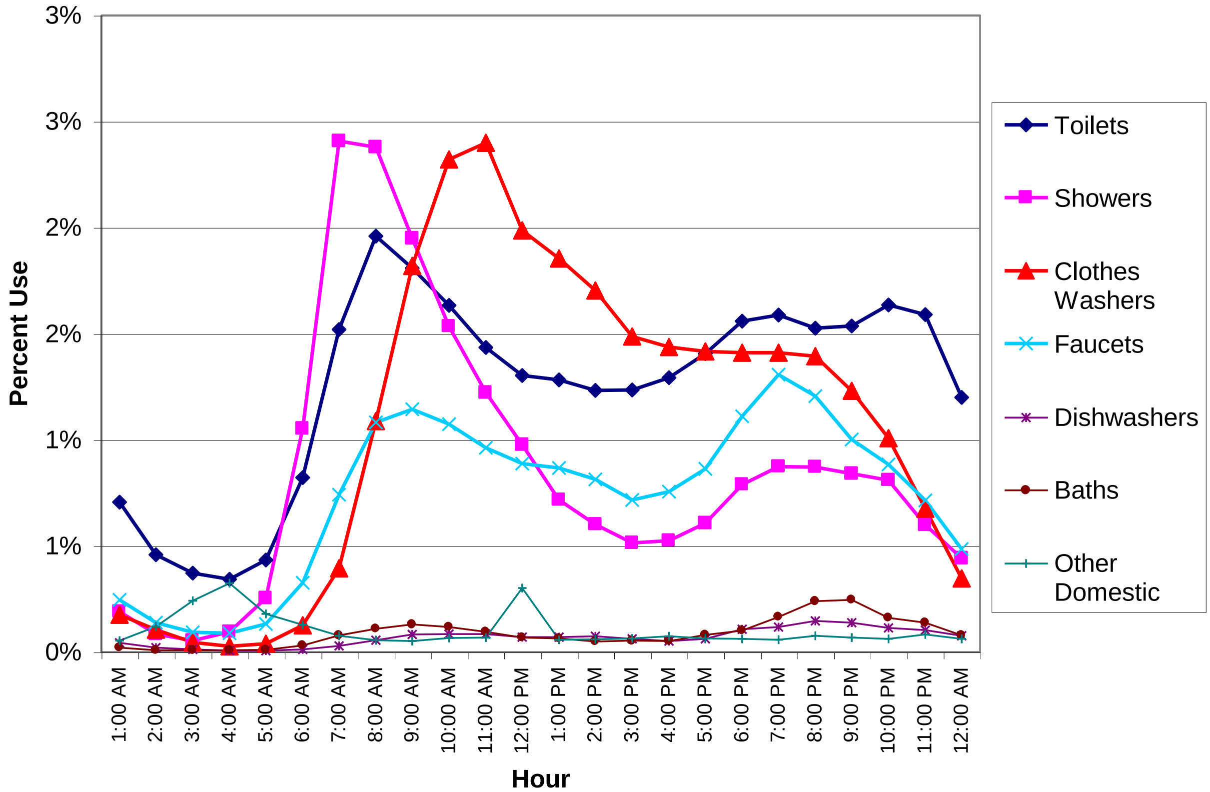

Figure ES.5 Indoor hourly use patterns, 12 study sites

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 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.

CHAPTER 1
INTRODUCTION

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 answer these and other questions and to provide specific data on the end uses of water in single-family residential settings across the country.

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.

Historically, planners have relied on mechanical estimates of savings based on manufacturer's specifications of the conservation devices being installed, *a priori* judgement, or on a comparison of seasonal or annual water use between randomly selected control and study groups. Each of these approaches is subject to systematic errors (Chestnut and McSpadden, 1991). Due to an inability to directly measure the residential end uses of water in an efficient and inexpensive manner from a sufficient sample, few alternatives were available.

Advances in computer and data logging technologies provide a solution. In this study, water consumption for various end uses was measured from a 1,200 home sample of residential housing in 14 North American cities using compact data loggers and PC-based flow trace analysis software. The products of this research effort include: A sizable residential water use database containing nearly two million individual water use "events" collected from 1,200 residences in 14 study cities; extensive household level information obtained through a detailed mail survey completed by approximately 6,000 people; historic water billing records from

12,000 residences. All of this information was collected to provide answers to many long standing questions about how much and where water is used in the residential setting and to explore for information on the savings available from various conservation measures.

In addition to presenting the findings from the data collection effort, the study also examined the relationships between the detailed end use information and household level socioeconomic data. Building from those relationships, a predictive model was developed using multiple regression techniques and a number of carefully chosen independent variables. This model allows planners to input critical variables from their own communities and generate predictions about water use and conservation savings based on actual data.

This report summarizes the methodology and important findings of this study and presents a number of analyses based on the database assembled over the course of the study. However, it would be impossible for this report (or any report) to exhaust to possibilities of analysis presented by the extensive database collected over this two year research effort. In anticipation of the many research and analysis possibilities, the database assembled for this study is available as a derivative product and can be obtained from the consultants and AWWARF. Appendix C of this report details the structure and scope of the database provides information on how it can be used to assemble sub-sets of data which can be used to answer specific questions and perform specific analysis.

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.

Creating national water use "averages" was not an objective of this study. 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.

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.

BACKGROUND

In 1993 AWWARF sponsored a workshop for water conservation professionals from the public and private sector and asked them to develop a list of research priorities. The *Special Report of the Expert Water Conservation Workshop* (Nelson, 1993), which prioritized urban water conservation needs in North America, identified the “Residential End Uses of Water” as the number one research priority for planners, water managers, and conservation specialists across North America. This group concluded that for water conservation planning, historic billing data is often inadequate because it does not provide direct measurement of water uses by specific purposes, hence the need for direct measurements and estimates. This call for research was one of the factors that influenced AWWARF to fund this research.

PROJECT TEAM

The Residential End Uses of Water Study contract was awarded to a team of consultants lead by Aquacraft, Inc. of Boulder, Colorado. The team included Planning and Management Consultants Ltd. (PMCL) of Carbondale, Illinois and John Olaf Nelson Water Resources Management (JONWRM) of Petaluma, California. The project team worked in close consultation to develop the organization, methodology, study procedures, and quality control assurance for the research effort. Then each member performed specific tasks over the two-year study period.

Aquacraft, Inc. lead the research effort and handled project management. Aquacraft, Inc. was also responsible for contracting with the participating water providers, coordinating the initial sample draw of 1,000 single-family residential accounts, collecting and analyzing the data logging records, developing the residential water use database, and preparing the final report.

PMCL was responsible for the sampling design of the research effort, developing the survey instrument, selecting the final study group, and the developing water use models that explore the causal relationships of water use.

JONWRM handled implementation and response coding of the written survey in each study site, and development and implementation of quality control and quality assurance procedures for the research effort.

HOW TO USE THIS REPORT

This report details the findings of the *Residential End Uses of Water Study* and is divided into eight chapters. Detailed appendices which include copies of questionnaires, letters, study procedures, and a guide to the project database are presented at the end of the report. The report chapters are briefly described here.

Executive Summary provides a brief overview of the research and findings.

Chapter 1 is an introduction the *Residential End Uses of Water Study.*

Chapter 2 is a brief review of some of the recent literature pertaining to residential water use.

Chapter 3 presents the study approach, procedures, and methodology used by the project team. This chapter includes details of study site selection, all sampling procedures and study group selection, end use data collection hardware and methods, supplemental data collection, and quality assurance and control procedures. Readers interested in selecting study groups and conducting similar research should find information in this chapter useful.

Chapter 4 is an analysis of the historic billing data collected from each of the 12 study sites. This analysis includes an exploration of annual and seasonal water use patterns.

Chapter 5 is an analysis of the water use survey implemented as part of the study. The survey included questions about demographics, water use hardware, and behavior. The analysis includes comparisons between the survey respondents and the general population and a comparison of survey results among study sites.

Chapter 6 details the results of the end use data collection component of the study. Analysis in this section includes daily use, indoor and outdoor use, per capita use and conservation effectiveness.

Chapter 7 describes the development of the predictive water use models and presents the model specification and selection. This chapter also describes how to use the models developed to predict water use.

Chapter 8 presents a summary of the findings, conclusions, and recommendations for further research.

Appendix A provides specific information about the mail survey component of this study including a copy of the survey instrument.

Appendix B describes the various quality assurance and quality control measures and tests used in this study.

Appendix C presents an introduction the database developed for this study. Those interested in obtaining a copy of this extensive database should contact AWWARF or Aquacraft.

CHAPTER 2
LITERATURE REVIEW

The June 1984 Department of Housing and Urban Development report, Residential Water Conservation Projects, (Brown and Caldwell, 1984) has been a standard reference on water use rates for selected residential appliances and fixtures. The HUD study quantified water savings from low-flow plumbing fixtures and devices which reduce water use in the typical residential setting.

Specifically, the HUD study collected data on water saved by 3.5 gallons per flush (gpf) toilets, 3 gallons per minute (gpm) showerheads, retrofit programs, advanced water saving fixtures, water pressure regulation, and water meters. Data collected from more than 200 single-family homes in California, Colorado, Washington D.C., Virginia, Georgia, and New Jersey were used as data sources for the HUD study. Important findings from this study included: breakdowns of water use in "non-conserving" and "conserving" homes on a per-capita basis; measurements of water savings due to conserving fixtures and other devices; water savings from retrofit programs; water savings due to metering; and the effect of reducing water pressure on water use. Until now, the HUD study has been relied upon by the water industry for information about the end uses of water in the single-family residential sector.

What the HUD study lacked was precise information on individual residential water uses and data from a larger sample of single-family homes. Techniques to monitor water use implemented in the HUD study, such as individual toilet flush counters and shower flow measurement devices, were the best available at the time but tended to be intrusive and cumbersome. Participants were always aware that they were being monitored. Because of the difficulty in obtaining accurate measurements of the end uses of water, the HUD study relied upon a mix of measurements and *a priori* judgement to get a specific task done. Also, the study was not designed to address outdoor residential irrigation demand. The standard reference on residential water use rates was due for an update.

A number of subsequent studies have collected specific data on residential water use rates using new technology not available in 1984. Six years after the HUD study was completed, a study conducted in California sponsored by the East Bay Municipal Water District (EBMUD) examined water use in 25 single-family homes in the Oakland area (Aher et. al. 1991). This study included a toilet and showerhead retrofit program as well as measurements of water temperature and pressure. Data on quantities of water used were collected using micro-meters on a few important fixtures wired to an on-site personal computer equipped with data collections and data transfer hardware. This study cost approximately $250,000 – or $10,000 per home – and did not attempt to break down water use into end use components beyond toilets and showers since the focus was on indoor use. Although expensive, this research proved that end uses in the residential sector could in fact be measured using modern technology.

A Tampa, Florida study also examined indoor water use in 25 single-family residences before and after a retrofit of ultra-low-flow (ULF) toilets and low-flow (LF) showerheads. Examination of end uses was again accomplished using the system developed for the EBMUD study (Anderson et. al. 1993). This study did attempt to quantify outdoor water use, but primarily focused on toilet and shower water use patterns. The data collection technique employed in this study, while effective, was intrusive and did not permit the full extent of end use disaggregation and the cost of this study was high.

While direct measurements of residential water use can usually only be made on small samples of single-family homes, statistical models which utilize historic water billing data and household level socioeconomic data can have large samples cast across entire service areas. One of the earliest efforts to estimate water demand is the classic 1940 report on estimating loading in plumbing systems by Roy Hunter (Hunter 1940). In this study fixture counts and characteristic load-producing values of commonly used plumbing fixtures were used to develop estimates of peak demands by means of a probability function. This work has been the basis for sizing water meters and service lines for nearly 60 years.

More recently PMCL's 1993 study of the Pasadena LITEBILL water and energy conservation program used a multivariate regression approach combining historic billing data and socioeconomic data obtained from a telephone survey to measure conservation effectiveness (Kiefer et. al. 1993). Findings from this study included estimates of the total water savings of the LITEBILL program.

In 1994 PMCL conducted an analysis of conservation programs in Phoenix, AZ which included a statistical disaggregation of residential end uses via forecast models consistent with the IWR-MAIN Water Use Forecasting System (Kiefer 1994). This study, which used billing data and telephone survey data from 494 single-family homes, found that statistical techniques are capable of identifying many single-family water use trends and characteristics, but limitations of the methodology were also noted. Kiefer recommended end-use metering of specific residential end uses to test and verify the modeling results.

To reconcile different findings of conservation water savings from numerous studies conducted in the early 1990s, PMCL introduced meta-analysis to account for differences in study quality, service area, and sample characteristics (Kiefer et. al. 1994). In this study cross-sectional estimates of household water savings from retrofits were represented as a function of these three variables and the meta-analytical function was estimated using linear regression.

A 1992 study of conservation effectiveness in Santa Monica conducted by A&N Technical Services used seven years of billing data from 23,000 homes in conjunction with household characteristics obtained from inspection surveys and follow-up telephone questionnaires to model residential demand (Chesnutt et. al. 1992a). In this study, water demand was specified as a continuous function of time to describe how climate affects demand and how demand and conservation vary throughout the year. This study also took great pains to eliminate unmeasured and mismeasured household characteristics which can be impact models of conservation savings.

Another A&N Technical Services study conducted for Irvine Ranch Water District estimated the savings from two pilot water conservation programs by developing models based on 8 years of historic billing data, household attributes, water-using behavior patterns, socioeconomic characteristics, and installation of conservation devices for participating and non-participating households (Chesnutt et. al. 1992c). Separate models were developed for detached single-family housing, condominiums, and townhouses and efforts were made to control for the "confounding forces" that affect water use so that the specific conservation effects of water saving devices and programs could be measured.

These previous statistical efforts have provided a number of useful models of urban water demands and conservation effectiveness. However, these statistical models have failed to fully accommodate the needs of conservation program planning because of their inability to accurately disaggregate water demands down to the end use level. These models have all relied upon monthly billing data which can be a rich and valuable data resource, but also present inherent problems such as: unequal billing periods, estimated meter readings, unusual usage levels, changes in customer occupancy, etc. (Dziegielewski 1993a). A model developed with billing data such as Linaweaver and Howe (1967), Howe (1982), Chesnutt et. al. (1992a), and IWR-MAIN (Dziegielewski et al. 1993b) can provide accurate information about water use and conservation effectiveness in the aggregate, but can be inaccurate in their attempts to quantify the amount of water dedicated to each individual end use (Stadjuhar 1997). Although aggregate water use models may be useful for forecasting short-term and long-term water demands, their "usefulness in water demand management is severely limited because of the insufficient disaggregation of water demand. Without adequate end use models, the effects of various demand management programs cannot be measured with a desired precision" (Dziegielewski et al., 1993a).

In Dziegielewski et al., 1993b, it was noted that the lack of precise measurements of the quantities of water used for shower, toilet flushing, and other purposes are obstacles to the development of reliable estimates of water conservation savings. It was further determined that improvements in quantifying the significant end uses of water can be achieved in two ways: (1) the actual end uses can be directly measured; and (2) a conditional demand analysis similar to those used by electric utilities can be developed to estimate end uses.

Several studies including Bowen, Metcalf, and Eddy, et al. (1993) and Buchberger and Wells (1996) used electronic data collection techniques on a small sample of single-family homes to determine instantaneous flows, peak flows, hourly consumption, and seasonal patterns. However, the data collection techniques used in these studies did not provided enough resolution to disaggregate the flows into individual process end uses.

The 1994 – 1996 Heatherwood Studies sponsored by the City of Boulder, Colorado and conducted by Aquacraft, Inc. implemented the concept of measuring residential water use first suggested in Dziegielewski et al., 1993b by collecting virtually instantaneous flow data directly from a customer's water meter (DeOreo and Mayer 1994; Mayer 1995; DeOreo et. al. 1996). In these studies battery powered data loggers were used to collect flow trace data at 10 second intervals from standard magnetic drive water meters at residential houses in Boulder. These flow traces were precise enough to permit disaggregation into individual water use events such as a toilet flush, a clothes washer cycle, or miscellaneous faucet use. These disaggregated flow traces revealed subtle variations in water use patterns that would have been masked in analyses relying on periodic billing data. The Heatherwood Study estimated water use for each fixture in 16 houses over the course of a summer at a cost of less than $30,000.

In 1996, Aquacraft, Inc. returned to the Heatherwood study group and used the flow trace analysis technique to measure the impacts of a conservation retrofit program in Boulder, Colorado (DeOreo and Mayer 1996). This study measured the impact of installing ULF toilets, LF showerheads and faucets, and horizontal axis clothes washers. For this study Aquacraft developed the first version of the Trace Wizard© software to more automatically disaggregate the recorded flow traces into specific end water uses such as toilets and showers which greatly increased the speed and accuracy of the analysis process. These studies showed that it was feasible to inexpensively collect and analyze end use data from single-family residences, providing unprecedented detail about water consumption habits.

CHAPTER 3
RESEARCH APPROACHES AND PROCEDURES

OVERVIEW OF RESEARCH PROCESS

The basic research process for the *Residential End Uses of Water Study* was developed by the project team in response to the AWWARF request for proposals. The general research plan laid out in that proposal has been followed throughout the research and modeling process. Once the project was awarded to the consultant team, a detailed work plan was developed to implement the research described in the initial proposal.

The general flow of the research effort moved from building the study team and formally contracting with participating water utilities through study group selection, survey implementation, data collection, data analysis, and modeling. Quality control and assurance measures were implemented at each stage of the research process to ensure a high level of accuracy in all aspects of the project.

Work on the project moved through an orderly development process for each site based on the flow chart model in Figure 3.1. Most of the process was repeated for each individual study site. The general process at each study site was to first obtain historic billing data for a random sample of 1,000 single-family detached accounts, survey this group and record the responses, select a sub-sample of 100 homes from the survey respondents for data logging, collect and analyze 4 weeks of disaggregated water use data from each of the 100 homes (data collection was divided into two, two-week intervals spaced in time to attempt to capture summer /peak and winter/off-peak water use) time frames, then analyze the results and develop predictive models. All of the items in Figure 3.1 are briefly detailed here and explained in greater depth later in the chapter.

1. **Selection of participating study sites**: a core group of utilities including City of Boulder, Denver Water, Seattle Public Utilities, Eugene Water and Electric Board, and Metropolitan Water District were included in the project proposal. Invitations to participate were sent to utilities across the country after the project was awarded and additional study sites were found. Participation required cash and in-kind service contributions from each utility.

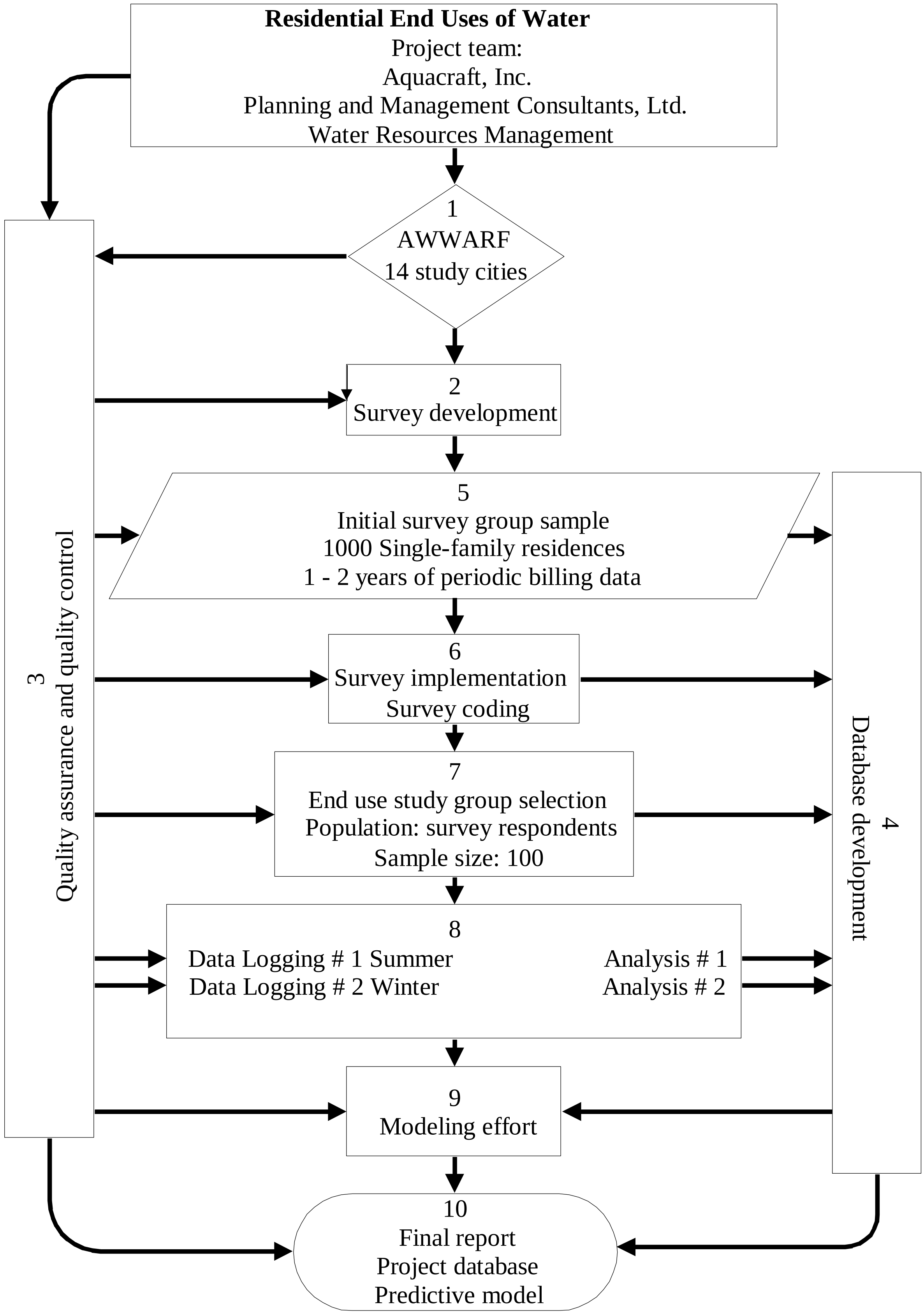

Figure 3.1 Residential End Uses of Water Study flow chart

2. **Survey development**: to explore the causal relationships in water use a detailed water use survey was developed through an iterative review process that included field pre-testing and review by the project advisory committee (PAC).
3. **Quality assurance and quality control (QAQC)**: procedures for each step of the study process were devised to ensure the quality of the data obtained.
4. **Database development**: all data collected in this study including historic water billing records, survey response data, and individual end use water data was stored in a Microsoft Access database.
5. **Initial survey group sample:** a sample of 1,000 single-family detached accounts to receive the survey were selected from each utility's population of single family accounts using a systematic sampling procedure with an initial random selection. Historic water billing records were obtained for each of the 1,000 accounts. **QAQC** – Statistical tests were performed to ensure the water use characteristics of each sample was statistically similar to that of the population.
6. **Survey implementation and coding**: surveys and cover letters were sent to each of the selected 1,000 single-family detached homes in each city. In most cases a follow-up postcard was sent to increase response. Completed surveys were shipped to the consultants and then typed into a computer database by hand. **QAQC** – Accuracy of the survey input was checked through a random sampling process during coding of the survey for each of the 12 study sites.
7. **End use study group selection**: a sample of 150 single-family detached accounts (100 primary and 50 replacements) were selected for the data logging portion of the study from the population of survey respondents. **QAQC** – Statistical tests were performed to ensure that water use characteristics of each sample was statistically similar to water use characteristics of the 1,000 home survey target group.
8. **End use data collection and analysis**: data loggers were installed on a sample of 100 homes in each of the 12 participating study sites. Two weeks of data was collected during a warm weather period and two weeks were collected during a cool weather period. The collected flow traces were analyzed using Aquacraft's flow trace analysis software, Trace Wizard. Disaggregated water use data was placed into an Access database. **QAQC** – Tests were performed to ensure the logging equipment was operating properly, that the loggers recorded flow through the water meter accurately, and that there was agreement between the

water meter and data logger. Further quality control tests checked the accuracy of the flow trace analysis.

9. **Modeling**: once the data collection and analysis was complete PMCL used all of the assembled information to develop analytical tools and relationships to explain single-family residential water use.
10. **Final products**: the final products of this research project include this final report, the derivative database, and the predictive model.

A companion study to the *Residential End Uses of Water* titled, “The Commercial and Institutional End Uses of Water” was commissioned by AWWARF to the consultant team in 1997 and should be completed sometime in 1999. As the title suggests, this companion study will focus on where water is put to use in commercial and institutional settings.

STUDY SITE SELECTION

The *Residential End Uses of Water Study* required cooperation, staff labor, and funding from all participating water utilities and agencies. The project team actively sought commitments for funding and in-kind services from numerous water providers. Invitations to participate in the Residential End Uses of Water Study were sent to water utilities and agencies all across North America during the grant application process in the hopes of recruiting the participation of a geographically diverse group of study sites. Study site openings were offered on a first-come-first-serve basis, but efforts were made to recruit sites from distinct regions across the continent.

Three utilities – the City of Boulder, Denver Water, Seattle Public Utilities and the Tampa Water Department – all had agreed to participate and committed cash an in-kind contributions to the project by the time the proposal was submitted to AWWARF. The Sonoma County Water Agency and the North Marin Water District agreed to serve as a backup if other tentative sites could not participate. Tentative commitments were made from various agencies and utilities to fund an additional nine study sites. Ultimately, 12 study sites spread over 14 cities agreed to participate in the project. Tempe and Scottsdale, Arizona combined to form one study site as did Cambridge and Waterloo, Ontario. This combined sites were accommodated at the request of the utilities, agencies, and purveyors involved who wished either to share costs or to spread participation in the study across service areas. In Seattle, single-family detached residences from four different water purveyors all in the Seattle metropolitan region were included in the study. These purveyors included Seattle Water, Northshore Water District, Highline Water District, and the Bellevue Water Department.

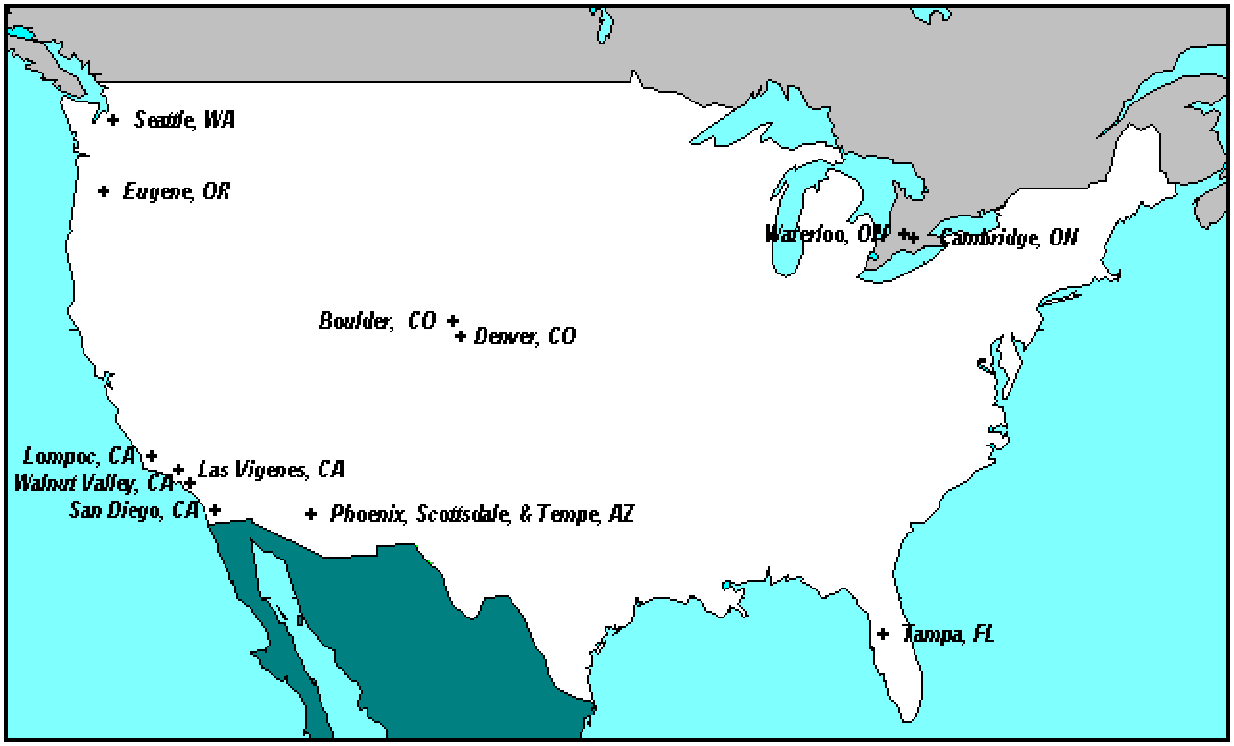

Figure 3.2 Residential End Uses of Water Study sites

Not surprisingly, utilities that have had an historic interest in water demand planning and management were the first to sign up. Therefore, the final 12 study sites are weighted towards the West and Southwestern region of the United States, but contain a wide variety of utilities serving a broad and diverse group of customers. Figure 3.2 is a map identifying the location of the all study cities. The participating utilities and supporting agencies were:

1) City of Boulder, Colorado
2) Denver Water Department, Colorado
3) Eugene Water and Electric Board, Oregon
4) Seattle Public Utilities, Washington
5) San Diego Water Department and the Metropolitan Water District, California

6) Tampa Water Department and the Southwestern Florida Water Management District, Florida
7) Las Virgenes Municipal Water District and the Metropolitan Water District, California
8) Walnut Valley Water District and the Metropolitan Water District, California
9) City of Phoenix and the Arizona Municipal Water Users Association, Arizona
10) Scottsdale and Tempe and the Arizona Municipal Water Users Association, Arizona
11) Regional Municipality of Waterloo and the Cities of Waterloo and Cambridge, Ontario, Canada
12) City of Lompoc and the Santa Barbara County Flood Control and Water Conservation District and Water Agency and California Department of Water Resources, California

INITIAL SURVEY GROUP SAMPLE

The research plan called for a selection of an initial sample of 1,000 single-family detached residences from each participating utility. The target of 1,000 single-family residences at each site was to allow for an adequate sample size of survey respondents to be able to make conclusions about the house and household characteristics at each study site. It was assumed that a 25 percent response rate would be the minimum needed to provide this.

A detailed questionnaire survey was mailed to each of these 1,000 residences and the final study group for the data logging portion of the study was selected from those people who returned the survey. The following outlines the procedures used to identify the initial sample at each site that was targeted to receive the mail survey. The detailed survey group selection procedures instructions used by each utility can be found in Appendix A.

At each participating site, the goal was to identify and retrieve a sample of 1,000 single-family detached accounts that were representative of the total number single-family water use accounts served by the water utility. In basic terms, the initial sample group was selected using a systematic sampling procedure with a random start. The sampling procedure was devised by the project team, but was implemented by each utility staff using their own customer information system (CIS). The project team worked closely with database programmers from each utility to ensure proper procedures were followed and a representative sample was selected. Once selected, the sample was carefully evaluated to ensure it was in fact representative of the overall population from which it was selected.

The first step in the sampling process was to determine the sampling frame. The sampling frame represents a list of all possible sampling units (e.g., all single-family detached accounts served by the water utility that met specified criteria). This step in the sampling process included, if possible, the elimination of accounts from the total number of single-family accounts that: 1) had closed during the most recent 12 months, 2) had not been in existence over the entire recent 12 months period, and 3) had a non-magnetic water meter at the account. The goal of this screening process was to eliminate accounts which would not have a complete one year history of water use records that was needed for subsequent water use modeling and/or which could not be part of the data logging process because magnetic meters were required for the data logging equipment. The resulting list of accounts thereby represented the sampling frame, and represented the population from which the sample of 1,000 residences targeted for the mail survey would be drawn.

The next step was to order the sampling frame (all single-family detached accounts that met the above criteria) either 1) in a purely random order (not alphabetical or in some other arrangement) for simple random sampling, or 2) sorted by decreasing annual water use for systematic sampling. All utilities took the later approach. For each account in the sampling frame, a full year of water consumption data was totaled into an annual consumption total. The residences in the sampling frame were then sorted by decreasing annual water use and then by using an initial random selection, the systematic sample of 1,000 accounts was drawn from the population. The use of a random start procedure to the sampling process ensured that all units in the sampling frame had an equal possibility of being selected.

For example, there may be 250,000 single-family accounts that exist in the service area that meet the specified criteria. The accounts in the sampling frame (e.g., all the 250,000 single-family accounts in the CIS) are sorted by decreasing annual water use for systematic sampling. When the accounts are ordered from the highest or lowest water use, the selection interval for retrieving the identity of an account for sampling from the CIS is equal for 250 (i.e., in our example: 250,000/1,000). The utility would then randomly select a number between 1 and 250 to be the first member of the sample. Assuming that the random number is 6, the utility would then select the 6th account on the list and then select every 250th thereafter, until the complete list of single-family accounts (i.e., all 250,000) is exhausted. This procedure will roughly provide a list of about 1,000 single-family accounts.

The only problem with this method is that the random number in the top stratum may have some impact on the mean water use in the sample because the largest users may be far apart (e.g., #3 may be 1,200,000 gal/year and #4 may be 300,000 gal/year). Depending on which of the top numbers is selected, the mean water use may fluctuate for successive samples. However, this would be expected to be more a problem for a listing of nonresidential customers than a listing of single-family customers. With the single-family sample of 1,000 homes, it was expected that small differences in the sample and population means could be tolerated. When problems occurred, additional samples were drawn.

For each of the identified mail survey targets at each site, the following types of information were collected from the CIS systems of each utility:

- Account number
- Service address
- Account status
- Date of account initiation
- Meter reading dates, meter readings, and consumption data for a 12 month period (this covers 7 meter readings on a bimonthly billing cycle, and 13 meter readings on a monthly billing cycle)

For each site the sample of 1,000 single-family detached homes was referred to as the "Q1000" database. The water consumption data were used in Quality Assurance and Control Tests (QAQC) and then were subsequently used in the water use modeling.

One of the QAQC tests was conducted on each of the site samples to determine whether the water use characteristics of the target mail survey sample (1,000 residences) were statistically representative of the population (i.e., all) of single-family detached water use accounts. Using the population and sample mean water use per account and standard deviation, statistical tests were used to determine whether "statistically significant differences" existed in water use characteristics among the groups. Appendix B shows the detailed forms used to conduct these tests for each study site. Summary results of these tests are presented in Table 3.1.

Table 3.1 shows that in all sites except for Tempe, Arizona, the initial survey sample of approximately 1,000 single-family accounts was statistically similar to the water use characteristics of the population of single-family water use accounts at that site. Tempe, Arizona, was one of three sites (Scottsdale/Tempe, Seattle/other purveyors, and Cambridge/Waterloo, Canada) where the sample was split amongst different water purveyors at the given site. In Tempe, the target for the mail survey was 400 single-family homes out of approximately 29,700 single-family homes. After repeated samples yielded "statistically significant differences" between the mean water use per account of the total number of single-family homes and the targets for the mail survey, it was decided to proceed with the survey process and then take corrective action, as necessary in the study group selection process.

SURVEY DEVELOPMENT AND IMPLEMENTATION

In order to explore the causal relationships of water use, it is necessary to obtain data on possible explanatory variables. These variables include information that can only be supplied by the household occupant. The goal of the survey element of the project was to obtain detailed information about water-using appliances and fixtures, water-using habits, household and landscape characteristics, and demographic information from the representative sample of 1,000 households in each study site.

A mail survey was selected to obtain information from household occupants because of the relative ease of implementation and low cost compared to other options such as on-site audits or phone surveys. Because the REUWS had 12 study sites spread across the continent, the project team determined that a mail survey would be the only feasible method for obtaining the required information given the available budget. The REUWS sampling framework was designed so that a 25 percent response rate (approximately 250 completed surveys) to the mail survey in each study site would be sufficient for selecting the data logging sample. In fact the response to the survey far exceeded this minimum requirement in each of the 12 study sites.

Survey Design

The project team developed the survey questionnaire through an iterative review process that included field pre-testing and review by the project advisory committee (PAC). The final survey questionnaire is shown in Appendix A.

The survey included questions about the number and type of water-using fixtures present in each residence, lot size and landscape characteristics, irrigation methods and habits, other exterior uses of water, water conservation actions taken or employed, type of residence, household demographics, size and value of home, education, household income, and others. The final survey was eight pages long (8.5 x 11 inches, 10 pt type), contained 41 multi-part questions and typically took 10 to 15 minutes to fill out. In the survey, 13 question pertained to indoor water use, 14 to outdoor water use, and 14 to both. There were 15 questions about hardware, 10 demographic questions, 7 behavioral questions, 5 geographical questions, 3 judgement questions, and one question about water supply. The back page of the questionnaire was devoted to the return address, postage and return instructions. The survey instrument was designed so that the respondents had only to complete the questionnaire, then fold it into a "U" fold and place it in the mail. Respondents were not asked to identify themselves or provide a return address.

The survey forms were printed by each of the participating utilities so that the appropriate utility logo, return postage preference (stamp or U.S. Post Office Business Reply Address) and return information could be included. After identifying the target mail survey sample, mailing labels were printed by Aquacraft using the service address information provided by the utility as part of the historic water use database. The project team opted to use the "service address" as opposed to the "billing address" in order to target the resident rather than a bill payer in case of rented single-family homes.

Use of KEYCODE to Preserve Customer Anonymity

The service address labels for the Q1000 mailing list was generated together with a separate label containing a corresponding number which identified the customer (usually the customer's billing account number). This number was called the CUSTID. The CUSTID was affixed to each survey form that was mailed to the Q1000 list. Each response therefore contained a unique CUSTID. This was loaded with the response record into an ACCESS database table. Each response record could therefore be linked to the historic water use database which also contained the CUSTID. At the time each response record was loaded, another number called the KEYCODE was assigned arbitrarily to each response record and also loaded. The first two digits of the KEYCODE designates the utility site and the next three digits denotes a responding residential customer. As other databases were created (such as the end use event databases), the KEYCODE was used to identify a given customer. At the conclusion of studies, the databases prepared for future researchers will not contain the CUSTID, service address or customer name thus preserving the anonymity of the participating customers.

Survey Implementation

A utility representative was designated by the utility to be responsible for survey implementation. This determination was requested when first contacting the utility at the start of the research work. This was a simple but very important step to assure that detailed instructions got to the right person and that accountability was maintained. A complete and detailed instructional packet containing all the necessary information and step-by-step instructions on how to prepare for and conduct the survey was sent to the utility. The procedure was reviewed in a detailed telephone call with the key water conservation official at the utility and then again, if necessary, with the contact person. The same implementation procedure was followed by each participating utility to assure uniformity between study sites and a successful response. To assure that the timetable was kept, periodic telephone calls were made to verify that the utility was anticipating the next work step and keeping on schedule. A copy of the instructional materials sent to the utility is contained in Appendix A. These materials represent the "road map" which the utility followed to assure a successful project. The survey implementation schedule is shown in Appendix A.

The survey packet mailed to the Q1000 customer contained a cover letter and the survey instrument. The utility was provided a draft sample of the cover letter but the final version was usually slightly different containing the utilities preferred language. This letter was printed on official "city" or "utility" stationary and was signed by the mayor or some high official in the water utility. A follow-up, more urgently worded postcard was also prepared. The posting strategy was the same for all participating utilities.

To facilitate respondent needs, a phone number for a utility staff person was made available to answer questions and provide assistance. Often a bilingual person versed on the survey form was also made available to assure Spanish-speaking respondent needs were fully met. Utilities reported that relatively few telephone calls were received and very few inquires for Spanish-speaking assistance.

As a back-up strategy, participating utilities were prepared to post a second, more strongly worded letter together with another survey instrument in the event the response rate did not achieve the minimum desired 25 percent. This never happened so posting of the second letter was never required. Also the utilities agreed to do some follow-up phone calling if needed to boost the response rate. This too was never necessary.

Returned surveys were collected by the responsible utility person and then shipped to the project team for entry into a Microsoft Access database table. A form was devised to facilitate table loading and enhance quality assurance. A copy of the form is contained in Appendix A. Data entry accuracy was tested by QA Test 3 (refer Appendix B for description).

Upon completion of the database entry work, the participating utility was informed of the final response rate and supplied a copy of comments received. The survey instrument contained a space for comments and occasionally respondents would enter a comment in the margins. The latter were designated with the question number they appeared opposite and were also entered into the “comment field”. The utility therefore had the option of responding to any comments as it deemed appropriate.

Upon completion of the survey entry work, a digital file containing the survey response table was incorporated into the master database established for that particular utility. A summary table was then created, totaling responses to all survey questions and calculating mean, median and mode response rates where appropriate. This was sent to the participating utility and the research team. Each participating utility received full feedback on their survey within about seven weeks of posting the initial 1,000 questionnaires.

STUDY GROUP SELECTION

Comparison of Survey Respondents with Survey Targets and Non-respondents

The percentage of mail survey respondents (relative to the mail survey target) ranged from 36 percent in Tampa, Florida to about 56 percent in Cambridge and Waterloo, Ontario. Part of the initial water use modeling task was to investigate the relationship between household characteristics obtained from the mail surveys and monthly water use characteristics of all survey respondents.

At the completion of the mail survey, the initial samples of 1,000 customers were each designated as survey respondents or survey non-respondents. The per account water use of the survey respondents was compared to the per account water use of survey non-respondents and the mail survey targets to determine if there were statistically significant differences in mean water use. The mean and standard deviation of water use per account was calculated based on the annual water use record. Given these statistics, a t-test, assuming unequal variances, was conducted at a 95 percent confidence level to determine if there was a statistically significant difference in the mean annual water use of respondents versus non-respondents or versus the mail survey targets. Also, if monthly water use statistics were available, additional t-tests were conducted to determine if there were statistically significant differences between the average monthly water use of respondents and non-respondents.

Table 3.1 shows some of the sample comparisons. In most of the study sites, there were no "significant differences" between the water use characteristics of the study groups. However, in San Diego, survey respondents were found to have statistically significantly different (i.e., lower) water use than mail survey targets and non-respondents. It was hypothesized that the mail survey respondents were more water conservation-oriented than non-respondents. In subsequent sampling steps for data logging, corrective actions were taken to account for the difference. In this case the corrective action involved using a matching sample approach to select the data logging sample for San Diego. Details of the sample comparisons are shown in Table 3.1.

In Las Virgenes MWD, California, initial tests showed statistically significant differences in water use among the test groups. However, after subsequent investigations, it was determined that there were five accounts that used excessive (and unlikely) amounts of water for a single-family account. Upon removal of these outliers, no significant differences among the study groups were observed.

In Lompoc, California, significant differences in water use between mail survey respondents and non-respondents were found. To further investigate this issue, t-tests were conducted to determine if there existed statistically significant differences in water use between the survey respondents and the sample population, i.e. those who received the survey and between the survey respondents and the population of single-family detached accounts in Lompoc. In both cases these two groups were not significantly different in their water use pattern. Based on these results, the survey respondents were still deemed to be a representative sample. No other course of action was taken.

Selection of Data Logging Sample

The next step in the sampling process was to identify single-family residences to be targets for the data logging. The goal of the project was to install data loggers and obtain end use data on 100 homes in each of 12 sites. Data logging targets were to be a subsample of the mail survey respondents.

To account for the fact that all homes targeted for the data logging might not wish to participate or that some might not have compatible meters to install the data loggers, a random sample of 125 or 150 (depending on the city) single-family accounts were selected for data logging. The data logging targets were selected using a computer random number generator.

Given the known importance of home value and household income on household water use, the lower, middle, and upper quartiles for both the reported (on the mail survey) household value and household income were determined for the logging sample and for the respondents to the mail survey. This procedure was performed to determine if the sample was representative of the home value and income levels of the mail survey respondents. This same procedure was performed for the responses to household income.

In order to determine the home values for all households responding to the mail survey, an estimate of home value was calculated for those households which were renter-occupied. The rent ranges were converted to equivalent home values using Equation 3.1:

$$F = \frac{(1+i)^n - 1}{i(1+i)^n} \tag{3.1}$$

where F = a series present worth discounting factor

i = Typical 1995 mortgage rate of 0.0067 per month (8.0 percent per year)

n = 360 months (30 years)

The product of monthly rent and the conversion faction, F, is the estimated home value. Monthly rent was determined by taking the mid-point of each rent range defined in the mail questionnaire.

The determination of quartiles allowed the comparison of the income and household value distributions of the respondents to the proposed logging sample. These comparisons were done to make sure the sample remains representative.

From the 125 (or 150) accounts designated as the logging sample, 25 (or 50) were randomly removed on the basis of home value quartile delineation and were designated to be used for replacement purposes. The remaining 100 accounts were the selected logging sample for the study area. Two tailed t-tests, assuming unequal variances, were conducted to determine if there was a significant difference between the mean daily water use of the proposed logging sample from the mean daily water use of (1) the total population of single-family detached units from with the mail survey sample was selected, (2) those receiving the mail survey, and (3) the mail survey respondents (see QAQC Test 5 in Appendix B). Only when the these t-tests were accepted at an alpha level of 0.05 was the data logging sample group approved for use in the study.

Once the data logging sample was finalized a consent letter (Appendix A) was mailed out to all accounts in the study group and replacement group. The letter explained that data logging would be conducted twice over the next year and that those wishing not to participate should contact the specified utility representative. Those who phoned in to be excluded were removed from the logging group and a replacement was selected from the same quartile as the drop out. Usually between two and five households at any given study site would opt not to participate. Over the course of the entire study approximately 40 households opted not to participate in the data logging portion of the study. Replacement households were used in place of those who opted out of the study.

Table 3.1 Sample comparisons for survey and logging groups

Study Site	**Total SF accounts**	**Targets for survey (Q1000)**	**Diff. Between survey targets and total SF accts.***	**Survey respon-dents**	**Diff. Between survey targets and respondents***	**Diff. Between survey respondents and non-respondents***	**Data logging sample (Q125 or Q150)**	**Diff. Between logging sample and survey respondents***	**Diff. Between logging sample and targets for survey***
Boulder	16,904	1,000	No	459	No	No	125	No	No
Denver	174,688	1,000	No	466	No	No	125	No	No
Eugene	27,523	983	No†	510	No	No	125	No	No
Seattle	303,000	985	___‡	497	No	No	150	No	No
San Diego	171,952	1,007	No	482	Yes**	Yes**	125	No§§	No§§
Tampa	60,830	1,017	No	366	No	No	150	No	No
Phoenix	254,781	1,000	No	426	No	No	150	No	No
Scottsdale	42,811	600	No	333	No	No	90	No	No
Tempe	29,700	401	Yes§	220	No	No	60	No	No
Cambridge	23,614	600	No	306	No	No	90	No	No
Waterloo	14,972	400	No	259	No	No	60	No	No
Walnut Valley	18,307	1,000	No	374	No	No	150	No	No
Las Virgenes	12,740	1,062	No	409	No††	No††	150	No	No
Lompoc	5,740	1,000	No	467	No	Yes‡‡	150	No	No

Footnotes:

* Significant differences measured between annual (or monthly) water use between the two groups using the Z-score statistic or the t-statistic at the 0.05 level.

† No significant differences after outliers removed.

‡ Population mean and standard deviation could not be calculated so test was not performed.

§ Because of smaller sample size, t-test indicated significant difference.

** Survey respondents were found to have significantly different (i.e., lower) water use than mail survey targets. Corrective action taken in subsequent steps.

†† Initial tests showed significant differences in water use. However, after 5 outliers were removed, no significant differences were found.

‡‡ Significant differences in water use were found between survey respondents and non-respondents. However, other comparisons showed no significant differences.

§§ Because significant differences were found between survey respondents and non-respondents and survey respondents and mail survey targets. A matching sample approach was used to select the data logging sample.

END USE DATA COLLECTION

Overview

The development of compact, battery powered, waterproof data loggers with extended memory capabilities along with advancements in personal computing made this research effort possible. The data loggers provided precise flow data at 10 second intervals and the computers allowed researchers to collect and analyze more than 288,000,000 data points over the course of the entire study consuming more than 6 gigabytes of computer storage memory.

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

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

Data Logging Equipment

Research was conducted into available data logging equipment that could meet the harsh conditions needed for this type of study. Based on the recommendation of staff at Seattle Water, a participating utility, the data logger ultimately used in this study was evaluated and subsequently selected for use. The logger selected was the Meter-Master 100EL manufactured by the F.S. Brainard Company of Burlington, NJ. The Meter-Master 100EL logger, shown in

Figure 3.3, offered the essential combination of data storage capacity, battery life, and ease of use. A total of 110 loggers were for use in the study. Only 100 loggers were used at a time at each study site and the extras provided backup if any logger failed to operate properly and had to be sent for repairs.

The data loggers used in this study are compact and sit comfortably out of sight in the meter box or pit during the logging period. Installation took between 3 and 7 minutes per logger (not including travel between houses) depending on the location and condition of the meter box. These loggers can be installed on most magnetic-driven water meters on the market although the positioning of the sensor varies by brand, model and, size. Adapters are also available so that the loggers can be used with mechanical meters, but magnetic-driven meters were a requirement for participation in this study and participating utilities replaced any meters that were not compatible with the logging system. Seattle Public Utilities chose to replace all of the water meters in their study group in an effort to improve accuracy and ease of installation. At other study sites, several incompatible meters were replaced by the utility with newer magnetic-drive meters for the study.

The basic assumption behind the data logging system in that the water meter is accurately recording flow volume. The logger is not truly measuring flows, but rather only records the spinning movement of the magnetic piston inside the water meter as water flows through the meter. The loggers records the number of magnetic pulses counted in a 10-second interval and once the data is downloaded, a the data logger control program automatically converts the pulse count into flow using the exact specifications of each water meter. Most of the water meters used in this study provided resolution of between 50 and 120 magnetic pulses per gallon. When the logger is downloaded, the logged volume is compared to meter readings taken at the time of installation and removal to ensure the accuracy of the flow trace.

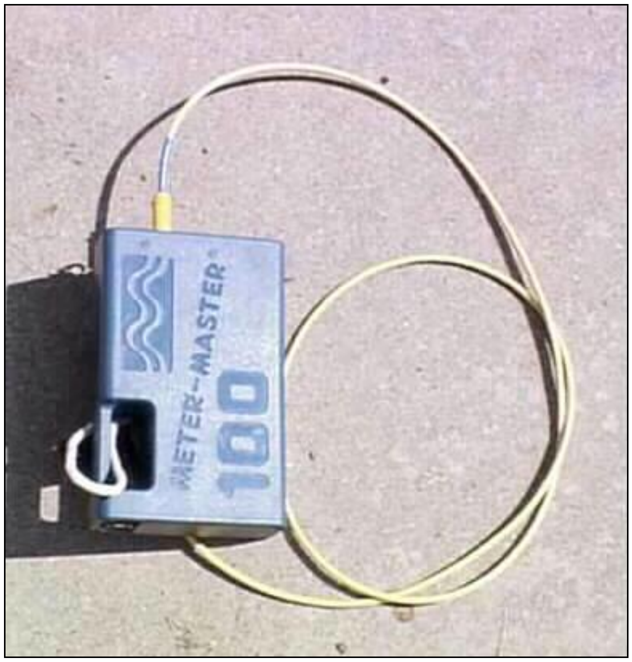

Figure 3.3 One of the 110 data loggers used in the study

The loggers were shipped from site to site in specially designed padded cases and the data logger installation schedule was set up to accommodate downloading, recharging, and shipping time.

Logger Installation

Logger installation followed a routine pattern at each study site using a team of two installers: one consultant from the project team, and a representative from the utility. It was rapidly discovered that the bulk of the time during logger installation was spent driving between different study sites rather than on installing the actual hardware which took very little time. A three or four day installation schedule was developed for each site with routing between study houses carefully planned to minimize driving time. The installation team could typically install five loggers per hour.

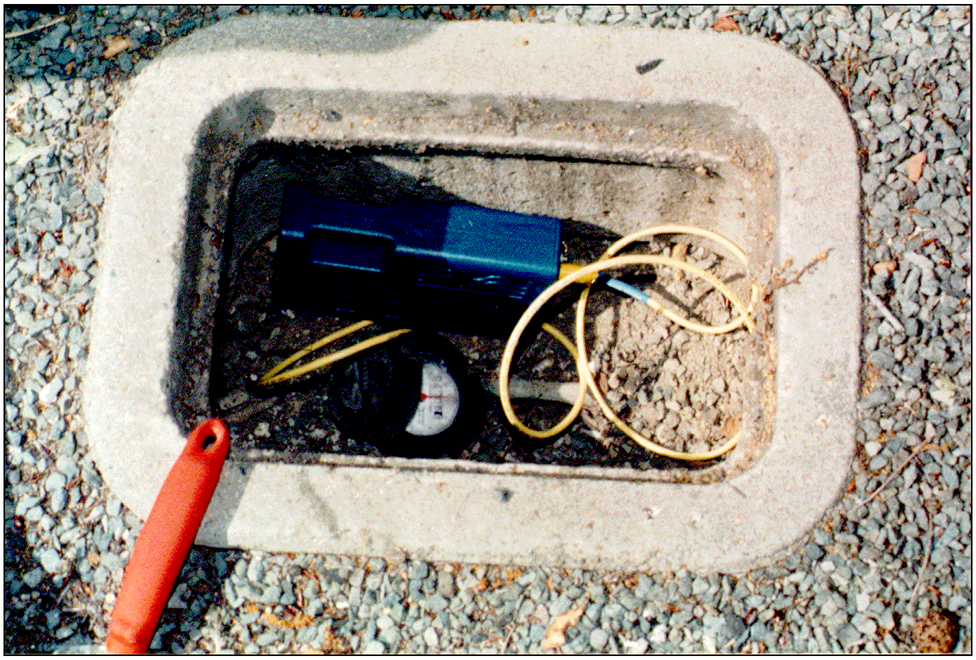

Figure 3.4 Brainard data logger in the meter pit

At the study residence one installer would open the meter box and prepare the meter and meter environment for the logger. The other installer readied the logger and recorded the following data for each study residence: date, time, logger number, meter brand, meter model, and starting meter reading. The sensor was fixed to the meter with a heavy Velcro strap and then the logger was turned on. The data logger responds to being turned on with two second flash of a red light so the installers were aware if the logger was working. Next, a small amount of water was run through an outside hose bib and a properly installed logger and sensor responded again with a red light flash indicating that magnetic pulses were being picked up and recorded by the logger. This insured that the installation was completed properly and the equipment was functioning at the time of installation. Finally the logger was placed in the meter box (or hung from a strap in deep meter pits) and the cover was replaced. A typical logger and sensor installation is shown in Figure 3.4.

Data Collection Schedule

The data collection objective of the study was to obtain a total of 28 days of data from each 100 study homes in the 12 participating study sites -- two weeks in the "summer" and two weeks in the "winter". To accomplish this goal a data collection schedule covering each year of the two study period was developed. The installation dates are shown in Table 3.2. Generally the project team member arrived at a site a few days ahead of time in order to meet with utility representatives and prepare equipment for installation. The data loggers were retrieved by the utility staff members without the assistance the project team member. The utility staff member simply removed the logging equipment, turned the logger off, removed the sensor, and placed the logger and sensor back into the packing cases. The loggers were then shipped either on to the next site or back to the project team office in Boulder, Colorado where they were downloaded, recharged, and re-conditioned.

Table 3.2 Dates of data collection

Site	**City**	**Data collection period**	
		1	**2**
1	Boulder, Colorado	May 21-June 7, 1996	Sep. 3-Sep. 19, 1996
2	Denver, Colorado	June 5-June 21, 1996	May 27-June 13, 1997
3	Eugene, Oregon	June 24,-July 11, 1996	Dec. 1-Dec. 20, 1996
4	Seattle, Washington	July 16 - Aug. 2, 1996	Jan. 7-Jan. 24, 1997
5	San Diego, California	Aug. 6 - Aug. 26, 1996	Feb. 3-Feb. 21, 1997
6	Tampa, Florida	Oct. 1 - Oct. 18, 1996	Mar. 3-Mar. 21, 1997
7	Phoenix, Arizona	May 6-May 23, 1997	Nov. 4-Nov. 21, 1997
8a,8b	Scottsdale & Tempe, Arizona	Oct. 29-Nov. 15, 1997	Dec. 2-Dec. 19, 1997
9a,9b	Waterloo & Cambridge, Ontario	June 24 - July 11, 1997	Oct. 7-Oct. 24, 1997
10	Walnut Valley, California	July 22 - Aug. 8, 1997	Jan. 6-Jan. 23, 1998
11	Las Virgenes, California	Aug. 12-Aug. 29, 1997	Jan. 27-Feb. 13, 1998
12	Lompoc, California	Sep. 9 - Sep.26, 1997	Feb. 24-Mar. 13, 1998

END USE DATA ANALYSIS

Flow Trace Analysis

Perhaps the most detailed and painstaking part of this research effort was the analysis of the end use data collected with the data loggers. Nearly 2400 continuous flow traces were recorded for this study (1200 homes for two seasons) and each was analyzed individually using Aquacraft's copyrighted software package Trace Wizard.

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

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

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

Meter-Master Data Loggers

A key to the success of the Residential End Uses of Water Study was obtaining a reliable data logger capable of enduring the extreme conditions in the water meter pit and with sufficient memory to store two weeks of data at 10 second intervals which amounts to more than 120,000 individual records. Data loggers from F.S. Brainard and Company of Burlington, New Jersey provided the only viable option. Furthermore, Brainard was willing to develop their Meter-Master for Windows software in tandem with Aquacraft's Trace Wizard package so that they work in together as part of a water meter data acquisition system.

Trace Wizard

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

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

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

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

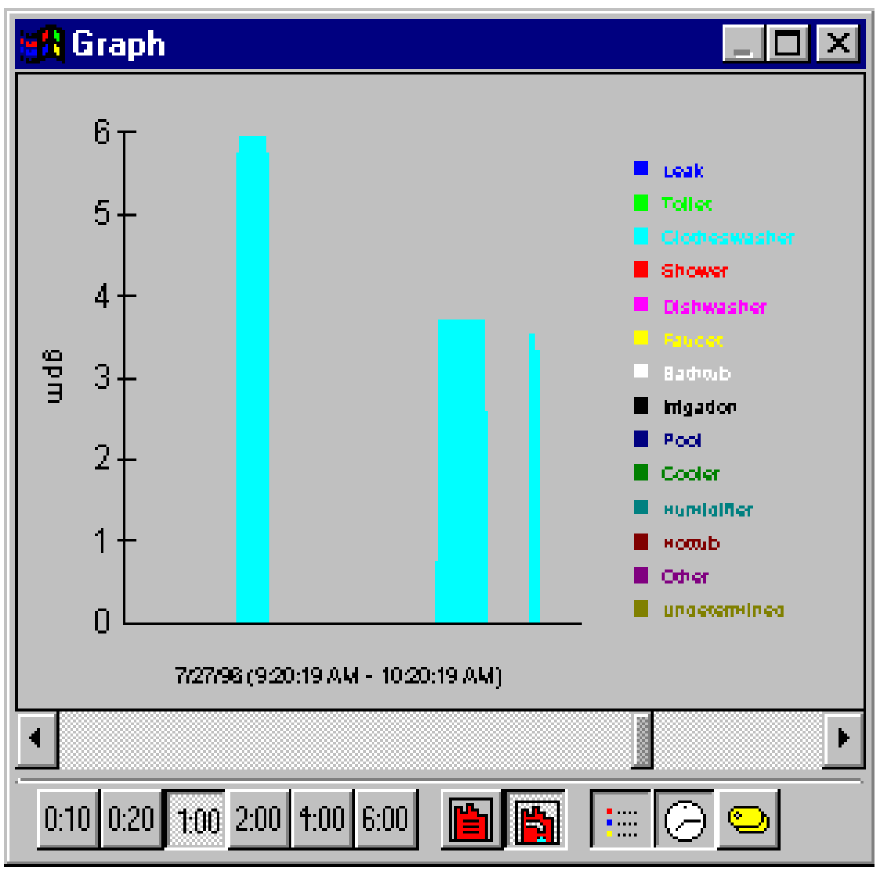

Figure 3.5 Sample flow trace from Trace Wizard showing a one hour view. Water events depicted include a three cycle clothes washer.

Figure 3.5 shows a one hour portion of a typical flow trace in Trace Wizard. The three light blue spikes are clothes washer cycles. The first is the wash cycle, the second is a rinse cycle, and the third is a spin cycle. Note that the times shown on the graph's x-axis are the time interval depicted in the graph. In Figure 2.4 this is a one hour time interval. The Trace Wizard graph has six time interval settings: 10 minutes, 20 minutes, 1 hour, 2 hours, 4 hours, and 6 hours. The analyst may use any of these "views" during the flow trace analysis process.

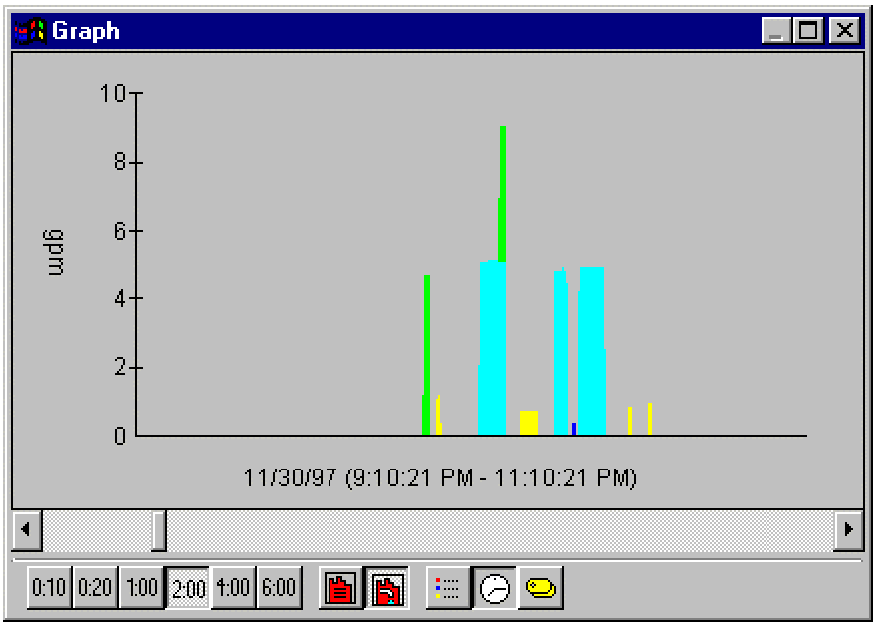

Figure 3.6 Sample flow trace from Trace Wizard showing a two hour view. Water events depicted include two toilet flushes, a three cycle clothes washer, and several faucets.

Figure 3.6 shows two toilet flushes, miscellaneous faucets, and another three cycle clothes washer. The first green spike in a toilet flush with a refill rate of approximately 5 gpm. The small yellow spikes are miscellaneous faucet uses and the small dark blue spike is a leak. The three light blue spikes are clothes washer cycles. A second toilet flush occurs during the first clothes washer cycle and is easily distinguished by Trace Wizard as a simultaneous event.

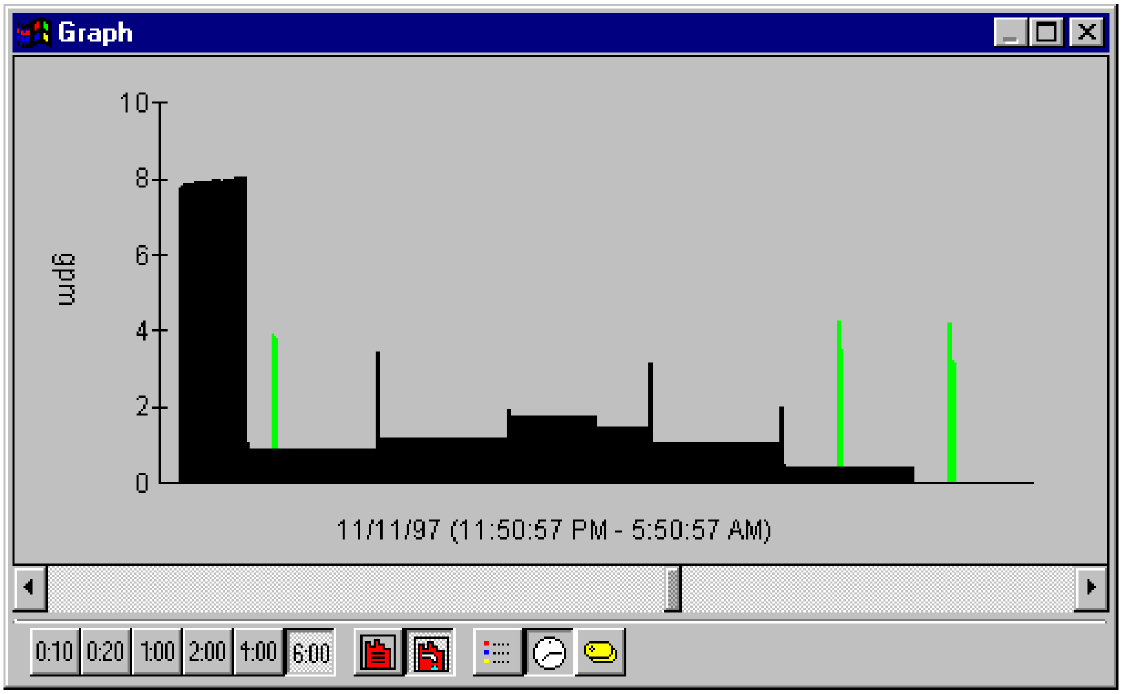

Figure 3.7 Sample flow trace from Trace Wizard showing a six hour view. Water events depicted include a multi-zone automatic irrigation system and three toilet flushes.

Additional simultaneous water use events can be seen in Figure 3.7 taken from a study home in Phoenix, AZ. Here, in a six hour view, two toilet flushes can be observed occurring simultaneously with a seven-zone drip/combination irrigation system. The irrigation system zones are clearly delineated by small and consistent differences in flow rate over the 4.5 hour irrigation session. The first zone with an 8 gpm flow rate is a turf area and the remaining six zones cover different drip irrigation areas.

At the conclusion of analysis, the final product is a database of water use events which have been given fixture identification. This database is created in the Microsoft Access 7.0 or 97 formats and can be further analyzed using either version of Access or any compatible database product. The seven-zone irrigation event from Figure 2.6 will appear in the database as a single water use event as will each of the three individual toilet flushes.

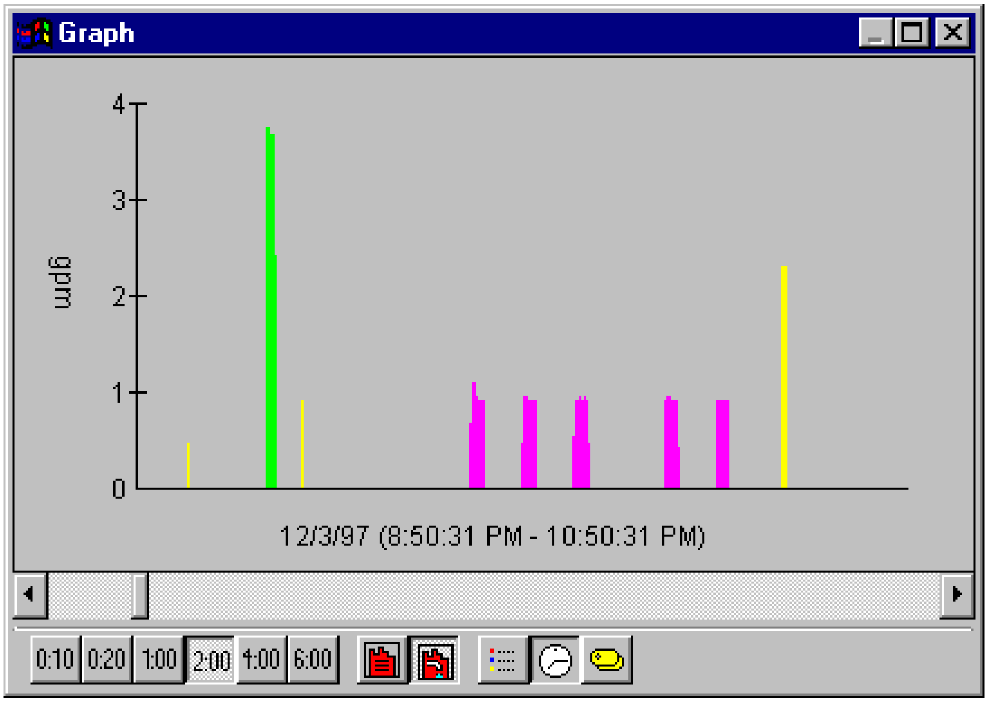

Figure 3.8 Sample flow trace from Trace Wizard showing a two hour view. Water events depicted include a toilet flush, a five cycle dishwasher, and various faucet uses.

Figure 3.8 shows a typical five cycle dishwasher that was run between approximately 9:30 and 10:30 p.m. Dishwashers typically have between three and eight cycles and use a total of between 8 and 20 gallons for a full load. They are easy to distinguish because of their box-like shape and consistent volume, flow rate, and duration.

Figure 3.9 shows the capability of Trace Wizard's simultaneous event calculating routine. The red shower event is typical of bath/shower combination traces. The water is started in the bath for about 30 seconds while the temperature is adjusted then the shower diverter valve is pulled and the water starts to flow through the showerhead – in this case a low-flow head which restricts the flow to 2.5 gpm. The shower continues for about 10 minutes at this consistent flow rate until the water is shut off. What makes this example unusual are the blue clothes washer extraction and rinse cycles which are plainly visible on top of the shower. The second set of extraction cycles occur shortly after the shower had ended.

Once analysis was complete the flow trace data was stored in two separate databases – an individual database for the city where the data was recorded and a project wide database which includes data from all 12 study sites. All databases for this study were developed in Microsoft Access.

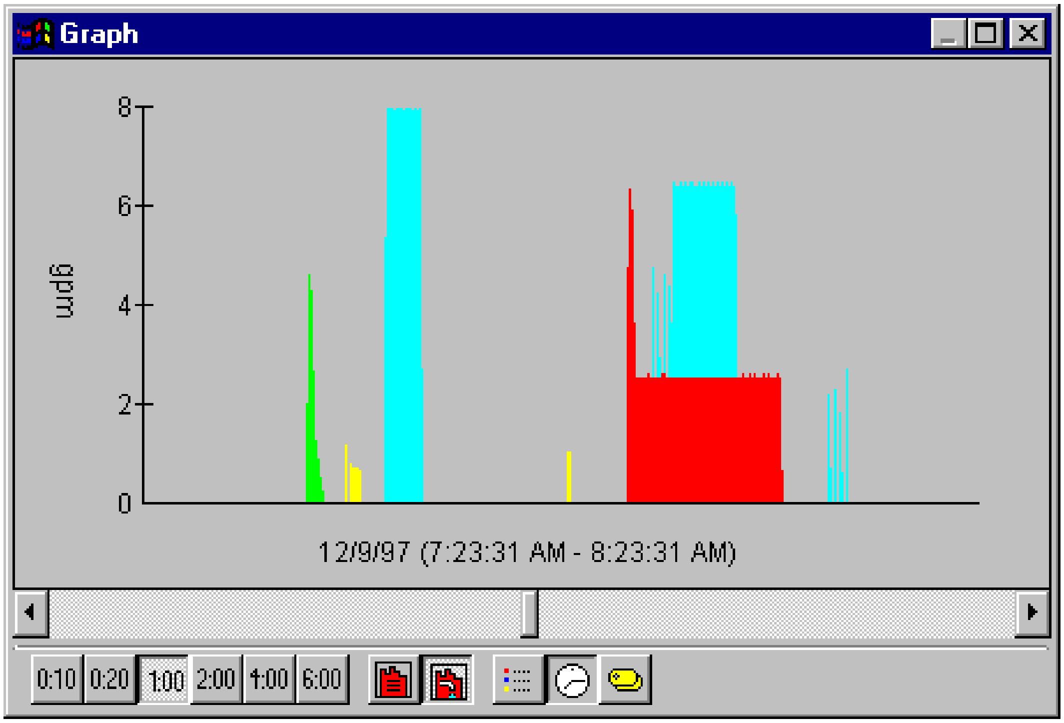

Figure 3.9 Sample flow trace showing a one hour view. Water events depicted include a toilet flush, multi-cycle clothes washer, and shower.

Database Development

Development of the database for the *Residential End Uses of Water Study* (REUWS) was an on-going process beginning with the historic billing data obtained from each of the 12 study sites. Microsoft Access uses the relational database format which organizes data into a series of tables which can be linked with a common field. For this study a separate database was developed for each of the participating utilities. Each utility's database contained the same set of tables:

- Q1000 – historic billing data on 1000 accounts
- Survey data – coded responses from the mail survey
- Comment – written comments from returned mail surveys
- Logging study group -- the 125 or 150 accounts selected for data logging
- Logging data 1 – end use data from the first logging period
- Logging data 2 – end use data from the second logging period

- Daily use data – daily water use by category for each logged residence.

Each of these tables contained a common field called "KEYCODE" which was a unique number assigned during survey coding. The KEYCODE field enabled linking of survey and logging data with historic billing data and allowed database programmers to develop any number of queries on the database to retrieve a wide variety of information. The KEYCODE also protected the privacy of individual participating residences.

The final database was built by combining the individual databases from each participating study site. Care was taken to strip all personal information about study participants from this database to preserve anonymity, but all survey responses are included. Appendix C provides an introduction to this database and describes how the database can be used to answer questions about residential water use and develop smaller data sets for analysis. The final database was used by the project team to develop the causal water use models.

Working Categories for Disaggregation

During the flow trace analysis process the following domestic water use fixture designations were assigned to water use events:

- Bath
- Clothes washer
- Dishwasher
- Faucet
- Irrigation
- Leak
- Toilet
- Cooler (evaporative)
- Hot tub
- Humidifier
- Treatment (softener)
- Swimming pool
- Unknown

Care was taken to distinguish the first cycle of multi-cycle events such as clothes washers and dishwashers so that an accurate count of the number of uses of these fixtures could be made.

The "unknown" category deserves some explanation. Flow trace analysis for residential water use is accurate, but not infallible. Regularly the analyst will encounter some water use which does not meet any of the signal recognition parameters. This may be due to simultaneous usage of different fixtures or abnormal usage of a faucet, hose, bathtub, shower, etc. When it is not possible to confidently assign a fixture designation to a water use event, it is assigned the "unknown" fixture. It is not known if unknown water use is indoor or outdoor usage, but it is a real amount of water that passed through the water meter.

For much of the analysis in this report several categories have been lumped together for simplicity. Coolers, humidifiers, hot tubs, and water treatment have been combined into the "other domestic" use category. These uses were not common to all study sites and usually comprised a very small portion of overall household water usage. These fixture designations have been preserved in the REUWS database so that further analysis of water usage in these categories is possible.

Irrigation and swimming pool water usage were also combined in some of the analyses under the heading of "outdoor" usage.

SUPPLEMENTAL DATA COLLECTION

Supplemental data were used to provide additional information about each logging period and each utility. These data were used in the model estimation process and to qualify end use measurements.

Weather Data

So that the relationship between weather and water use could be explored during the data logging end use analysis and the water use model development, weather data including daily high and low temperature and measured precipitation were obtained from a representative weather station (or several scattered stations) at each participating study for the logging period. The weather data were incorporated into the database developed for each site. Weather data were also obtained corresponding with the same period of time as the historic billing data obtained for each site.

These data included the minimum and maximum temperature and daily precipitation at each study site. Often these data were available over the Internet. In some cases, data were purchased from the operators of specific weather stations. When several weather stations were available in a given study city, data were obtained from all stations so that each study home could be linked to the nearest station. The weather data permitted calculation of evapotranspiration (ET) which gives a measure of the irrigation requirement for each site. ET was calculated using the Modified Blaney-Criddle method detailed in Chapter 4.

Conservation Program Data and Price and Rate Structure

The project team requested additional information about water rates and rate structure as well as details about conservation programs from each utility. A survey questionnaire was sent to the contact person at each utility which requested the information along with other supplemental documentation. Follow-up contacts were made to ensure that each utility responded to the data request. Information requested included:

- Percent of single family homes with water meters
- Water rates, rate structure, and length of billing period
- Sewer rates and rate structure
- Years (if any) when city experience water shortages
- Details of abnormal weather events
- Conservation regulations
- Water supply master plan
- Water conservation master plan
- Recent conservation measures undertaken by utility
- Typical water pressure

QUALITY ASSURANCE AND QUALITY CONTROL

The research team took care during every step of the project to ensure that the data collected and assembled for this study were as accurate as possible. To ensure a high level of quality and accuracy, a number of quality assurance and quality control tests were developed and implemented at various stages of the study.

The project team met at the beginning of the study and devised the eight major quality assurance (QA) tests to be conducted in conjunction with each study site to assure data collected would be representative and accurate. The test designations and purposes are:

- QA Test 1 - Test validity of service address used for the Q1000 survey mailing
- QA Test 2 - Test to see if the water use of the Q1000 sample is representative
- QA Test 3 - Check accuracy of survey response data entry
- QA Test 4 - Test if water use of survey respondents is representative
- QA Test 5 - Test if 150 potential single-family sites selected for logging are representative
- QA Test 6 - Test data logger to see that it is recording properly
- QA Test 7 - Check accuracy of data logger vs. meter
- QA Test 8 - Check accuracy of event database created by Trace Wizard software

These tests are described in detail in Appendix B and a summary of the results is presented. In addition to the eight major tests, a number of additional steps were taken to assure quality control:

1) To assure quality control of the survey, a detailed procedure addressing proper preparation and presentation of the survey form to the Q1000 sample address list was designed and followed by each participating utility.
2) When the Q1000 customer address list with associated water consumption for a one year period was generated, a histogram of the data was prepared to obtain a visual picture of annual water use. Typically this would be a lognormal distribution. This was a quick and preliminary check to see if there was potentially something seriously wrong with the Q1000 sample draw.

3) A Microsoft Access form was designed to enter survey responses into the Access data base with the aim of minimizing data entry error for survey responses. Error limit checks were designed into this form. For example the KEYCODE entered for a given site would always be the two digit number assigned to said sites followed by a three digits having a value from one to 600 which encompassed the maximum number of survey responses expected from a given site. Therefore a KEYCODE entry in the Access table for Boulder (whose assigned code number was “10") had to have a value of 10001 to 10600. Any number outside of this range would immediately generate an error message. Other checks were included in the data entry form. A sample of the data entry form is included in Appendix B.
4) The utilities customer identification (CUSTID) number appearing on the returned survey form was also entered into an Access database table. After the survey response database table was created for a given study site, the CUSTID from each survey was cross-checked by the project team with the CUSTID in the historic water use database table to assure an exact match.
5) Once the survey database table for a given study site was created, certain response columns could be quickly visually or arithmetically checked for the absence or presence of certain types of data entry errors. These types of checks were routinely made to further “truth” the database.
6) A carefully designed schedule was prepared and followed to assure that the field data collection work was accomplished on time and with a minimum of problems. All utility contacts were appraised of this schedule and commitments obtained to keep on track.

Accuracy of Flow Trace Analysis

During flow trace analysis portion of this research effort, numerous additional quality control checks were performed to ensure the accuracy of:

1) The water meters from which the flow trace data were recorded
2) The data loggers and sensors which recorded the data
3) The actual analysis of the flow trace data using Trace Wizard

4) The accuracy of the final database where the flow trace data resides

The excellent results from all of these quality control measures, make the water uses measured for this study are best and most accurate available.

Water Meter and Data Logger Accuracy

Flow trace data are only as accurate as the water meters they are recorded from and the devices that sense and record the data. Several participating cities in the *Residential End Uses of Water Study* (REUWS) decided to replace some or all of the water meters at the study homes prior to the data logging period. These cities included Seattle, San Diego, and Walnut Valley. Other cities relied upon their standard meter testing and replacement regimen to ensure meter accuracy.

Over the course of the entire study 94 percent of the successfully recorded flow traces were accepted and judged to be accurate representations of the actual flow through the water meter and 6 percent of the recorded flow traces were rejected because of logger failure or poor data quality. Overall the flow trace recording process had an error factor of plus or minus five percent.

The most important check of the accuracy of the flow trace data were the meter readings taken at each study house when the data logger was installed and then removed. These meter readings enabled the project team to compare the volume of water recorded by the data logger during the two week logging period against the volume of water during the same period as measured by the water meter. If these volumes differed by less than 5%, then the recorded data was immediately accepted. Eighty-five percent of the accepted flow traces met this accuracy requirement. Volumes which differed by less than 15% but more than 5% were examined more closely and in most cases a conversion factor was applied to the flow trace data evenly across the entire two week data set which raised or lowered the volume to match exactly the volume measured by the meter. Ten percent of the accepted flow traces were met this 5 to 15% threshold and had a conversion factor applied. In one percent of the accepted flow traces, incomplete or possibly erroneous meter readings were evident. In these cases the recorded volume from the data logger was accepted.

Occasionally, a recorded logger volume would differ from a meter volume by a factor of 0.5 or 2. After consultations with the logger manufacturer and close examination of the data itself it was determined that this phenomenon could be the result of the sensor picking up two poles from a four pole magnet or four poles from a two pole magnet resulting in either half or double the expected volume to be recorded. In 3.2 percent of the accepted traces, after a close inspection of the data, a conversion factor of 0.5 or 2.0 was applied and used.

Finally, six percent of recorded flow traces were discarded because the recorded volume did not match at all with the meter volume and an inspection of the data itself showed it to be suspect. Because each flow trace was examined carefully from start to finish by an analyst, it was easy to identify flow traces where the logger did not operate properly or which contained abnormal data.

At the suggestion of PAC member Allan Dietemann of Seattle Water, the project team performed three separate quality control field tests of meter and data logger accuracy. One test was performed in Seattle where new Neptune meters that had been recently bench tested were installed on all participating study homes. A second test was performed in Tampa which featured a wide variety of water meters which had been in service between 1 and 20 years. A third test was conducted in the Las Virgenes Municipal Water District which featured a similar variety of meters which had been in service between 1 and 10 years.

For these tests, a five gallon bucket was volumetrically calibrated, using testing equipment from the meter shop of each utility. A black line was drawn clearly delineating the exact 5 gallon point on the bucket. For these tests, a random group of homes were selected along the logger installation routes in Seattle, Tampa, and Las Virgenes MWD. At each selected home the logger was installed and a meter reading was taken down to a 0.1 gallon or 0.01 cubic foot level of accuracy. The logger was then switched on and the bucket was filled to the measured 5 gallon mark using an outside hose bib. After the hose was shut off, a second meter reading was taken, again to the most precise level of accuracy available. The logger was allowed to continue recording for the two week logging period. When the data was down loaded and analyzed, the first water use event observed on the trace was the filling of the five gallon bucket.

The logged volume of this water use event was noted along with the volume measured by the meter. Results from these bucket tests are shown in Table 3.3.

Results from the bucket tests confirm that the Brainard data loggers are volumetrically accurate within 5 percent of a calibrated bucket and water meters in the field. The results from Tampa and Las Virgenes also confirm the accuracy of older residential meters in the field.

Table 3.3 Bucket test results

Characteristic	Seattle	Tampa	Las Virgenes
Number of meters tested	11	10	10
Bucket volume	5 gallons	5 gallons	4.6 gallons
Avg. meter read volume	4.9 gallons	5.2 gallons	4.6 gallons
Avg. data logged volume	4.8 gallons	5.1 gallons	4.6 gallons
% Difference: Logger vs. Bucket	3.2%	2%	0.4%
% Difference: Meter vs. Bucket	1.6%	4.2%	0.4%
% Difference: Logger vs. Meter	1.6%	2.1%	0.0%

Flow Trace Analysis Accuracy

Accuracy of flow trace analysis using Trace Wizard was ensured by re-analysis by a different person of a random selection of 10 percent of the analyzed flow trace files from each logging session at each city. Once all the flow trace files for a logging session had been analyzed, 9 or 10 files were randomly selected for re-analysis. The re-analysis task for each trace was assigned to a different analyst than one who performed the first analysis. The results from the first and second analysis were compared by aligning the total volumes assigned to each category over the entire flow trace. Figure 3.10 shows an example of this comparison result.

The volumes assigned to each water use category over the entire two week flow trace were compared and then the total percent error was calculated by dividing the total difference by the total volume of the flow trace. In the example in Table 2.4, the total difference was calculated as 2 percent so the analyst's trace was "passed". While a maximum difference of 15 percent was deemed acceptable, the average of all the maximum differences was 6.5 percent. If significant differences were detected in a quality control file, then the analyst's trace was re-checked for any systematic errors. If any systematic errors were found, then the trace was completely re-analyzed and the analyst was provided with additional training to prevent similar errors.

16093	=Keycode Number		
	Analyst	**Checker**	**Difference**
	Gal./Trace	Gal./Trace	Gal./Trace
Bath			0
Clothes washer	410.49	411.04	0.55
Cooler			0
Dishwasher	70.94	70.27	0.67
Faucet	553.63	559.57	5.94
Humidifier			0
Irrigation	802.47	806.53	4.06
Leak	44.9	44.9	0
Shower	412.32	382.04	30.28
Toilet	827.3	845.99	18.69
Unknown	4.98	6.69	1.71
TOTAL	3127.03	3127.03	0
Total percent error = 2%		Analysis = passed	

Figure 3.10 Sample flow trace analysis comparison form

Final quality control checks were performed on every single analyzed trace prior to their inclusion in the database of analyzed water use events. These quality assurance checks tested for erroneous fixture names, erroneous volumes, duration, and peak flow values as well as ensuring that clothes washer and dishwasher cycles were properly labeled.

From the results of the flow trace analysis quality control including bucket tests, meter vs. logger accuracy checks, and trace analysis/checker quality control the researchers determined an overall range of confidence of 90 percent to the analyzed water use events.

CHAPTER 4
COMPARISON OF STUDY SITES

UTILITY SERVICE AREA CHARACTERISTICS

The 14 study cities in the *Residential End Uses of Water Study* were located in six distinct regions of North America.

1) West Coast– San Diego, Walnut Valley Water District, Las Virgenes MWD, and Lompoc, California
2) Southwest – Phoenix, Scottsdale, and Tempe, Arizona
3) Northwest – Seattle, Washington and Eugene, Oregon
4) Mountain – Boulder and Denver, Colorado.
5) Midwest/Canada – Cambridge and Waterloo, Ontario.
6) Southeast – Tampa, Florida.

Even study sites which were in close geographic proximity had unique characteristics ranging from price of water to recent conservation efforts to specific household and landscape features. Single-family homes in these study sites also differed in their water consumption patterns. This section compares some of the service area characteristics for the 12 REUWS sites. Figures 4.1 – 4.12 show different homes in each of the 12 study sites. As illustrated by these photos, just from looking at the outside of a few of the households which participated in the study, a wide variety of landscape designs and varieties are represented in the study group. Even within each study site there was tremendous variability in the size, level of maintenance, and landscaping of the participating homes.

Figures 4.7 and 4.8 represent two extreme landscape types found in the study sites in Arizona. While Figure 4.7 shows a house in Phoenix with a hardscape landscape punctuated by a few native desert plants, Figure 4.8 shows an elaborately landscaped home in neighboring Scottsdale which features well kept flower beds as well as a lush green lawn.

Figure 4.1 Participating house in Boulder, Colorado

Figure 4.2 Participating house in Denver, Colorado

Figure 4.3 Participating house in Eugene, Oregon during data logger installation

Figure 4.4 Participating house in Seattle, Washington

Figure 4.5 Participating house in Tampa, Florida and Tampa Water employee Philip Elkins

Figure 4.6 Participating house in Waterloo, Ontario

Figure 4.7 Participating house in Phoenix, Arizona

Figure 4.8 Participating house in Scottsdale, Arizona during data logger installation

Figure 4.9 Participating house in San Diego, California during data logger installation

Figure 4.10 Participating house from the Walnut Valley Water District, California

Figure 4.11 Participating house in Lompoc, California

Figure 4.12 Participating house from Las Virgenes Municipal Water District

Water and Sewer Rates

Water and sewer rates and rate structures in the 12 participating study sites varied tremendously. Table 4.1 presents the water and sewer rates (normalized to U.S. dollars and k gallons) for all 12 study sites during each of the logging periods. Water rates ranged from a uniform rate of $0.76 per kgal. in Eugene, Oregon to an elaborate 5 tier 4 block rate structure in Las Virgenes MWD. The highest rate for water in any study site was $5.98 per kgal. in Las Virgenes for tier 5 block 5. In Phoenix, Arizona the first 4.49 kgal are free followed by a uniform rate of $1.59 per kgal. for everything after that. In Boulder, Colorado the block size is based on the historic average winter consumption (average monthly consumption for December – March) for the previous year. Each block is a multiplier of the average winter consumption.

Sewer charges were not assessed in many of the study sites including three of the Seattle purveyors (Bellevue, Highline, and Northshore), Las Virgenes MWD, Walnut Valley WD, and Lompoc. In some of these cases the sewer district charges a flat fee which appears on the customers property tax bill. In Phoenix, the sewer assessment is for one year at a time and is based on a percent of the January, February, and March water consumption. Sewer charges in cities which linked sewer charges with water use ranged from $0.36 per kgal. of water consumption in Tempe to $5.41 per kgal. in Seattle proper.

Some water rates actually changed in between the two data logging periods of the REUWS. Table 4.1 presents the water rates during each logging period for this reason. Water and sewer rate information was provided by each study site as part of the supplementary data collection effort.

Table 4.1 Water and sewer rates during logging periods, 12 study sites

Study site	Log period	Block 1		Block 2		Block 3		Block 4		Block 5		Block 6	Sewer rate
		Rate	Size	Rate	Size	Rate	Size	Rate	Size	Rate	Size	rate	Per kgal.
Boulder*	1	$1.20	1.00	$1.55	2.50	$2.85							$1.27
Boulder*	2	$1.20	1.00	$1.55	2.50	$2.85							$1.27
Denver	1	$1.25	22.00	$1.50									$1.95
Denver	2	$1.25	22.00	$1.50									$1.95
Eugene	1	$0.76											$1.85
Eugene	2	$0.76											$1.85
Seattle	1	$1.88	3.74	$2.95									$5.41
Seattle	2	$1.93											$5.41
Seattle/Bellevue	1	$1.40	14.96	$1.95	22.44	$2.46	74.80	$4.36					NA
Seattle/Bellevue	2	$1.51	14.96	$2.09	18.70	$2.69	56.10	$4.36					NA
Seattle/Highline	1	$2.50											NA
Seattle/Highline	2	$2.58											NA
Seattle/Northshore	1	$1.34	11.22	$2.07	14.96	$2.81	22.44	$3.54					NA
Seattle/Northshore	2	$1.47	5.24	$2.21	11.97	$2.94	22.44	$3.74					NA
San Diego	1	$1.84	14.96	$2.03									NA
San Diego	2	$1.89	14.96	$2.07									NA
Tampa	1	$1.20	9.72	$1.95									$3.72
Tampa	2	$1.20	9.72	$1.95									$3.72
Phoenix	1	$0.00	4.49	$1.59									NA
Phoenix	2	$0.00	4.49	$1.59									NA
Scottsdale	1	$1.22	6.00	$1.89									$1.18
Scottsdale	2	$1.22	7.50	$1.95									$1.27
Tempe	1	$0.79	8.00	$0.84	15.00	$0.93	25.00	$0.99	50.00	$1.09	100.00	$1.13	$0.36
Tempe	2	$0.79	8.00	$0.84	15.00	$0.93	25.00	$0.99	50.00	$1.09	100.00	$1.13	$0.36
Waterloo	1	$1.87											$2.00
Waterloo	2	$1.87											$2.00
Cambridge	1	$1.64											$1.66
Cambridge	2	$1.64											$1.66
Las Virgenes MWD Tier 1	1	$1.58	8.98	$1.94	17.95	$2.83	149.60	$3.85					NA

(continued)

Study site	Log period	Block 1 Rate	Block 1 Size	Block 2 Rate	Block 2 Size	Block 3 Rate	Block 3 Size	Block 4 Rate	Block 4 Size	Block 5 Rate	Block 5 Size	Block 6 rate	Sewer rate Per kgal.
Las Virgenes MWD Tier 1	2	$1.58	8.98	$1.94	17.95	$2.83	149.60	$3.85					NA

Table 4.1 Continued

Study site	Log period	Block 1 Rate	Block 1 Size	Block 2 Rate	Block 2 Size	Block 3 Rate	Block 3 Size	Block 4 Rate	Block 4 Size	Block 5 Rate	Block 5 Size	Block 6 rate	Sewer rate Per kgal.
Las Virgenes MWD Tier 2	1	$1.99	8.98	$2.35	17.95	$3.25	149.60	$4.26					NA
Las Virgenes MWD Tier 2	2	$1.99	8.98	$2.35	17.95	$3.25	149.60	$4.26					NA
Las Virgenes MWD Tier 3	1	$2.47	8.98	$2.83	17.95	$3.73	149.60	$4.75					NA
Las Virgenes MWD Tier 3	2	$2.47	8.98	$2.83	17.95	$3.73	149.60	$4.75					NA
Las Virgenes MWD Tier 4	1	$2.78	8.98	$3.14	17.95	$4.04	149.60	$5.05					NA
Las Virgenes MWD Tier 4	2	$2.78	8.98	$3.14	17.95	$4.04	149.60	$5.05					NA
Las Virgenes MWD Tier 5	1	$3.70	8.98	$4.06	17.95	$4.96	149.60	$5.98					NA
Las Virgenes MWD Tier 5	2	$3.70	8.98	$4.06	17.95	$4.96	149.60	$5.98					NA
Walnut Valley WD	1	$1.93											NA
Walnut Valley WD	2	$1.93											NA
Lompoc	1	$2.18											NA
Lompoc	2	$2.18											NA

Footnotes:

All block rates and sizes have been converted to U.S. dollars and Kgal.

* Boulder's block sizes are multipliers of each household's previous average monthly winter consumption (Dec-Mar).

Utility Sponsored Conservation Programs and Local Conservation Regulations

As part of the supplemental data request, details about recent utility sponsored water conservation programs and local conservation regulations were requested from the contact person at each participating utility. Some of the responses to this query are presented in Table 4.2.

All participating utilities reported implementing some conservation programs since 1990 and all but two utilities reported the existence of state or local regulations governing conservation or low flow plumbing fixtures. Participants like San Diego, Phoenix, La Virgenes MWD, Eugene, Tampa, and the Regional Municipality of Waterloo have all implemented extensive conservation programs involving the distribution of thousands of conservation plumbing fixtures over the past 10 years. Participants like Boulder and Lompoc have more modest conservation programs. Tampa instituted mandatory irrigation restrictions which were in effect during the two data collection periods. Three participants did not complete the section of the questionnaire related to levels of conservation implementation.

INFORMATION FROM BILLING DATA

Periodic billing data were obtained from each participating study site as part of the initial survey group selection process. Billing data from a total of approximately 12,000 accounts (1,000 per study site) were obtained. These data when coupled with the survey response data and the end use data comprised a powerful tool for examining annual and seasonal water use trends. Billing data are also a convenient way to compare and contrast water use between study sites and examine differences in consumption.

Table 4.2 Conservation measures implemented by participating utilities

Study site	**Are there state or local conservation regulations?**	**Has utility implemented conservation since 1990?**	**Conservation measures distributed through utility over the past 10 years**									
			LF shower heads	**Faucet aerators**	**Toilet tank devices**	**ULF toilets**	**Clothes washers**	**Interior water audit**	**Exterior water audit**	**Sprink. shut-off devices**	**L.scape prog.**	**School prog.**
Walnut Valley WD	Yes	Yes	988	1937	1190	890		1622	1622			Annually
Phoenix	Yes	Yes	109679	29335	147533	808						Yes
Las Virgenes MWD	Yes	Yes	20290		9710	4037		3418	3418			Annually
Boulder	No	Yes				Rebate	Rebate			Rebate	Lit.*	Annually
Denver	Yes	Yes	DNR	DNR	DNR	DNR	DNR	DNR	DNR	DNR	DNR	DNR
Eugene	Yes	Yes	28894	47515			999					
Lompoc	Yes	Yes	618	618	618	800					Regs.†	Annually
San Diego	Yes	Yes	439559	50868	440000	86723		14770	4033		Lit.	Annually
Scottsdale	Yes	Yes	DNR	DNR	DNR	DNR	DNR	DNR	DNR	DNR	DNR	DNR
Seattle	No	Yes	DNR	DNR	DNR	DNR	DNR	DNR	DNR	DNR	DNR	DNR
Tampa	Yes	Yes	89720	245000	167500	8117			775	675		Annually
Tempe	Yes	Yes	4000	4000	4000							Yes
Waterloo & Cambridge	Yes	Yes	200000	200000	200000	16500					Demo garden & lit.	Annually

DNR = did not respond to this portion of the data request

* Literature about low-water-use landscaping

† Regulations which restrict landscape installations on new development

Annual Use Patterns

The 12 study sites in the *Residential End Uses of Water Study* represent a diverse collection of single-family water use patterns. Table 4.3 is a statistical summary of the annual water use in each study site. The median annual consumption across all sites was 123 kgal which was lower than the mean which was 146 kgal. The standard deviation was 104 kgal.

The distribution of annual water use over all 12 study sites shown in Figure 4.13 clearly depicts the variability in water use consumption among the 12,055 homes from the 12 study sites. Note that the bins in this graph are unequal. From 0 to 400 kgal per year the bins increase in increments of 20 kgal. From 500 to 1,000 kgal per year the bins increase in increments of 100 kgal. The rise in the 500 kgal bin caused by the shift in bin increments from 20 to 100 kgal. This distribution includes the billed annual water consumption from all 12,055 homes who comprised the REUWS survey sample.

Figure 4.14 is a box plot which shows a comparison of the annual water use for single-family homes in each study site. The "box" portion of the plot shows the 10th, 25th, 50th (median), 75th, and 90th percentiles of annual use. Values above the 90th and below the 10th percentile are plotted as points. The average per-household water use for all 12 study sites was 146 thousand gallons (kgal) per year. Waterloo, Ontario had the lowest average annual use – 69.9 kgal per year and Las Virgenes MWD in California had the highest average annual use – 301 kgal per year.

Table 4.3 Annual water use statistics from initial survey samples (1,000 accounts per study site)

Study Site	Sample Size*	Total annual water use from billing records Mean† (kgal)	Median (kgal)	Std. Dev. (kgal)
Waterloo/Cambridge	1,000	69.9	63	57.0
Seattle	985	80.1	55	48.6
Tampa	1,017	80.6	61	57.6
Lompoc	1,000	103.0	96	51.5
Eugene	983	107.9	98	59.8
Boulder	1,000	134.1	122	74.5
San Diego	1,007	150.1	129	100.2
Denver	1,000	159.9	142	111.1
Phoenix	1,000	172.4	150	113.3
Scottsdale/Tempe	1,001	184.9	152	150.4
Walnut Valley WD	1,000	208.8	182	127.8
Las Virgenes MWD	1,062	301.1	230	289.6
12 Study sites	12,055	146.1	123.3	103.5

Footnotes:

* Samples drawn from the population of single-family accounts in each study site.

† Based on most recent available complete year of historic billing data.

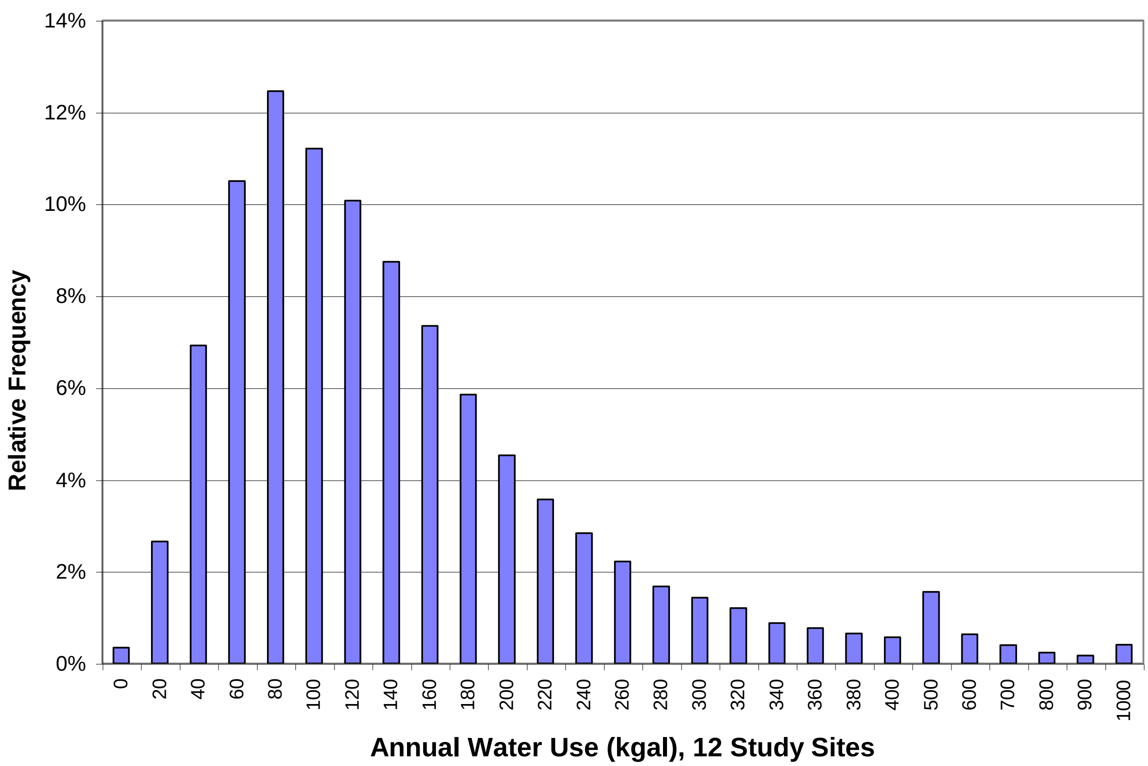

Figure 4.13 Annual water use distribution, 12 REUWS study sites, 12,055 homes

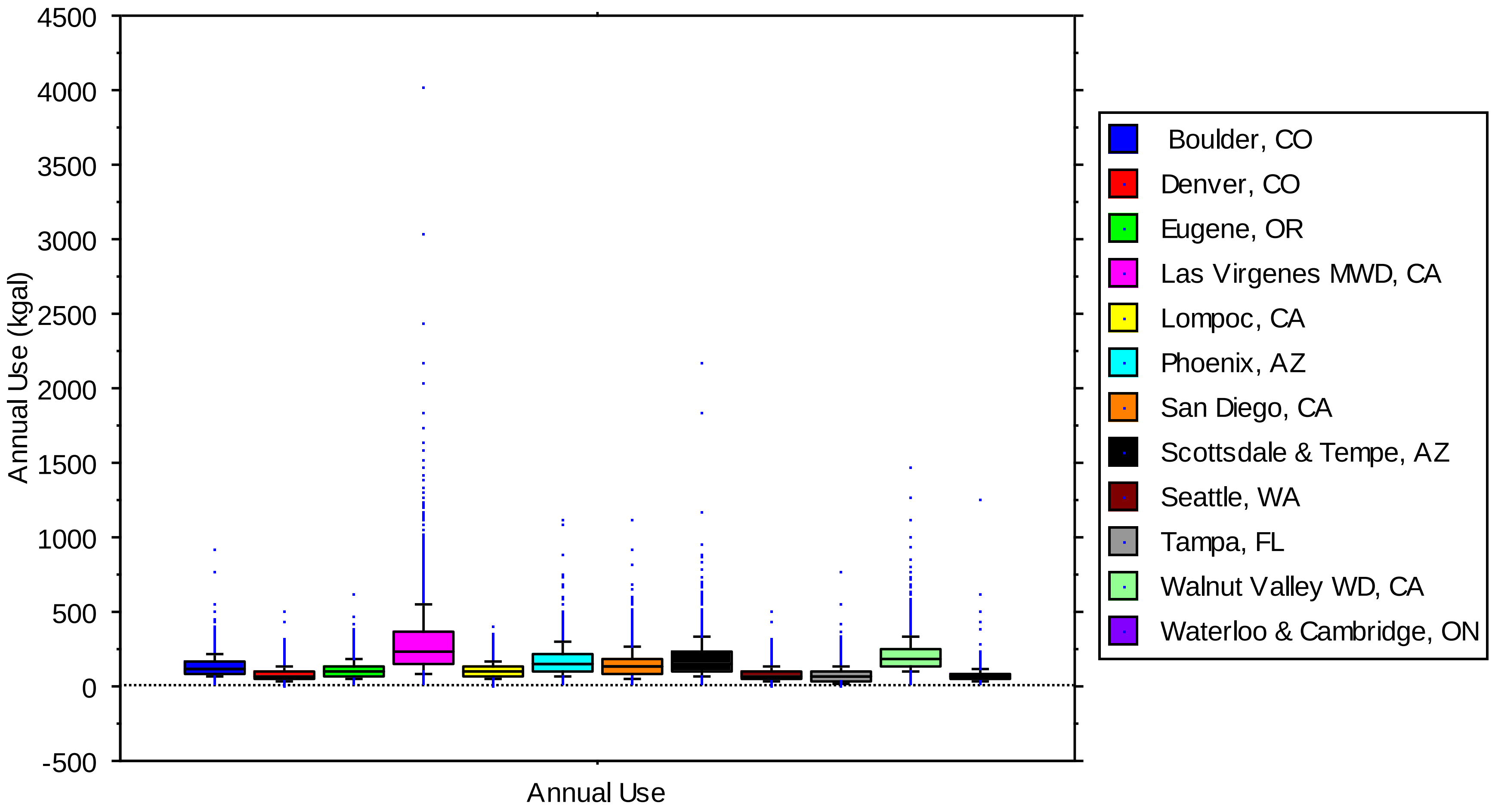

Figure 4.14 Box plot of per household annual water use

Seasonal Water Use

Outdoor water use was much more variable from city to city than indoor use due largely to profound differences in climate among different study sites. Table 4.4 shows the average annual outdoor consumption for the survey sample in each city as well as the total precipitation, average temperature, average outdoor use, and net evapotranspiration (ET) for the year and the month of minimum and maximum average consumption.

Evapotranspiration or Net ET for turf gives a measure amount of water required to maximize growth of turf grass at each site and was calculated using the modified Blaney-Criddle method shown in equation 4.1 (Soil Conservation Service, 1970).

$$U = KF = \sum_{i=m}^{n}(kf) = \sum_{i=m}^{n}(k_t \cdot k_c \cdot f) \quad (4.1)$$

Where U = Consumptive use of turf for the growing season

K = Empirical consumptive-use turf grass co-efficient for the growing season

F = Sum of monthly consumptive-use factors for the growing season.

k = Empirical consumptive-use turf coefficient for a month.

f = Monthly consumptive use factor

m = first month of the growing season for each study site

n = last month of the growing season for each study site

k_t = 0.0173t-0.314 where t = mean air temperature from 36 to 100 degrees F.

k_c = A coefficient reflecting the growth stage of the crop (turf).

Effective rainfall was assumed to be 80 percent of the total rainfall for a given day. If effective rainfall exceeded the calculated ET for any given day then the ET was set to zero.

Annual precipitation varied from 4.02 inches in Phoenix, Scottsdale, and Tempe, Arizona to 54.17 inches in Tampa, Florida. The mean precipitation for all 12 study sites was 24.1 inches. Waterloo had the lowest ET at 15.6 inches while Phoenix, Scottsdale, and Tempe had the highest requirement at 73.4 inches. The mean ET rate for all 12 study sites was 41.8 inches.

The seasonal or outdoor water use component for each study site was calculated from the most recent year of periodic billing data using equation 4.2. This method assumes the minimum month usage contains no outdoor component. This assumption, while frequently relied upon to estimate outdoor use, can lead to inaccurate estimates, particularly in hot, dry climates where irrigation occurs year-round.

$$S = \frac{Q_{annual} - (Q_{\min month} \times 12)}{Q_{annual}} \tag{4.2}$$

Where:

S = percent seasonal use

Q_{annual} = mean annual per household water use

$Q_{min\ month}$ = mean minimum monthly per household water use

Waterloo/Cambridge which had the smallest component of outdoor water use also had the lowest percentage of seasonal use (7 percent) followed by Seattle, San Diego, and Tampa. Boulder and Denver Colorado which both have pronounced climate differences between seasons exhibited the highest seasonal use component. Not surprisingly, February was most frequently the month of minimum household consumption and July was most frequently the month of maximum household use.

The relationship between ET and outdoor water use is well documented (Danielson et. al. 1980; Duble 1997; Mayer 1995; Stadjuhar 1997; Aquacraft, Inc. 1997). ET, however, is only one of many factors which influence irrigation rates in single-family homes. These factors include lot size, irrigation method, landscape type, and landscape quality to name a few. Figure 4.15 shows a graph of ET vs. mean annual outdoor use for the 12 study sites. The outlying point comes from the Las Virgenes MWD district where customers have comparatively large lots and used the most water for irrigation on average.

A linear regression analysis of ET and outdoor water use yielded a coefficient of determination (R^2) of 0.17. This signifies that a straight line model explains only approximately 17% percent of the variability in the relationship between mean outdoor use and ET in the 12 REUWS study sites. This result indicates a fairly weak relationship between annual ET and mean outdoor use calculated using the minimum month approach. The calculation of mean annual outdoor use didn't take into consideration the size of the lots at each household and also includes water consumption for swimming pools and other non-irrigation outdoor purposes which potentially weakened the relationship to ET.

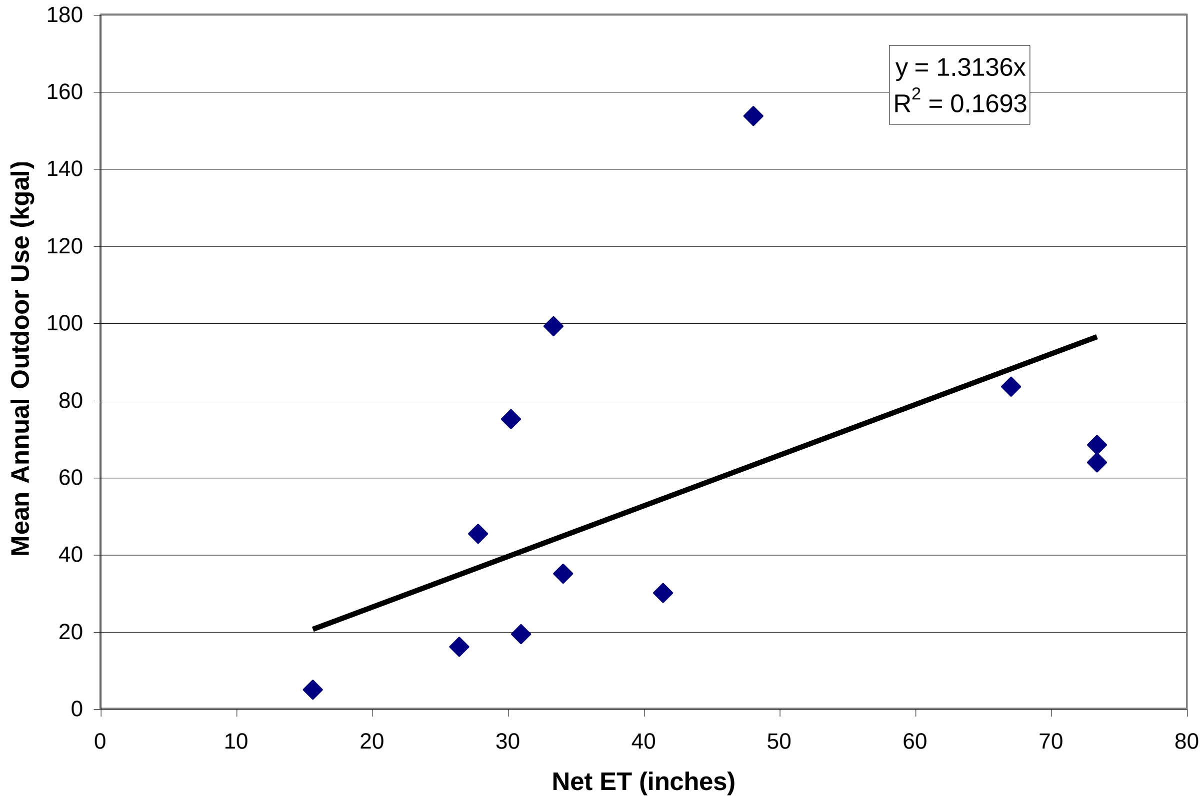

Figure 4.15 Net annual ET for turf vs. mean annual per household outdoor use

Table 4.4 Climate data and outdoor use, surveyed homes, 12 study sites

Study site	**Year of Data**	**Annual Precipitation** (inches)	**Average Annual Temperature** (F°)	**Net ET** (inches)	**Seasonal /outdoor use** (kgal)	**Month of minimum use**	**Month of maximum use**
Boulder	1994	16.84	51.60	30.24	75.1 (56%)	March	July
Denver	1994	10.50	51.94	33.38	99.1 (62%)	February	July
Eugene	1994	46.66	53.65	27.82	45.3 (42%)	February	July
Las Virgenes MWD	1996	17.36	65.02	48.10	153.6 (51%)	February	August
Lompoc	1996	17.97	60.00	34.07	35.0 (34%)	January	July
Phoenix	1996	4.02	72.20	73.40	63.8 (37%)	February	June
San Diego	1995	17.07	63.99	41.44	30.0 (20%)	February	August
Scottsdale & Tempe	1996	4.02	72.20	73.40	68.4 (37%)	January	June
Seattle	1995	37.12	55.34	26.44	16.0 (20%)	December	July
Tampa	1995	54.17	73.04	30.97	19.3 (24%)	October	July
Walnut Valley WD	1996	22.42	66.84	67.06	83.5 (40%)	February	August
Waterloo & Cambridge	1996	41.00	44.47	15.65	4.9 (7%)	November	August

SURVEY RESPONSES

Survey Response Rate

Cooperation of customers receiving surveys was superb in all participating utilities and ranged from a low of 36 percent to a high of 65 percent based on usable responses. The mean weighted average rate was 46 percent and the median was 48 percent. Response rates for each of the participating utilities is shown in Table 4.5. Respondents who obliterated or removed the KEYCODE sticker or failed to return a sufficiently complete survey numbered 212 or 3.7 percent of the respondents. In addition to the gross returns reported in the table, some mailings came back due to an incorrect address. A tally of these was not kept but based on some data reported by the utilities are estimated to have numbered a total of about 100 to 150 across all study sites.

Table 4.5 Survey response rates

Study site	Date posted	Surveys posted	Total returned	Response rate	Returned Unusable	Usable	Net response rate
Boulder	3/96	1,000	494	49.4%	34	459	45.9%
Denver	3/96	1,000	487	48.7%	21	466	46.6%
Eugene	4/96	983	531	54.0%	21	510	51.9%
Seattle	4/96	985	517	52.5%	20	497	50.5%
San Diego	6/96	1,007	501	49.8%	19	482	47.9%
Tampa	7/96	1,017	390	38.3%	24	366	36.0%
Phoenix	2/97	1,000	436	43.6%	10	426	42.6%
Scottsdale	3/97	600	342	57.0%	9	333	55.5%
Tempe	3/97	401	234	58.4%	14	220	54.9%
Cambridge	4/97	600	312	52.0%	6	306	51.0%
Waterloo	4/97	400	262	65.5%	3	259	64.8%
Walnut Valley	5/97	1,000	383	38.3%	9	374	37.4%
Las Virgenes	6/97	1,062	422	39.7%	13	409	38.5%
Lompoc	6/97	1,000	476	47.6%	9	467	46.7%
All sites		12,055	5,787	48.0%	212	5,574	46.2%

A typical response curve (in this case for the City of Tampa) is shown in Figure 4.16. This curve is very typical. It is interesting to note that 90 percent of the responses were received within about 20 days of posting the survey.

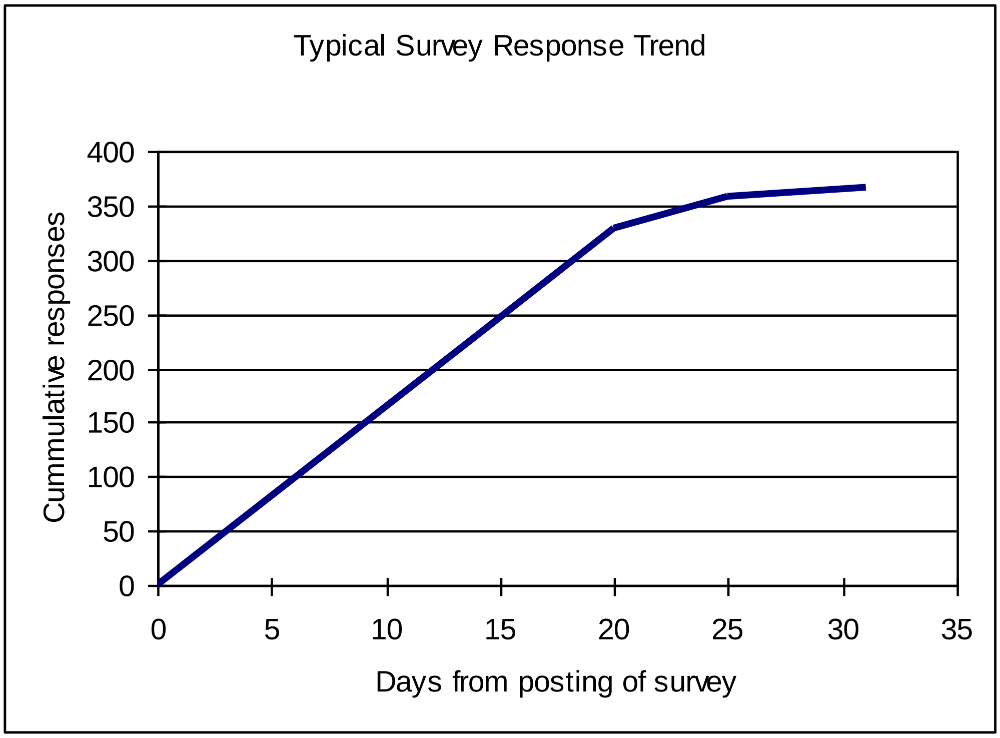

Figure 4.16 Typical survey response curve

The study group comprises a wide variety of single-family detached homes across the U.S. and Canada. Survey responses reveal a diverse population with wide ranging home sizes, household incomes, and attitudes towards conservation. End use study homes included mansions in gated communities and dilapidated one bedroom cabins. The landscapes ranged from lush turf grass and elegant xeriscape to horse pastures, hardscape and untamed weeds. Across all 12 data logged study groups, the average household size was 2.78 people and the median was 2.0 people.

Across all survey respondents from all study sites, the median annual household income was between $50,000 and $60,000. Approximately 77 percent of survey respondents had completed at least some college and nearly 20 percent reported having either a Master's degree or higher. Nearly 92 percent of the surveyed homes were owner occupied and 8 percent were rental units. Of the study homes, 67.8 percent were built before 1980, 23.5 percent were built between 1980 and 1992, and 4.2 percent were built since 1993 when new U.S. national plumbing codes went into effect as part of the Federal Energy Policy Act. A copy of the survey and responses for all 12 study sites is presented in Appendix A.

Comparison of Survey Responses Across Study Sites

This section presents a set of descriptive comparisons of survey responses across the 12 REUWS study sites and 14 participating cities to provide information on the range of conditions affecting water use across the country. The comparisons in this section are based on all survey respondents rather than just those who were included in the data logger portion of the study. Because of this there may be differences between some of these results and those based only on logged homes. (A complete summary of responses to each question on the mail survey for each study city is presented in Appendix A.)

In the opinion of the researchers, the mail survey respondents represent a representative mix of homes taken from the service areas of the participating utilities. The central selection criterion for the mail survey was annual water use of the homes based on historic billing data and every member of the population had an equal possibility to receive a survey. While precautions were taken to insure a wide range of home values were included, no attempt was made to select homes on the basis of other criteria such as age, type of appliances etc, so there is no built in bias towards a specific group of single family residences.

Understanding the nature of the survey respondents is particularly important when using the REUWS results to evaluate the future potential for water conservation in the single-family residential sector. If the survey results showed a high degree of water conservation activities already being practiced by the respondents, then it could be concluded that the water use patterns exhibited by the group are approaching optimum conditions, and little additional water savings are possible. On the other hand, a low degree of efficiency activities in the survey group would suggest significant room for water savings and a high degree of potential for water conservation from retrofits and other efficiency programs.

Categories of Survey Questions

The REUWS mail survey consisted of a 7 page questionnaire which was sent to the initial sample of 1000 homes (Q1000). The survey contained 41 multiple part questions about the physical, demographic and behavioral factors relating to water use in the home. These 41 questions can be divided into six categories which are presented in Table 4.6. Because many of the questions were multi-part, the actual number of responses was greater than 41, but each of the questions dealt with a single topic. Nearly 27 percent of the questions pertained to physical water use fixtures, appliances, and landscape at each home. Another 24 percent pertained to demographics, followed by requests for geographical information, behavior, judgement, and finally a single question on whether or not the house had an alternate water supply available. (Houses using alternate supplies were excluded from the logging sample.) A copy of the survey questionnaire is presented in Appendix A.

Table 4.6 Mail survey question categories

Question Category	**Number of questions**	**Percent of total**	**Description of survey questions**
Hardware	15	26.6%	Presence of fixtures, appliances, pools, sprinklers, etc.
Demographic	10	24.4%	Number of residents, age, income, employment
Behavioral	7	17.1%	Individual water use habits
Geographic	5	12.2%	Lot area, irrigated area, landscape
Judgement	3	7.3%	Opinions about landscape appearance and drought status
Supply	1	2.4%	Are alternate water supplies used?

Hardware Survey Responses

There were a number of survey questions pertaining to the number and types of water using fixtures and appliances in the surveyed homes. The first question on the mail questionnaire requested information about the water using fixtures and hardware found in the home. Table 4.7 shows a comparison of the average number toilets, bath/shower combinations, bathtubs only, and shower stalls only found in homes in each study city. Separate response rates are reported for the two combined study sites: Tempe/Scottsdale, and Waterloo/Cambridge.

The average number of toilets per house for the entire group of survey respondents was 2.27, and ranged from a low of 1.76 in Tampa Fl, to a high of 3.23 in Las Virgenes, CA. There were an average of 1.21 bathtub/shower combinations, 0.22 bathtubs only, and 0.74 showers only per household for the entire group of survey respondents. Count of toilet fixtures and showers and baths can be used as a measure of the relative size of the homes in each study city. Based on this comparison the largest homes (by far) would be found in Las Virgenes MWD followed by Walnut Valley WD, Boulder, and Scottsdale. The smallest homes were found in Tampa, Eugene, and Lompoc.

Clothes washers were the most popular mechanical appliance found in survey respondents homes. About 98 percent reported having some kind of a clothes washer while only 75 percent reported owning a dishwasher. Table 4.8 presents a comparison of the saturation rates of top-loading and front-loading clothes washers, and dishwashers. Top-loading washers were much more prevalent than front-loading machines. While 95.7 percent of the homes reported owning a top-loading washing only 2.3 percent reported owning a front-loading machine. Dishwashers were most common in Las Virgenes MWD (94.4 percent) and Scottsdale (93.4 percent) while the lowest saturation rates of dishwashers was found in Tampa (44.0 percent) and Cambridge, Ontario (50.7 percent). There was significant variability between study sites in the frequency of swimming pools and hot tubs. Figure 4.17 presents the saturation rates for hot tubs and swimming pools as a bar graph. More than 50% of the survey respondents in Scottsdale reported having a swimming pool.

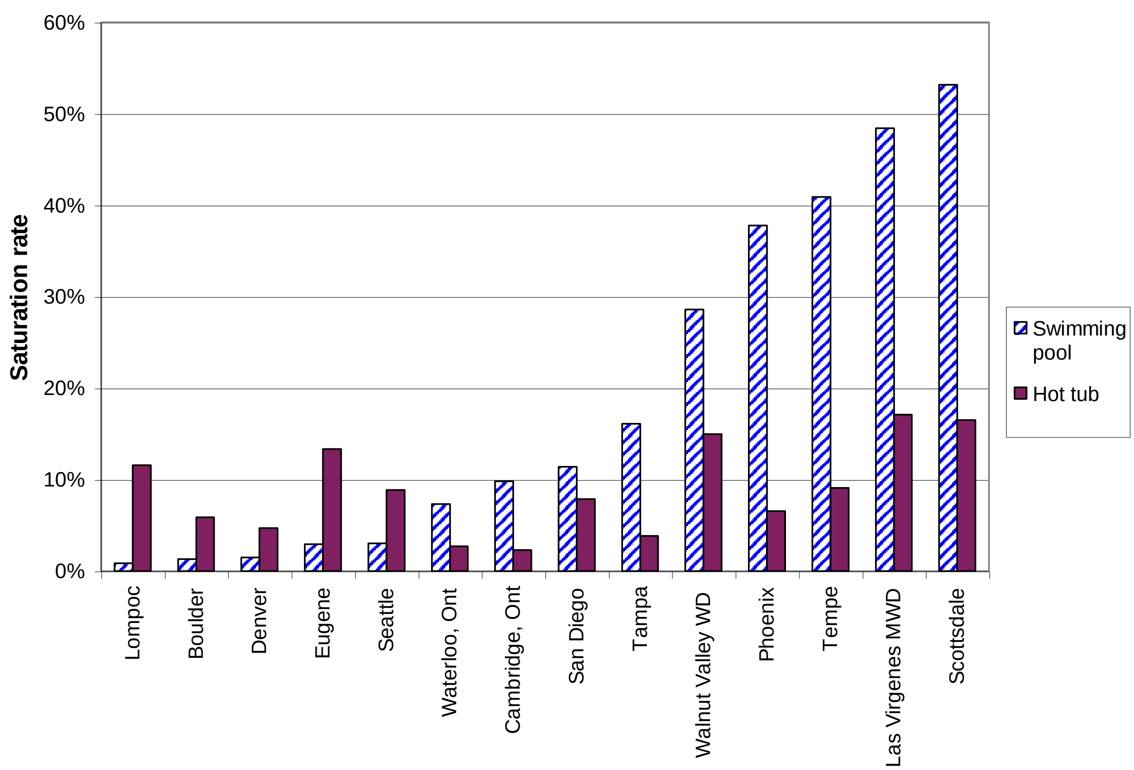

Figure 4.17 Swimming pool and hot tub saturation rates, all study cities

Table 4.7 Mean, median, and mode of the reported number of toilets, baths, and showers from mail survey

Study city	Survey question 1: Count of water using appliances fixtures in each home											
	Q1a Toilets			Q1b Bathtubs w/shower			Q1c Bathtub only			Q1d Shower only		
	Mean	**Median**	**Mode**	**Mean**	**Median**	**Mode**	**Mean**	**Median**	**Mode**	**Mean**	**Median**	**Mode**
Boulder, Colorado	2.48	2	2	1.32	1	1	0.15	0	0	0.73	1	1
Denver, Colorado	2.33	2	2	1.16	1	1	0.20	0	0	0.73	1	1
Eugene, Oregon	1.91	2	2	1.05	1	1	0.16	0	0	0.57	1	1
Seattle, Washington	2.20	2	2	1.21	1	1	0.13	0	0	0.62	1	1
San Diego, California	2.18	2	2	1.15	1	1	0.20	0	0	0.75	1	1
Tampa, Florida	1.76	2	2	1.15	1	1	0.11	0	0	0.46	0	0
Phoenix, Arizona	2.19	2	2	1.30	1	1	0.24	0	0	0.75	1	1
Tempe, Arizona	2.13	2	2	1.18	1	1	0.19	0	0	0.79	1	1
Scottsdale, Arizona	2.45	2	2	1.32	1	1	0.36	0	0	0.90	1	1
Waterloo, Ontario	2.40	2	2	1.07	1	1	0.14	0	0	0.69	1	1
Cambridge, Ontario	2.00	2	2	1.09	1	1	0.15	0	0	0.42	0	0
Walnut Valley WD	2.51	2	2	1.40	1	1	0.30	1	1	0.93	1	1
Las Virgenes Valley WD	3.23	3	3	1.56	1	1	0.48	1	0	1.25	1	1
Lompoc, California	2.04	2	2	1.01	1	1	0.21	0	0	0.77	1	1
14 Study Cities	2.27	2	2	1.21	1	1	0.22	0	0	0.74	0	0

Table 4.8 Saturation of dishwashers and clothes washers from mail survey, all study cities

Study city	Survey question 2: Do you have these water-using appliances or fixtures in your home?								
	Q2b Top loading washer			Q2c Front loading washer			Q2d Dishwasher		
	Yes	**No**	**NR**	**Yes**	**No**	**NR**	**Yes**	**No**	**NR**
Boulder, Colorado	96.3%	3.5%	0.0%	2.4%	87.4%	10.0%	86.3%	12.0%	1.5%
Denver, Colorado	94.6%	4.7%	0.6%	2.6%	86.5%	10.9%	75.1%	22.5%	2.4%
Eugene, Oregon	96.1%	3.1%	0.8%	2.5%	84.3%	13.1%	80.6%	16.9%	2.5%
Seattle, Washington	96.6%	3.0%	0.4%	1.6%	84.5%	13.9%	80.5%	16.9%	2.6%
San Diego, California	94.4%	4.8%	0.8%	2.9%	86.3%	10.8%	67.6%	30.7%	1.7%
Tampa, Florida	89.9%	9.6%	0.5%	2.7%	84.7%	12.6%	44.0%	50.5%	5.5%
Phoenix, Arizona	96.9%	2.8%	0.2%	1.2%	89.0%	9.9%	77.0%	22.3%	0.7%
Tempe, Arizona	95.5%	4.1%	0.5%	0.5%	95.0%	4.5%	85.0%	13.6%	1.4%
Scottsdale, Arizona	98.8%	0.9%	0.3%	1.5%	85.6%	12.9%	93.4%	5.7%	0.9%
Waterloo, Ontario	96.1%	3.1%	0.8%	2.7%	86.9%	10.4%	60.2%	36.7%	3.1%
Cambridge, Ontario	94.1%	4.2%	1.6%	3.9%	84.3%	11.8%	50.7%	44.4%	4.9%
Walnut Valley WD	97.1%	2.4%	0.5%	3.2%	74.3%	22.5%	89.3%	8.3%	2.4%
Las Virgenes Valley WD	96.3%	2.4%	1.2%	2.4%	84.8%	12.7%	94.4%	4.6%	1.0%
Lompoc, California	96.8%	1.9%	1.3%	2.1%	84.2%	13.7%	70.2%	25.7%	4.1%
14 Study Cities	95.7%	3.6%	0.7%	2.3%	85.6%	12.1%	75.3%	22.2%	2.5%

Swimming pools were also common in Las Virgenes MWD, Tempe, and Walnut Valley WD. Lompoc, Boulder, and Denver had the least number of swimming pools among the 14 cities. Hot tubs were most common in Lompoc, Eugene, Walnut Valley WD, Las Virgenes MWD, and Scottsdale and were least common in Cambridge and Waterloo and Tampa.

Other important water related devices which were reported in the survey were evaporative coolers (also known as "swamp" coolers), and home water treatment systems or water softeners. Table 4.9 presents a comparison of the saturation rates of these two devices. Evaporative coolers were most common in the study sites in Arizona (Phoenix, Tempe, and Scottsdale) which have hot and dry climates, and in Denver and Boulder, Colorado which also have a dry climate. Swamp coolers are most effective in regions without much humidity so it is not surprising to find that they are most popular in Arizona and Colorado. Evaporative coolers were almost non-existent in the humid regions such as Seattle, Eugene, Waterloo and Cambridge, Tampa, and Lompoc.

Table 4.9 Saturation of evaporative coolers and water treatment systems, all study cities

Study city	**Survey question 2: Do you have these water-using appliances or fixtures in your home?**					
	Q2g Evaporative cooler			**Q2i Water treatment system**		
	Yes	**No**	**NR**	**Yes**	**No**	**NR**
Boulder, Colorado	9.4%	82.8%	7.6%	8.3%	84.1%	7.4%
Denver, Colorado	18.7%	75.3%	6.0%	7.1%	85.2%	7.7%
Eugene, Oregon	0.2%	89.6%	10.2%	2.2%	87.6%	10.2%
Seattle, Washington	0.0%	89.9%	10.1%	5.6%	85.7%	8.7%
San Diego, California	1.2%	91.7%	7.1%	25.3%	69.3%	5.4%
Tampa, Florida	0.3%	90.7%	9.0%	13.7%	77.9%	8.5%
Phoenix, Arizona	37.8%	58.9%	3.3%	21.4%	75.6%	3.1%
Tempe, Arizona	37.7%	59.5%	2.7%	25.0%	73.2%	1.8%
Scottsdale, Arizona	17.4%	75.4%	7.2%	36.6%	59.8%	3.6%
Waterloo, Ontario	0.4%	92.7%	6.9%	73.0%	23.2%	3.9%
Cambridge, Ontario	0.7%	90.8%	8.5%	55.9%	39.2%	4.9%
Walnut Valley WD	1.6%	81.6%	16.8%	29.4%	58.0%	12.6%
Las Virgenes Valley WD	2.4%	89.7%	7.8%	26.2%	67.7%	6.1%
Lompoc, California	0.2%	89.9%	9.9%	22.3%	70.9%	6.9%
14 Study Cities	9.1%	82.8%	8.1%	25.1%	68.4%	6.5%

Water treatment systems were reported in 25.1 percent of the homes who responded to the mail survey. These devices were most frequent in Waterloo and Cambridge, Ontario and were also found in about a quarter or more of the homes in Walnut Valley, Las Virgenes, Tempe, Scottsdale, and San Diego. Water treatment systems are generally more common in regions with "hard" water or which have more minerals in the water. Treatment systems were least common in Eugene, Seattle, Denver and Boulder.

Demographic Survey Responses

One of the most fundamental demographic variables is the number of people per household. In the REUWS mail survey, respondents were asked to report the number of adults, teens, and children living in the house during the summer months and during the winter months. Summarized responses to these questions are presented in Table 4.10. The average number of residents across all survey respondents was 2.71. Scottsdale had the least number of people, and Walnut Valley had the most. There was some variation evident in the number or residents reported in the summer and in the winter, but the total average number of residents during each period was the same. The biggest difference was in Scottsdale where there were an average of 0.17 more people per household during the winter.

One of the demographic questions on the mail survey which resulted in a difference in responses rates between cities concerned the highest level of education achieved by survey respondents. Of the survey respondents, 90% had completed at least some college and 46% had advanced degrees. A comparison of educational levels across study sites is shown in Figure 4.18. This figure shows the percent of survey respondents with education through high school, undergraduate/college, and graduate degrees. The list is ranked in order of respondents with college degrees. Boulder had the highest combined percent of respondents with college and graduate (Master's or Doctorate) degrees. Las Virgenes had the second highest combined total. Cambridge had the lowest number of combined advanced degrees. Denver, Eugene, and San Diego all had close balance in the number of high school, college, and graduate degrees reported.

Table 4.10 Mean number of residents in winter and summer, all study cities

Study city	**Survey question 30: Mean number of winter residents**				**Survey question 31: Mean number of summer residents**			
	Adults (18 years +)	**Teenagers (13-17 years)**	**Children (under 13 years)**	**Total**	**Adults (18 years +)**	**Teenagers (13-17 years)**	**Children (under 13 years)**	**Total**
Boulder, Colorado	2.00	0.17	0.40	2.57	2.03	0.18	0.39	2.60
Denver, Colorado	1.92	0.21	0.47	2.60	1.95	0.22	0.48	2.65
Eugene, Oregon	1.95	0.23	0.39	2.57	1.97	0.23	0.39	2.59
Seattle, Washington	2.04	0.16	0.36	2.56	2.07	0.18	0.37	2.62
San Diego, California	2.10	0.17	0.34	2.61	2.09	0.17	0.34	2.60
Tampa, Florida	2.06	0.20	0.34	2.60	2.06	0.20	0.34	2.60
Phoenix, Arizona	2.08	0.22	0.48	2.78	2.05	0.23	0.46	2.74
Tempe, Arizona	2.10	0.15	0.50	2.75	2.07	0.17	0.52	2.76
Scottsdale, Arizona	2.02	0.11	0.29	2.42	1.83	0.13	0.29	2.25
Waterloo, Ontario	2.22	0.22	0.48	2.92	2.15	0.20	0.47	2.82
Cambridge, Ontario	2.14	0.31	0.52	2.97	2.17	0.30	0.52	2.99
Walnut Valley WD	2.42	0.26	0.54	3.22	2.44	0.27	0.55	3.26
Las Virgenes Valley WD	2.17	0.21	0.45	2.83	2.20	0.22	0.46	2.88
Lompoc, California	1.95	0.21	0.46	2.62	1.91	0.20	0.45	2.56
14 Study Cities	2.08	0.20	0.43	2.71	2.07	0.21	0.43	2.71

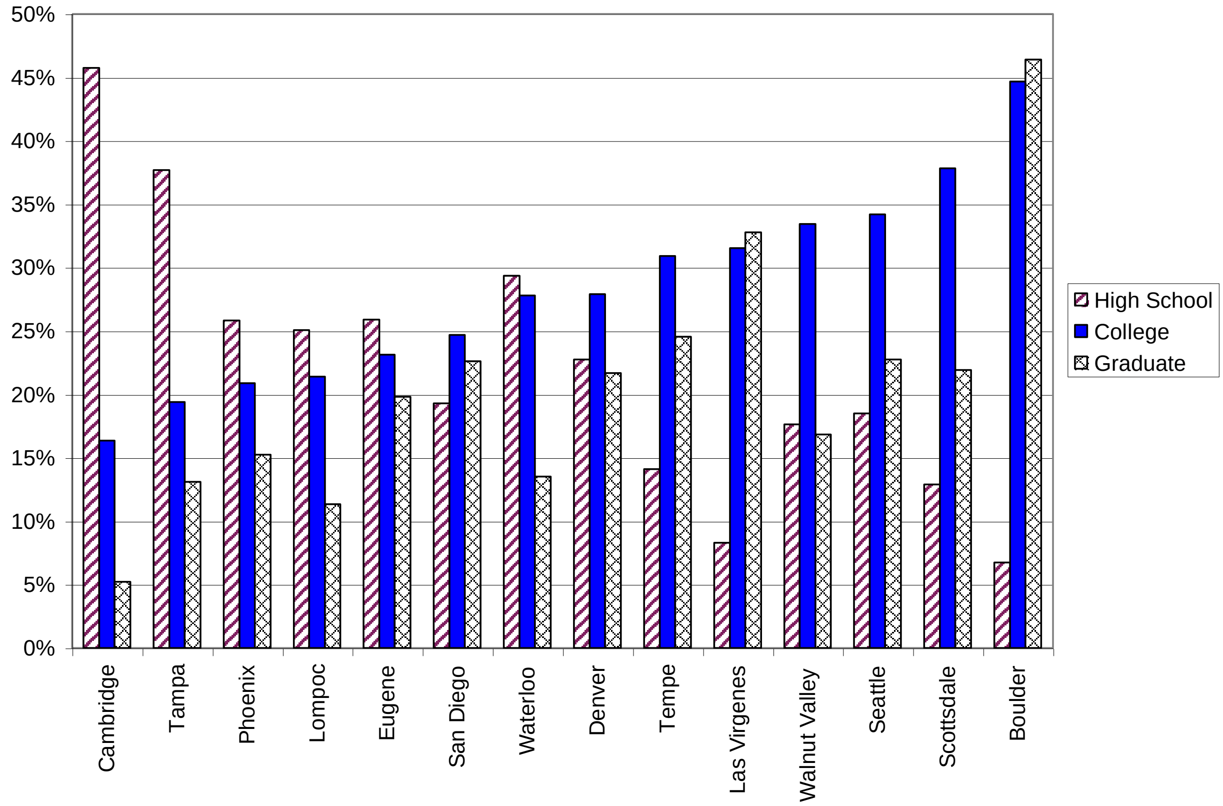

Figure 4.18 Highest level of educational attainment, all study cities

Another demographic question from the mail survey which distinguishes different study cities is the reported household income of survey respondents. Figure 4.19 shows a comparison of the household income chosen from 20 brackets for the 14 study cities. For Figure 4.19, these brackets have been combined into three groups: less-than $50,000 per year, between $50,000 and $150,000 per year, and more than $150,000 per year. The data are arranged in order of the percent of homes in the middle income bracket ($50,000 - $150,000). Las Virgenes had the highest percent of survey respondents in the high income category and the smallest number in the low income category. Walnut Valley had the highest percentage in the middle income category while Tampa and Eugene had the highest number of respondents in the lower income category (<$50,000).

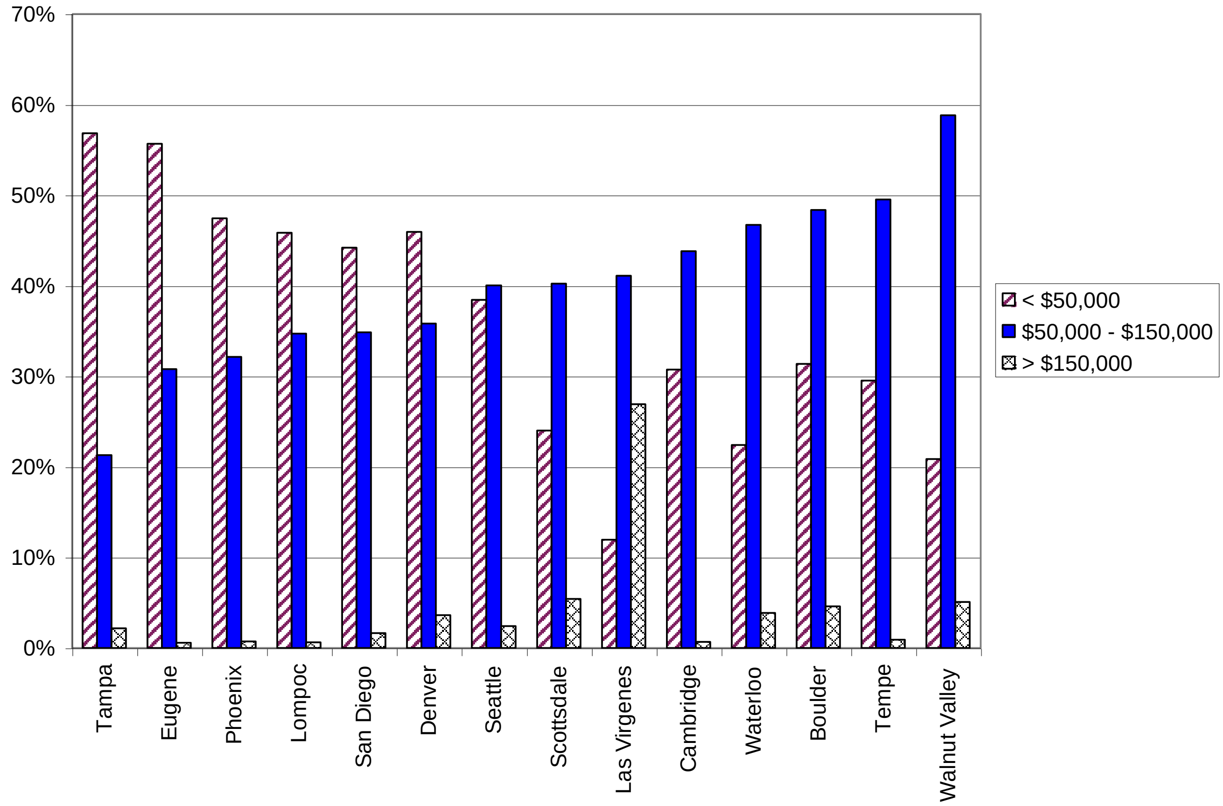

Figure 4.19 Combined household income, all study cities

Behavioral Survey Responses

Seven mail survey questions related to the water use behavior of the respondents. Four of the questions requested information about outdoor water use habits. Over 30 percent of the survey respondents reported irrigating outdoors during the winter months at least 2 times per month. During the summer months, most survey respondents indicated that they irrigated 3 times per week Only six percent of the homes reported irrigating between zero and a few times per month during the summer. Figure 4.20 shows a comparison of the percent of homes from each city which reported irrigating 3 times per week or more during the summer. The three eastern most cities – Tampa, Waterloo, and Cambridge – had the fewest number of homes irrigating this often while cities in California, Arizona, and Colorado had the highest number of homes irrigating at this frequency. Tampa was under outdoor watering restrictions during the study period.

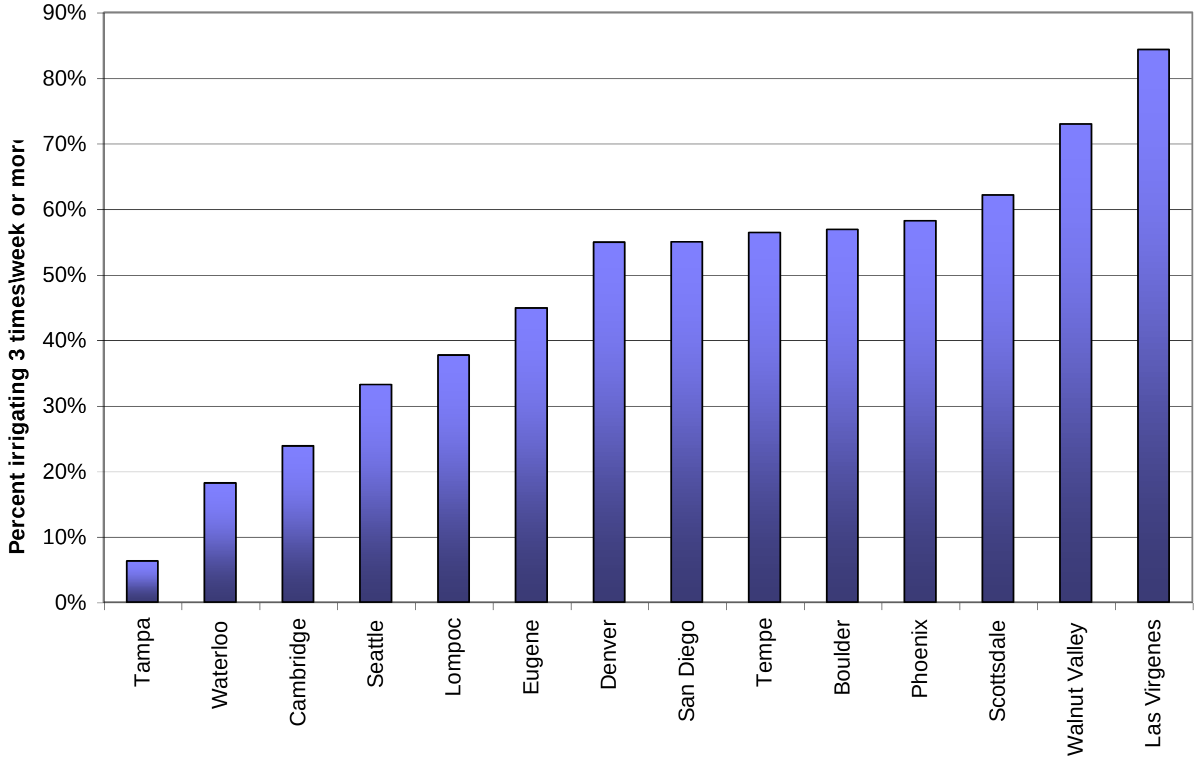

Figure 4.20 Percent of homes irrigating 3 times per week or more, all study cities

Respondents were also asked to rank the importance which they ascribe to water conservation on a scale of 1 to 5 with 5 being the highest level of importance. Figure 4.21 shows the percent of respondents in each study city who gave a high rank the importance of conservation. This result shows that conservation is considered important in at least 70% of all those responding to the question. However, within this group there appears to be three levels of perceived importance. Boulder, Denver and Eugene rank water conservation slightly lower in importance than the average. At the other end, Tampa and San Diego give a slightly higher ranking to the importance of water conservation. However, the difference between percent of respondents who ranked the importance of conservation a 4 or 5 ranged only from 70 percent to just over 90 percent, indicating that a strong majority of all respondents value water conservation.

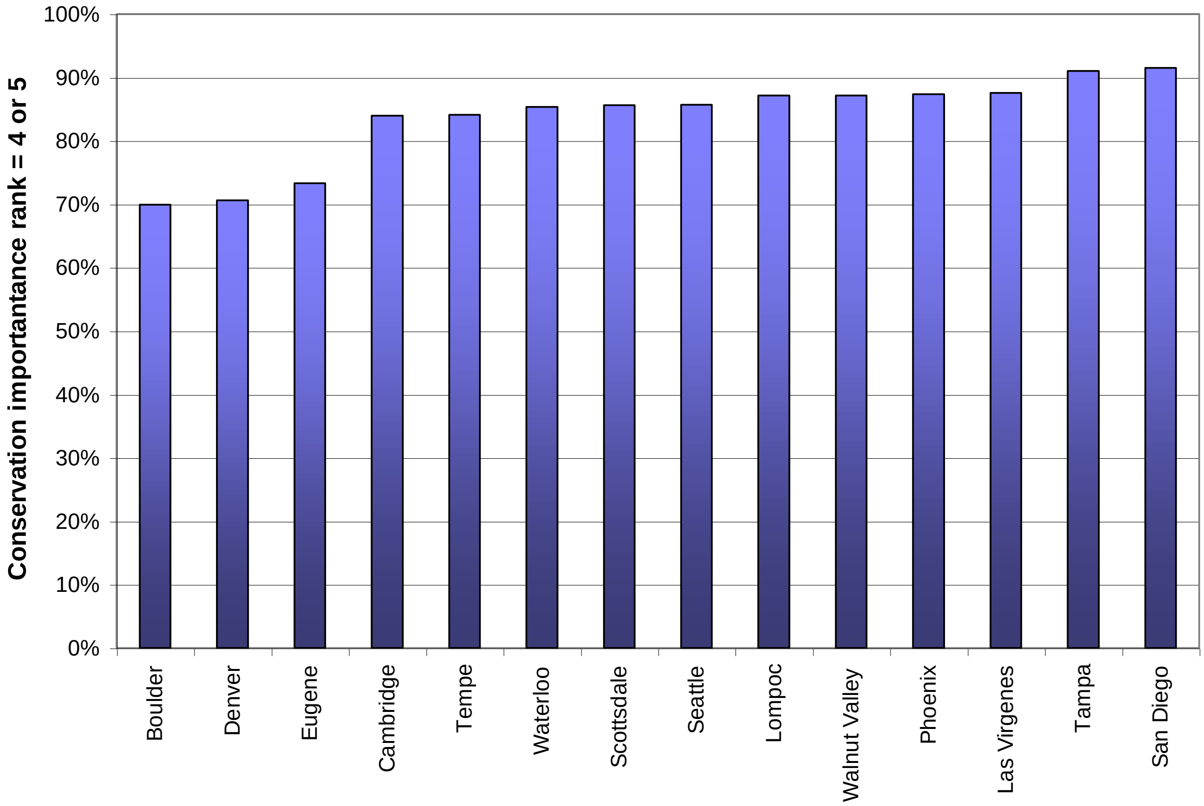

Figure 4.21 Conservation importance, all study cities

Judgement Survey Responses

The judgment questions on the mail survey requested opinions from the respondents about the quality and nature of their landscape and whether or not the region was experiencing drought. On a scale of 1-5, with 5 being the best, most people (34 percent) rated the quality of their landscape a 4, and more people gave their landscape the highest grade of 5 (17 percent) than the lowest grade of 1 (4 percent).

The perception that the region is experiencing some level of drought should be an important factor in explaining water use. Figure 4.22 shows the distribution of the perception of drought in the 14 surveyed cities. The graph compares the percent of respondents who felt there was no drought to those who felt there was some level (mild, moderate or severe) of drought. It is interesting to note that Tampa, Florida, the only city with outdoor water use restrictions in place during the study, had the highest level of drought perception. Eugene, Oregon which experienced very high rainfall and near flood stage river levels during the portions of the study had the lowest perception of drought.

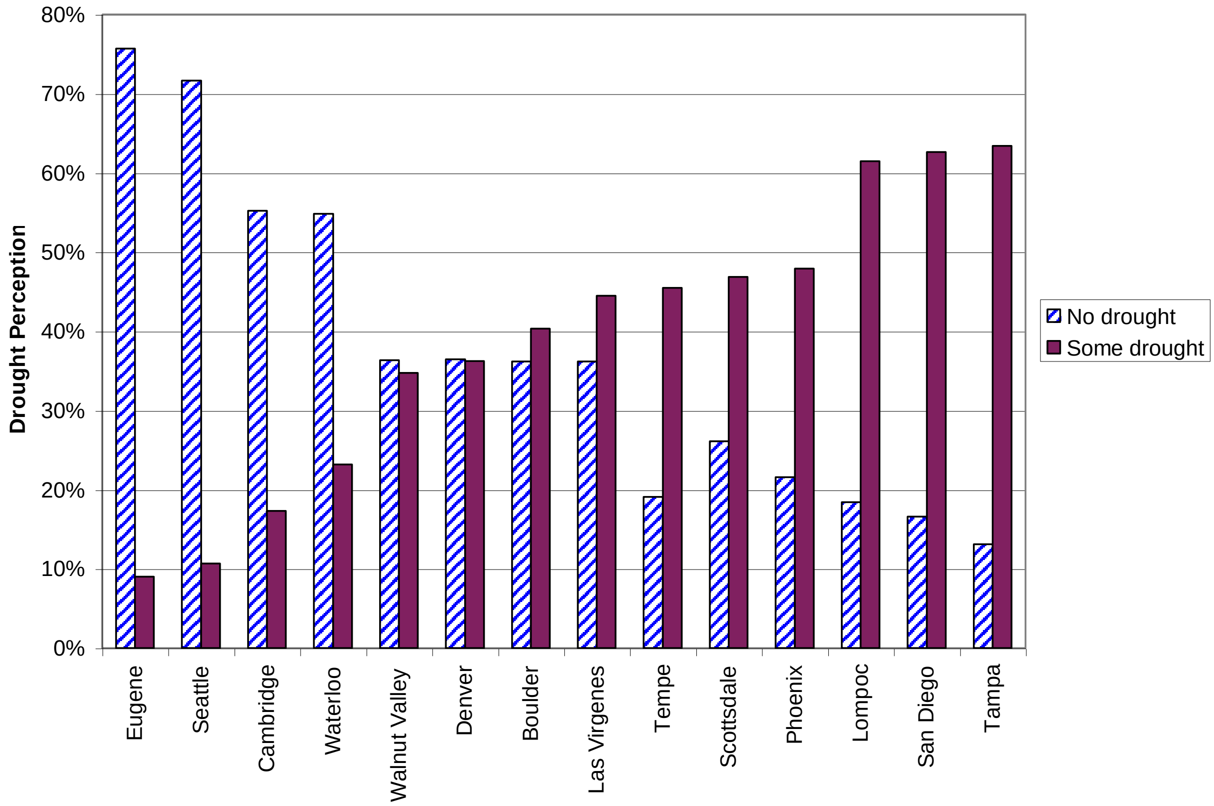

Figure 4.22 Perception of drought, all study cities

CHAPTER 5
END USE DATA ANALYSIS

The disaggregated end use data collected for the *Residential End Uses of Water Study* provide a wealth of information about how, how much, where, and when water is used in the single-family setting. Embedded in these data are unique details of human behavior ranging from the mundane (how many loads of laundry does a family do per week) to the more personal (how long do people spend in the shower). It is anticipated that the database of disaggregated end uses developed for this study will be a resource for researchers and planners to explore for years to come, particularly if it is maintained and updated through additional research projects.

This chapter presents some of the fundamental findings from the end use data collection and analysis portion of the study. These findings include the mean gallons per capita per day used for different fixtures, the frequency and intensity of use of various fixtures, and the variability of water use in single-family homes. Analyses are presented for each of the participating cities individually and for the pooled sample of 1,188 households. Keep in mind that this study did not set out to estimate national "averages" of residential water use, and this sample was not selected to be representative of the entire United States and Canada. The pooled results are presented for summary and comparative purposes alone.

No analysis and presentation of these data could hope to answer all of the questions which readers may have. No doubt there will be specific questions or analyses which are desired, but have not been presented here. The database assembled for this study is available and details about the database and how to obtain a copy are presented in Appendix D. Part of the purpose of this report is to detail the structure and scope of the database and to explain how it can be used to assemble sub-sets of data which can be used to answer specific questions and perform specific analysis.

DAILY HOUSEHOLD USE

The following sections provide summaries of daily household use without any attempt to normalize the results on the basis of number of occupants or other variables from the surveys.

From the standpoint of the water provider, they represent an important way of looking at demands, since the basic unit of water service is the household account.

Total Daily Use

A total of 28,015 complete days of end use data were recorded from the 1,188 study homes in the REUWS. The average daily use was calculated for each of the 1,188 study homes and then plotted as a scatter diagram in Figure 5.1. These data are plotted in order of the Keycode, which represents the order in which sites were sampled starting with Boulder, Colorado and ending with Lompoc, California. Figure 5.1 shows that the vast majority of homes used less than 1000 gallons per day on average. The mean was 409 gpd with a standard deviation of 486 gpd. The median daily use was 311 gpd. Two of the study homes used an average of more than 9000 gpd over the two logging periods because of enormous irrigation demands, and including these two outliers expanded the y-scales, making it hard to see the detail for the majority of users, of whom 95 percent used less than 1000 gpd and 75 percent used less than 500 gpd.

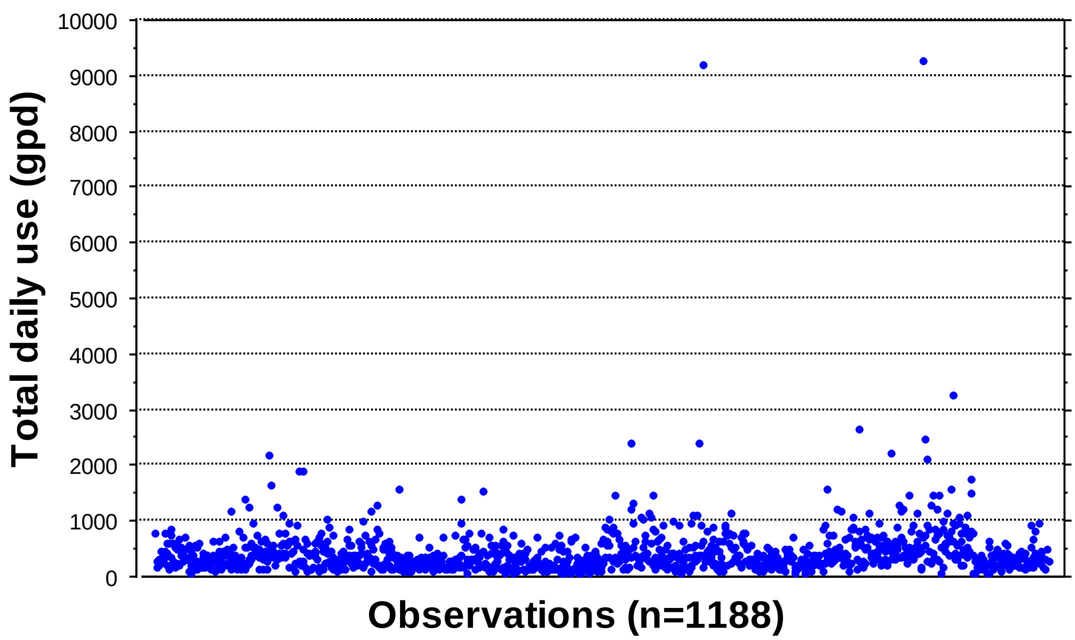

Figure 5.1 Scatter diagram of average daily water use, 1,188 homes

Figure 5.2 is a box diagram of the same average daily use data. This figure shows the 10, 25, 50 (median), 75, and 90 percentiles of average daily use. For emphasis, the area between the 25th and 75th percentiles are shaded. All data above the 90th and below the 10th percentile are shown as points, but to avoid the loss of detail, the two outliers are not shown in this figure.

Daily Indoor Use

The same set of analyses were performed on the logged average daily indoor water use from the 1,188 home study group. Indoor use excludes water uses like irrigation and swimming pool refilling, but does include all leakage. There was far less variability in indoor use than outdoor use. The mean daily indoor use was 173 gpd with a standard deviation of 94 gpd. The median was 157 gpd. Figure 5.3 provides a scatter diagram of the average indoor use for the 1,188 study homes. As for figure 5.1 these data were plotted in order of the Keycode.

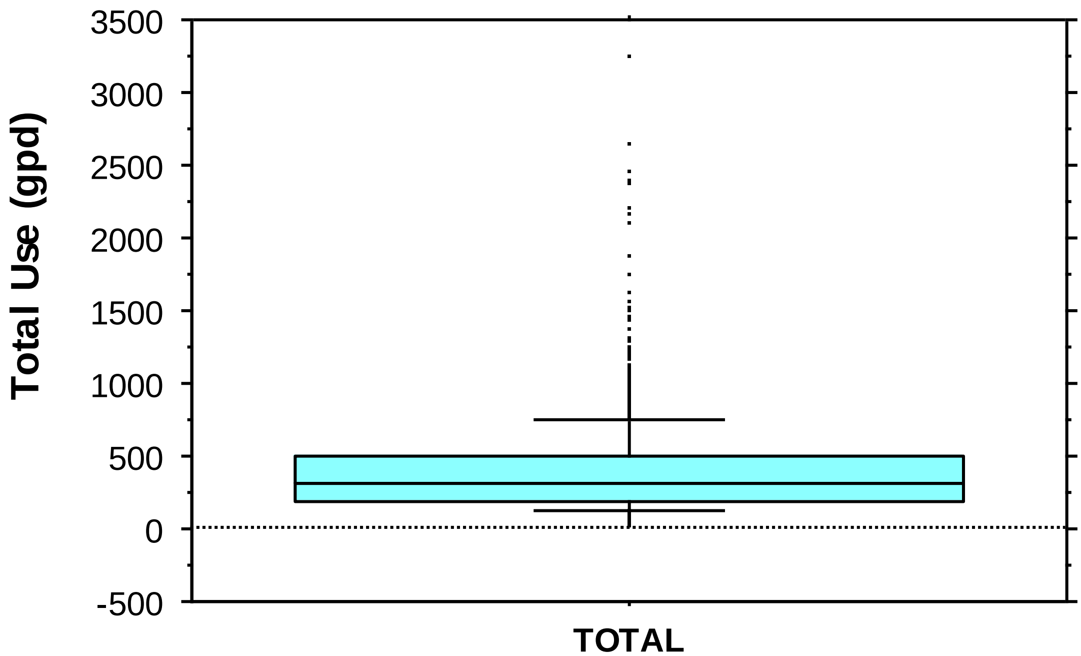

Figure 5.2 Box diagram of average daily water use, 1,188 study homes

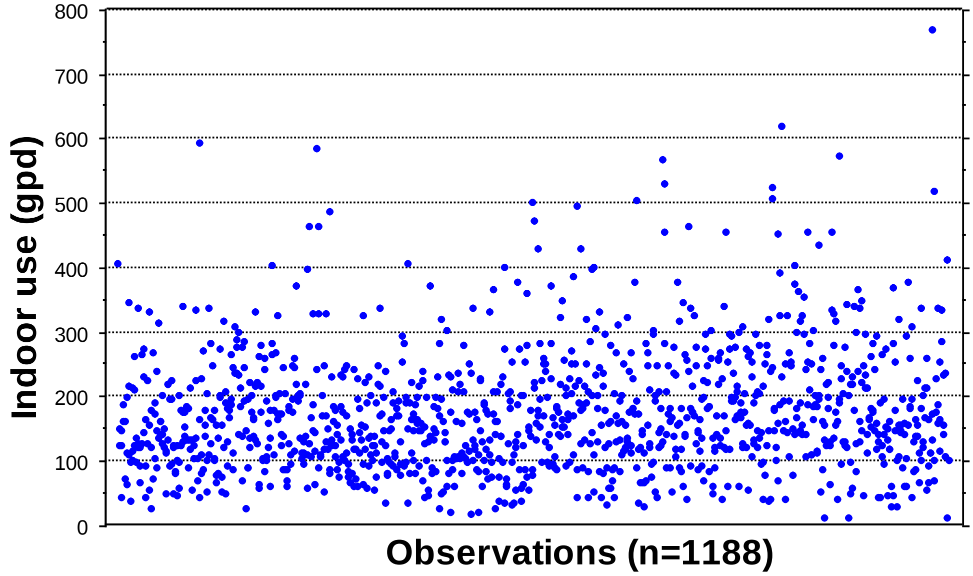

Figure 5.3 Scatter diagram of average daily indoor water use, 1,188 study homes

Figure 5.4 is a box diagram, using the same plotting conventions as in Figure 5.2, but showing the average daily *indoor* water use from the study homes. It is noteworthy that ninety percent of the daily indoor use was below 300 gpd on average. The highest observed average daily indoor use was 769 gpd. The median use is approximately 150 gpd, which is equivalent to 54,750 gallons per year or 4560 gallons per month for each household.

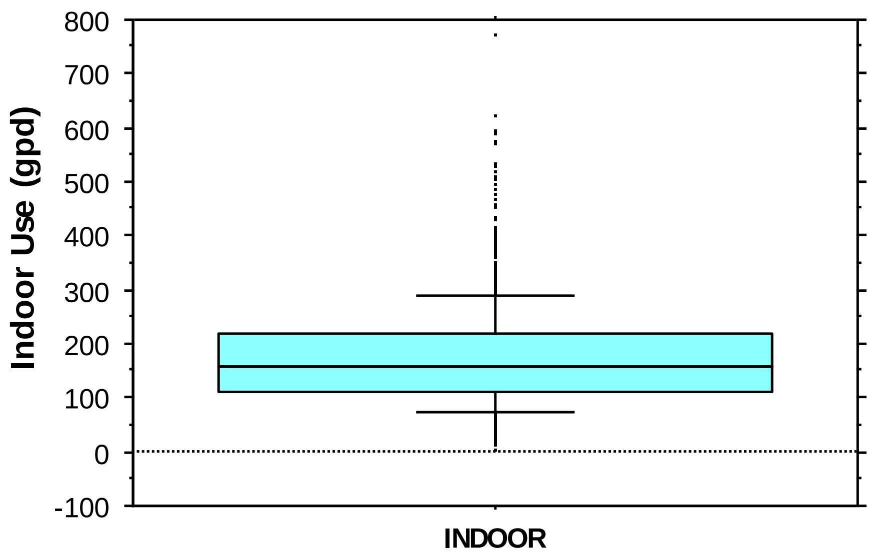

Figure 5.4 Box diagram of average daily indoor water use, 1,188 study homes

INDOOR PER CAPITA USE

Per capita water use was calculated for each individual study home using the daily water use obtained from the flow trace analysis results and the reported number of residents during the summer and winter from the mail survey. Averages of per capita use were made from the daily per capita use calculated for each household. Toilet flushing was the largest component of indoor per capita water use among all data logged homes in the REUWS study. Toilets accounted for 26.7 percent of indoor water use. Figure 5.5 shows the percentage breakdown of all indoor water uses collected from the logged homes in the REUWS project. Clothes washers were the second largest component of indoor use at 21.7 percent followed by showers and baths at 18.5 percent, faucets at 15.7 percent, and leaks at 13.7 percent. This figure is based on the per capita water use calculated for each indoor end use category from the 1,188 data logged homes in all 12 study sites.

For comparison, the 1984 HUD study found comparable indoor water use rates in homes which had similar mean per capita per day consumption. The HUD study found toilets to be 28 percent, clothes washers 22 percent, showers and baths 28 percent, faucets 13 percent, and leaks 7 percent of indoor water use in homes which used an average of 68.4 gpcd for indoor purposes.

Leaks are included in as an indoor use category in the REUWS although it is not known precisely where the leakage occurred. During analysis it was not possible to accurately determine if estimated leakage occurred inside a home or not. However, in homes with particularly high leakage rates it appeared that faulty toilet flapper valves were frequently the cause. Leaks are discussed in more detail later in this chapter.

Mean Per Capita Daily Water Use

In the REUWS, the average total daily per capita usage was found to be 172 gpcd with 69.3 gpcd coming from indoor uses, 101 gpcd coming from outdoor uses, and 1.7 gpcd from unknown or unidentified indoor or outdoor use. Figure 5.2 shows the average gallons per capita per day measured during the REUWS. Outdoor use was calculated using a combination of flow trace data collected and analyzed during the study and historic billing data provided by each study site. Billing data were used to calculate outdoor use because the data logging equipment was not in the field long enough to accurately measure average outdoor use over an entire irrigation season. The measured indoor use for each participating house was pro rated to an annual amount which was subtracted from their total annual consumption to arrive at the annual outdoor use figure. As per capita per day usage is not a particularly useful way to study outdoor water consumption, outdoor use is more closely examined in subsequent sections of this report.

The “unknown” category includes water use that could not be assigned any specific use category during the flow trace analysis process. Because of this uncertainty this use category has not been included in either indoor or outdoor per capita per day totals, but is added into the total per capita per day usage.

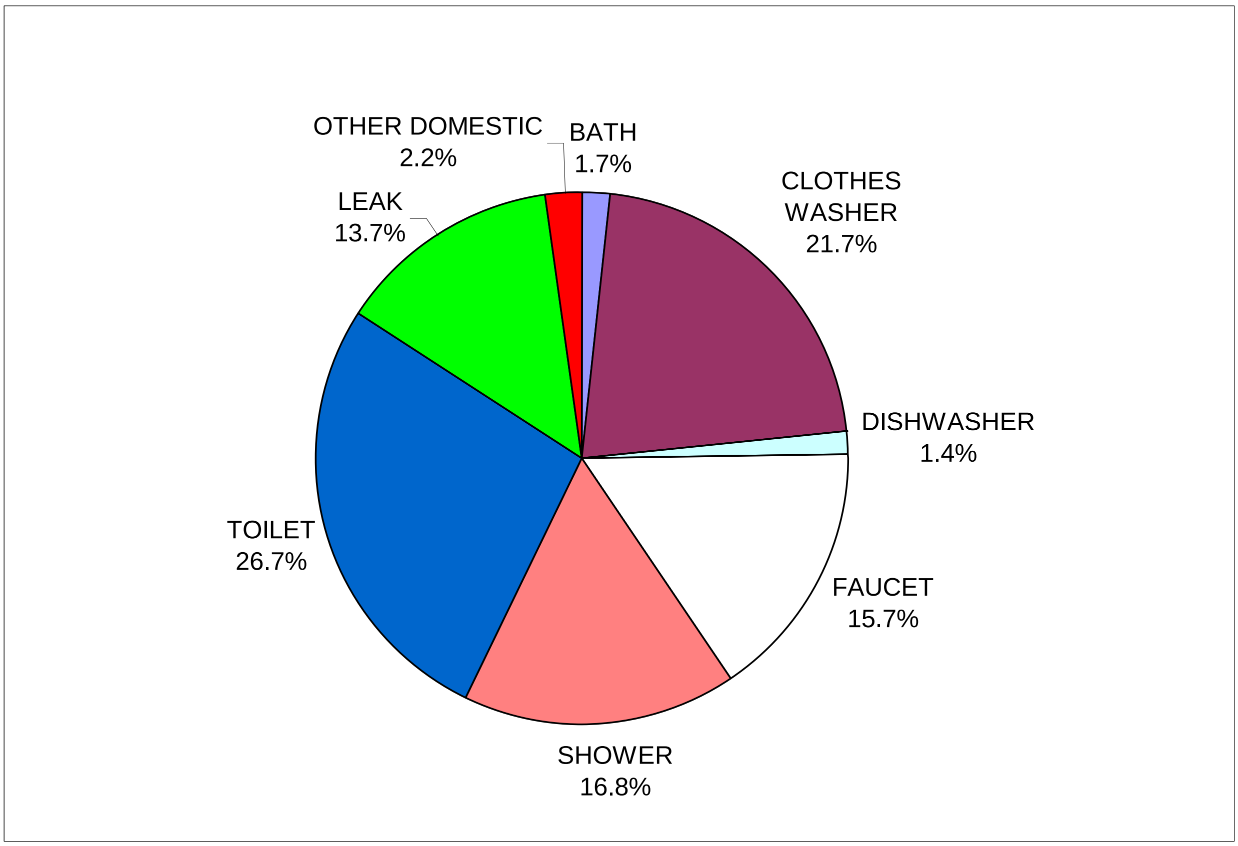

Figure 5.5 Indoor per capita water use percentage including leakage, 1,188 study homes

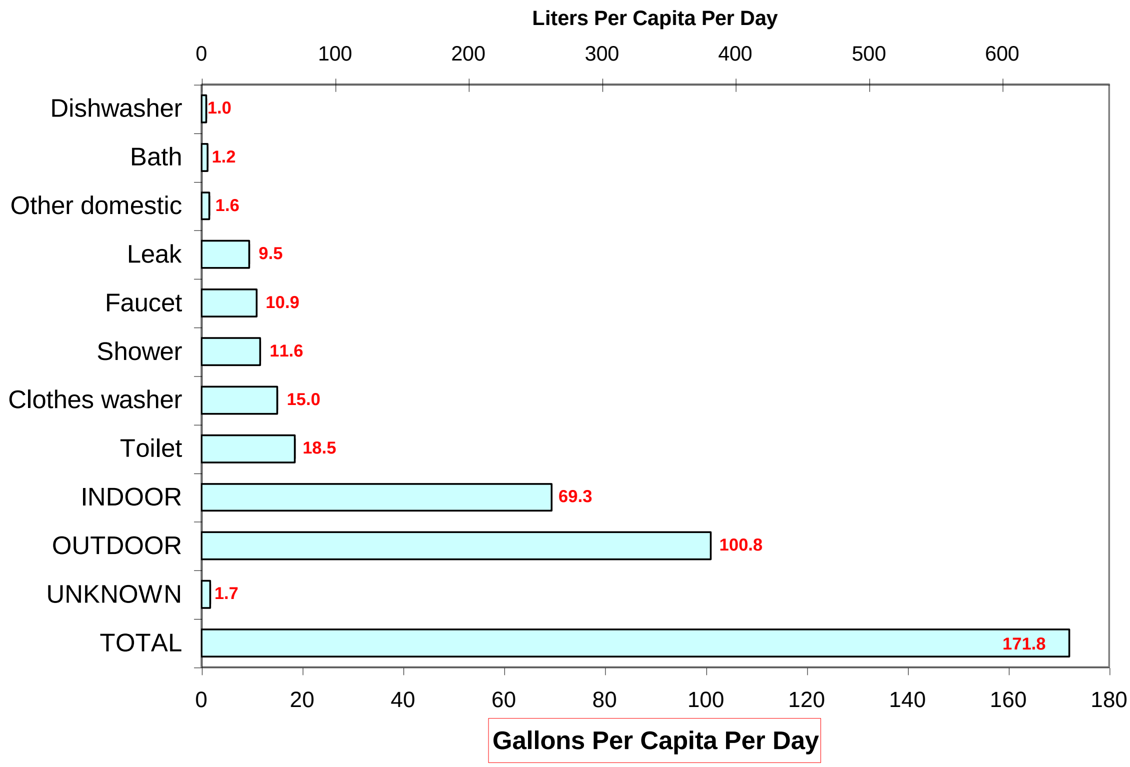

Figure 5.6 Average per capita per day usage (gpcd), 1,188 data logged homes

The distribution of mean household daily per capita indoor water use is shown in Figure 5.7. Based on the mean indoor gpcd calculated for each of the 1,188 data logged homes, the distribution is focused around homes which used between 40 and 90 gpcd for indoor purposes. As shown in Figure 5.6, the mean daily per capita indoor water use for the sample was 69.3 gallons. As evidenced by the variability shown in the distribution in Figure 5.7, the standard deviation of mean daily per capital indoor use was 42.6 gpcd. The median indoor use was 60.1 gpcd.

As would be expected, indoor water use increase as household size increase, but use per person decreases. This result is shown in Figure 5.8. Per capita use in households with only one occupant is 97.4 gpcd, but this amount decreases to 44.7 gpcd in households with eight occupants. There appear to be efficiencies associated with an increase in the number of occupants in a household which could be related to the age of the occupants and/or the amount of water needed for cleaning, washing clothes and dishes, and general maintenance.

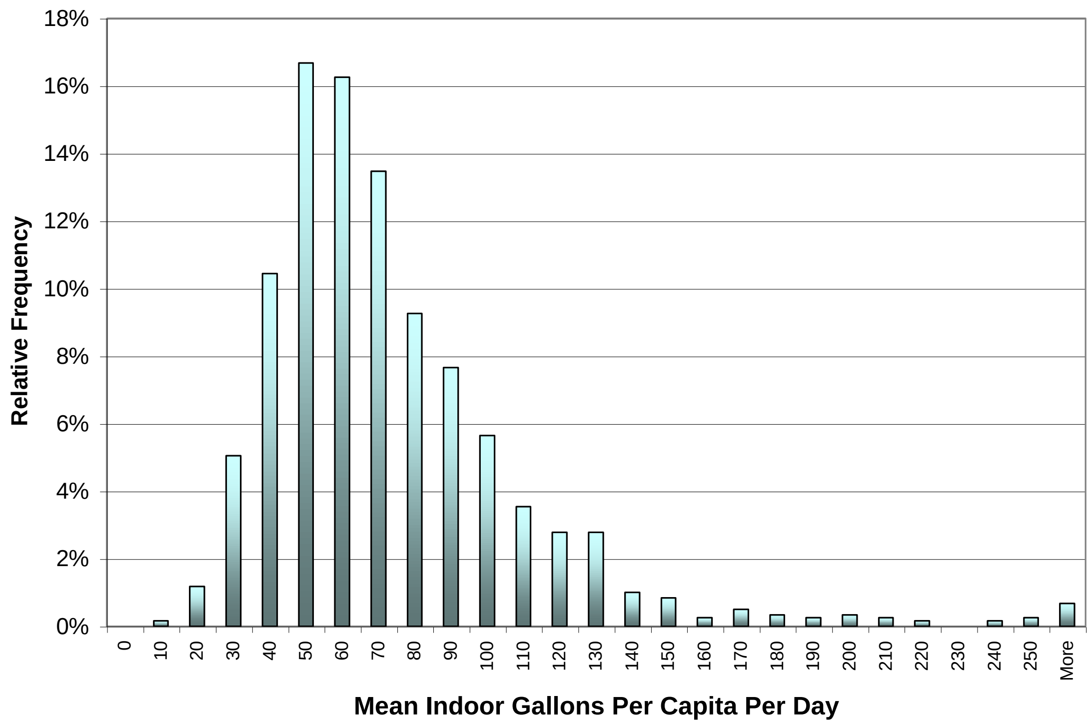

Figure 5.7 Distribution of mean household daily per capita indoor water use, 1,188 study homes

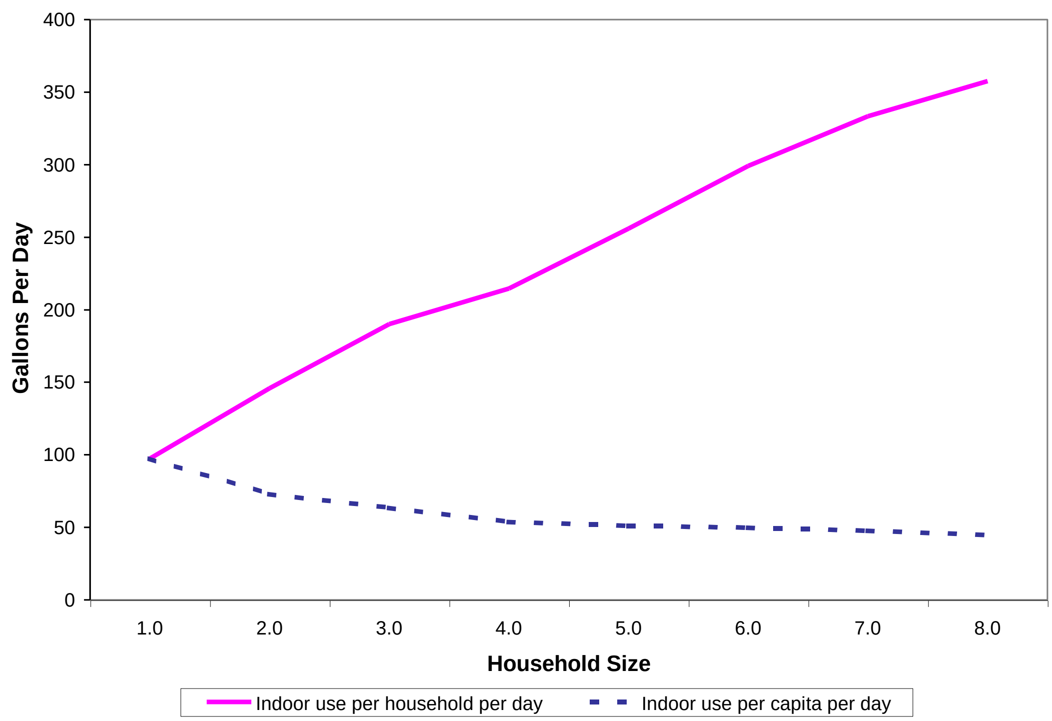

Figure 5.8 Indoor water use by household size

In order to quantify the increase in total indoor water use with household size, a least squares regression line was fit to the indoor per household per day data and equation 5.1 was obtained. The coefficient of determination (R^2) for this equation is 0.9944 indicating an excellent fit.

$$y = 37.2x + 69.2 \tag{5.1}$$

where y = indoor use per household per day and

x = the household size (number of people per household)

This equation indicates that there is an increase of approximately 37 gallons per day for each extra person in the household with a "threshold" water use of about 69 gallons per day.

Study Site Comparison

Mean indoor use patterns in the 12 study sites differed by up to 26.4 gallons per capita per day (gpcd). The average per capita per day indoor usage ranged from 57.1 gpcd in Seattle to 83.5 gpcd in Eugene, Oregon with a mean for the entire study of 69.3 gpcd. Results for all 12 study sites are presented in Table 5.1. The median use was less variable, with only a 12.9 gpcd difference between the extremes. This result is important because the calculation of the median avoids the right hand tail effect from outliers. The importance of outliers is shown by the large difference between the mean and median for each city. The standard deviation of daily per capita indoor use ranged from 23.4 in San Diego to 68.9 in Eugene. The Tempe/Scottsdale and Eugene, Oregon study sites had the highest daily per capita indoor water use and standard deviation because of a small number of outliers who used considerably more water due to excessive leakage and the possibility that additional persons may have been staying at the home during one of the logging periods.

Leaks

The mean per capita rate of leakage (9.5 gpcd) should be of concern to utilities, water providers, and consumers. This is not the first study that has found residential leakage rates in this range. The 1984 HUD study found leakage rates ranging from 5 to 13 percent of indoor use (Brown and Caldwell 1984). The Boulder Heatherwood Studies found leakage to be 11.5 percent of indoor use, but this was reduced to 5.5 percent after a significant ULF toilet retrofit in each participating home (DeOreo and Mayer 1996). In the REUWS, leakage comprised 12.7 percent of indoor use.

To put the 9.5 gpcd leakage rate in world-wide perspective, studies in Turkey, Indonesia, Egypt, and Hong Kong found that the entire indoor domestic consumption among lower income groups ranged from 12.4 to 18.5 gpcd (Twort, et. al., 1994).

Table 5.1 Comparison of daily per capita indoor water use, 12 study sites

Study site	**Sample size**	**Mean persons per household**	**Mean daily per capita indoor use** (gpcd)	**Median daily per capita indoor use** (gpcd)	**Standard deviation of per capita indoor use** (gpcd)
Seattle	99	2.8	57.1	54.0	28.6
San Diego	100	2.7	58.3	54.1	23.4
Boulder	100	2.4	64.7	60.3	25.8
Lompoc	100	2.8	65.8	56.1	33.4
Tampa	99	2.4	65.8	59.0	33.5
Walnut Valley	99	3.3	67.8	63.3	30.8
Denver	99	2.7	69.3	64.9	35.0
Las Virgenes	100	3.1	69.6	61.0	38.6
Waterloo & Cambridge	95	3.1	70.6	59.5	44.6
Phoenix	100	2.9	77.6	66.9	44.8
Tempe & Scottsdale	99	2.3	81.4	63.4	67.6
Eugene	98	2.5	83.5	63.8	68.9
12 study sites	1188	2.8	69.3	60.5	39.6
Range	5	1.0	26.4	12.9	45.5

Table 5.2 shows the mean daily per capita leakage rates for all 12 study sites. Leakage varied from 3.4 gpcd in Boulder, Colorado to 17.6 gpcd in Tempe and Scottsdale, Arizona. The three sites with the highest mean daily per capita leakage rate (Eugene, Phoenix, Tempe, and Scottsdale) were also the same three sites with the highest overall mean per capita indoor use, indicating to what extent leaks can contribute to daily water use patterns.

One of the limitations of the flow trace analysis technique used in this study was impossible to determine the exact source of the leakage in each study house. However, it was apparent during the analysis of the recorded flow trace data that toilet flapper leaks (which appear in Trace Wizard as regular spikes of water use following toilet flushes) were the primary contributor followed by continuous faucet/hose bib leaks in homes with exorbitant leakage. In some homes with automatic irrigation systems it appeared that there may have been leaks in irrigation valves. Lacking an adequate method to apportion leaks between indoor and outdoor uses, it was decided to include leaks with indoor use for several reasons: (1) Flow trace analysts agreed that the majority of the leakage appeared to be from indoor sources such as faulty toilet flappers and faucets; (2) Including leaks with indoor use more effectively shows the significance of water lost to leakage; and (3) Leaks were included with indoor use in the 1984 HUD study making for easier comparisons.

Table 5.2 Comparison of daily per capita leakage rates, 12 study sites

Study site	**Sample size**	**Mean daily per capita leakage** (gpcd)	**Median daily per capita leakage** (gpcd)	**Standard deviation of per capita leakage** (gpcd)
Boulder	100	3.4	1.3	6.0
San Diego	100	4.6	1.5	7.9
Denver	99	5.8	1.2	11.6
Seattle	99	5.9	1.2	20.1
Walnut Valley WD	99	7.6	3.0	10.8
Waterloo & Cambridge	95	8.2	3.3	16.1
Lompoc	100	10.1	3.3	23.6
Tampa	98	10.8	1.7	20.2
Las Virgenes MWD	100	11.2	2.7	17.9
Eugene	98	13.6	2.5	46.6
Phoenix	100	14.8	5.8	23.3
Tempe & Scottsdale	99	17.6	5.5	40.3
12 study sites	1188	9.5	2.7	20.4

Figure 5.9 is a histogram of the average daily leakage measured from each of the 1,188 study homes. 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 per household 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 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.

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.

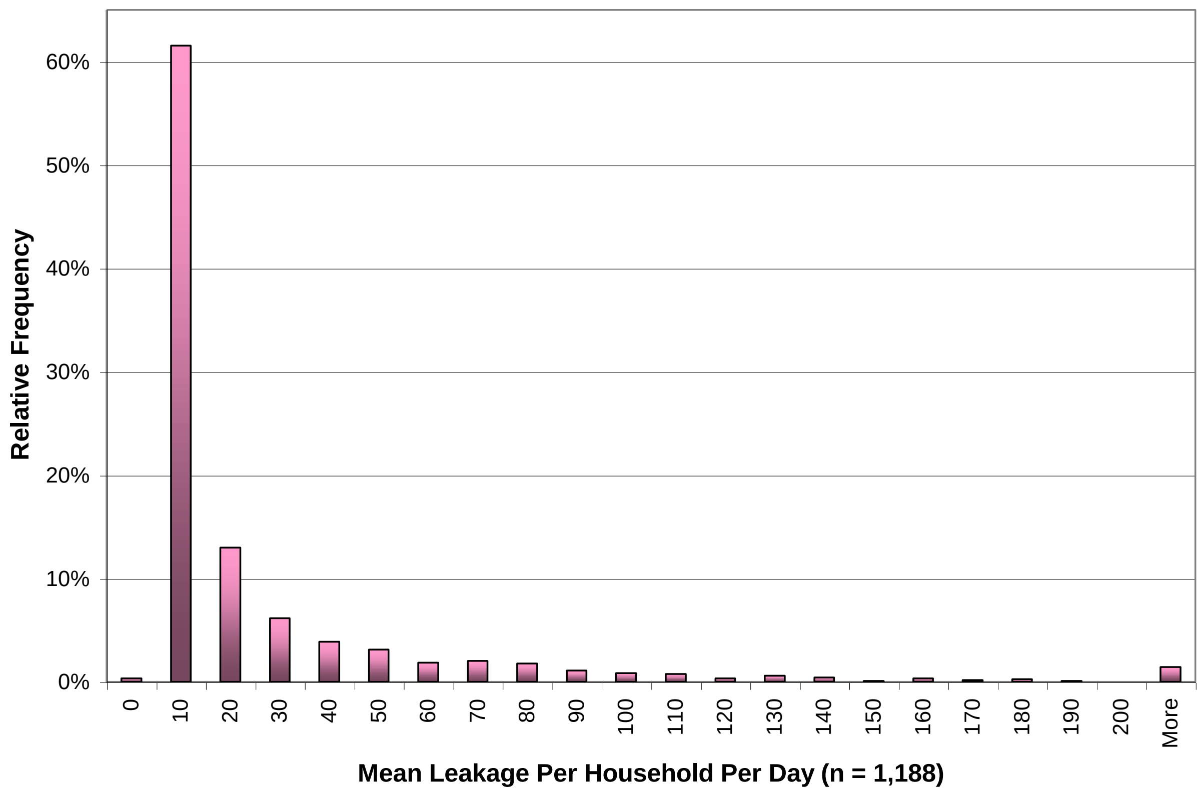

Figure 5.9 Distribution of mean daily leakage, 1,188 study homes

Although not a stated objective of this project, this result suggests that identifying and repairing leaks in the top 5 to 10 percent of leaking homes would provide greater benefit in terms of water savings than a general non-targeted leak detection and repair program. The difficulty lies in accurately identifying the large leak accounts in an inexpensive and systematic manner. A good approach, suggested by the data, would be to target homes in the top tier of winter water use. For the twelve study sites, the data logging results indicate that there is a 76 percent probability that a single family home occupied by four persons or less having winter water use (essentially indoor use) exceeding 12,000 gallons per month (400 gallons per day) has a major leak problem exceeding 4,000 gallons per month (130 gpd). Water utilities may want to target single family accounts with winter water use exceeding 400 gpd to receive a high consumption notice accompanied by suggestions of searching for and repairing leaks.

Fixture Utilization Per Capita Per Day

The data set developed for the REUWS made it possible to calculate the number of times per day each fixture was used in each study home. For toilets, baths, showers, clothes washers, and dishwashers the count of uses per day is a meaningful value. For faucets, it is more instructive to examine the duration of usage per day. Results are shown in Table 5.3.

The average number of toilet flushes per capita per day ranged from 4.49 in Seattle to 5.62 in Eugene with a study-wide mean of 5.05. Study participants took an average of 0.75 showers and baths per day. Participants in Eugene bathed the most often while participants in Waterloo and Cambridge bathed least frequently. Clothes washers were run an average of 0.37 times per capita per day across all 12 study sites and dishwashers were run 0.10 times per capita per day on average. A typical family of four in the study ran nearly 1.5 loads of laundry and 0.4 loads of dishes per day. Faucets were utilized for an average of 8.1 minutes per person per day at an average flow rate of 1.34 gpm.

Fixture utilization was an important finding of the 1984 HUD study and the HUD findings are compared with the REUWS results in Table 5.4.

These results on fixture utilization for the REUWS and HUD study are similar for showers and baths, but differ somewhat in mean toilet flushes per capita per day and in clothes washer and dishwasher loads per capita per day. The HUD study did not collect data on duration of faucet utilization.

Table 5.3 Fixture utilization per capita per day, mean and standard deviation, 12 study sites

Study site	**Toilet flushes per capita per day**		**Showers & baths per capita per day**		**Clothes washer loads per capita per day**		**Dishwasher loads per capita per day**		**Faucet minutes per capita per day**	
	Mean	**St.Dev.**	**Mean**	**St.Dev.**	**Mean**	**St.Dev.**	**Mean**	**St.Dev.**	**Mean**	**St.Dev.**
Boulder	4.79	2.25	0.81	0.53	0.34	0.22	0.13	0.10	8.4	4.9
Denver	5.10	2.71	0.80	0.48	0.37	0.26	0.11	0.10	7.5	4.4
Eugene	5.62	3.40	0.90	0.65	0.40	0.32	0.13	0.14	9.1	6.6
Seattle	4.49	2.28	0.75	0.51	0.30	0.17	0.10	0.11	6.9	4.4
San Diego	5.20	2.39	0.63	0.32	0.42	0.27	0.10	0.08	8.1	4.0
Tampa	4.85	2.61	0.70	0.54	0.36	0.24	0.06	0.10	9.4	6.5
Phoenix	5.31	3.00	0.77	0.49	0.40	0.29	0.08	0.07	6.7	3.6
Tempe & Scottsdale	5.12	2.67	0.82	0.73	0.36	0.24	0.11	0.08	8.6	7.2
Waterloo & Cambridge	5.51	3.31	0.63	0.64	0.35	0.21	0.08	0.11	8.0	6.0
Walnut Valley WD	4.69	2.50	0.74	0.37	0.34	0.20	0.07	0.07	9.0	6.1
Las Virgenes MWD	4.73	2.38	0.74	0.44	0.40	0.28	0.09	0.07	8.2	5.4
Lompoc	5.19	2.82	0.71	0.43	0.38	0.20	0.09	0.10	7.5	5.1
12 study sites	5.05	2.69	0.75	0.51	0.37	0.24	0.10	0.09	8.1	5.3

Table 5.4 Fixture utilization per capita per day

Measurement	Mean utilization per capita per day	
	HUD Study	REUWS
Toilet flushes	4.00	5.05
Showers and baths	0.74	0.75
Clothes washer loads	0.30	0.37
Dishwasher loads	0.17	0.10
Faucet utilization	-	8.1 minutes

Toilets

According to mail survey results, there were an average of 2.27 toilets per household in the entire REUWS study group. A total of 348,345 toilet flushes were recorded during the 28,015 days for which data were collected for an average of 12.4 flushes per household per day and 5.05 flushes per capita per day. The average toilet flush volume across all study sites was 3.48 gallons per flush (gpf) with a standard deviation of 1.19 gpf. The distribution of toilet flushing volumes of all recorded flushes is shown in Figure 5.10. This distribution shows the range of toilet flush volumes that were be found in the study homes. The majority of flushes fell in the 3 to 5 gpf range but here is a distinct secondary peak in the 1.5 to 2 gpf range indicating that while 3.5 gpf toilets predominate, the data logged group contains a significant number of ULF toilets.

A comparison of toilet flushing in all 12 study sites is presented in Table 5.5. Included are comparisons of mean flush volume, mean gpcd toilet usage, and mean per capita flushing frequency. The mean toilet usage across all data logged sites was 18.5 gpcd and the mean toilet flush volume was 3.48 gpf. San Diego, Las Virgenes MWD, and Lompoc had the lowest average toilet flush volume. Not surprisingly, these three cities also had the lowest mean daily per capita toilet water use. These cities also have implemented ULF toilet retrofit programs. Differences between usage at these sites is examined in more detail later in this chapter.

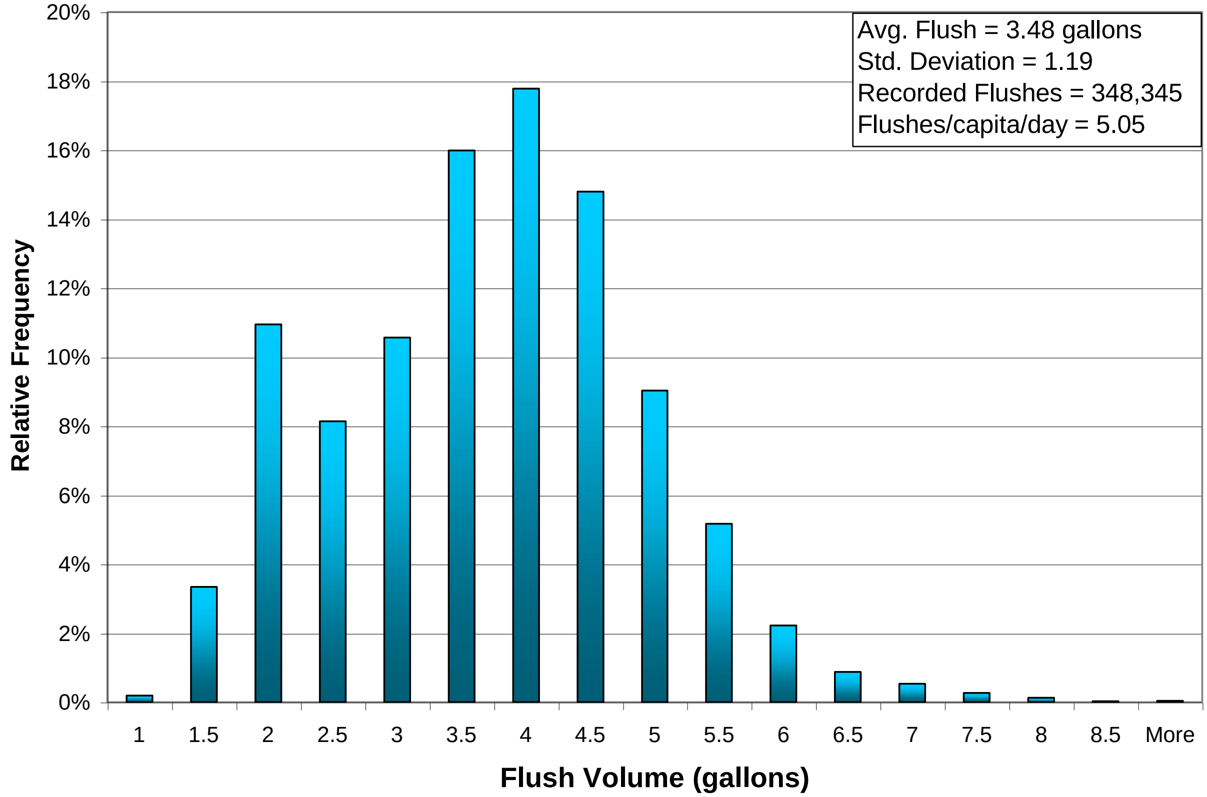

Figure 5.10 Toilet flush distribution, all recorded toilet flushes

Results from this research about the variability of toilet flush volumes indicate that toilets do not flush in neat little intervals like 1.6, 3.5, or 5.0 gpf. A toilet rated to flush at 3.5 gpf or 1.6 gpf will seldom use precisely that amount of water for a single flush, even when the toilet is new. Modifications to toilets such as new flapper valves, toilet dams, displacement devices, and float valve adjustments can also affect the flush volume (Webster, McDonnell, and Koeller 1998; Babcock 1999). Other studies have also found that each toilet is different, even if they are the same make and model (Honold and Ewald 1994; DeOreo and Mayer 1996). Further research on the actual flush volumes of toilets in the field is warranted given the variability found in this study and the potential impact of modification to ULF toilets to water planning scenarios.

An examination of ULF toilets, conservation savings, and flushing frequency is presented later in this chapter.

Table 5.5 Toilet flush volume, per capita use, and utilization, 12 study sites

Study site	Sample size	Toilet flush volume		Daily per capita toilet use		Toilet flushes per capita/day	
		Mean (gpf)	Std. Dev. (gpf)	Mean (gpcd)	Std. Dev. (gpcd)	Mean	Std. Dev.
Boulder	100	3.87	0.97	19.8	9.9	4.79	2.25
Denver	99	3.84	1.34	21.1	13.0	5.10	2.71
Eugene	98	3.91	1.04	22.9	14.5	5.62	3.40
Seattle	99	3.69	1.12	17.1	8.7	4.49	2.28
San Diego	100	2.88	1.17	15.8	7.8	5.20	2.39
Tampa	99	3.32	1.21	16.7	9.4	4.85	2.61
Phoenix	100	3.63	1.06	19.6	12.5	5.31	3.00
Tempe & Scottsdale	99	3.50	1.25	18.4	11.0	5.12	2.67
Waterloo & Cambridge	95	3.49	0.96	20.3	14.3	5.51	3.31
Walnut Valley WD	99	3.65	1.05	18.0	10.8	4.69	2.50
Las Virgenes MWD	100	3.04	1.22	15.7	10.3	4.73	2.38
Lompoc	100	3.09	1.22	16.6	10.8	5.19	2.82
12 study sites	1188	3.48	1.19	18.5	11.1	5.05	2.69

Showers

According to mail survey results, there were an average of 1.98 showers per household in the entire REUWS study group. Of these showers, 1.22 (62 percent) were part of a combined shower-bathtub fixture and 0.76 (38 percent) were stand alone showers. A total of 48,727 individual shower events were recorded over the two year REUWS research effort. The average shower used 17.2 gallons and lasted for 8.2 minutes and the average flow rate was 2.1 gpm. This indicates that on average people shower at a flow rate below the 1993 U.S. national plumbing code standard of 2.5 gpm. The distribution of shower volume is shown in Figure 5.11. This classic binomial distribution shows that most showers used between 7.5 and 20 gallons of water per event.

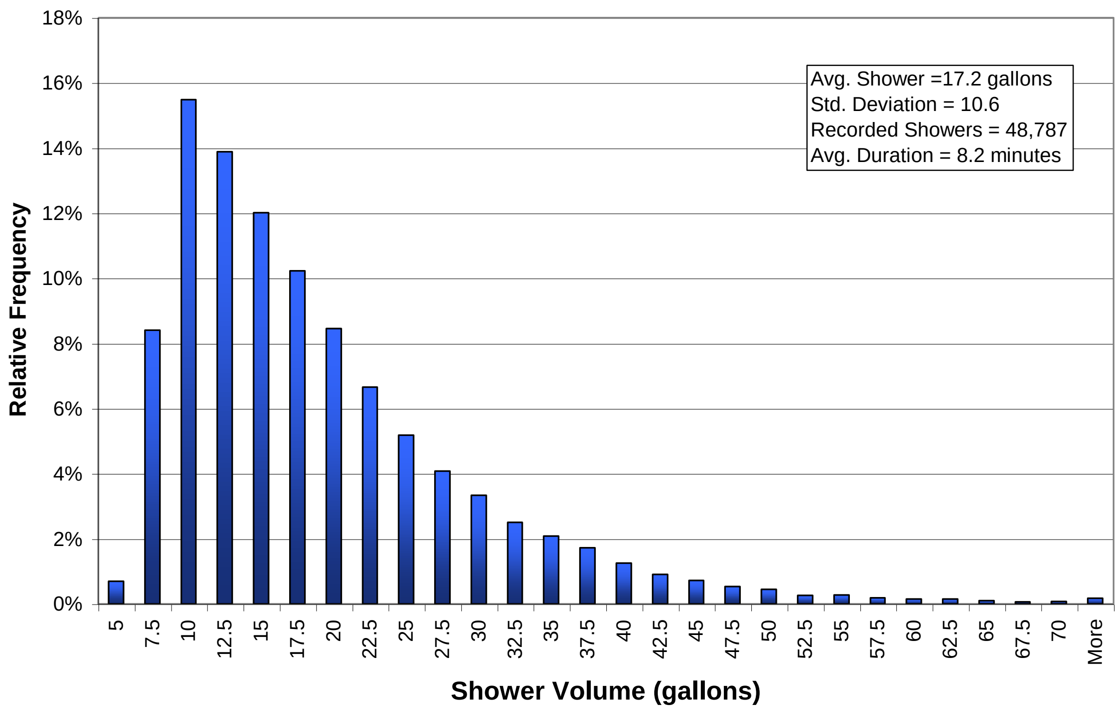

Figure 5.11 Shower volume distribution diagram

The distribution of shower durations for all recorded shower events is shown in Figure 5.12. In this figure, 71.5 percent of all showers were between 4 and 10 minutes in length with a mean of 8.2 minutes, a median of 7.2 minutes, and a standard deviation of 4.5 minutes. Less than 10 percent of all recorded showers were longer than 15 minutes in duration. An analysis of the start time of showers revealed that 36.5% of all showers were taken between 5 a.m. and 9 a.m., 32.7% of all showers were taken between 9 a.m. and 5 p.m., 27.6% were taken from 5 p.m. and midnight, and 3.2% were taken from midnight to 5 a.m.

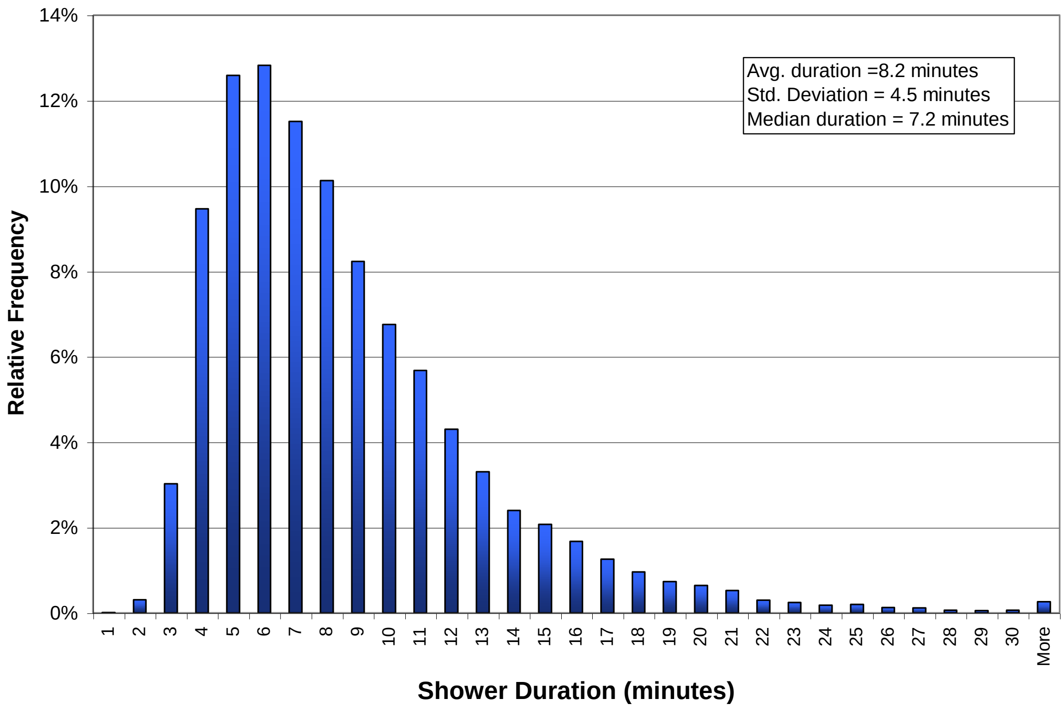

Figure 5.12 Shower duration distribution

The distribution of shower flow rates for all recorded showers is shown in Figure 5.13. For this chart the mode flow rate statistic generated by Trace Wizard during flow trace analysis was taken as the actual shower flow rate because it best represents the flow during the shower itself. An average flow rate might over estimate shower flows because many showers start at a high flow rate as water is run through the bathtub spigot and the temperature adjusted then the flow is restricted when the shower diverter valve is used and flow is constricted through the shower head.

The mean shower flow rate across all 12 study sites was 2.2 gpm with a median of 2.02 gpm and a standard deviation of 0.95. The distribution of shower flow rates appears more normally distributed than either the distribution of shower volumes or the distribution of shower durations. More than 70 percent of the showers recorded during the study were taken at a flow rate below 2.5 gpm although only 50.6 percent of the mail survey respondents indicated that they had installed a low-flow shower head.

An analysis of showering and conservation savings in presented later in this chapter. A comparison of showering and shower usage between study sites is presented in Table 5.6.

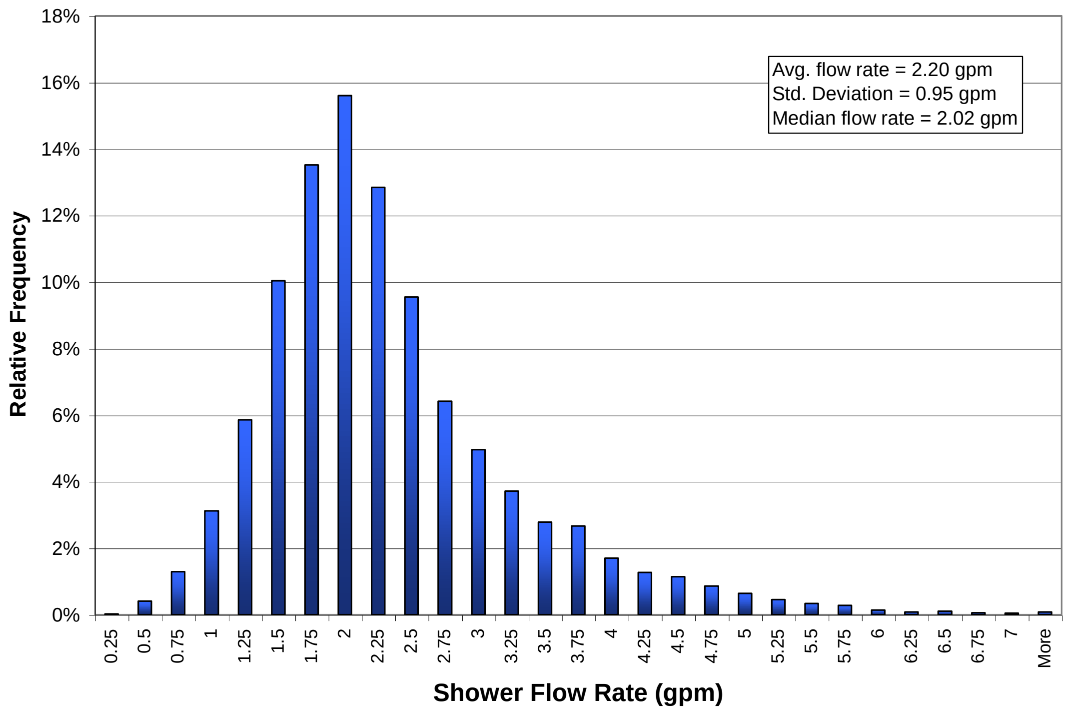

Figure 5.13 Shower flow rate distribution

Table 5.6 Shower per capita use, volume, duration, and flow rate, 12 study sites

Study site	Daily per capita water use for showering (gpcd)			Shower volume (gallons)			Shower duration (minutes)		Shower flow rate (gpm)	
	Mean	**Median**	**Std. Dev.**	**Mean**	**Median**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Boulder	13.1	11.5	7.4	18.6	18.0	11.3	7.9	4.2	2.44	0.99
Denver	12.9	11.3	7.9	18.4	18.3	11.6	8.1	5.1	2.39	1.00
Eugene	15.1	13.1	11.5	18.3	18.2	10.9	8.1	4.3	2.26	0.96
Seattle	11.4	10.0	7.0	17.1	16.2	12.9	7.9	4.8	2.21	0.94
San Diego	9.0	8.4	5.1	14.9	14.3	9.2	7.9	4.8	1.95	0.92
Tampa	10.2	9.1	7.1	16.2	15.4	8.6	8.2	4.3	2.02	0.84
Phoenix	12.5	11.8	6.8	18.1	17.3	10.5	8.0	4.2	2.32	1.17
Tempe & Scottsdale	12.6	10.3	10.1	17.4	15.6	12.1	7.9	5.2	2.25	1.03
Waterloo & Cambridge	8.3	7.1	6.3	15.4	14.8	8.0	6.8	3.9	2.35	1.04
Walnut Valley WD	11.7	11.1	6.3	16.7	16.2	8.5	8.2	4.4	2.09	0.78
Las Virgenes MWD	11.4	11.1	6.3	17.0	16.2	9.8	8.1	5.0	2.19	0.86
Lompoc	11.1	9.9	7.2	17.2	16.6	9.8	8.3	5.8	2.14	0.81
12 study sites	11.6	10.4	7.4	17.2	16.4	10.6	8.2	4.5	2.22	0.95

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.

Table 5.7 shows the mean daily per capita usage for each household size ranging from one to eight persons. Also shown are the number of households in each of these groups. Households which did not use a clothes washer during the two logging periods were excluded from this analysis.

Table 5.7 Per capita clothes washing use

Household size (# of residents)	**Mean clothes washing** (gpcd)	**Standard deviation** (gpcd)	**Number of households in the interval**
1	18.8	14.4	142
2	16.4	10.5	450
3	14.7	10.0	225
4	12.4	6.2	191
5	13.0	6.3	78
6	12.9	5.6	28
7	14.0	5.3	7
8	12.7	4.6	5

Generally as the size of the household increases, the amount of water used for clothes washing decreases. There were a significant number of households with between 1 and 5 residents, but there is much less data from houses with 6, 7, and 8 residents. Nevertheless, it appears that the amount of water used for clothes washing does decrease as the number of residents increases. This trend continues until the household size reaches 4 residents, then levels off. The average daily per capita usage among households with 4 or more residents is 12.6 gpcd (calculated using a weighted average to account for the number of households in each bin).

The standard deviation in per capita usage actually decreases as the size of the household increases, perhaps as a result of the increased frequency in use of the washing machine, thus decreasing the number of zero use days.

Figure 5.14 is a frequency distribution of the volume of all clothes washer loads measured during the REUWS. 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. The distribution itself looks typically gaussian (normal). Seventy-five percent of the 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.

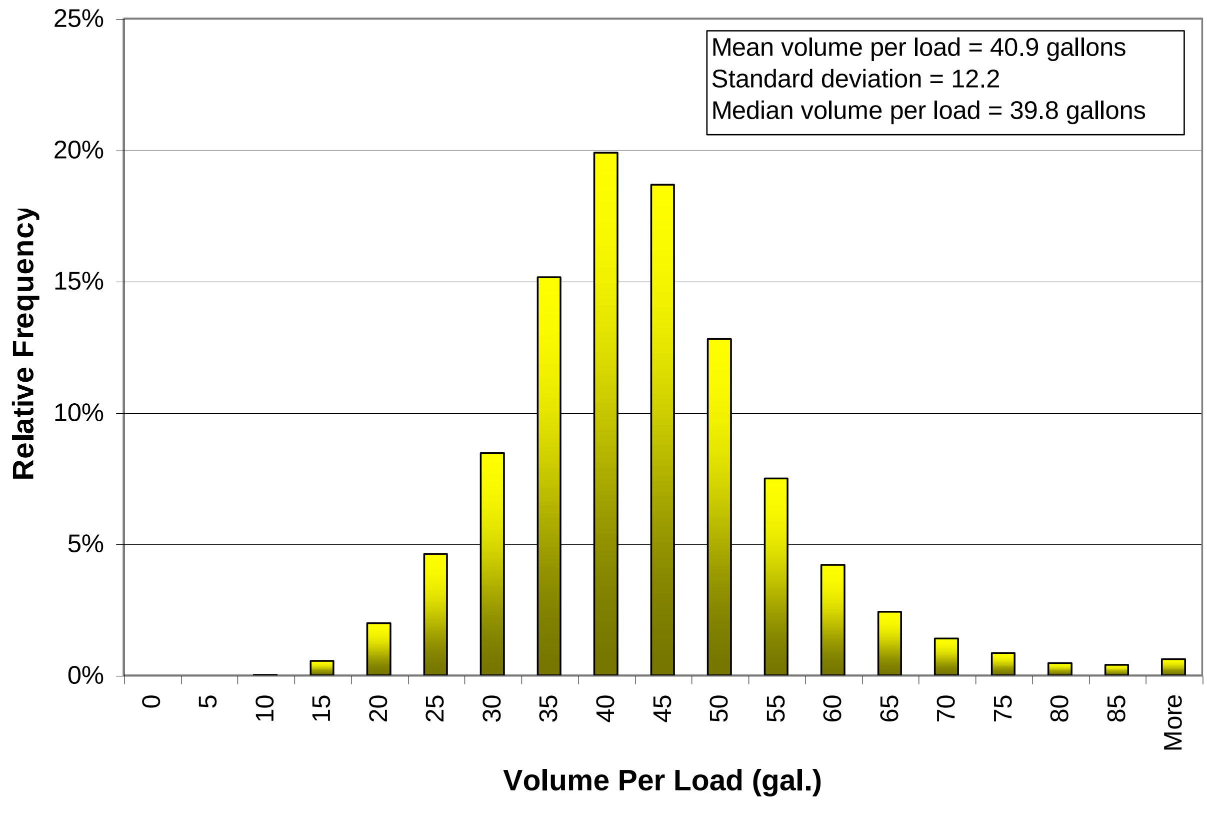

Figure 5.14 Clothes washer volume per load distribution

Analysis of Variance in Indoor Water Use

Indoor GPCD

Mean indoor per capita usage was calculated for each study home in each study site and an ANOVA analysis performed to determine the extent to which geographic variations could be found, and then to assess the likelihood that these variations were due to conservation practices undertaken by the participating cities. In some cases clear geographic differences in water use which were independent of behavior were detected. For example, cities with higher saturation of ULF toilets used less water for toilet flushing. This suggests that conservation programs may be affecting water use. For other water uses, such as showers the use patterns were much more strongly linked to behavior rather than hardware. To the extent that indoor per capita use varies, it appears to be the result of a combination of the types of fixtures and appliances present and personal behavior, habits, and individual preferences. Some people prefer to take 20 minute showers, some people wash their clothes more often, and some people wash their hands frequently – all irrespective of the hardware present in their homes.

A comparison of average indoor per capita water use is shown in Table 5.8. For this table the average per capita indoor use was calculated for each of the 12 study sites on a fixture by fixture basis. Seattle had the lowest average daily per capita usage at 57.1 gpcd and Eugene had the highest usage at 83.5 gpcd. The relative percentage each end use contributes to total indoor use is presented in Table 5.9.

Toilets were the largest component of mean daily per capita use is all 12 study sites followed by clothes washers which were the second largest. For most study sites, mean daily per capita shower usage was the third largest component of indoor use, but in three sites (San Diego, Tampa, and Waterloo/Cambridge) faucet usage exceed showering. In five study sites (Lompoc, Las Virgenes MWD, Phoenix, Scottsdale/Tempe, and Eugene) per capita leakage rates exceeded faucet consumption.

Analysis of variance, or ANOVA, are a set of statistical procedures for the analysis of quantitative data. Multiple comparisons in ANOVA are techniques which allow ranking the means of various treatments with 95 percent confidence that all confidence intervals comparing the means contain the true differences between the treatment means (McClave, J.T. et. al. 1997). Tukey developed a procedure specifically for pairwise comparisons when the sample sizes of the treatments are equal which is essentially the case in the REUWS. Tukey's procedure involves the use of a probability distribution called the Studentized range distribution and the result is a collection of simultaneous confidence statements about the true values of all differences between true treatment means (Devore, J. 1991).

Table 5.8 Average indoor gallons per capita per day usage, 12 study sites

Study site	Toilet	Clothes washer	Shower	Faucet	Leak	Other domestic	Bath	Dishwasher	Indoor Total
Seattle	17.1	12.0	11.4	8.7	5.9	0.0	1.1	1.0	57.1
San Diego	15.8	16.3	9.0	10.8	4.6	0.3	0.5	0.9	58.3
Boulder	19.8	14.0	13.1	11.6	3.4	0.2	1.4	1.4	64.7
Lompoc	16.6	15.3	11.1	9.9	10.1	0.9	1.2	0.8	65.8
Tampa	16.7	14.2	10.2	12.0	10.8	0.3	1.1	0.6	65.8
Walnut Valley WD	18.0	14.1	11.7	12.3	7.6	2.3	1.0	0.8	67.8
Denver	21.1	15.6	12.9	10.5	5.8	0.5	1.6	1.2	69.3
Las Virgenes MWD	15.7	16.8	11.4	11.2	11.2	1.1	1.3	0.9	69.6
Waterloo & Cambridge	20.3	13.7	8.3	11.4	8.2	6.0	1.9	0.8	70.6
Phoenix	19.6	16.9	12.5	9.6	14.8	2.2	1.2	0.8	77.6
Scottsdale & Tempe	18.4	14.5	12.6	11.2	17.6	5.0	0.9	1.1	81.4
Eugene	22.9	17.1	15.1	11.9	13.6	0.1	1.5	1.4	83.5
12 study sites	18.5	15.0	11.6	10.9	9.5	1.6	1.2	1.0	69.3

In order to determine which differences is water uses were statistically significant, multiple comparison tests for significance using Tukey's procedure were performed on the per capita consumption for each end use in each study city at the 95 percent level of confidence. This multiple comparisons procedure provided a relatively simple methodology for developing simultaneous confidence statements from multiple sets of data such as the different daily per capita water use found for each study site in the REUWS. While Tukey's procedure may not be as sensitive in detecting differences in some situations as other methods (Bonferroni or Scheffe), it offered an appropriate and effective methodology to use for the REUWS per capita usage data.

Table 5.9 Percentage of average indoor gallons per capita per day usage, 12 study sites

Study site	Toilet	Clothes washer	Shower	Faucet	Leaks	Other domestic	Bath	Dishwasher	Indoor total
Seattle	29.9%	21.0%	20.0%	15.2%	10.3%	0.0%	1.9%	1.8%	100.0%
San Diego	27.1%	28.0%	15.4%	18.5%	7.9%	0.5%	0.9%	1.5%	100.0%
Boulder	30.6%	21.6%	20.2%	17.9%	5.3%	0.3%	2.2%	2.2%	100.0%
Lompoc	25.2%	23.3%	16.9%	15.0%	15.3%	1.4%	1.8%	1.2%	100.0%
Tampa	25.4%	21.6%	15.5%	18.2%	16.4%	0.5%	1.7%	0.9%	100.0%
Walnut	26.5%	20.8%	17.3%	18.1%	11.2%	3.4%	1.5%	1.2%	100.0%
Denver	30.4%	22.5%	18.6%	15.2%	8.4%	0.7%	2.3%	1.7%	100.0%
Las Virgenes MWD	22.6%	24.1%	16.4%	16.1%	16.1%	1.6%	1.9%	1.3%	100.0%
Waterloo & Cambridge	28.8%	19.4%	11.8%	16.1%	11.6%	8.5%	2.7%	1.1%	100.0%
Phoenix	25.3%	21.8%	16.1%	12.4%	19.1%	2.8%	1.5%	1.0%	100.0%
Scottsdale & Tempe	22.6%	17.8%	15.5%	13.8%	21.6%	6.1%	1.1%	1.4%	100.0%
Eugene	27.4%	20.5%	18.1%	14.3%	16.3%	0.1%	1.8%	1.7%	100.0%
12 study sites	26.7%	21.7%	16.8%	15.7%	13.7%	2.2%	1.7%	1.4%	100.0%

This analysis revealed that the differences in total indoor per capita daily use is only statistically significant when comparing a few sites. The sites for which statistically significant differences were detected at the 95 percent level were: Seattle vs. Phoenix, Scottsdale/Tempe, and Eugene; and San Diego vs. Scottsdale/Tempe and Eugene. All other comparisons were found not to be significant at the 95 percent confidence level.

Of particular interest are statistically significant differences in per capita toilet, clothes washer, shower, and faucet usage between sites. These are areas where local conservation programs could have impacted domestic water use. Average water used for toilet flushing varied from 15.7 gpcd in Las Virgenes MWD and 15.8 gpcd in San Diego to 22.9 gpcd in Eugene. The overall average was 18.5 gpcd. The ANOVA found that statistically significant differences were only observed between Eugene and Las Virgenes MWD, San Diego, Lompoc, Tampa, and Seattle; and between Denver and Las Virgenes MWD and San Diego. These results are shown in Table 5.10.

Table 5.10 Toilet statistics in cities with significantly different per capita usage

Study site	**Mean daily toilet use** (gpcd)	**Mean flush volume** (gal.)	**Median flush volume** (gal.)	**Mean flushes per capita per day**	**% ULF flushes*** (<2.0 gpf)	**% of housing built after 1993†**
Denver	21.1	3.84	3.9	5.10	10.8%	1.4%
Eugene	22.9	3.91	3.9	5.62	4.0%	2.0%
Las Virgenes	15.7	3.04	3.1	4.73	29.4%	3.5%
San Diego	15.8	2.88	2.7	5.20	30.0%	2.5%
Lompoc	16.6	3.09	3.1	5.19	25.1%	2.5%
Tampa	16.7	3.32	3.3	4.85	17.6%	3.0%
Seattle	17.1	3.69	3.7	4.49	8.2%	2.2%

Footnotes:
Dotted line separates groups of sites where the mean daily toilet use differs significantly at the 95 percent confidence level. Only cities which had statistically significant differences are presented in this table.
* Calculated as the percentage of toilet flushes less than 2.0 gpf recorded at study site.
† From mail survey responses.

Differences in daily per capita toilet usage appear to be primarily a function of the saturation of ULF toilets in the study group. The three cities with the lowest average daily per capita usage, Lompoc, San Diego, and Las Virgenes MWD, had the highest saturation of ULF toilets in the study. This is further illustrated by the low average and median flush volumes in those three study sites. The values of mean flushes per capita per day in Lompoc, San Diego, and Las Virgenes MWD were also lower overall than in Eugene, but for the most part this only amounted to half a flush per day difference. The saturation of ULF toilets in Lompoc, San Diego, and Las Virgenes MWD does not appear to be directly related to the predominance of newer houses in the study. Rather the presence of ULF toilets in these cities is due to retrofits undertaken through utility sponsored programs or the home owner's own initiative.

Daily per capita shower usage ranged from 8.3 gpcd in Waterloo/Cambridge to 15.1 gpcd in Eugene. Results of the ANOVA showed statistically significant differences in per capita showering at the 95 percent confidence level as shown in Table 5.11. Statistically significant differences at the 95 percent confidence level were found between the sites separated by the dotted line.

The most noticeable difference in showering habits between these seven cities evident in Table 5.11 is the mean number of showers per capita per day. Study participants from the samples in San Diego and Waterloo simply took fewer showers per capita than the participants in the other five cities. Without this reduction in daily showering, the differences in per capita per day shower use would not have likely been statistically significant. This points out the importance of family composition and personal preference and habits in determining residential water consumption.

Table 5.11 Shower statistics in cities with significantly different per capita usage

Study site	**Mean daily shower use** (gpcd)	**Mean shower volume** (gal.)	**Median shower volume** (gal.)	**Mean showers per capita per day**	**Mean Shower flow rate** (gpm)	**Mean shower duration** (min.)
Eugene	15.1	18.3	18.2	0.82	2.3	8.1
Tempe/Scottsdale	12.6	17.4	15.6	0.77	2.3	7.9
Boulder	13.1	18.6	18.0	0.76	2.4	7.9
Denver	12.9	18.4	18.3	0.74	2.4	8.1
Phoenix	12.5	18.1	17.3	0.72	2.3	8.0
San Diego	9.0	14.9	14.3	0.60	2.0	7.9
Waterloo/Cambridge	8.3	15.4	14.8	0.53	2.4	6.8

Footnotes:
Dotted line separates sites where mean daily shower use differs significantly at the 95 percent confidence level.
Only cities which had statistically significant differences are presented in this table.

The fact that most people appear to be showering at or below the 2.5 gpm threshold suggests that additional research is needed to determine whether showerhead replacement programs save much water. If people naturally gravitate towards showering at flow rates below 2.5 gpm regardless of the actual shower head fixture this would this would be an important finding.

For clothes washers there was remarkably little variability between study sites in daily per capita use and the ANOVA found only one comparison, between Eugene and Seattle to be statistically significant at the 95 percent confidence level.

For faucets there was little variability between study sites and significant variability within each study site in daily per capita use and the ANOVA found only one comparison, between Walnut Valley WD and Seattle to be statistically significant at the 95 percent confidence level.

The ANOVA for dishwasher usage showed statistically significant differences at the 95 percent confidence level in paired comparisons between the two study sites with the highest per capita dishwasher use (Eugene and Boulder) and five sites with the lowest per capita dishwasher use (Tampa, Walnut Valley WD, Waterloo/Cambridge, Phoenix, and Lompoc). The mean daily per capita dishwasher use across all data logged homes was 1.0 gpcd, the median was 0.7 gpcd and the standard deviation 1.0. Tampa had the lowest per capita dishwasher use at 0.6 gpcd and Eugene had the highest at 1.4 gpcd. Study participants in Tampa ran an average of 0.06 dishwasher loads per person per day while in Eugene participants used their dishwashers an average of 0.13 times per person per day, more than twice as often.

The study sites with statistically significant difference in per capita dishwasher usage appear to differ primarily because of the frequency of use. The difference is dishwasher usage appears to be related to the saturation of dishwashers at each study site and the average number of dishwasher loads per day. In Boulder and Eugene residents tended to use their dishwashers more frequently, probably in part due to the higher frequency of washers in those sites. The actual gallons used per load of dishes in these seven cities was quite similar in the range of 9.3 to 10.6 gallons per load of dishes washed.

OUTDOOR USE

Historically, household outdoor water use has been estimated by subtracting the average winter consumption (AWC) from the metered consumption. AWC is normally represented by the consumption during the minimum one to three months during the winter. In this approach the AWC is used as a proxy for indoor use by assuming that there is no outdoor use during the period which the AWC is calculated. In many cities this can lead to over estimates of indoor use since many people use water outdoors during the winter months. Even in colder climates, outdoor use frequently occurs in the winter during dry spells. Problems with the AWC approach are further compounded in utilities which use a bi-monthly billing cycle in which case the minimum two month period is even more likely to contain significant outdoor use.

On the other hand, the flow trace data was also prone to errors in estimating outdoor demand because of the limited duration of the logging periods. In general, historic billing data should preferred over the logged data for deriving estimates of annual water use because only four weeks of flow trace data were obtained from each study home. The two two-week long logging periods at each site could not provide a precise measure of irrigation usage throughout the entire year.

For the REUWS, rather than rely exclusively on estimated measurements of outdoor use from AWC or from the data logging periods, outdoor water use estimates were obtained using a combination of two different data sources - historic billing data and logged indoor usage data. The availability of logged information allowed a leveraged approach to development of estimates of outdoor consumption from the historic billing data. Using the leveraged approach, outdoor use was extracted from the historic billing data from each site by calculating the average daily indoor consumption for each household from the data logging results, extrapolating this consumption over an entire year, and subtracting this from the historic billing consumption. This calculation uses the best available information about indoor consumption in order to calculate outdoor consumption.

The leveraged approach assumes that indoor use remains fairly consistent across seasons. This assumption was tested (in part) by comparing the average daily indoor water use from logging periods 1 and 2 for each study site. Two-tailed paired t-tests for significance were conducted on the paired data from all 14 study cities. This test compares two samples and determines the likelihood that the observed difference occurred by chance. The probability that the difference in the means is due to chance is shown by the p value. A low p value indicates that there is a low probability that the difference is due to chance, and hence there is a significant difference between the means. As shown in Table 5.12, the only site in which there was a significant difference between indoor use between the two logging periods was Tampa, Florida. The remaining sites, which were all sampled during different seasons showed no significant difference in indoor use. This result suggests that indoor use remained fairly constant through the year and hence could provide reasonable estimates of annual indoor demand.

Table 5.12 Statistical comparison of indoor use between logging periods

Study city	**Log 1 avg. per household indoor use** (gpd)	**Log 2 avg. per household indoor use** (gpd)	**t-statistic**	**P value**	**Statistically significant difference between logging periods?**
Boulder	146.8	156.3	-1.26	0.21	No
Cambridge	198.8	196.9	0.19	0.85	No
Waterloo	169.7	174.5	0.19	0.71	No
Denver	167.0	176.1	-0.91	0.36	No
Eugene	176.9	172.2	0.46	0.65	No
Las Virgenes MWD	195.5	196.3	-0.06	0.95	No
Lompoc	176.6	177.9	-0.31	0.76	No
Phoenix	192.8	191.6	0.13	0.90	No
San Diego	152.2	149.1	0.89	0.37	No
Scottsdale	165.1	163.1	0.12	0.90	No
Seattle	142.5	149.7	-0.77	0.44	No
Tampa	127.0	153.3	-2.85	0.01	Yes
Tempe	162.2	190.8	-1.24	0.22	No
Walnut Valley WD	199.1	205.9	-0.69	0.49	No

The leveraged approach and AWC approach are compared for each study city in Table 5.13. The leveraged approach estimated higher outdoor use than the AWC approach in cities with warmer climates such as San Diego, Scottsdale, Phoenix, Tempe, and Las Virgenes. In cities with cooler and/or wetter climates such as Waterloo, Cambridge, and Tampa the leveraged approach estimated lower outdoor use than the AWC approach. In the remaining cities the two techniques generated reasonably similar estimates of outdoor use.

The subsequent analysis in this section of this report was completed using outdoor use estimated from the leveraged approach.

Table 5.14 shows the estimated indoor, outdoor, and total annual use for the logging group calculated from the billing data and logging data using the leveraged approach to estimate outdoor use.

Table 5.13 Annual outdoor use using different estimation techniques

Study site	**Sample size**	**Leveraged approach*** (kgal/home)	**AWC approach†** (kgal/home)	**Difference** (kgal)	**Percent difference**
Waterloo	37	7.8	15.5	-7.7	-49.7%
Cambridge	58	7.8	15.4	-7.6	-49.4%
Tampa‡	99	30.5	48.2	-17.7	-36.7%
Lompoc	100	39.9	52.9	-13.0	-24.6%
Seattle	99	21.7	24.8	-3.1	-12.5%
Eugene	98	48.8	55.1	-6.3	-11.4%
Denver	99	104.7	107.2	-2.5	-2.3%
Walnut Valley WD	99	114.8	93.7	21.1	22.5%
Boulder	100	73.6	59.9	13.7	22.9%
Tempe	40	100.3	78.8	21.5	27.3%
Las Virgenes MWD	100	213.2	160.5	52.7	32.8%
Scottsdale	59	156.5	116.2	40.3	34.7%
Phoenix	100	161.9	113.2	48.7	43.0%
San Diego	100	99.3	54.2	45.1	83.2%

Footnotes:

* Uses extrapolated indoor logged use and historic billing data to estimate outdoor demand: outdoor use = annual use – extrapolated indoor use measured from logging periods.

† Uses minimum 1 to 3 months of use from billing data to estimate indoor use and then outdoor use

‡ Watering restrictions which limited lawn watering to two days per week were in effect during both logging periods.

Table 5.14 Annual indoor, outdoor, and total use for the logging samples

Study site	**Sample size**	**Outdoor Annual Use** (kgal/home)	**Indoor Annual Use** (kgal/home)	**Total Annual use** (kgal/home)
Waterloo	37	7.8	67.7	75.5
Cambridge	58	7.8	71.2	79.0
Tampa	99	30.5	56.1	86.6
Lompoc	100	43.5	62.1	105.6
Seattle	99	21.7	54.1	75.8
Eugene	98	48.8	65.1	113.9
Denver	99	104.7	61.9	166.6
Walnut Valley WD	99	114.8	76.3	191.1
Boulder	100	73.6	54.4	128.0
Tempe	40	100.3	65.2	165.5
Las Virgenes MWD	100	213.2	70.9	284.1
Scottsdale	59	156.5	60.1	216.6
Phoenix	100	161.9	70.8	232.7
San Diego	100	99.3	55.3	154.6

Irrigated Area Update

The mail survey component of the REUWS included questions about customer lot size, landscape, and irrigation habits. Analysis of the use patterns based on the survey information showed a lower than expected correlation between irrigated area and outdoor water use. It was suspected that this was at least partially due to inaccuracies in the self reported data, and that these relationships would be improved if they were based on more accurate information on the landscape area of each participating study home. Using funds provided by the US Bureau of Reclamation and the study sites, and with the contract support of the American Water Works Association Research Foundation (AWWARF), measurements of the lot size and building footprint for each study home were obtained in the Spring of 1999 as an add-on study to the REUWS, which was referred to as the Irrigated Area Update study.

The measurements of areas and building footprints came from a variety of sources including: assessor databases, digitized aerial photographs, computerized mapping systems, plat maps, real estate databases, and field measurements. Using the measurements of lot area, building footprint, and in some cases pavement areas, reasonable estimates of the potential irrigable areas for each study house were made. The irrigable area was defined as the portion of a lot which was not covered by a house, garage, driveway, sidewalk, or other impermeable material; it is the area which could support grass, shrubs, trees or other plant material and hence has the potential to be watered. The researchers did not attempt to define the actual area irrigated at each study home since this would require far more detail and survey work than the budget would allow. Furthermore, from the planning standpoint the potentially irrigable area is a parameter which is possible to estimate *a priori* far more easily than the irrigated area since the former is a function of the typical lot geometry, and the latter is a function of personal preference and behavior.

Measurements of irrigable area were obtained from 1,130 of the 1,188 homes in the REUWS. Based on the mail survey responses the median lot size across all study sites was 11,000 sf. From the results of the irrigated area measurements it was determined that the median lot size across all study sites was 8,083 sf - a difference of 3,000 sf or 27 percent.

The combination of estimates of annual outdoor water use, climate and ET data, and measurements of irrigable area obtained from the REUWS provide a good analysis tool for evaluating irrigation efficiency in the study homes. While the data used in this study were obtained through a variety of detailed and painstaking processes, the information required for most of the homes should be available to utilities with functional geographical information systems (GIS) linked to historic billing data.

Outdoor Use and ET

As noted in Chapter 4, the relationship between ET and outdoor water use is well established. In Chapter 4, ET was plotted against average annual outdoor use for the Q1000 survey group calculated using the AWC approach (Figure 4.15). The coefficient of determination (R^2)for that analysis was 0.17. An identical regression analysis was performed using the average annual outdoor use from the data logged group calculated using the leveraged approach and the Net ET. As shown in Figure 5.15, the least-squares fit of a straight line to these data yielded a coefficient of determination of 0.59, a marked improvement over the model derived from the AWC approach. This indicates a strong relationship between climate and average outdoor water use. The equation for this line is: $y=2.06x$ which means that for each inch of ET requirement a city might expect an additional 2000 gallons of outdoor demand per single-family account. This analysis suggests that net ET alone can explain more than 50 percent of water use in these study homes when outdoor use is measured using the leveraged approach rather than AWC.

The obvious outlying point in Figure 5.15 represents the Las Virgenes Municipal Water District which had the largest average lot size in the study. If this point is removed from the analysis the coefficient of determination improves to 0.78.

While Figure 5.15 shows a good relationship between outdoor water use and net ET, one of the main purposes of obtaining the measurements of irrigable area was to investigate the actual irrigation application rates of the sampled residential customers, and to compare this to the net ET as a measure of their efficiency of irrigation. This can not be determined from volumetric data, but must be based on a knowledge of the relevant area to which this volume is applied.

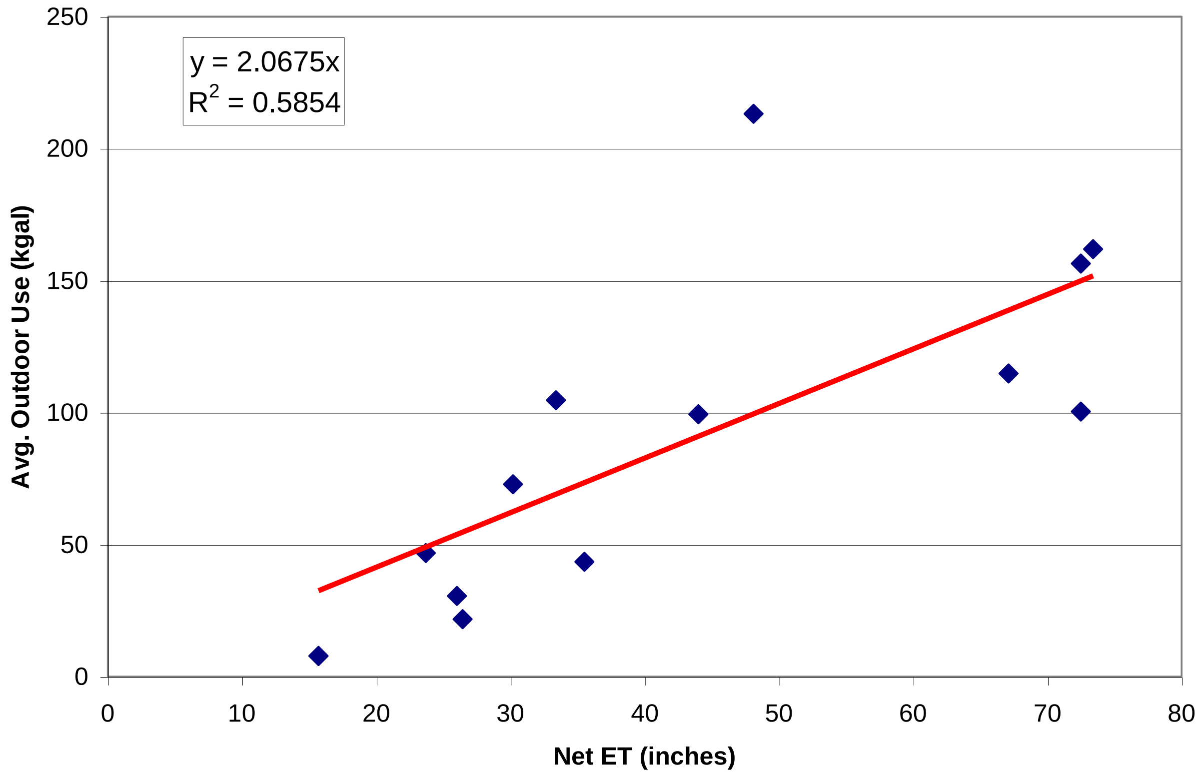

Figure 5.15 Outdoor use vs. net ET

Irrigable Area and Application Rate

Irrigable area can be described as the portion of a lot which has the potential to support a landscape which, depending on the desires of the occupants, could be irrigated at least part of the year. For this study, the irrigable area was calculated for each study home as the lot size minus the building footprint and paved area. In many cases the information on paved areas was not available, so non-irrigable areas such as driveways and sidewalks were estimated to be 7.5% of the total lot size. For example, a 10,000 sf lot with a 1500 sf building footprint would have an irrigable area of 7,750 sf (10,000 - 1500 - (10,000*0.075)).

The application rate of water for a property is the depth of water applied over the entire irrigable area during a single year. Application rates are usually calculated in inches so that they can be easily compared with net ET which is a measurement of the application requirement for maximum plant growth. In this study, application rates were calculated for each study home using the irrigable area and the annual outdoor demand for that home as shown in Equation 5.1.

$$A = \frac{V \times 0.134\,(ft^3/gal) \times 12\,(inches/ft)}{I} \qquad (5.1)$$

where A = inches of water applied to the irrigable area

V = annual outdoor use in gallons

I = irrigable area in square feet

Table 5.15 shows the average irrigable area for the study homes in each participating city, the average application rate, ET, and average application as a percent of ET.

There was considerable variability in irrigable areas across the study cities as there was in application rates. The average irrigable area in Las Virgenes was more than twice as large as the average irrigable area in ten other cities. Application rates ranged from a low of 18.4 percent of ET in Waterloo to 85.0 percent in Denver. Homeowners in all participating cities in the study irrigated well below the calculated theoretical requirement for the year on average. This suggests that on the whole, homeowners in this study irrigated efficiently when compared with the theoretical requirement for maximum growth of turf grass.

Table 5.15 Irrigable area and application rate

Study City	**Avg. Irrigable Area** (sf)	**Avg. Annual Outdoor Use** (kgal)	**Avg. Application Rate** (inches)	**Net ET for Turf Grass** (inches)	**Application as a Percent of ET**
Cambridge, ON	6998	7.8	3.1	15.7	20.0%
Waterloo, ON	5951	7.8	2.9	15.7	18.4%
Seattle, WA	6058	21.7	7.7	26.4	29.0%
Tampa, FL	12361	30.5	6.3	26.0	24.2%
Lompoc, CA	4696	39.9	14.9	35.5	41.9%
Eugene, OR	6863	46.7	16.9	23.7	63.4%
Boulder, CO	6512	72.9	16.7	30.2	68.4%
San Diego, CA	5904	99.3	33.1	44.0	75.3%
Tempe, AZ	7341	100.3	47.5	72.5	65.6%
Denver, CO	7726	104.7	28.3	33.4	85.0%
Walnut Valley WD	10282	114.8	27.4	67.1	40.8%
Scottsdale, AZ	4968	156.5	34.9	72.5	48.1%
Phoenix, AZ	9075	161.9	38.6	73.4	52.6%
Las Virgenes MWD	16306	213.2	36.0	48.1	74.8%

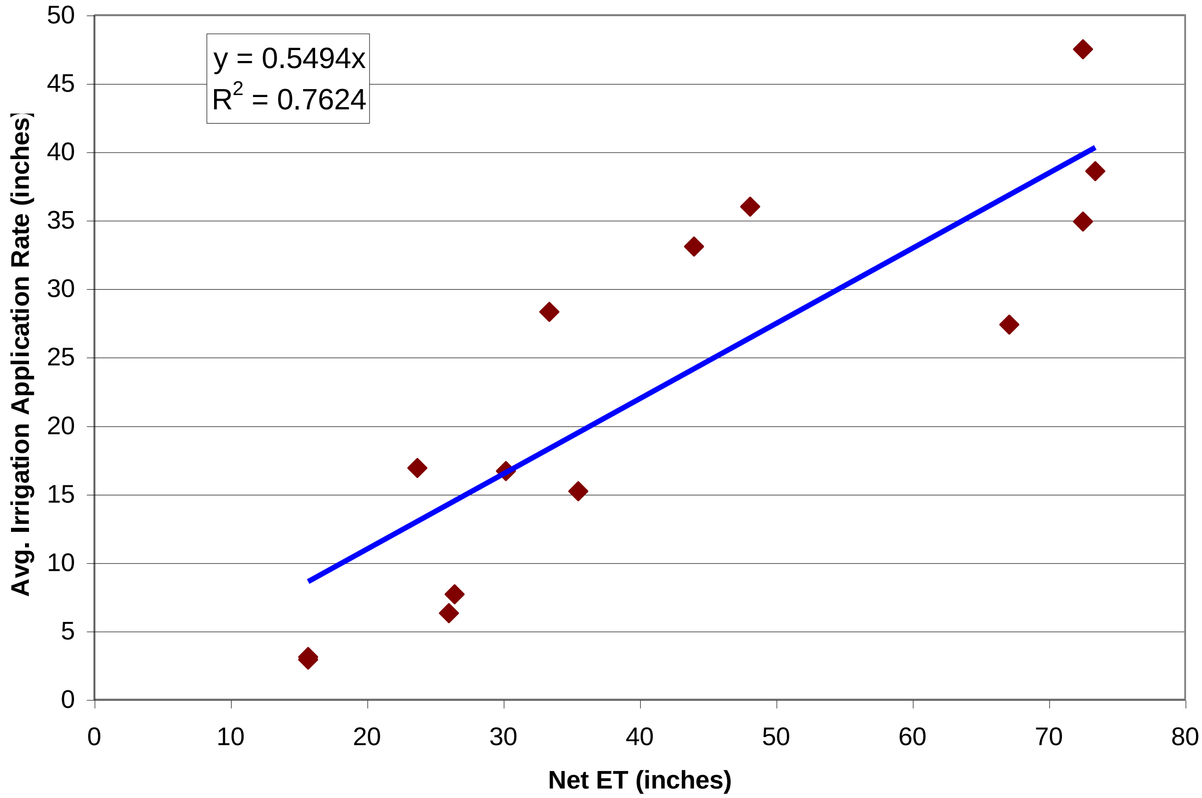

Figure 5.16 Irrigation application rate vs. net ET

Figure 5.16 is a plot of average annual irrigation application rate for each study city vs. the net ET. A regression line was fit to these data and the R^2 was 0.76 indicating a good relationship between climate and average irrigation application. The equation for this line is: *y=0.55x* which means a city might expect their single family accounts to apply roughly 55 percent of the ET requirement on their irrigable area over the course of a year. In practice this application would be expected to be heavier in certain areas of the landscape such as turf grass and lighter in un-landscaped areas, but average application for the entire irrigable area is around 55 percent.

Variability in Outdoor Water Use

The preceding analysis suggests that in aggregate there is a good relationship between the prevailing climatic conditions and amount of water people apply on their landscapes. This analysis also indicates that on average the participants in this study applied significantly less water to their landscapes than the climate conditions would dictate for maximum plant growth. But when the data from each household are shown individually, a different picture emerges. It turns out that within each participating city and across the study group there is considerable variability in application rates and because of this variability it becomes much more difficult to predict water use on the individual account level.

Figure 5.17 is a frequency diagram (histogram) showing the distribution of application rates as a percent of ET for all households in the study. Nearly 22 percent of the participating households applied less than 10 percent of the theoretical requirement to their landscapes and 51 percent of the households applied less than 40 percent of the ET requirement. Nearly 17 percent of the households applied more than 100 percent of the ET requirement to their irrigable area.

A scatter diagram which plots each individual application rate against the net ET (n = 1130) further illustrates the variability in irrigation habits among study participants. Figure 5.18 shows this distribution and a regression line fit to this data. Unlike the averaged application rate plot shown in Figure 5.16, the regression line in Figure 5.18 is not nearly as good a fit of the data. The R^2 in this case was 0.1645 indicating a much weaker relationship between climate and individual irrigation application rates. On the individual household level, the relationship between outdoor water use, lot size, and net ET for this study group is less clear.

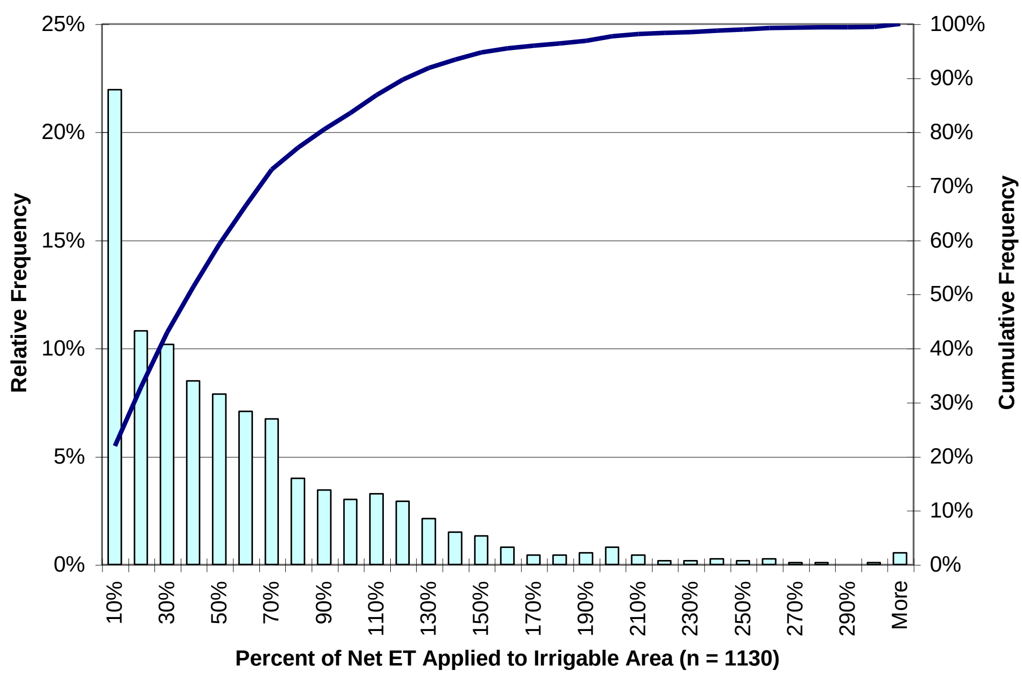

Figure 5.17 Histogram of percent of net ET applied to irrigable area

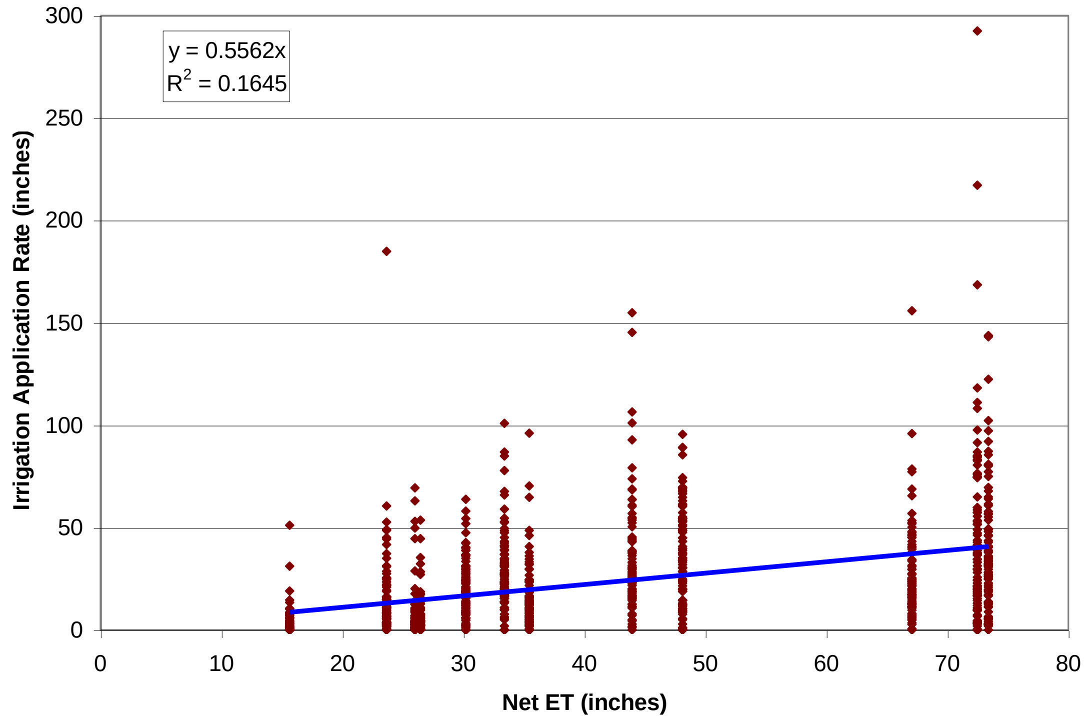

Figure 5.18 Scatter diagram of irrigation application rates vs. net ET

PEAK USE

Peak demands are often the driving factor for facility expansions and facility design. The REUWS database provided an excellent opportunity to study peak usage during the data logging periods. Peak instantaneous and peak day usage results were obtained.

Peak Instantaneous Demand

Peak instantaneous water use is the highest flow rate observed during a given time interval. It is important to understand these flow rates when sizing water meters or designing pipe networks. In the REUWS, flow rates were recorded every 10 seconds so it was possible to calculate the peak instantaneous demand for each logged day from each of the 1,188 study homes. Figure 5.19 is the frequency distribution of the peak instantaneous flow rate observed during each of the logged days for each study house. 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 this figure. Days without any water use were excluded from Figure 5.19, so a total of 27,579 logged days are included in this distribution.

More than 85 percent of the water meters serving the REUWS study homes were either 5/8" or 3/4" in size. But there were a small number of 1" meters and an even smaller number of 1 ½” meters. The rated peak flow capacity of a 5/8” meter (the most common size in the REUWS) is approximately 25 gpm. The rated peak flow capacity of at 3/4" meter is approximately 35 gpm and the peak flow capacity of a 1 ½” meter (unusual in the single-family sector) is 100 gpm. The highest peak flow recorded in this study was 64.6 gpm. The mean peak flow was 8.2 gpm, the standard deviation was 5.0 gpm, and the median peak flow was 6.7 gpm. Just over 98 percent of the observed peak instantaneous flows fell below 25 gpm. This suggests that almost every home in the study could have been adequately served with a 5/8" water meter.

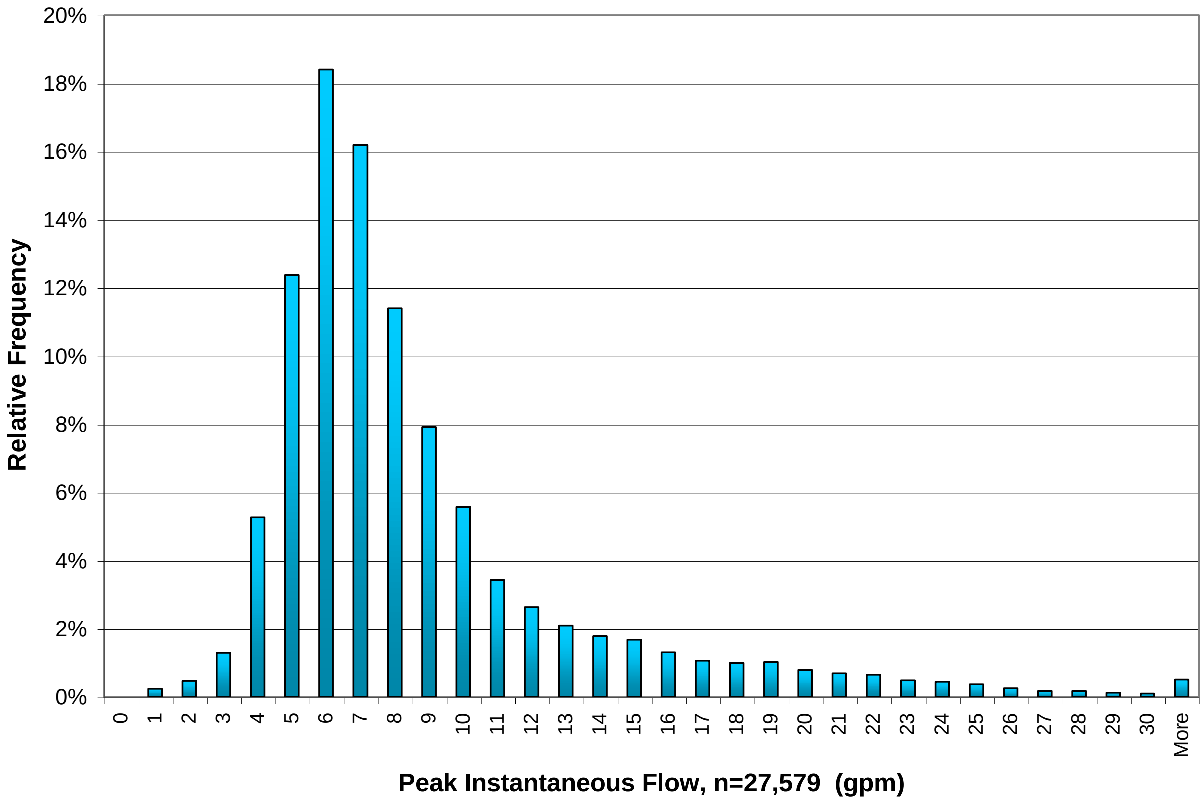

Figure 5.19 Peak instantaneous flow rate distribution

Peak Day Demand

When sizing water treatment facilities, peak day demand is one of the critical design criteria. Few utilities have good measurements of peak day demands in individual sectors of their service area. Using the REUWS database, the peak day demand (logged day with the maximum volume usage) for each of the 1,188 study homes was calculated. These data were assembled into a frequency distribution shown in Figure 5.20. The mean peak day demand was 1411.2 gpd and the standard deviation 1896.0 gpd. The median peak day demand was 953.5 gpd. Peak day demand ranged tremendously from below 1 gallon in an unoccupied home to 36,810 gallons in a home with an enormous automatic sprinkler system. Seventy-nine percent of the recorded peak days were between 300 and 3,000 gallons.

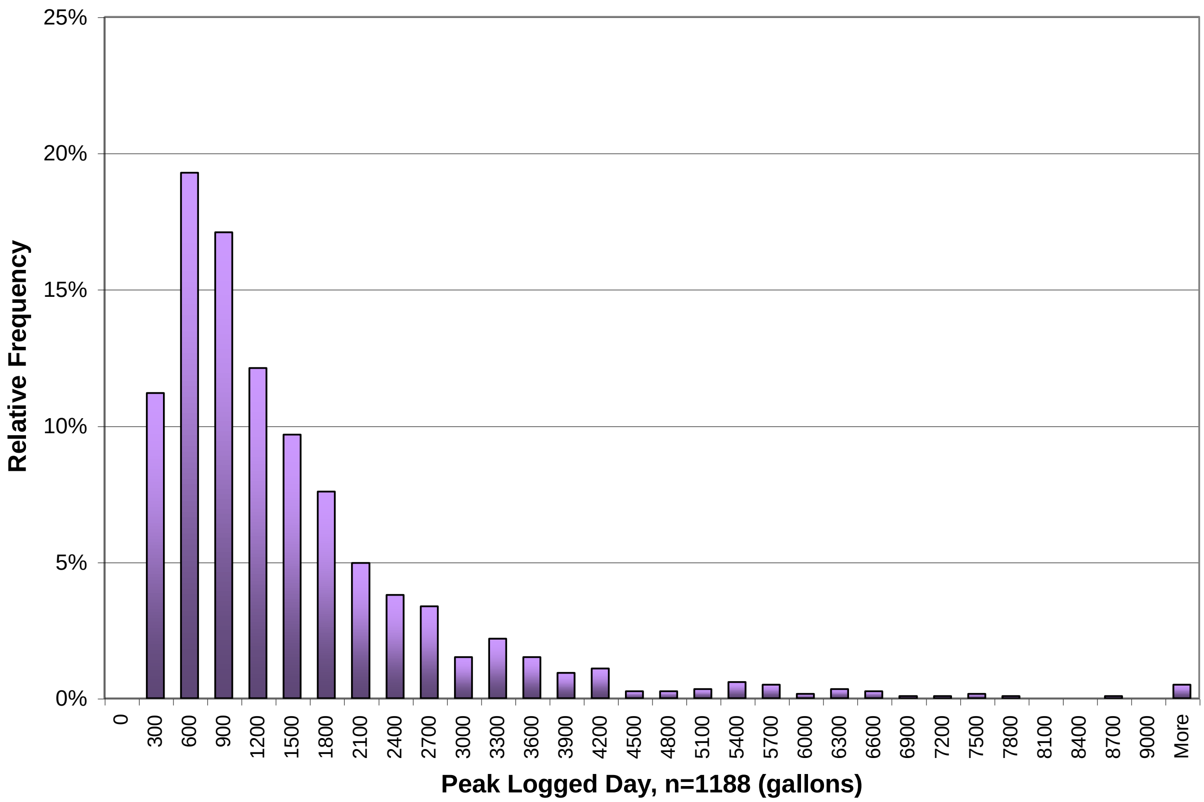

Figure 5.20 Distribution of peak logged day demand

Water Pressure Delivery Ranges

One of the factors that can influence peak demand is the ambient water pressure in the delivery system. As part of the REUWS each participating water utility and provider responded to a questionnaire about their water system. One of the questions asked for information about the typical range of water pressure found in their specific system. Table 5.16 presents the responses to this question from each participating utility. Most utilities responded to the question by reporting the range of water pressure found at the customer meter. However, based on the high pressures reported by Las Virgenes MWD and Walnut Valley WD it appears that not all respondents interpreted the question in the same way.

Table 5.16 Water pressure ranges in distribution systems

Utility/Provider	**What are the range of pressures in your water distribution system?**
Boulder, Colorado	80 – 160 PSI
Cambridge, Ontario	20 – 100 PSI
Waterloo, Ontario	20 – 100 PSI
Denver, Colorado	40 – 110 PSI
Eugene, Oregon	40 – 80 PSI
Las Virgenes MWD, California	30 – 500 PSI
Lompoc, California	85 – 120
Phoenix, Arizona	60 – 120 PSI
Municipal Region of Waterloo	50 – 70 PSI
San Diego, California	40 – 85 PSI
Scottsdale, Arizona	40 – 120 PSI
Seattle, Washington	40 - 80
Tampa, Florida	20 - 65 PSI Typical = 45 PSI
Tempe, Arizona	50 – 90 PSI
Walnut Valley WD, California	40 – 180 PSI

HOURLY USE

The 1993 AWWARF report Residential Water Use Patterns (Bowen et. al.) documented the hour by hour water use patterns of single family homes in five American cities. That study also used portable flow data loggers to obtain their data. Few other studies have been able to document the hourly water use patterns of single-family customers. 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. This type of analysis has been performed by water and wastewater treatment facilities for years to assist in planning for treatment capacity. Measurements in these cases are usually made with production and inflow meters. It was known that urban water use followed a diurnal curve with peaks occurring the morning and early evening.

Figure 5.21 presents the hourly patterns for indoor, outdoor and total water use. These curves were calculated by summing the volume of all water use events across all 12 study sites that began during each hour irrespective of the date. For example, all irrigation events from Eugene that started between 7 a.m. and 8 a.m. are lumped with irrigation events from Lompoc (an all other study sites) that started between 7 a.m. and 8 a.m. and so on.

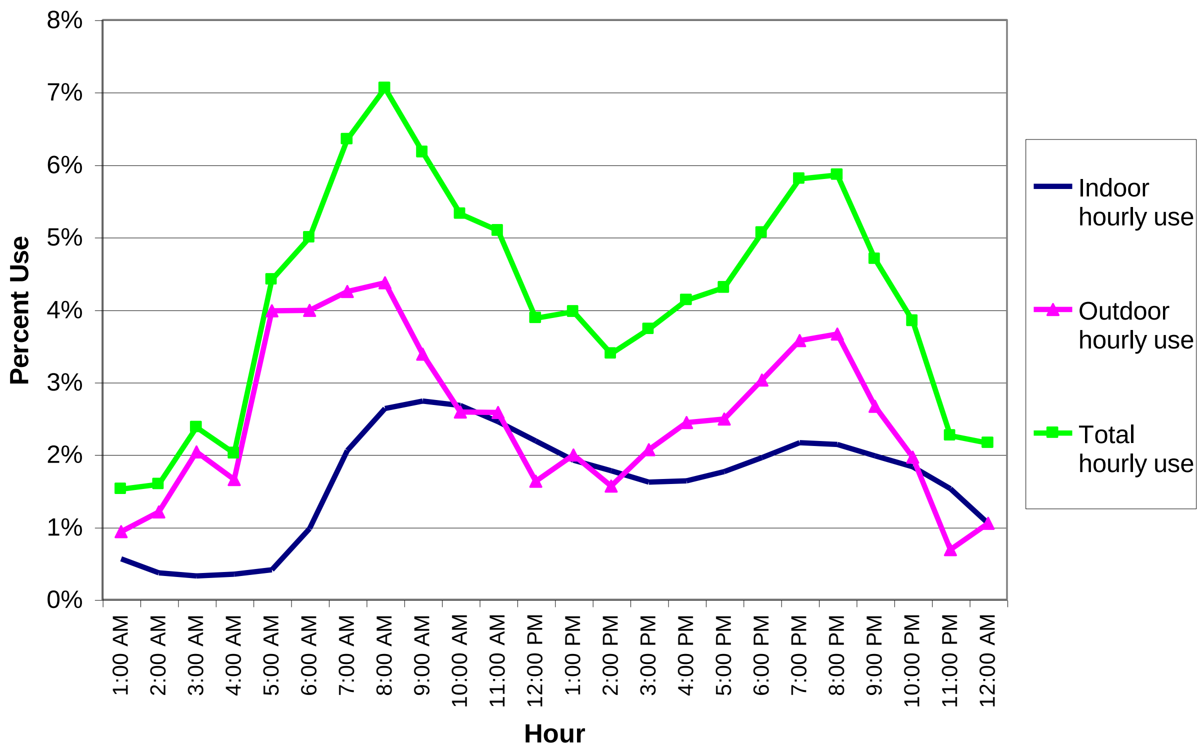

Figure 5.21 Hourly use pattern, averaged for all 12 study sites

Indoor, outdoor and total use all follow the diurnal curve pattern described by water treatment and wastewater operators. Outdoor use rose dramatically at 5 a.m. driven by automatic sprinkler systems which were programmed to begin watering in the early morning. The morning outdoor peak continued through to 9 a.m. as the automatic irrigators were joined by manual irrigators or "hose draggers". Outdoor use declined from 11 a.m. to 2 p.m. The second outdoor peak increased more gradually from 2 p.m. to 8 p.m. when it decreased sharply for the night.

Indoor use followed a smooth diurnal curve pattern. Indoor use ramped up steeply starting at 6 a.m. and peaking at 9 a.m. fueled by toilet, shower, and faucet usage. The evening indoor peak began at 5 p.m., peaked at 7 p.m., and diminished after 11 p.m. The combined indoor and outdoor peaks occurred at 8 a.m. and 8 p.m.

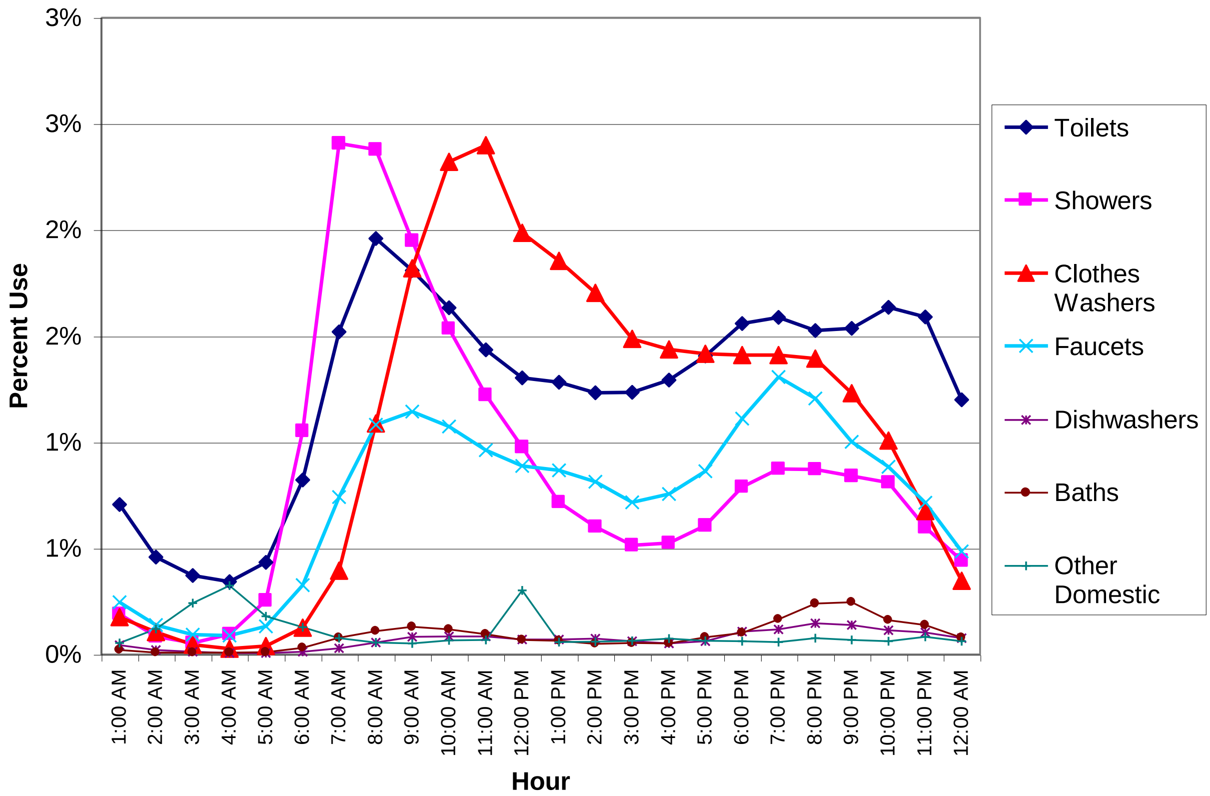

Figure 5.22 Disaggregated indoor hourly use patterns, averaged across 12 study sites

The disaggregated hourly indoor use patterns throughout the day are shown in Figure 5.22. These curves represent the same total volume shown in the indoor use curve in Figure 5.21, but here indoor use is broken down by specific end use. To develop these curves, the volume for each indoor end use recorded in all 12 study sites was summed based on the hour in which the end use event started. Toilets, showers, clothes washers, and faucets are the most prominent end uses shown in Figure 5.22.

Toilet use occurs 24-hours a day, but increases steeply starting at 6 a.m. Toilet use peaks between 8 and 9 a.m., decreases slightly during the later morning and afternoon and increases again in the evening between 6 and 11 p.m. Shower use is virtually non-existent from 3 to 5 a.m., then ramps up sharply peaking from 7 to 9 a.m. Shower use then decreases sharply for the rest of the morning and early afternoon, but reaches a secondary but lower peak from 6 to 10 p.m.

Clothes washer use is also very low during the early morning hours, but increases dramatically just after the toilet and shower peak period, from 8 a.m. to noon. Clothes washer use is fairly steady for the remainder of the day, decreasing down to almost nothing starting a 9 p.m. Faucet use also follows a diurnal pattern, but peak faucet use occurs between 6 and 9 p.m. The slightly smaller morning faucet peak occurs from 7 to 10 a.m.

The pattern of use for the lower volume end uses (baths, dishwashers, and other domestic) is harder to distinguish. Bath usage is highest between 8 and 10 p.m. Dishwasher usage is relatively constant throughout the day starting at 9 a.m. The other domestic category has two small peak periods, one in the early morning from 3 to 5 a.m. and the other at noon. Both of these peaks are due to home water softening equipment which operates on a timer and tends to be programmed to operate in the early morning hours when there is little other water use. Water treatment was most common in homes in Waterloo and Cambridge and in Scottsdale and Tempe.

COMPARISON OF REUWS RESULTS WITH OTHER STUDIES

A number of studies over the past 15 years have attempted to physically measure single-family residential water use including the classic HUD study (Brown and Caldwell, 1984), the East Bay MUD Water Conservation Study (Aher et. al. 1991), the impact of conserving fixtures study in Tampa, Florida (Anderson et. al., 1993), and a series of Aquacraft end use studies in Boulder and Westminster, Colorado (Aquacraft, Inc., 1995; 1996; 1998). One of the most striking differences between these previous studies and the REUWS is the sample size. The

HUD study had the largest sample size of these studies with 210 homes while the REUWS had a final sample size of 1,188 homes for which data loggers were installed and end use quantities successfully estimated. All of these studies made careful measurements of residential end uses using a variety of techniques and technologies ranging from toilet flush counters and shower flow measurement devices to elaborate PC-based data collection systems wired to individual fixtures within each home. It is worthwhile to compare results of these previous studies to the findings from the REUWS.

Per Capita Per Day Comparison

Because the measurement techniques and level of disaggregation of end uses varied from study to study it is not always possible to make direct comparisons of usage rates and fixture utilization. Only the recent Aquacraft studies, conducted in Boulder and Westminster Colorado, offered disaggregation of end uses at the same level of detail as the REUWS, and that is chiefly because of the data collection and analysis technique were the same. Table 5.17 presents a comparison of the measurement of gallons per capita per day (gpcd) from each of these studies.

The total gallons per capita per day measured by each of these studies ranges from 40 gpcd to 69.3 gpcd. The two studies with the largest sample size, the REUWS and the HUD study, were quite close in the estimates of total daily per capita usage, differing by only 3.1 gpcd overall. The variability in per capita use can be seen in the comparison of usage among the different participating cities in the REUWS and in the analysis of variability for different end uses presented in earlier sections of Chapter 5. These results suggest that regional differences may partially explain the variability in indoor water use which may account for some of the differences in findings between the REUWS and previous studies shown in Table 5.16. The regional variability in indoor water use found in the REUWS underscores the importance of obtaining local data for measuring conservation effectiveness, calibrating conservation models, and forecasting future demands.

Table 5.17 Comparison of indoor gallons per capita per day water use found in previous studies and the REUWS

Fixture	1984 HUD Study	1991 East Bay MUD	1993 Tampa Study	1994 Heatherwood Study	1995 Westminster pre-1977 housing	1995 Westminster post 1984 housing	1998 REUWS
Toilet	24.3	12.8	13.7	15.1	18.4	14.1	18.5
Shower & Bath	18.9	13.5	11.0	11.1	14.1	14.1	12.8
Laundry	12.6	-	-	14.4	14.7	13.0	15.0
Faucets (kitchen and lavatory)	10.4	-	-	9.1	6.7	5.3	10.9
Dishwasher	-	-	-	1.9	0.8	0.7	1.0
Other Domestic	-	13.7	26.0	-	7.3	0.1	1.6
Leaks	-	-	-	7.2*	1.5*	3.3*	9.5*
TOTAL	66.2	40.0	50.7	58.8	63.5	50.6	69.3
Sample size, # of homes	210	25	25	16	20	20	1188

Footnote:
* Includes outdoor leakage as well

Fixture Utilization Comparison

Previous residential end use studies also measured fixture utilization by study participants. These utilization values include the flushes per capita per day, showers per capita per day, as well as clothes washer and dishwasher loads per capita day. The REUWS was able to add duration of faucet usage per capita per day to this list. A comparison of the fixture utilization results from previous studies is shown in Table 5.18.

Findings of fixture utilization from previous studies are similar to the REUWS for faucets and clothes washers. Per capita toilet utilization in the REUWS was found to be 25 percent higher than the 1984 HUD study (5.05 vs. 4.0 flushes per capita per day). Interestingly, the REUWS daily per capita toilet flushes was almost identical to the value published in a 17 year old AWWA conservation handbook, 5.05 vs. 5.0 flushes per capita per day (AWWA, 1981). However, per capita dishwasher utilization was found to be about 60 percent less in the REUWS than in the AWWA manual. The difference in per capita dishwasher utilization between the REUWS and the HUD study was 0.07 dishwasher loads per capita per day, a difference of 41 percent. The per capita clothes washer utilization found in the REUWS was 0.07 loads per day more than the HUD study or the AWWA manual, a difference of 23 percent.

Table 5.18 Fixture utilization values from REUWS and previous studies

	Fixture utilization per capita per day (daily uses per capita)				
Fixture	**1981 AWWA Handbook**	**1984 HUD Study**	**1991 East Bay MUD**	**1993 Tampa Study**	**1998 REUWS**
Toilets	5.0	4.00	3.2	3.8	5.05
Showers and baths	0.9	0.74	-	0.7	0.75
Clothes washers	0.3	0.30	-	-	0.37
Dishwashers	0.25	0.17	-	-	0.10
Faucets	-	-	-	-	8.1 minutes

CONSERVATION EFFECTIVENESS

While the primary purpose of this study was to quantify water use in single family homes, it is possible to use the assembled database to evaluate water use in homes equipped with conserving and non-conserving fixtures. This section presents the observed water savings achieved through the use of ULF toilets and LF showerheads in the 1,188 study homes. While these results are certainly indicative of savings achievable with high efficiency fixtures the sample sizes are too small for them to be considered the final word in the measurement of conservation effectiveness.

Ultra-Low-Flush Toilets

While many studies have documented the water savings achievable from the installation of ultra-low-flush (ULF – 1.6 gallons per flush (6.0 lpf)) toilets (Aher et. al. 1991, Anderson et. al 1993), few studies have physically measured the savings and no study has the quality and sheer volume of real world data of the REUWS. 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. A frequency distribution of all recorded toilet flushes was shown in Figure 5.10.

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 to the "non-ULF" homes is therefore is 10.5 gpcd. These results are shown in Table 5.19.

Table 5.19 ULF and non-ULF toilet use across 12 study sites

Toilet category	**Sample size**	**Toilet use per household** (gpd)		**Toilet use per capita** (gpcd)		**Flushes per capita per day**	
		Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
ULF only	101	24.2	10.3	9.6	4.4	5.06	2.65
Mixed toilets	311	45.4	18.7	17.6	7.4	5.39	2.72
Non-ULF	776	47.9	19.3	20.1	8.5	4.92	2.50
All homes	1188	45.2	18.4	18.5	7.9	5.05	2.69

A two tailed z-test for significance was performed on the mean daily per capita usage for the ULF and non-ULF study homes with the hypothesis that they were not statistically different. The hypothesis was rejected and the difference between the means of 10.5 gpcd was found to be significant at the 99 percent confidence level. A similar test was performed on the per capita flushes per day and the difference of 0.14 flushes per capita per day was not found to be statistically significant at the 99 percent confidence level.

These findings from the REUWS indicate that a complete ULF retrofit in a single-family detached home without any existing ULF toilet fixtures can achieve a potential water savings of 10.5 gpcd or approximately 8,650 gallons per year. The often hypothesized and reported ULF problem of double flushing was not detected in this study. The average flushes per capita per day for the ULF homes and non-ULF homes were not statistically different, indicating that study homes which exclusively use ULF toilets are not flushing more frequently than homes without any ULF toilets. It appears that double flushing of ULF toilets does not happen any more often than double flushing of non-ULF toilets.

Ultra-Low-Flush Toilet Savings Found in Other Studies

A number of studies have measured water savings achievable from installing ULF toilets. These studies include the Stevens Institute of Technology micro-metering studies for East Bay MUD and Tampa, Florida (Aher et. al. 1991; Anderson et. al. 1993), A&N Technical Service's statistical models developed for MWD (Chesnutt et. al. 1992a, 1992b; 1994), and Aquacraft's small scale retrofit study in Boulder, Colorado (DeOreo et. al. 1996). The per capita per day toilet savings found in these studies is compared with the REUWS results in Table 5.20.

Table 5.20 Comparison of ULF savings from other studies

Research project	**Per capita savings from ULF toilets** (gpcd)	**Saturation rate of ULF toilets in conserving homes**
REUWS	10.5	100%
MWD 1992 - 1994*	11.4	73%
Tampa, Florida 1993†	6.1	100%
East Bay MUD 1991‡	5.3	100%
Boulder Heatherwood 1996§	2.6	50%

Footnotes:
* Chesnutt et. al. 1992a, 1992b; 1994
† Anderson et. al. 1993
‡ Aher et. al. 1991
§ DeOreo et. al. 1996

The savings found in the REUWS were higher than found in all the other studies except for the statistical models developed for Southern California. It should be noted that the REUWS was not retrofit study and no conserving hardware was installed as part of this research. Rather, the ULF savings estimates were calculated as the difference between the mean per capita toilet usage in homes which exclusively used ULF toilets and homes in the study which did not use a ULF. An intervention study in which the same group of homes are retrofit with conserving fixtures would be a logical next step to better quantify the savings achievable through the installation of ULF toilets.

Low-Flow Showerheads

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 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. These results are shown in Table 5.21.

Table 5.21 LF and non-LF daily shower use

Shower category	**Sample size**	**Shower use per household** (gpd)		**Shower use per capita per day** (gpcd)		**Shower duration** (minutes)	
		Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
LF houses	177	20.7	14.2	8.8	6.6	8.5	3.4
Mixed houses	712	32.2	20.9	11.8	8.2	8.0	3.8
Non-LF houses	289	34.8	24.7	13.3	10.3	6.8	3.1
12 study sites	1178	31.1	20.8	11.7	8.4	7.8	3.6

A two tailed t-test for significance assuming unequal variance was conducted at an alpha level of 0.05 to determine if there was a significant difference between the mean per capita usage for the LF and non-LF study homes. He null hypotheses was that the two means were equal; they alternate hypothesis was that they were not equal. The difference in per capita use between the LF and the non-LF per capita shower usage was found to be significant (at the 0.05 probability level) given the t-statistic of 6.8 is greater than the critical value of 1.97. The same interpretation can be made by looking at the p-value which is less than 0.05, thus the conclusion that the means are significantly different. A similar test was performed on the average shower duration for the LF and non-LF group and the difference of 1.7 minutes per shower was found to be statistically significant at the 95 percent confidence level.

The difference between the two groups suggests that a retrofit of a non-LF home could result in annual water savings of approximately 4,500 gallons per year. It was also shown that households which shower at a lower average flow rate do tend to take longer showers. A statistically significant difference was observed in the mean shower duration in the LF and non-LF shower homes. This result suggests that greater shower water savings would be available if the LF occupants could reduce the duration of their showers to the level of the non-LF homes.

Low-Flow Showerhead Savings Found in Other Studies

A number of studies have measured water savings achievable from installing low-flow shower heads. These studies include the Stevens Institute of Technology micro-metering studies for East Bay MUD and Tampa, Florida (Aher et. al. 1991; Anderson et. al. 1993) and the 1984 HUD study (Brown & Caldwell 1994). The per capita per day shower savings found in these studies is compared with the REUWS results in Table 5.22.

Table 5.22 Comparison of LF showerhead savings from other studies

Research project	**Per capita savings from LF showerheads** (gpcd)	**Saturation rate of LF showerheads in conserving homes**
REUWS	4.5	100%
HUD 1984*	7.2	NA
Tampa, Florida 1993†	3.6	100%
East Bay MUD 1991‡	1.7	100%

Footnotes:
* Brown and Caldwell 1984
† Anderson et. al. 1993
‡ Aher et. al. 1991

The savings found in the REUWS were higher than found in all the other studies except for the HUD study. It should be noted that the REUWS was not retrofit study and no conserving hardware was installed as part of this research. Rather, the LF showerhead savings estimates were calculated as the difference between the mean daily per capita shower usage in homes in which the residents showered exclusively at or below the 2.5 gpm flow rate and homes in which the residents showered exclusively above the 2.5 gpm flow rate. An intervention study in which the same group of homes are retrofit with conserving fixtures would be a logical next step to better quantify the savings achievable through the installation of LF showerheads.

Landscape Measures

The practice of replacing traditional turf grass with low-water-use native plants, commonly know as Xeriscape™, offers potential water savings in the single-family detached sector – particularly in the hot and dry Southwestern United States. A number of studies have found that that a Xeriscape landscape can save a measurable amount of water compared with traditional turf grass landscaping (Nelson 1994).

The REUWS mail survey requested information on conservation landscape measures by asking respondents if they had installed "low-water-use landscaping" and if they had altered their irrigation habits. Of the 1,188 logged study houses, 176 responded that they had installed low-water-use landscaping and 1,012 responded that they had not. A comparison of average annual outdoor consumption between these groups resulted in the finding that the low-water-use landscape group actually used slightly more water outdoors annually than the standard landscape group.

However, when the irrigable areas were taken into consideration (using reported parcel size and percent of landscaped area from the survey) it was seen that the application rates of the low-water-use homes were lower than the standard group. The low-water-use group applied an average of 20.3 gallons of water per square foot of irrigated area over an entire year, while the standard landscape group applied 22.8 gallons per square foot for a difference of 2.5 gallons per square foot. However, a two-tailed z-test performed on these two sets of data found that there was not a statistically significant difference in the two application rates (at a 95 percent confidence interval). As a result it is not possible to draw conclusions about the conservation potential of low-water-use landscaping from this study.

There are several possible explanations for this inconclusive finding. First and foremost is the potential inaccuracy in the reported irrigable areas from mail the surveys. Improved measurements of actual lot size, irrigable areas, and landscape characteristics could greatly improve the accuracy with which estimates of the outdoor use can be drawn from the data set. Secondly, new low-water-use landscaping usually requires additional water to become established. This could be a factor here. Third, this simple analysis comparing application rates did not take into account differences in climate and seasonality among the different study areas.

A more in-depth analysis which corrected for these factors might well detect a measurable difference in water use between the low-water-use and standard landscape groups.

Additional Conservation Potential

Clothes washers

After toilets, clothes washers are the next largest component of indoor water use in the single-family sector. While a great number of studies have documented the conservation effectiveness of ULF toilets and many utilities have implemented toilet replacement incentive programs, clothes washers have received less attention. Beginning in the mid-1990s, cost effective water- and energy-conserving horizontal axis clothes washers have finally made their way to the North American market. These horizontal axis machines, which are often referred to as “front-loaders” because the clothes are placed in the machine through a door on the front rather than the top of the machine, have been popular in Europe for many years. These clothes washers had been prohibitively expensive for the American consumer with machines ranging in price from $800 to $1,200 (substantially higher than the more standard vertical axis top-loading washing machines).

Although generally absent from the residential market, horizontal axis machines have been popular in laundromats and commercial laundries. The horizontal axis design has been around for many years and these machines were popular in the late 1940s and 1950s. Due to patent problems, major U.S. manufacturers stopped making horizontal axis washers even as they continued to be developed, manufactured, and sold in Europe and the rest of the world. These machines use less water than the traditional top loading machines because instead of filling up a large tub with water and agitating the fully submerged clothes, the horizontal axis machines fill up only a small portion of the wash cylinder and then moves the clothes back and forth through this supply of water. Horizontal axis machines also spin at a much faster rate which renders the washed clothes with a much lower moisture content. With a lower moisture content, the drying time for clothes is greatly reduced.

In the past two years almost every major North American manufacturer of clothes washers has introduced a horizontal axis clothes washer for the residential market including

Maytag, Whirlpool, and Frigidaire. The proliferation of these machines in the residential sector could result in significant water and energy savings.

Clothes washer water savings represent one of the greatest potential untapped areas for water conservation. Several recent studies have started to document the impact of the new horizontal axis machines (Hill et al. 1996; Dietemann and Hill 1994). In Bern, Kansas (pop. 204) the Department of Energy monitored the population's water and energy consumption for two months and then replaced every single clothes washer in town with a new Maytag horizontal axis machine (Tomlinson and Rizy 1998). A total of 103 clothes washers were provided free of charge to the citizens of Bern. Average clothes washer water consumption in Bern fell from 41.5 gallons per load at the beginning of the study to 25.8 gallons per load with the new horizontal axis machines, a savings of 38 percent. Energy consumption including washer energy and hot water heating was reduced by 58 percent. A small scale study by Aquacraft, Inc. which retrofit four homes with conserving clothes washers found that clothes washer water savings of 20 to 80 percent were possible with these machines (Aquacraft, Inc., 1996b).

In the REUWS, results on horizontal axis clothes washer savings were inconclusive. Only 24 of the 1,188 logged houses reported owning a "front-loading clothes washing machine" on the mail survey. However, because the survey portion of this study was implemented several months before the widespread introduction the new conserving horizontal axis washing machines so it is unlikely that these 24 households owned any of the new conserving machines. Of these 24 survey respondents, four reported that their front-loading washing machine was manufactured in the 1960s and 70s. Several other respondents indicated that their machines were more recent White Westinghouse front-loaders – one of the few domestically built horizontal axis machines available in the early 1990s. One household reported owning a Swedish built Asko machine and one an older American made Gibson. A few of the 24 respondents reported owning a clothes washer built by a manufacturer who did not make front loading machines during the reported year of purchase such as Kenmore and GE.

An analysis of the average gallons per capita per day used for clothes washing by the 24 front-loading accounts and the accounts who reported owning top loading machines was performed. The top-loading group averaged 14.9 gpcd and the front-loading group averaged 15.2 gpcd, but this difference in water use was not found to be statistically significant. It is suspected that a number of the front-loading washer respondents erroneously answered that question on the survey.

The conservation potential of clothes washers is an important area for further study. Cities like Boulder, Colorado are starting to offer conservation rebates to encourage purchase of horizontal axis machines. A systematic study of the impacts of conserving clothes washers in the residential setting would be of great value to the conservation community.

Leak Detection

As noted earlier in this report, leakage represents a significant component of residential water consumption. Households in the REUWS averaged 9.5 gpcd in leaks alone. This amounts to nearly 3,500 gallons per person per year wasted due to leaks. Effective leak detection and repair programs could significantly reduce domestic consumption.

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 per household was 21.9 gallons, the median leakage rate was only 4.2 gallons per household per day indicating a definite skewness in the leakage rates across the study homes. 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.

This result suggests that identifying and repairing leaks in the top 5 to 10 percent of leaking homes would provide the most benefit in terms of water savings than a general leak detection and repair program. The difficulty lies in accurately identifying the large leak accounts in an inexpensive and systematic manner. A good approach to this, suggested by the data, would be to target homes in the top 10 percent of winter water use. In the winter when there is little or no outdoor use, high domestic consumption is more likely attributable to high leakage rates.

Another technique for identifying houses with significant leaks is a sorting and filtering routine which operates in a utility's billing database and flags accounts which have dramatically altered their usage patterns – possibly due to a leak.

Once a potential high leakage account has been identified the utility has a variety of options for further investigation. One relatively simple technique is to install a data logger, similar to those used for this study, on the customer's water meter. Data could be collected for 24 or 48 hours and then analyzed using Trace Wizard software. Persistent leaks due to faulty flapper valves or broken pipes are easily identified. When the existence of a major leak has been confirmed, the customers could be notified and encourage to make repairs. The utility might also offer some form of assistance in cases of need.

Other Opportunities

Additional conservation opportunities in the single-family sector include: installation of low flow faucet aerators to reduce miscellaneous faucet usage, recirculating systems for bleedoff water in evaporative coolers, recirculating systems to decrease the amount of water run through faucets and showers while waiting for hot water to arrive; grey-water reuse systems to augment irrigation water, various landscape retrofits and irrigation control devices, and conservation education programs. The REUWS did not specifically examine the savings available from any of these conservation techniques, but other studies in the literature provide information about many of these approaches.

CHAPTER 6

STATISTICAL MODELS OF END USE MEASUREMENTS

INTRODUCTION

The preceding analyses have clearly demonstrated that differences in water use among single-family households are attributable to the presence and mix of various water using appliances and purposes. Further, the analyses identified a degree of variance in the amount of water used by each end use. Various factors operate behind the scenes to produce this variance, which are related to the *intensity* of water use. For example, two different irrigators will likely apply different amounts of water to the lawn if they face different normal climates, different current weather conditions, and different prices for water. Similarly, the quantity of water demanded for indoor purposes might be expected to differ with the number of people residing at a particular residence and their ability to pay for water.

There have been several studies of single-family water use that have linked differences in weather, price, and socioeconomic factors to differences in monthly, seasonal, and annual use among households. Unfortunately, the general reliance on customer billing records that reflect *total* billed use for a given time frame has up to this point limited the ability to differentiate the effect of these explanatory factors on the various indoor and outdoor end uses of water.[1] The availability of end use measurements made possible through data logging represents an important milestone for water demand planning in that it provides an opportunity to examine how and to what degree end usage varies with household demographics and other pertinent geographic and climate characteristics.

This chapter develops and presents statistical models for explaining water use at the individual end use level. The purpose of these models is to generate knowledge on water use determinants and to demonstrate that (1) end usage can be predicted and (2) certain determinants

[1] For general reference and comparison with the results of the end use models, Appendix D contains a set of more typical water use models estimated from monthly total billing data for the entire sample of households surveyed as part of this study.

are instrumental and can be manipulated to change water use. Ten separate end use models are developed to explain household water use among the following end uses of water:[2]

1. Toilet flushing
2. Shower and bathtub use
3. Faucet and water treatment system use
4. Dishwasher use
5. Clothes washer use
6. Leaks
7. Outdoor use (including swimming pool use and landscape irrigation)
8. Other/unknown use (including evaporative cooler, humidifier, and hot-tub use, and use that could not be assigned to any particular end use of water)

Figure 6.1 illustrates the process for developing models and predictions for the eight end uses of water and generally structures the presentation of the remaining elements of this chapter. First, end use logging data were combined with household survey and price data to develop *inferential* models of water demand at the end use level. The models estimated were designed exclusively to search for and reveal household and home property characteristics that explain, from a statistical perspective, variation in water use from household to household. Using these inferential models as a basis, a *predictive* system of end use models was developed that relies on fewer data inputs. The reduced-form nature of this system is intended to make it somewhat easier to apply the models in their own setting with more accessible data.

The fact that the data logging took place at different times of the year in different locations makes it difficult to test and measure the effects of weather, season (time of year), and climate on the water demanded by the various end uses , particularly the outdoor uses. With this in mind, monthly billing data for the entire sample of single-family households was modeled, using predictions from the reduced-form models as inputs *and* variables denoting weather conditions and time of year. This two-step procedure results in water use predictions for total monthly water use, indoor use, and outdoor use. These predictions were compared with actual

[2] Notice that in some instances end uses have been aggregated. This was performed for some end uses and end use events that occurred only at a few residences, namely for bathtub, water treatment, evaporative cooling, humidifiers, and hot-tub uses.

end use logging and monthly billing data for the logging group to test the general performance of the models in reproducing actual water use.

The discussion begins with an overview of the data used to develop the models, to include a discussion of the household and home property characteristics of logged households and supplemental weather and price data. Following the discussion of the data, results of each of the inferential models are presented and analyzed separately, yet, in the context of other results. The discussion then turns to the development of the predictive system of end use models that can be used to predict average monthly water use with fewer data inputs. The predictive performance of the system is assessed with and without adjustments for weather and seasonality. Details on statistical estimation procedures and the statistical output of all regression models are found in Appendix D, which is referenced in the discussion below.

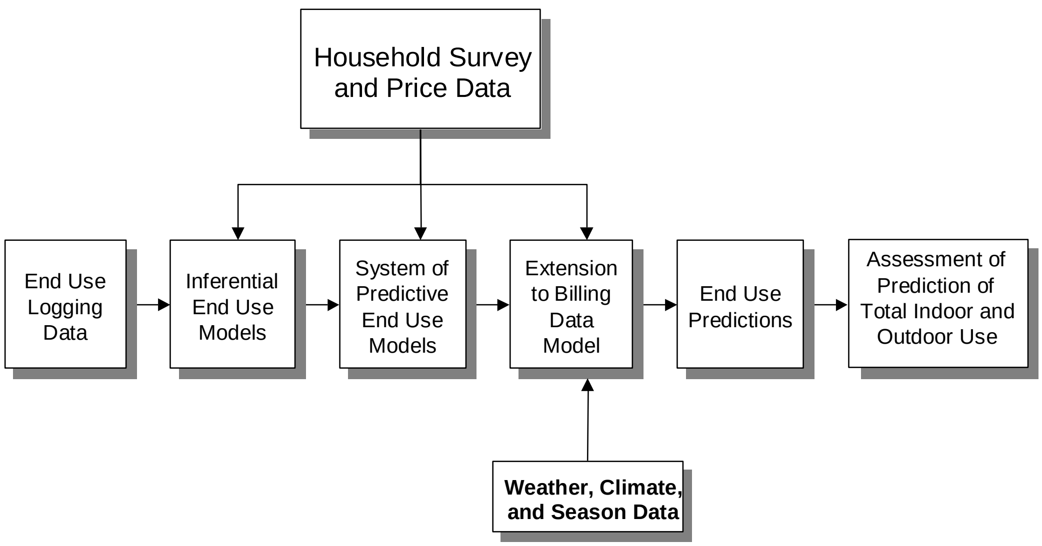

Figure 6.1 Analytical process of model development and verification

SURVEY CHARACTERISTICS OF THE DATA LOGGING SAMPLE

Tables 6.1 – 6.4 present a summary of selected survey characteristics for the sample of households that were logged and used to develop the statistical models. Each table presents a component related to socioeconomic and home property characteristics, the presence of particular end uses, types of irrigation technology utilized, and reported water conservation efforts.

Table 6.1 Reported socioeconomic and home property summary, from survey

Variable	Mean/ percent	Standard error	N
Household size	2.77	0.04	1,187
Number of adults (18+)	2.12	0.02	1,187
Number of teens (13-17)	0.21	0.02	1,188
Number of children (0-12)	0.44	0.02	1,188
Number of toilets	2.32	0.03	1,185
Number of baths/showers	2.33	0.05	673
Household income	64,700	1,400	972
Household lot size (sq. ft.)	10,900	300	960
Household living area (sq. ft.)	2,070	25	1,075
House renters	8.5%		1,165

The average number of persons per household in the sample is 2.77, the majority of which are adults. The average annual household income among the sample (as calculated from the midpoints of the survey categories) is $64,700. The sample average home is approximately 2,000 square feet in size, with about two baths. The average lot size is 10,900 square feet. Less than 10 percent of the sample rent their homes.

Table 6.2 Reported presence or absence of end use, from survey

Variable	Percent	N
Clothes washer	84.8%	1,188
Front-loading Clothes washer	1.6%	1,036
Dishwasher	80.0%	1,158
Swimming Pool	19.0%	1,101
Cooler	9.7%	1,088
Garden (vegetable/flower)	61.2%	1,188

About 85 percent of the logged sample had a clothes washing machine, as opposed to 98 percent in the entire survey group. Only a very small fraction reported having a front-loading clothes washer. Eighty-percent of sample households own a dishwasher. Nineteen-percent of sample households have a swimming pool. Only about 10 percent of the sample reported having an evaporative cooler.

Table 6.3 Reported irrigation technology, from survey

Variable	**Percent**	**N**
Irrigate	95.9%	1,188
In-ground Sprinkler	49.3%	1,188
Sprinkler Timer	37.8%	1,188
Sprinkler Sensor	2.9%	1,188
Hand Hose Sprinkler	34.7%	1,188
Drip Irrigation	15.0%	1,188

Almost the entire sample (96 percent) reported that they irrigated the lawn. Almost one-half of logged households have an in-ground sprinkler system. Almost 40 percent of the sample have a system operated with a timer. Fifteen percent of the sample reported having a drip irrigation system.

Table 6.4 Reported conservation measures, from survey

Variable	**Percent**	**N**
Change in outdoor water using behavior	73.4%	1,188
Change in outdoor water use technology	17.7%	1,188
Change in indoor water using behavior	75.7%	1,188
Change in indoor water use technology	77.5%	1,188
Ultra-low-flush toilet ratio (# of ULFTs/# of toilets)	39.8%	1,051
Homes verified to use ULF toilets only	8.5%	101
Ultra-low flow shower ratio (# of ULFS'/# of showers)	66.6%	892

The majority of the logged households reported taking either behavioral or technological actions to conserve water. Technological changes related to outdoor use (such as a change in system hardware) was mentioned the least. The ultra-low-flush toilet and ultra-low-flow shower ratios, measure the fraction of the total number of toilets and showers in a home that have been retrofitted with the ultra-conserving variety, respectively. On average, it was reported that about 40 percent of toilets are ultra-low-flush, while almost two-thirds of showerheads are ultra-low-flow. These levels of retrofit are much higher than one would expect, given current experience and evidence on the market saturation of ultra-low-flow plumbing devices. Therefore, it is likely that some survey respondents incorrectly classified some of their fixtures as ultra-low-flow, though it is possible some of these fixtures could be classified as conserving (e.g., 3.5 gallons per flush (gpf) toilets instead of 1.6 gpf). With this is mind, the logging traces were analyzed to identify homes in which all toilet flushing events were 2.0 gpf or less. These homes, considered completely retrofitted with ULFTs, comprised approximately 9 percent of the logging sample. A similar check was performed on shower flow rates and it was found that 73.4 percent of the logged homes had average shower flow rates at or below 2.5 gpm.

Price of Water and Sewer

In Chapter 4, Table 4.1 summarizes the marginal (volumetric) prices and rate structures faced by the sample by study location. Most households faced an increasing block scale, usually two blocks, while other households encountered a uniform rate or some seasonal combination of uniform and block rates. Marginal prices range from $0.76/kgal in Eugene to over $5.00/kgal for the Las Virgenes MWD. Half of the locations also included a marginal sewer rate that is based upon billed water use. These rates vary from $0.36/kgal in Scottsdale to $5.41/kgal for the city of Seattle. Locations without a listed marginal sewer rate bill for sewer service through fixed service charges. Compared with recent rate surveys, the water and sewer rates faced by the sample are generally comparable to rates faced nationwide, but are higher than average in some cities and more skewed toward the increasing block rate structure.

An important implication of block rate structure is that marginal price, which may be specified as an independent variable, is in fact *dependent* upon the level of water use. This results in a feedback relationship between the left- and right-hand sides of the regression model (see Appendix D for a discussion on multiple regression), in that price implies a level of water use, which in turn implies a certain marginal price under the block rate scheme, etc. This *endogeneity* results in biased regression estimates. To deal with this estimation problem, observations on marginal price are set to reflect volumetric water rates of the second consumption block for each location with a block structure. The uniform volumetric rate is assigned for marginal price for those locations that do not have a block rate structure. Therefore, this instrument for marginal price varies across locations and time (inasmuch as rate changes took place between logging periods), but not across the households designated by a particular location.

OMITTING WEATHER AND SEASONALITY FROM END USE MODELS

Since outdoor water use can be expected to vary systematically with the season and with fluctuations in weather during any particular time period, daily weather data originally were obtained for each individual household and logging period from appropriate local weather measurement stations. The total number of cooling degree days, total precipitation, and the average of daily high temperatures were calculated to match exactly the weather occurring during each logging period for each household.

Table 6.5 Weather and climate patterns during logging periods

Location	Seasonal ET (Apr-Oct)	Cooling degree days*		Max temperature		Total precipitation	
		Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Boulder	46.0	4.06	15.11	66.88	75.25	3.87	1.43
Denver	42.4	46.84	0.00	84.14	58.03	0.95	0.07
Eugene	29.7	18.24	0.00	80.48	47.08	0.02	5.27
Las Virgenes	39.2	202.36	0.00	91.06	55.47	0.01	11.84
Lompoc	29.9	52.01	0.00	82.61	66.51	0.00	0.27
Phoenix	58.6	188.29	6.74	96.36	74.23	0.00	0.08
San Diego	28.2	124.15	1.13	85.09	69.51	0.00	0.35
Scottsdale	58.8	181.04	0.00	94.56	63.80	0.00	0.63
Seattle	29.5	69.92	0.00	80.26	45.47	0.25	3.02
Tampa	38.2	140.90	99.30	82.97	82.49	2.62	0.55
Walnut Valley	39.3	233.61	8.42	97.33	72.06	0.00	4.07
Waterloo	29.5	49.73	0.79	77.48	62.38	0.55	0.15

* Cooling degree days represent the number of degrees Fahrenheit by which the average temperature for a day exceeds 65 degrees. Cooling degree days were recorded for each day in each logging period/location and then totaled for each logging period/location.

Table 6.5 reviews the mean weather and climate data for the logging periods by study locations. The table suggests a relatively wide range of weather and climate among the locations and logging periods. Specifically, there are differences in normal climates across locations and differences in daily weather between logging periods. Furthermore, the normal climate associated with a location may vary between logging periods, as well. In other words, *place* is directly associated with time of calendar year (i.e., season) and climate, which would lead to unreliable and potentially biased estimates of the impact of weather on water use. Therefore, the effects of weather and seasonality are omitted from the inferential models that are discussed below. Later in the chapter, an analysis of monthly billing data is used to extend the end use models to account for both weather conditions and the time of year in which water use occurs.

INFERENTIAL ANALYSIS

Consistent with the inferential nature of the modeling process, the selection of variables to include among the end use models was exploratory in nature, focusing on the many statistical inferences that can be made from the cross-sectional survey data. From the available data, certain variables were selected a priori, based on practical knowledge of causal influences. For example, the number of persons residing in a household was specified in models pertaining to indoor end uses, and lot size was specified in the outdoor model. In general, to measure the effects of standard of living, either household income or home square footage was specified (but not both variables), depending on the relative marginal contribution of each variable to any particular model. The instrument for marginal price was specified in all models to test for the effects of price at the end use level and to display and compare price elasticities.[3] Other variables were specified and retained based primarily on an assessment of statistical significance.[4]

The models that are presented below represent statistical water use relationships estimated for households that had non-zero logged water use for the particular end use under

[3] Elasticity is a useful concept for analyzing the responsiveness of water use to changes in certain variables such as price and household income. Within the context of analyzing water use, elasticity is defined as the percent change in water use that is caused by a one percent change in the independent variable of interest. Economic theory suggests that price elasticity should be negative, or that, everything else kept constant, an increase in price should lead to a decrease in water use. On the other hand, economic theory tells us that income elasticity should be positive for most goods and services.

[4] Statistical significance of parameters in the regression model is determined by comparing the magnitude of the coefficient estimate with its standard error. The *t-value* provided by most statistical packages corresponds to the ratio of the parameter estimate to its standard error. Thus, the higher the t-value, the higher the confidence that one may place in the reliability of the parameter estimate. The reader is referred to the following texts for a more comprehensive treatment of the meaning, interpretation, and caveats in the use of t-values for statistical inference, as well as for other special topics on interpreting regression results: Kennedy (1992), Kmenta (1986), Judge et. al. (1988).

investigation. In other words, sample households without a particular end use or end use events were left out of the regression analysis.5 In addition, those who were logged for less than five days were removed, as well as those who were logged in only one of the two logging periods. Thus, each model is derived from a *balanced* sample of a particular group of cross-sections that had logged usage in each of two logging periods of at least five days in length. Therefore, the size of the sample (i.e., the number of observations in the regression set) varies, depending on the end use under investigation.[6]

Estimation results are presented below for each of eight inferential end use models. Interpretations are provided first for the indoor end uses, next for the outdoor end uses, leaks, and then for other/unknown flows. Tables of statistical output, including parameter estimates, standard errors, and other pertinent information related to the model estimation process are contained in Appendix D.

Toilet Use

The estimation results for the toilet end use model validate some expectations and verify other interesting relationships. Household size is shown to be an important indicator of water use for toilet flushing. The results suggest 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 results suggest that the impact depends on the age group of the new addition. The coefficients 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-

[5] The omission of zero values helps limit the impact of outliers on model estimation. However, the nature of the data logging and the fact that the sampling periods reflect specific two-week periods in time can still introduce a significant amount of noise (or randomness) into the modeling process. For example, members of a household may leave town for a couple of days, miss a customary washing or lawn watering day, or deviate from normal water-using behaviors because of a variety of circumstances. To the extent that this noise is present in the data, this increases the amount of unexplained variance in the water use data and models.

[6] In addition, the number of observations varies among end use models with respect to the set of independent variables specified. The regression procedure omits an observation, if data are missing for any of the independent variables.

time outside of the home. For those employed outside the home, flushing at work displaces some flushing at home.

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. The coefficient for this variable indicates that water use for toilet flushing increases with the size of the house. The toilet use model also shows a statistically significant, yet *inelastic* price effect. A one-percent increase in marginal price is estimated to lead to a 0.16 percent decrease in water use.[7]

Variables included to account for the decade in which the home was built show an interesting pattern. The modeling results suggest that homes built in the 1950s and 1990s are more likely to have new, more efficient, toilets through retrofit or as a result of the national uniform plumbing codes. One may deduce from these findings that homes built between the 1960s and 1980s are probably better targets for retrofit and ultra-low-flow toilet (ULFT) rebate programs.

Finally, the toilet model confirms 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.[8] 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.

[7] An inelastic relationship is one in which a one percent change in an independent variable (e.g., price) brings about a less than one percent change in the dependent variable (e.g., water used for toilet flushing).

[8] This is estimated by substituting a ULFT ratio of 1 into the toilet model of Appendix D and performing the following calculation: $e^{-0.1066(1)} - 1 \cong -0.10$

Shower and Bath Use

The number of persons residing in a household is a significant factor for explaining variation in shower and bath use. As expected, the coefficient estimates indicate that water use for showers and baths increases with household size. The results also suggest that children and teens use incrementally more water for showers and baths than do adults. In addition, shower and bath use increases with the number of persons employed outside the home, suggesting a higher frequency of use for those who must prepare for or clean-up after work. Shower and bath use is positively related to household income, though the response to changes in income is small. On average, those who rent their homes use more water for showers and baths, given the effects of other variables in the shower/bath model. The estimated price elasticity of shower and bath use is more than twice the price elasticity for toilets. The coefficient for marginal price suggests that a one percent increase in price will bring about a 0.40 percent decrease in water use.

The coefficient estimate for the fraction of showers that are of the low flow variety retains the expected and desired sign. Households that reportedly have all of their showers retrofitted with low-flow showerheads on average use about 10 percent less water for showers than households that are not completely retrofitted (everything else held constant). It is suspected that this estimate of savings is significantly understated because of errors in self-reporting.

Faucet and Water Treatment System Use[9]

Just like the other indoor uses discussed thus far, 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

[9] Because so few households displayed treatment system use within the logging data, treatment system use was added to faucet use for the modeling process. Estimation of the effects of having a treatment system was performed by specifying a binary (0/1) variable in the faucet/treatment model. Therefore, the model is structured primarily to predict faucet use. The estimation results suggest that households with water treatment systems averaged about 32 percent higher faucet and treatment system use than households that did not have treatment systems.

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

As expected, 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.

Leaks

Many variables are found to explain the variance in leakage rates. The quantity of water leaks shows a statistically significant relationship with both the marginal price for water and the marginal price for sewer. The coefficient estimates imply that a one-percent increase in the marginal price of water will lead to a 0.45 percent decrease in the amount of leakage, while a one-percent increase in the marginal price of sewer will lead to a 0.25 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 actively seek to minimize costs.

Following a pattern generally consistent with the indoor end uses, the amount of leakage is positively related to the number of persons in a household and the amount of home living space.

The amount of leaks is shown to increase with the number of toilets in the home. In addition, modeling results suggest that leakage is *higher* in households that have:

- Water treatment systems
- Whirlpool bathtubs
- Evaporative coolers
- Swimming pools[10]

Further, leakage is found to be higher in homes that were built in the 1970s. Interestingly, leakage is found to be generally *lower* for households that use drip irrigation systems or use a hand-held hose for watering.

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

[10] The results indicate that households with swimming pools have a 55 percent greater amount of leakage on average than other households.

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[11]
- 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.

Other/Unknown Use

Other/unknown is taken as the sum of evaporative cooler, hot-tub, and humidifier use, as well as logged traces of water use that cannot be attributable to specific end uses. Only a very small set of sample households had water uses attributable to the use of evaporative coolers, hot-

[11] The modeling process did not capture any significant effects of having a soil moisture or rain sensor as part of the automatic watering systems, likely because of the small segment of the sample that reported having these shut-off

tubs, and humidifiers. Survey data allowed an analysis of the impact of having evaporative coolers and/or hot-tubs on average other/unknown use. Households with evaporative coolers are estimated to use 56 percent more water for other/unknown purposes than households that do not have coolers. Households with hot-tubs displayed, on average, 23 percent higher other/unknown use.

Other/unknown use is shown to increase with household size and decrease with household income. Other/unknown use is positively related to the logged flows attributable to leaks, showers, faucets, and outdoor uses and negatively related to logged flows associated with clothes washers. The coefficient estimates imply that other/unknown use is the most sensitive to changes in the amount of faucet use.

PREDICTIVE ANALYSIS

The inferential end use models reveal many interesting relationships among the end uses of water and the price and survey data. For example, the age and employment make-up of the household has an effect on the amount of water used for toilets, showers, clothes washing, etc., the amount of leakage is associated with the presence of many end uses, and various irrigation techniques contribute to outdoor use differently. Unfortunately, however, many of the independent variables used to estimate the inferential models are accessible only through the implementation of special customer surveys or baseline studies. As a result, this would make it difficult for many water agencies to use the inferential models to predict water use at the end use level within their own service areas. With the objective of making it easier to predict end usage, this section removes many independent variables from the inferential end use models and retains those that are relatively accessible from utility records and secondary sources of demographic information. In this regard, the models designed for prediction may be considered reduced-form versions of the inferential models. A systems approach is then used to develop the predictive end use models. The systems approach, which is explained in Appendix D, accounts for the possibility that errors in predicting water use associated with one end use may be related to errors in predicting water use associated with another end use.

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devices. The finding above should be interpreted literally, in that households with automatic water systems tend to apply more water to the lawn than households that do not employ such systems, everything else held constant.

Estimated System of End Use Models

The set of equations presented below form the predictive end use models. Each end use equation is *multiplicative* in nature, in that terms are raised to given powers (i.e., exponents) and then multiplied to obtain a prediction for a given end use. The "hat" (^) symbols denote that a end usage prediction is obtained upon substituting model inputs into the equations. The equations can be used to formulate predictions of water use for each end use given assumptions about the demographic make-up of a particular water service area. Conceptually, one may derive a prediction of end usage over time from these equations as household and property characteristics change over time (e.g., study the effects of growth in household sizes, incomes, and home and lot sizes). In addition, the toilet and shower models build in a mechanism to study the impact of particular water conservation programs that seek to replace inefficient fixtures.

Toilet Water Use Model (gallons per household per day)

$$\hat{q}_{TOILET} = 14.483 \cdot (MPW)^{-0.225} \cdot (HS)^{0.509} \cdot (HSQFT)^{0.117} \cdot e^{-0.091(PRE60s) - 0.164(POST80s) - 0.076(ULTRATIO) - 0.539(ULTONLY)} \qquad (6.1)$$

where MPW = marginal price of water ($/kgal.)

HS = Household size (average number of persons)

HSQFT = Home square footage (average)

e = base of the natural logarithm (=2.718282)

PRE60s = fraction of homes built before 1960

POST80s = fraction of homes built after 1989

ULTRATIO = fraction of all toilets that are ultra-low-flow

ULTONLY = fraction of customers that are completely retrofitted with ULF toilets

Shower/Bath Water Use Model (gallons per household per day)

$$\hat{q}_{SHOWER} = 3.251 \cdot (MPW)^{-0.514} \cdot (HS)^{0.885} \cdot (INC)^{0.171} \cdot e^{0.349(RENT) - 0.160(ULSRATIO)} \qquad (6.2)$$

where MPW = marginal price of water ($/kgal.)

HS = Household size (average number of persons)

INC = Household income ($, average)

e	= base of the natural logarithm (2.718282)
RENT	= fraction of customers that rent
ULSRATIO	= fraction of all showerheads that are low-flow

Faucet Water Use Model (gallons per household per day)

$$\hat{q}_{FAUCET} = 7.972 \cdot (HS)^{0.498} \cdot (HSQFT)^{0.077} \cdot e^{-0.254(RENT)+0.238(TRTMENT)} \qquad (6.3)$$

where

HS	= household size (average number of persons)
HSQFT	= home square footage (average)
e	= base of the natural logarithm (=2.718282)
RENT	= fraction of customers that rent
TRTMENT	= fraction of customers with home water treatment systems

Dishwasher Water Use Model (gallons per household per day)

$$\hat{q}_{DISHWASHER} = 0.409 \cdot (MPW)^{-0.5171} \cdot (HS)^{0.345} \cdot (INC)^{0.196} \qquad (6.4)$$

where

MPW	= marginal price of water ($/kgal.)
HS	= household size (average number of persons)
INC	= household income ($, average)

Clothes Washer Water Use Model (gallons per household per day)

$$\hat{q}_{CLOTHESWASHER} = 2.293 \cdot (HS)^{0.852} \cdot (INC)^{0.162} \qquad (6.5)$$

where

HS	= household size (average number of persons)
INC	= household income ($, average)

Leak Water Use Model (gallons per household per day)

$$\hat{q}_{LEAKS} = 1.459 \cdot (MPW)^{-0.485} \cdot (MPS)^{-0.160} \cdot (HS)^{0.392} \cdot (HSQFT)^{0.217} \cdot e^{-0.264(RENT)+0.712(POOL)} \qquad (6.6)$$

where MPW = marginal price of water ($/kgal.)

MPS = marginal price of sewer ($/kgal.)

HS = household size (average number of persons)

HSQFT = home square footage (average)

e = base of the natural logarithm (= 2.718282)

RENT = fraction of customers who rent

POOL = fraction of customers with swimming pools

Outdoor Water Use Model (gallons per household per day)

$$\hat{q}_{OUTDOOR} = 0.046 \cdot (MPW)^{-0.887} \cdot (HSQFT)^{0.634} \cdot (LOTSIZE)^{0.237} \cdot e^{1.116(SPRINKLER)+1.039(POOL)} \tag{6.7}$$

where MPW = marginal price of water ($/kgal.)

HSQFT = home square footage (average)

LOTSIZE = size of lot (average in square feet)

e = base of the natural logarithm (= 2.718282)

SPRINKLER = fraction of customers with in-ground sprinkler systems

POOL = fraction of customers with swimming pools

Other/Unknown Water Use Model (gallons per household per day)

$$\hat{q}_{OTHER} = 1.024 \cdot (\hat{q}_{TOILET})^{0.117} \cdot (\hat{q}_{FAUCET})^{0.253} \cdot (\hat{q}_{CLOTHESWASHER})^{-0.054} \cdot (\hat{q}_{LEAKS})^{0.083} \cdot (\hat{q}_{OUTDOOR})^{0.086} \cdot (HS)^{0.162} \cdot (INC)^{-0.058} \cdot e^{0.507(HOTTUB)+0.263(COOLER)} \tag{6.8}$$

where HS = household size (average number of persons)

INC = household income ($, average)

e = base of the natural logarithm (=2.718282)

HOTTUB = fraction of customers with hot-tubs

COOLER = fraction of customers with evaporative coolers

Applying End Use Models: An Example

An example of how the end use models detailed above might be applied is presented in step by step fashion below. This example shows how the Toilet Water Use Model might be applied to determine the amount of water used for toilet flushing.

1. Service area assumptions for single family sector:

   MPW = $2.00

   Average household size = 3 persons per household

   Average square feet of single-family homes = 1,500 square feet

   Fraction of single-family homes built prior to 1960 = 0.05

   Fraction of single-family homes built after to 1989 = 0.15

   Fraction of all toilets in single-family homes that are ultra-low-flow = 0.20 (estimated)

   Fraction of single-family customers that are completely retrofitted with ULF toilets = 0.10 (estimated)

2. Substitution of Service Area Assumptions into Toilet Model

$$\hat{q}_{TOILET} = 14.483 \cdot (2.0)^{-0.225} \cdot (3.0)^{0.509} \cdot (1{,}500)^{0.117} \cdot e^{-0.091(0.05) - 0.164(0.15) - 0.076(0.20) - 0.539(0.10)}$$
$$\cong 44.4 \text{ gallons per day per household in single-family sector}$$

3. Substitution of New Assumptions Related to Active ULFT Toilet Replacement Program

   Fraction of all toilets in single-family homes that are ultra-low-flow = 0.30

   Fraction of single-family customers that are completely retrofitted with ULF toilets = 0.15

$$\hat{q}_{TOILET} = 14.483 \cdot (2.0)^{-0.225} \cdot (3.0)^{0.509} \cdot (1{,}500)^{0.117} \cdot e^{-0.091(0.05) - 0.164(0.15) - 0.076(0.30) - 0.539(0.15)}$$
$$\cong 42.9 \text{ gallons per day per household in single-family sector}$$

4. Average Total Expected Water Savings from ULFT Program

   44.4 – 42.9 = 1.5 gallons per day per household in single-family sector

Comparison of Logged Use with End Use Model Predictions

It is common practice to assess the predictive abilities of a water use model by comparing model predictions to observed use. Because these models operate at the end use level, the end usage allocated through data logging provides a basis with which to compare the general performance of the models. Table 6.6 presents a comparison of allocated end usage derived from the data logging and end use predictions obtained from application of the models.

The comparisons of Table 6.6 indicate that the predictive models perform satisfactorily for most common indoor end uses. However, seemingly, there is a tendency for the models to under-predict the logged use across the board. The most obvious discrepancy is between logged and predicted outdoor use. This, however, should be an expected result, given the intentional omission of weather and season variables from the outdoor equation. As shown in the table, if one were to presented a choice of estimating outdoor use with the outdoor model as it stands or by using the minimum month method, the minimum month method would likely get the nod.

Extending the End Use System to Predict Total Use

As suggested above, the system of predictive end use models should by themselves be adequate for developing conservative estimates of water use for the indoor end uses. However, the inability of the outdoor component to track uses sensitive to weather and climate, makes the system of equations insufficient for predicting average total use in any given time period and location. To improve the ability of the models to track outdoor and total use, monthly billing data of the logging group were analyzed and modeled. Figure 6.2 illustrates the process by which these improvements were performed.

First, the system of end use models was used to develop predictions of water use at the end use level for each household during the log time period using the required data inputs, which have been referenced in the above. These predictions are then used as inputs into a new model that explains variation in average total daily household use over the calendar months and across households and study locations. The new extended model incorporates weather (temperature and precipitation) and time of year (seasonality) into the process of predicting average total daily water use.

Table 6.6 Trace-allocated (and predicted) daily end use for logged households (gallons per household per day)

Location	#	Toilet	Clothes washer	Shower Bath	Faucet/ Treatment	Leaks	Dishwasher	Other	Indoor	Outdoor	Outdoor*
Boulder	1	43.7 (40.8)	35.0 (28.6)	32.4 (28.4)	25.4 (21.3)	5.5 (5.9)	3.6 (2.8)	2.6 (3.0)	148.1 (130.9)	198.3 (58.0)	234.2
Boulder	2	47.7 (42.2)	30.9 (30.1)	38.7 (30.1)	26.5 (21.9)	10.5 (6.0)	2.9 (2.9)	1.4 (3.0)	158.5 (136.2)	180.0 (56.6)	464.9
Denver	1	48.5 (41.8)	40.2 (30.7)	40.7 (30.6)	25.7 (23.4)	9.1 (6.0)	2.7 (2.8)	6.5 (3.1)	173.3 (138.4)	603.6 (49.5)	627.2
Denver	2	50.0 (41.8)	37.5 (31.2)	35.9 (30.5)	24.3 (23.7)	17.6 (6.0)	3.1 (2.8)	2.6 (3.1)	171.1 (139.2)	33.0 (48.5)	33.8
Eugene	1	51.7 (43.3)	39.1 (27.9)	36.7 (32.4)	25.8 (21.2)	21.3 (6.7)	3.4 (3.1)	2.8 (3.0)	180.8 (137.6)	390.4 (49.7)	364.5
Eugene	2	48.4 (42.0)	38.8 (26.6)	36.3 (31.5)	23.1 (20.6)	23.1 (6.3)	3.0 (3.0)	4.2 (2.9)	176.8 (132.9)	8.9 (43.1)	35.0
Las Virgenes	1	42.6 (40.8)	47.3 (40.0)	33.8 (33.5)	35.6 (27.8)	27.9 (10.9)	2.3 (3.0)	7.8 (3.4)	197.3 (159.4)	921.9 (144.3)	778.4
Las Virgenes	2	46.3 (41.4)	52.3 (40.9)	41.8 (34.5)	30.1 (28.0)	27.9 (11.7)	3.1 (3.2)	8.4 (3.5)	209.8 (163.2)	111.3 (160.1)	60.0
Lompoc	1	43.6 (38.5)	45.2 (33.3)	36.7 (30.2)	25.1 (24.9)	22.3 (6.3)	2.1 (2.6)	1.6 (3.1)	176.5 (138.8)	170.0 (38.2)	195.7
Lompoc	2	40.1 (38.9)	43.3 (33.2)	35.5 (30.5)	25.2 (24.7)	24.0 (6.2)	2.3 (2.5)	4.7 (3.1)	175.2 (139.1)	36.7 (36.8)	29.6
Phoenix	1	47.0 (43.9)	38.0 (32.5)	37.0 (31.5)	24.1 (25.1)	38.3 (10.0)	1.9 (2.8)	12.5 (3.9)	198.9 (149.7)	389.2 (94.8)	495.2
Phoenix	2	49.6 (43.6)	45.3 (32.3)	36.4 (30.9)	27.8 (25.1)	28.5 (10.0)	2.4 (2.8)	4.4 (4.0)	194.3 (148.7)	207.9 (94.1)	158.5
San Diego	1	42.1 (36.7)	47.2 (32.1)	24.1 (29.0)	28.3 (24.6)	6.6 (6.9)	2.7 (2.6)	4.5 (2.9)	155.5 (134.8)	266.0 (55.4)	277.5
San Diego	2	40.3 (35.9)	38.1 (31.9)	28.8 (27.7)	27.5 (24.3)	17.5 (6.8)	1.8 (2.6)	3.3 (2.8)	157.4 (132.0)	88.3 (54.4)	46.5
Scottsdale	1	40.1 (41.2)	29.5 (30.3)	29.4 (29.6)	24.2 (24.5)	30.6 (9.5)	2.3 (3.0)	17.3 (3.9)	173.3 (141.9)	546.7 (116.8)	414.8
Scottsdale	2	42.5 (41.7)	34.6 (30.1)	30.0 (30.3)	26.1 (24.3)	37.0 (9.8)	2.3 (3.0)	7.8 (3.9)	180.2 (143.1)	187.3 (118.9)	109.4
Seattle	1	44.9 (39.7)	30.5 (31.3)	34.3 (26.4)	22.8 (22.9)	9.3 (5.4)	2.6 (2.4)	2.8 (2.5)	147.2 (130.6)	204.2 (21.1)	209.4
Seattle	2	45.4 (41.4)	34.9 (31.7)	31.6 (28.9)	20.8 (23.2)	17.1 (5.9)	2.4 (2.6)	2.3 (2.6)	154.4 (136.3)	4.5 (24.6)	34.4
Tampa	1	37.1 (35.3)	34.4 (24.8)	24.3 (23.5)	24.6 (21.8)	11.9 (5.7)	1.6 (2.3)	7.0 (2.7)	140.8 (116.1)	46.0 (57.2)	47.2
Tampa	2	38.0 (36.2)	31.1 (25.8)	29.4 (24.5)	27.8 (22.2)	31.8 (5.8)	1.4 (2.3)	5.9 (2.8)	165.3 (119.6)	96.9 (59.5)	87.3
Walnut Valley	1	53.3 (47.0)	43.9 (38.0)	41.3 (34.0)	42.7 (27.5)	22.9 (9.1)	1.8 (2.9)	9.2 (3.3)	215.0 (161.9)	525.0 (91.0)	482.6
Walnut Valley	2	53.9 (46.7)	46.9 (37.5)	41.5 (32.7)	37.4 (27.1)	24.7 (8.9)	2.3 (2.9)	3.6 (3.3)	210.2 (159.1)	38.5 (84.9)	37.4
Waterloo	1	51.4 (43.9)	37.5 (36.0)	28.5 (33.3)	50.3 (28.7)	17.0 (6.6)	2.1 (2.9)	3.8 (2.9)	190.4 (154.3)	74.2 (27.6)	64.7
Waterloo	2	58.3 (44.4)	40.6 (36.4)	30.2 (33.3)	42.0 (28.9)	15.3 (6.7)	2.4 (2.9)	1.5 (2.9)	190.3 (155.6)	3.0 (23.0)	38.9
All Sites		46.0 (41.3)	39.3 (32.3)	34.0 (30.4)	28.8 (24.5)	20.9 (7.6)	2.4 (2.8)	5.4 (3.2)	171.4 (144.8)	228.7 (68.7)	229.0

Figures in parentheses are SURE (regression model) end use predictions unless otherwise designated.

* Minimum month method was used to calculate these outdoor estimates (by subtracting either the average of the three lowest monthly bills or the lowest bimonthly bill from a selected period total).

As explained in Appendix D, this extended model is capable of producing improved predictions of average total use, indoor use, and outdoor use, using simple algebraic manipulations. The reader is referred to Appendix D for a complete discussion of the extended model. The Appendix contains a ready look-up table that can be used to derive the model for predicting total water use in any particular calendar month and location.

Table 6.7 presents a comparison of allocated logged usage with predictions of use generated via the extended model, which incorporates inputs from the system of end use models, billing data, and weather data. It should be noted that the two-week logging periods never included a complete billing period and that billing data for logged households were not available for the general time in which the households were logged.[12] Therefore, the predictions presented in Table 6.7 reflect (1) estimated water use for billing periods encompassing the times of year (periods) in which the logging samples were monitored, but (2) estimates from a different year than the year in which the logging sample were taken. This incongruency prohibits a precise assessment of the accuracy of the models, but does allow a general diagnosis of model performance.

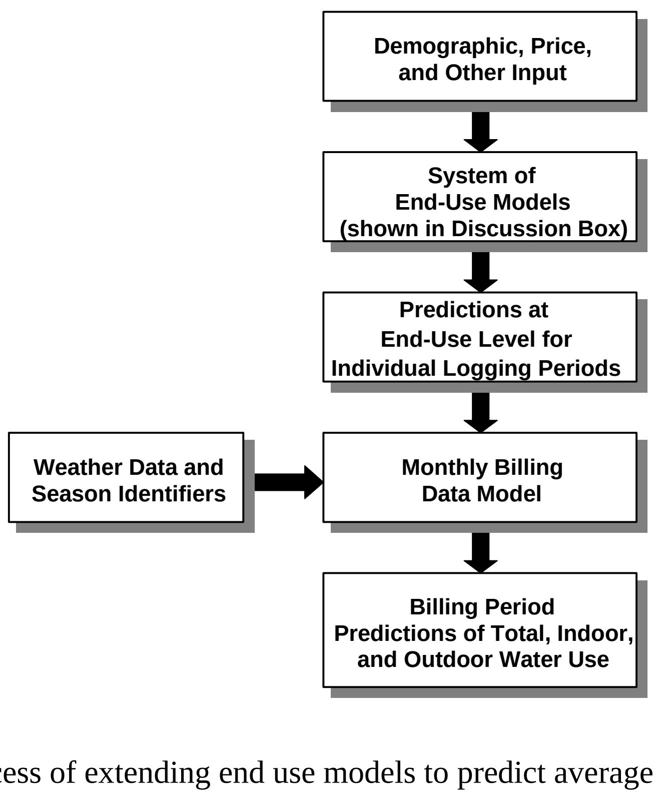

Figure 6.2 Process of extending end use models to predict average total monthly use

[12] Where appropriate, the billing data and predictions were weighted to reflect the interval of logging as closely as possible.

Table 6.7 Comparison of observed and predicted average daily water use (logged households)

Location	Logging Period		Logging Data Avg. Daily Use (gpd)			Billing Data (gpd)	Model Predictions Avg. Daily Use (gpd)		
	#	Date	Total	Indoor	Outdoor	Total	Total	Indoor	Outdoor
Boulder	1	May 21-June 6	346.5	148.1	198.3	374.6	369.4	174.2	196.0
Boulder	2	Sept 1-Sept 19	338.5	158.5	180.0	604.9	618.2	164.7	453.5
Denver	1	June 5-June 21	776.9	173.3	603.6	805.3	747.4	184.4	563.0
Denver	2	Oct 29-Nov 14	209.9	171.1	33.0	207.2	173.2	164.1	9.2
Eugene	1	June 25-July 11	571.1	180.8	390.4	538.3	423.3	210.0	213.2
Eugene	2	Dec 2-Dec 20	185.8	176.8	8.9	196.4	184.9	188.6	-3.7
Las Virgenes	1	Aug 19-Sept 3	1120.3	197.3	921.9	1125.9	1139.5	238.0	901.5
Las Virgenes	2	Jan 27-Feb 10	321.1	209.8	111.3	420.0	381.0	185.5	195.5
Lompoc	1	Sept 9-Sept 23	346.6	176.5	170.0	408.9	465.6	161.4	304.2
Lompoc	2	Feb 24-Mar 9	212.8	175.2	36.7	232.1	274.3	149.9	124.4
Phoenix	1	Apr 29-May 15	588.3	198.9	389.2	846.8	782.8	178.2	604.6
Phoenix	2	Nov 4- Nov 18	403.3	194.3	207.9	506.0	456.4	177.3	279.1
San Diego	1	Aug 7-Aug 25	422.0	155.5	266.0	571.6	503.3	190.1	313.2
San Diego	2	Feb 5-Feb 22	245.7	157.4	88.3	337.0	289.4	149.7	139.7
Scottsdale	1	May 20-June 3	720.2	173.3	546.7	711.9	541.7	171.3	370.5
Scottsdale	2	Dec 2-Dec 18	368.8	180.2	187.3	425.4	327.6	194.2	133.4
Seattle	1	July 17-Aug 1	351.3	147.2	204.2	392.9	372.2	185.9	186.2
Seattle	2	Jan 8-Jan 24	158.8	154.4	4.5	210.0	199.1	153.9	45.2
Tampa	1	Sept 30-Oct 17	189.8	140.8	46.0	188.7	213.5	151.5	62.1
Tampa	2	Mar 5-Mar 20	262.2	165.3	96.9	249.1	281.4	142.2	139.2
Walnut Valley	1	July 29-Aug 12	740.0	215.0	525.0	738.2	673.9	236.9	437.0
Walnut Valley	2	Jan 6-Jan 20	249.0	210.2	38.5	276.6	271.2	192.2	78.9
Waterloo	1	June 23-July 10	270.1	190.4	74.2	214.8	218.6	212.4	6.3
Waterloo	2	Oct 7-Oct 27	193.7	190.3	3.0	185.5	188.1	178.9	9.2

Predictions are based upon the extended billing model.

As shown, the predictions track average total household water use among the locations and time periods quite well, particularly considering the significant amount of variation in use found in the sample. The largest inconsistencies in the comparisons of Table 6.7 appear to occur in the first logging intervals for Eugene and Scottsdale. These particular time intervals may reflect important transition periods in water use in these cities that are difficult to capture in the modeling process.

As would be expected, the predictions of outdoor use improve markedly over the end use model predictions reported in Table 6.6.[13] In addition, the predictions of indoor use generally appear to increase from the values shown in Table 6.6, which suggests that it is important to account for the time of the year in which water consumption occurs when predicting indoor use.

To analyze the abilities of the extended model in predicting total average water use in households that are generally outside of the logging group, Table 6.8 presents a comparison of observed average and predicted average use for the entire survey sample for which data were collected as part of the study (including both log and un-log of households). For cross-comparison with Table 6.6, the same time intervals are analyzed. The extended model again seems to perform well. The prediction for the first time interval for Scottsdale is still troublesome, though the prediction for the first time interval in Eugene is much closer to the observed use than in the comparison of Table 6.7.

[13] The table reports a negative value for outdoor use for the second logging interval for Eugene. For practical purposes, it is recommended (1) that any negative outdoor values be added to the indoor prediction and (2) that the outdoor component then be set to 0.

Table 6.8 Comparison of observed and predicted average daily water use (all households)

Location	**Logging Period**		**Daily Use From Billing Data**		**Projected Daily Use Per House**		
	#	**Date**	**N**	**Total** (gpd)	**Total**	**Indoor** (gpd)	**Outdoor**
Boulder	1	May 21-June 6	910	422.2	375.8	179.4	196.2
Boulder	2	Sept 1-Sept 19	458	623.7	620.2	169.8	450.4
Denver	1	June 5-June 21	444	786.5	747.3	179.7	567.6
Denver	2	Oct 29-Nov 14	375	209.4	169.5	157.9	11.6
Eugene	1	June 25-July 11	1020	475.9	442.7	215.3	226.4
Eugene	2	Dec 2-Dec 20	510	199.2	189.4	193.3	-3.8
Las Virgenes	1	Aug 19-Sept 3	388	1099.1	1097.9	235.7	862.3
Las Virgenes	2	Jan 27-Feb 10	405	395.4	372.9	187.0	185.9
Lompoc	1	Sept 9-Sept 23	465	380.9	432.1	155.2	276.9
Lompoc	2	Feb 24-Mar 9	463	233.2	254.8	144.4	110.4
Phoenix	1	April 29-May 15	421	867.7	739.9	169.2	570.7
Phoenix	2	Nov 4- Nov 18	404	481.8	423.9	166.8	257.1
San Diego	1	Aug 7-Aug 25	536	498.5	483.2	192.4	290.8
San Diego	2	Feb 5-Feb 22	532	283.2	271.5	152.0	119.5
Scottsdale	1	May 20-June 3	554	676.3	557.3	172.3	385.0
Scottsdale	2	Dec 2-Dec 18	550	359.0	341.2	200.8	140.4
Seattle	1	July 17-Aug 1	503	400.0	393.3	188.2	205.1
Seattle	2	Jan 8-Jan 24	432	227.7	201.2	152.7	48.5
Tampa	1	Sept 30-Oct 17	340	201.9	203.1	156.7	46.4
Tampa	2	Mar 5-Mar 20	438	219.3	261.1	141.3	119.8
Walnut Valley	1	July 29-Aug 12	374	772.7	696.1	237.2	459.0
Walnut Valley	2	Jan 6-Jan 20	330	314.6	264.2	186.1	78.1
Waterloo	1	June 23-July 10	565	208.3	217.4	212.8	4.6
Waterloo	2	Oct 7-Oct 27	651	182.4	187.2	177.2	9.9

Predictions are based upon the extended billing model.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

The *Residential End Uses of Water Study* examined where water is put to use in the residential setting and provided specific data on end uses for the purpose of improving estimates of residential water consumption and conservation effectiveness. 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.

Findings in this study included measurements of the daily end uses of water for individual fixtures and in aggregate; comparisons of annual indoor, outdoor, seasonal, and total water use in 12 study sites across North America; saturation rates of water using fixtures and devices; comparisons of conservation implementation; hourly use patterns; evaluation of the water savings achieved through ULF toilets and LF showerheads; predictive water use models which can be used to project demands based on a number of factors. The products of this research effort include this report, the predictive water use models, and the database containing all information collected during the two year study.

This report has detailed where water is used in the single-family residential setting and provided predictive models for projecting residential water demands. While this is an important urban demand sector there are many other areas which were not covered in this report such as multi-family residential water use and commercial and institutional water use. Commercial and institutional water use will be the subject of a subsequent AWWARF report by the same project team.

CONCLUSIONS

A review of the data and statistical analysis resulted in a number of conclusions regarding water use in single-family residences in this study.

Annual Use

Annual water use from historic billing data from approximately 1,000 accounts in each of the 12 study sites ranged from 69.9 kgal. per year in Waterloo and Cambridge, Ontario to 301.1 kgal. in Las Virgenes MWD. The mean annual water use for all 12 sites was 146.1 kgal. with a standard deviation of 103.5 kgal. Across all study sites 42% of annual water use was for indoor purposes and 58% 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 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 to calculate water consumption and mail survey responses to count the number of people per household. Across all 12 study sites the mean per capita indoor daily water use was 69.3 gallons (including leakage). Toilet use was calculated at 18.5 gpcd (27.6%), clothes washer use was 15.0 gpcd (21.7%), shower use was 11.6 gpcd (16.8%), faucet use was 10.9 gpcd (15.7%), leaks were 9.5 gpcd (13.7%), baths were 1.2 gpcd (1.7%), dishwasher use was 1.0 gpcd (1.4%), and other domestic use was 1.6 gpcd (2.2%).

Mean per capita indoor water use in each study site ranged from 57.1 gpcd in Seattle, Washington to 83.5 gpcd in Eugene, Oregon.

Leakage

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 per household 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.

Although not a stated objective of this project, this result suggests that identifying and repairing leaks in the top 5 to 10 percent of leaking homes would provide greater benefit in terms of water savings than a general non-targeted leak detection and repair program. The difficulty lies in accurately identifying the large leak accounts in an inexpensive and systematic manner. A good approach, suggested by the data, would be to target homes in the top tier of winter water use. For the twelve study sites, the data logging results indicate that there is a 76 percent probability that a single family home occupied by four persons or less having winter water use (essentially indoor use) exceeding 12,000 gallons per month (400 gallons per day) has a major leak problem exceeding 4,000 gallons per month (130 gpd). Water utilities may want to target single family accounts with winter water use exceeding 400 gpd to receive a high consumption notice accompanied by suggestions of searching for and repairing leaks.

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.

Toilets

The mean toilet flush volume across all 12 study sites was 3.48 gallons per flush (gpf) with a standard deviation of 1.19 gpf. Study participants used an average of 18.5 gpcd for toilet purposes and they flushed the toilet an average of 5.05 times per person per day. San Diego had the lowest mean toilet flush volume at 2.88 gpf and Eugene had the highest mean toilet flush volume at 3.91 gpf.

Showers

The mean shower volume across all 12 study sites was 17.2 gallons with a standard deviation of 10.6 gallons. The mean shower duration was 8.2 minutes and the mean shower flow rate was 2.22 gpm. Study participants used 11.6 gpcd for showering purposes. Participants in Waterloo and Cambridge used the least amount of water for showering at 8.3 gpcd and participants in Eugene used the most water for showering, 15.1 gpcd on average.

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.

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 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 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.

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 with four distinct typical characteristics:

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

This diurnal pattern in overall water use was observed in all 12 study sites. Indoor and outdoor use both followed diurnal patterns similar to the overall patter, 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. 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.

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 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.

Modeling Conclusions

The statistical inferences and models presented in this report have clearly increased the current scope of knowledge about the determinants of water demand. The end use models have confirmed some previous beliefs and have offered additional insights about the time-series and cross-sectional phenomena that affect water use. For the first time, differences in water use at the end use level have been attributed to causal factors related to price and socioeconomic characteristics.

The predictive system of end use models generally has considerable predictive power for the indoor end uses, and may be used to prepare conservative estimates of water use for the indoor end uses and total indoor use. However, the inability of the models to reproduce actual total use is traceable to the outdoor component of use and the structure of the data used to develop the models. The use of monthly billing data extended the system of equations so that systematic seasonal and weather influences on water demand could be represented. This greatly enhanced the ability of the models to reproduce reasonable monthly estimates of water use. The extended prediction model allows one to use local weather and demographic characteristics to create estimates of total , indoor, and outdoor use, but does not allow one to create predictions of use for individual indoor end uses. Though its performance is yet to be seen, the model and the instructions presented in Appendix D can be used as a starting point for estimating water use in any water service area.

RECOMMENDATIONS

This research and modeling effort points to some important areas for further study suggests areas for improvement in data development and study design.

1. *Indoor residential retrofit*. The REUWS study group and database represents a tremendous resource of baseline data on single-family water use. A carefully designed conservation retrofit study could provide tremendous information to conservation professionals about the actual real-life impacts of various conservation technologies and techniques. A carefully selected sample of homes from the baseline study group could be retrofit with advanced conservation equipment including toilets, clothes washers,

showerheads, faucets, pressure reducers, as well and a complete leak detection regime. End use data from these homes would then be collected and analyzed using data loggers and flow trace analysis techniques. This "intervention" style study would provide before and after measurements of water use and would permit detailed cost benefit analysis of a wide variety of conservation measures.

2. *Commercial and institutional end uses of water*. While much conservation emphasis has been placed on the single family sector, there appears to be great potential in the ICI sector. This study is currently underway and results should soon be available thorough AWWARF.

3. *Multi-family end uses of water*. The success of the *Residential End Uses of Water Study* points out the importance of extending this type of research into the multi-family sector. With the growing popularity of sub-metering in multi-family housing, research techniques employed in the REUWS could be applied with success.

4. *Development of REUWS database*. The REUWS database contains a tremendous amount of information about residential water use which will be of use to researchers for years to come. In its current form the database is accessible to users familiar with Microsoft Access and the querying tools it provides. A more advanced and user-friendly "front end" could be developed for this database which would enable less experienced computer users to gain access to the data set. Such a front end would assist users in extracting data sets and performing database queries.

Modeling Recommendations

Over time, additional research should be undertaken to improve the ability to model statistical relationships at the end use level. Particularly, there is a great need to incorporate seasonal patterns of use in the end use modeling process. Though the two-step approach presented here seems to work adequately, it would be less cumbersome to work with a single model (or model system) that can successfully incorporate weather and seasonal influences directly. This and other lessons learned lead to some specific recommendations related to study design and refinement of the end use models:

- *Extend the data logging periods*. At the maximum, the data logging periods for this study are 15 days in length. A longer data logging period would generate more knowledge about the variance in end usage and may allow one to uncover and assign additional flows that may not be present in any particular time period because of unique circumstances.
- *Increase the number of logging periods*. This study concerns an analysis of water use in two intervals of time. As demonstrated in this chapter, this is insufficient for modeling and predicting total water use that fluctuates seasonally. Increasing the number of logging periods and placing these periods strategically throughout the low, moderate, and high water-using seasons would benefit the analysis of irrigation use and would likely enhance the predictive ability of the set of end use models, without the need to incorporate information from billing data.
- *Adopt uniform logging periods across locations*. Because of practical considerations, the timing of logging periods was staggered throughout the year across locations, and not all locations were logged during the same general time of year. Unfortunately, this structure for collecting data associates location with time of year. Because weather and climate vary geographically, this presents difficulties for distinguishing the effects of climate from the effects of weather within a particular climate setting. If all study locations were to be logged during the same general time periods, it would be possible to represent and measure these factors more accurately and would likely increase the predictive ability of the outdoor model.
- *Increase the geographic coverage of the sample*. The current study is comprised of observations from 14 cities, most of which lie west of the Mississippi River. Increasing the geographical coverage of study participants would not only benefit sample size, but might also introduce a greater range of water use, price, weather, climate, and socioeconomic characteristics into the modeling process. Everything else being the same, this would increase the applicability of the models.

- *Consider the use of field surveys*. Field surveys hold an advantage over mail surveys in that they offer the ability to generate more precise and complete data. Although they can be more costly, field surveys allow one to verify home property characteristics and the presence of end uses. The use of field surveys to collect household data would also decrease the number of missing observations, which would enhance the size of the samples used in the modeling process.

Expansion of this end use research according to these recommendations would build upon and strengthen the predictive foundation presented here for future water demand planning, management, and evaluation.

APPENDIX A

RESIDENTIAL END USES OF WATER SURVEY

DETAILED SURVEY GROUP SELECTION PROCEDURES

The following document was sent to all participating utilities to assist them with selecting the sample of 1,000 residential accounts to receive the water survey.

Survey Group Selection Procedures (11/25/96)

The goal of this procedures document is to assist you (the participating utility) in selecting a representative sample of 1,000 single-family residential accounts from your customer billing data base. The consultants have attempted to make these procedures as simple and straight forward as possible, but if at any point you have a question or a concern, please call Peter Mayer of Aquacraft at 617-623-5013.

In order to successfully use the systematic random sampling technique developed by Planning and Management Consultants, Ltd. to select 1,000 accounts from your data base, we have divided the procedure into 5 steps. A box is provided so that you "check off" each step in the procedure once it has been completed. We realize that each utility will have a distinct system for maintaining their water customer billing records and we have attempted to keep this set of procedures as general as possible to that it will apply broadly to all participating utilities.

Step 1 -- Provide Consultants Information About Your Water Billing Database

Description: Prior to any sampling from your water billing data base, we would like to know specifically the "fields" of information that you maintain. We also need to know if your utility reads water meters and bills its single-family customers on a monthly, bimonthly, or quarterly basis as well as the units of water use measurements contained in your data base -- typically either in hundred cubic feet (CCF or HCF) or 1,000 gallons (Kgal). Once we have this information from your data base, we will specify the fields we would like you to provide us.

Action: Please fax, e-mail, or phone in to Peter Mayer a list of all fields contained in your water customer billing database, the standard billing period, and the units of water use measurement used by your utility. *Peter's phone, fax and e-mail are listed at the end of this document.*

We are interested in the following fields:

- ∃ Account Number (number which remains with the ***service address***)
- ∃ Service Address (the following is often is separate data field)
  - Street Number
  - Street Name
  - Suffix (Rd ., St., Lane, etc.)
- ∃ Service city
- ∃ Service state
- ∃ Service zip code
- ∃ Home telephone number (if available)
- ∃ Status (when doing the selection; you may have to screen on a field that denotes Aactive" accounts)
- ∃ Date of account initiation (i.e., when the account was started)
- ∃ Meter size
- ∃ Lot size (we are interested in any basic demographic data that is part of your system; including lot size, building size etc.)

- ∃ Individual periodic consumption data and the read date for each account in addition to the annual summary. This data should include the most recent 13 months (13 meter read dates and consumption on a monthly cycle or 7 meter read dates and consumption if on a bimonthly billing cycle)
- ∃ Days of each billing period. The number of days covered in a given billing period.

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

1) ACCTNO -- Individual number which remains with service address.
2) NAME -- Name of the account holder.
3) ST_NO -- Service address number
4) ST_NAME -- Name of Service Street
5) ST_TYPE -- Type of Service Street (Ave., Blvd. etc.)
6) CITY -- Service City name
7) ZIP -- Service Zip code
8) ACCT_TYPE -- Type of account (single-family, commercial, industrial, etc.)
9) METER_SIZE
10) JAN96 -- Water consumption for January 1996
11) JANDATE -- Read date for January 1996 consumption
12) JANDAYS -- Number of days in the January 1996 consumption period
13) DEC95 -- Water consumption for December 1995
14) DECDATE -- Read date for December 1995
15) .... You get the idea.

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

When does Aquacraft need this information? ASAP. We cannot proceed with selection of the 1,000 account sample until we have this information.

Step 2: Data Base Preparation -- Screening and Sorting

Description: Our goal is to retrieve a sample of **1,000** single-family (detached) accounts which is representative of the entire population of single-family accounts. For the purposes of our study we will only look at the billing periods in the most recent 12 months conveniently available in your customer billing data base. Before we can select our sample, we need to separate out all active <u>single-family detached residential</u> accounts.

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

1) First separate out all the single-family detached home account records in your data base -- this is usually accomplished by sorting on the "account type" field or the "residential code" field.
2) Second we need to screen out accounts closed out during the selected 12 month period. This screened database will be our ***population*** of single-family residential accounts.
3) Next we need to sort our screened database in ascending (or descending) order of water consumption using the 12 month total water use field as the primary sort key.
4) Create a number field and number all the records in the sorted data base from 1 to 35,000 (what ever the number of records in the sorted data base).

Example: The Watertown data base was first queried to select out all single-family detached residential accounts using the ACCT_TYPE field. Accounts closed out in 1995 were screened out with another query. The screened data base, containing 35,000 records, was then sorted based on the 12TOTAL field (or the AVG_DAY field) from lowest to highest annual water use. A field called NUMBER was created and each record was given a number starting with 1 and ending with 35,000.

When do we do this data base work? Once Aquacraft receives the information from ***Step 1***, we will get back to you promptly with the files we would like you to download for us and any special requirements for your database and you can then do the data base work outlined in ***Steps 2 -5***.

Step 3: Calculating Summary Statistics

Description: In order to evaluate the representativeness of the random sample you will be selecting it will be essential to have some summary statistics about your screened data base of single-family detached homes. We need to calculate the mean and standard deviation for each of the billing periods in the most recent 12 months conveniently available and also for a new field containing the total consumption for these 12 months.

Action:

1) Depending on the information in your data base there are two options:
   a) If it doesn't exist already, we need to create and populate a field for the total water use for the most recent 12 months for each single-family account record you have assembled. This field can be titled 12TOTAL.

   OR

   b) If your data base contains a DAYS field which contains the actual number of days in each billing period, please calculate the average daily use during the most recent 12 months for each single-family account record you have assembled. This field can be titled AVG_DAY. For each account, sum consumption of the selected 12 month period and divide by the number of days covering the 12 month period to provide average daily water use during that 12 month period.
2) Calculate the mean water use by dividing all water billed to single-family customers in a given month by the number of single-family accounts billed in a given month. This should be done for each month in the most recent year and for the total water use field (12TOTAL) or the average daily use field (AVG_DAY).
3) Calculate the standard deviation of single-family per account water use for each month and for the annual total. This is easily done as many data base software packages have a pre-programmed routine to calculate standard deviation.
4) Print out these summary statistics and send the printout to the consultants along with the final sample data from the 1000 records selected for the sample.

Example: The Watertown data base was first queried to select out all single-family detached residential accounts using the ACCT_TYPE file. The 12TOTAL field was created and was populated by summing all water use in the most recent 12 months for each account. The mean and standard deviation in water use were calculated for each of the most recent 12 months of data -- February 1995 - January 1996 and for the 12TOTAL field -- these values were printed out so they can be sent to Aquacraft.

Step 4: Systematic Random Sample[14]

Description: Now we can select our random sample of 1,000 accounts which (if we did Step 3 properly) will be representative of the entire population of single-family accounts. A systematic random sampling procedure will be used.

Action:

1) Divide the total number of accounts in our screened, sorted data base by 1,000 to generate a sampling interval. For example, if you have 35,000 accounts, the sampling interval would be 35.
2) Select a random number between 1 and the sampling interval. For example, use Excel to select a random integer between 1 and 35. (If necessary Peter can quickly generate a random number for you).
3) The random number will be the first member of the sample. Assuming that the random number is 6, the utility should select the 6th account from the screened and sorted data base, and then select every 35th (fill in your own interval) thereafter, until the complete list of single-family accounts (i.e., all 35,000) is exhausted. This procedure will roughly provide a list of 1,000 single-family accounts.

Example: The screened and sorted Watertown data base has exactly 35,852 single-family residential accounts. The selection interval is calculated to be 35.85 -- which is rounded ***down*** to 35. Using the RANDBETWEEN(1, 35) function in Excel (forcing the cell to be an integer) the random number 22 was selected. Beginning with 22

[14]*If any other method of random selection is used by the utility then it should first be cleared with the consultants and a detailed description of the selection process must be included with the lists of 1,000 single-family accounts.*

then 57 then 92 (adding 35 at a time) a list of 1,024 numbers is generated. These 1,024 numbers are then used in a data base query to select out the 1,024 accounts with a corresponding NUMBER field. These accounts will be the Watertown sample.

Step 5: Export the Sample Group Data Base

Description: We are now done with selecting the sample and all that remains is to send the data base including all the data fields requested in ***Step 1*** to the consultants along with the summary data calculated from the population database in ***Step 3***.

Action: Once selected, the sample of approximately 1,000 accounts should be saved to its own file. Please include all fields specified by the consultants for your particular system. These fields will be specified at the end of ***Step 1.*** This final sample group data base file can then be saved as a DBase 3, DBase 4, ASCII delimited, or Microsoft Access file, stored to disk and mailed to Peter Mayer. Please call if you have any questions about file format. A hard copy of the mean and standard deviation of water use for the population of single-family accounts (outlined in Step 2) should be included.

Example: The Watertown sample data base of 1,024 accounts along with 20 accompanying fields (address, water consumption, lot information and account information -- all specified by the consultants for Watertown) was saved to a comma and quote delimited file. This file was then put onto a floppy disk and mailed off along with the printout of the mean and standard deviation in water use calculated for each of the most recent year of billing data and for the 12TOTAL field.

When does Aquacraft need this data? The consultants hope to mail surveys approximately 2 months before they begin installation of data loggers. In order to print mailing labels and check the accuracy of the sample data base we need an additional two weeks. So for example, if your utility is scheduled to begin data logging on July 1, we need to have your sample data base no later than May 15.

INSTRUCTIONS FOR HANDLING SURVEY FORMS

The following set of instructions was sent to each participating utility to assist them with implementing the water survey.

Step-By-Step Instructions for Handling Survey Forms

North American End Use Study (11/25/96)

I. Procedure for Preparing and Mailing Survey Form:

(1) "Final" the Cover Letter (cover1 and, if a second survey mailing is anticipated, cover2) on City/Utility letterhead and have signed by highest appropriate official.

(2) Take the Residential Water Use Survey (Survey Form) supplied on diskette by consultants and type in the City/Utility's address in the center of unnumbered page 8 (Back Page). This is the address that the respondent will return the Survey Form too. An "ATTN:" should be added containing the name and title of the Manager of the Water Utility/Dept. or other appropriate official (see Back Page of sample Survey Form provided by consultants).

(3) Print 1,000+ copies each of the Cover Letter, Survey Form, and follow-up Postcard. The Survey Form should be printed on 11" x 17" paper and be folded and stapled on the left binding edge (see sample provided by consultants).* (Note, if it is projected that it will be difficult to obtain a 25% response rate using just a survey mailing and postcard follow-up, the number of forms printed should be increased to a 1,900 to accommodate mailing forms a second time to non-respondents.)

(4) Hand stick the proper postage on the Back Page of the Survey Form. (Double check the weight of your Survey Form, but you will probably find that a 324 stamp will do. The sample Survey Form provided by the consultant weights 0.7 ounces.)*

(5) Obtain 1,000 flat envelopes that will accommodate five 82" x 11" unfolded sheets of paper.

(6) Assemble a trial package containing Cover Letter and Survey Form and determine proper first class postage. Then pre-frank the 1,000 transmittal envelopes through your postage meter.

(7) Coordinating closely with Peter Mayer, prepare two sets of stick-on (Avery type) mailing labels. The first set should contain the Address Label (service address with generic name such as "Valued Water Customer" or actual <u>resident</u> name if known/possible to extract from database) in the left hand column and the CUSTID# Label immediately to the right in the right hand column. The second set of labels is for the Postcard and will not include the CUSTID# Label. (Be prepared to generate another set of Address and associated CUSTID# Labels from this database later if a second mailing of the Survey Form is required.) (In the case of Tampa, Peter will print the address labels and corresponding CUSTID# labels and mail them to you.)

(8) Assemble and post initial survey mailing. **Important!: In order to be sure that the Address Label and associated CUSTID# Label don't get mixed up, it is very important that the following three steps be done by one person as a single process for each service address:**

Step 1. Place a Cover Letter on top of a Survey Form. (Do not staple the two together.)

Step 2. Turn over and stick the CUSTID# Label for "110 Maple St." customer on the bottom of the Back Page within the area that says "FOR Utility USE ONLY:"

Step 3. **Immediately** slip the Cover Letter and Survey Form into the transmittal envelope **and then immediately** stick the corresponding Address Label for "110 Maple St." on the outside of the transmittal envelope.

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* If your City/Utility has a Business Reply Account already setup with the U.S. Postal Service, you will find it saves money to have the printer print the Survey Form and Postcard with your business reply address and identifying postal code.

II. Procedure For Handling Responses and Follow-up Mailings

(9) Open returned Survey Forms and remove staples and tape customer used to seal form. Do not remove staples on binding edge or reproduce form (for fear of getting pages separated). Just straighten out crease lines and lay forms flat in an 82 x 11 stack. (Placing a weight on the forms to help flatten them would be appreciated and help speed later data input.) If it was projected that it will be difficult to obtain a 25% response rate, keep track of who responds by checking off a Master List of the 1,000 service addresses sorted by CUSTID# in order to identify non-respondents who will be mailed the Survey Form a second time.

(10) **On the fourth (or no later than the seventh) calendar day** after the day the Cover Letter/Survey Forms were posted, post the follow-up Postcard to the entire original list of 1,000 service addresses. Do not skip this mailing. The idea is to boost response from customers who intended to fill out the form before the form gets mislaid or thrown out.

(11) **As soon as 200+ responses have been received** (and if necessary checked off the master list), **using priority mail (US Postal Service*/Federal Express/UPS two day service), commence <u>weekly</u> mailings** of Survey Forms returned to date to:

John Olaf Nelson Water Resources Management
1833 Castle Drive
Petaluma, CA 94954

(* I have found US Postal Service Priority 2 day service "maybe" to be very adequate. It costs $3.00 per 2 lbs of material.)

(12) If **fourteen calendar days** after the initial mailing, 250 responses have not been received, repeat actions (4), (5), (6), and (8). **Anticipate this step** by screening label database and printing out Address Label and associated CUSTID# Label for each non-respondent and printing the more strongly worded Cover Letter (cover2).

(13) Survey Forms sent to John Nelson will not be reproduced. The data they contain will, however, be entered into an ACCESS database and a KEYCODE number will be entered in ink next to the CUSTID# Label. Once that task is completed and the statisticians have identified the 125+ target sites for data logging, all Survey Forms will be mailed back to the City/Utility.

(14) The **City/Utility shall then retain the Survey Forms** for three years or until the date the AWWARF Study is completed, whichever shall first occur.

(15) If a sufficient number of respondents leave important questions unanswered, it may be necessary for the City/Utility to do some additional follow-up telephone calls. This will not immediately be known - probably not until 7 working days after the date the Survey Forms start to be received by John Nelson. Such additional call-backs are expected to be rare and will be handled on a case-by-case basis as the need occurs.

SUGGESTED COVER LETTER FOR WATER SURVEY

The following sample letter was provided to all participating utilities for possible use in conjunction with the water survey. Some utilities opted to develop their own cover letter wording.

<Utility's Letterhead and Logo>

<Month and day Survey with cover letter is posted>, 199_

Dear Valued Water Customer:

An essential part of planning for a safe, secure water future that considers both customer needs and the environment we cherish, involves knowing how our customers use water. With better information, we can make wiser decisions and thus be better stewards of the public's money and the public resources entrusted to *<Utility's Name>*.

You can play a vital role in helping shape a sensible yet sensitive water future by filling out and returning the enclosed form. Out of all our single-family residential customers, your home has been statistically selected to be part of a small group of customers which, when taken together, make up a representative sample of all single-family home water use in *<name of City or Utility's service area or simply "our service area" if appropriate>*. It is therefore most important that you take the 10 or 15 minutes required to fill out the form. Please answer each and every question.

The information you provide will be used solely for planning purposes..

It would be most helpful if you could, this very evening, sit down and fill out the form, fold it, staple or tape it shut, and put it in tomorrow's mail (return postage has been included on the form). If you set the form aside with the intent to fill it out later, we would be most appreciative if you would complete and mail it by no later than *<enter return deadline date here - set at 14 calendar days from date surveys are posted>*. This is the date that a comprehensive analysis of residential water use will commence. Should you have any questions, please call *<designated Utility phone #>* and ask for *<first and last name of a designated staff contact person>*.

On behalf of *<name of City or Utility>* and residential water customers throughout our service area, thank you for responding to this request and helping us plan the best possible and most sensible water future that we can.

Sincerely yours;

_______________, *<General Mgr., Pres. of Board, Mayor or other appropriate high official>*

Type in Spanish:
[Notice! If you are a Spanish speaking person and have difficulty reading this letter, it is most important you call *<insert phone number of knowledgeable Spanish speaking staff person>* at your earliest convenience and the contents of the letter will be carefully read to you. Your participation in this survey is very important to us. Thank you.]

Enclosure: Residential Water Use Survey

RESIDENTIAL WATER USE SURVEY

To help your water utility to better plan for future water needs, please answer each of the following questions. This information is being collected for research purposes. Results of this study will be reported only in anonymous summary form. Thank you for taking the time to help us with this important research.

PLEASE CHECK (✔) OR PROVIDE YOUR MOST APPROPRIATE RESPONSE FOR EACH AND EVERY QUESTION. When you have answered all of the questions, please see the back page for instructions about returning this questionnaire. Thank you.

1. Indicate <u>how many</u> of the following types of water-using appliances or fixtures you have in or around your home.

a. Toilets	Y 0	Y 1	Y 2	Y 3	Y 4 Y 5 Y 6 Y 7 or more
b. Bathtub with shower	Y 0	Y 1	Y 2	Y 3	Y 4 Y 5 Y 6 Y 7 or more
c. Bathtub only	Y 0	Y 1	Y 2	Y 3	Y 4 Y 5 Y 6 Y 7 or more
d. Shower only	Y 0	Y 1	Y 2	Y 3	Y 4 Y 5 Y 6 Y 7 or more
e. Whirlpool bathtub with jets	Y 0	Y 1	Y 2	Y 3	Y 4 Y 5 Y 6 Y 7 or more
f. Bathroom sink	Y 0	Y 1	Y 2	Y 3	Y 4 Y 5 Y 6 Y 7 or more
g. Kitchen faucet	Y 0	Y 1	Y 2	Y 3	Y 4 Y 5 Y 6 Y 7 or more
h. Indoor utility/garage sink	Y 0	Y 1	Y 2	Y 3	Y 4 Y 5 Y 6 Y 7 or more

2. Do you have any of the following types of water-using appliances, fixtures, or purposes in or around your home?

a. Garbage disposal	Y No	Y Yes
b. Top-loading clothes washing machine	Y No	Y Yes
c. Front-loading clothes washing machine	Y No	Y Yes
d. Dishwashing machine	Y No	Y Yes
e. Swimming pool (in ground or above ground)	Y No	Y Yes
f. Free-standing hot tub with jets	Y No	Y Yes
g. Evaporative/swamp cooler	Y No	Y Yes
h. Pressure regulator on main house service line	Y No	Y Yes
i. Home water treatment system attached to water system or faucet (like a water softener or reverse osmosis)	Y No	Y Yes
j. Greenhouse	Y No	Y Yes
k. Flower garden (seasonal)	Y No	Y Yes
l. Vegetable garden (seasonal)	Y No	YYes

3. Do you have any water-using appliances and fixtures that were not listed in Questions 1 and 2?

Y No Y Yes

3a. If yes, please specify:____

____

4. If your home has a clothes washing machine, please specify the year the appliance was manufactured or purchased and the brand name of the appliance.

☐ No clothes washer [0] __________Year ____________________Brand Name

5. If your home has a dishwasher, please specify the year the appliance was manufactured or purchased and the brand name of the appliance.

☐ No dishwasher [0] __________Year ____________________Brand Name

6. On average, about how many times each week is a **LOAD OF DISHES HAND WASHED** in your household?

☐ 0 [0] ☐ 3-4 [2] ☐ 7-8 [4] ☐ 11-12 [6] ☐ More than 14 [8]
☐ 1-2 [1] ☐ 5-6 [3] ☐ 9-10 [5] ☐ 13-14 [7] ☐ Don't know [99]

7. How many of the showers in your home have low-flow (water conserving) showerheads?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 or more ☐ Don't know [99]

8. How many of the toilets in your home are ultra-low-flush toilets (1.6 gallons per flush)?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 or more ☐ Don't know [99]

9. Please indicate the approximate total lot (parcel) area of your residence (both in and around your home).

1 acre = 43,560 square feet; 3/4 acre = 32,670 sq. ft.; 1/2 acre = 21,780 sq. ft.; 1/4 acre = 10,890 sq. ft.

☐ Less than 2,000 sq. ft. [1]
☐ 2,000 - 3,999 sq. ft. [2]
☐ 4,000 - 5,999 sq. ft. [3]
☐ 6,000 - 7,999 sq. ft. [4]
☐ 8,000 - 9,999 sq. ft. [5]
☐ 10,000 - 11,999 sq. ft. [6]
☐ 12,000 - 13,999 sq. ft. [7]
☐ 14,000 - 15,999 sq. ft. [8]
☐ 16,000 - 17,999 sq. ft. [9]
☐ 18,000 - 19,999 sq. ft. [10]
☐ 20,000 - 24,999 sq. ft. [11]
☐ 25,000 - 29,999 sq. ft. [12]
☐ 30,000 - 34,999 sq. ft. [13]
☐ 35,000 - 39,999 sq. ft. [14]
☐ 40,000 sq. ft. or greater [15]
☐ Don't know [99]

10. What percent (%) of your total lot area is landscape? (Note: Whereas the total lot area includes the house, driveway, and all surrounding grounds, the landscape area is only that area which may be covered with grasses, trees, shrubs, flower beds, etc.)

________% ☐ No landscape area [0] ☐ Don’t know [99]

11. What portion of your <u>landscape area</u> is the lawn area?

☐ No lawn area [0]	☐ 31 - 40% [4]	☐ 71 - 80% [8]
☐ 1 - 10% [1]	☐ 41 - 50% [5]	☐ 81 - 90% [9]
☐ 11 - 20% [2]	☐ 51 - 60% [6]	☐ 91 - 100% [10]
☐ 21 - 30% [3]	☐ 61 - 70% [7]	☐ Don't know [99]

12. When you do water (irrigate) your landscape, what percent of your <u>landscape area</u> do you typically tend to water?

☐ None [0]	☐ 31 - 40% [4]	☐ 71 - 80% [8]
☐ 1 - 10% [1]	☐ 41 - 50% [5]	☐ 81 - 90% [9]
☐ 11 - 20% [2]	☐ 51 - 60% [6]	☐ 91 - 100% [10]
☐ 21 - 30% [3]	☐ 61 - 70% [7]	☐ Don't know [99]

13. During the <u>winter</u> months of the year (generally December - February), how many <u>days</u> each week do you typically water any part of your landscape?

☐ None [0]	☐ 1 day/week [4]	☐ 5 days/week [8]
☐ Less than 2 times per month [1]	☐ 2 days/week [5]	☐ 6 days/week [9]
☐ A few times per month [2]	☐ 3 days/week [6]	☐ 7 days/week [10]
☐ Less than 1 day/week [3]	☐ 4 days/week [7]	☐ Don't know [99]

14. During the <u>summer</u> months of the year (generally June - August), how many <u>days</u> each week do you typically water any part of your landscape?

☐ None [0]	☐ 1 day/week [4]	☐ 5 days/week [8]
☐ Less than 2 times per month [1]	☐ 2 days/week [5]	☐ 6 days/week [9]
☐ A few times per month [2]	☐ 3 days/week [6]	☐ 7 days/week [10]
☐ Less than 1 day/week [3]	☐ 4 days/week [7]	☐ Don't know [99]

15. In addition to the water purchased from your water utility, do you use any of the following sources of water for your outdoor water needs?

☐ No additional sources of water used [1]	☐ Well water [4]
☐ Canal/ditch [2]	☐ Stream/river [5]
☐ Cistern [3]	

☐ Other (please specify) ____

16. How would you characterize your sprinkling system? (*Please check all that apply*.) [0/1]

☐ No sprinkling system (only check this if none of the below apply)
☐ In-ground sprinkler system - front yard
☐ In-ground sprinkler system - back yard
☐ Drip irrigation or bubbler system
☐ Soaker hose
☐ Garden hose with sprinkler attached
☐ Hand-held garden hose with or without a nozzle
☐ Other (please specify) ____

17. If there is an in-ground sprinkler system in the front yard, how is it usually operated?

- ☐ No in-ground sprinkler system in front yard [0]
- ☐ Turn on each valve by hand [1]
- ☐ Automatic time clock/controller [2]
- ☐ Don't know [99]

18. If there is an in-ground sprinkler system in the back yard, how is it usually operated?

- ☐ No in-ground sprinkler system in back yard [0]
- ☐ Turn on each valve by hand [1]
- ☐ Automatic time clock/controller [2]
- ☐ Don't know [99]

19. If you have an in-ground sprinkler system controlled by an automatic time clock, does the system also have an override shut-off device such as a soil moisture sensor or rain sensor?

- ☐ No in-ground sprinkler system or automatic clock/controller present [0]
- ☐ No override shut-off device [1]
- ☐ Yes, soil moisture sensor installed [2]
- ☐ Yes, rain sensor installed [3]
- ☐ Yes, both soil moisture sensor and rain sensor installed [4]
- ☐ Don't know [99]

20. On a scale of 1 to 5, with 5 being best, please judge the overall appearance and level of care and maintenance provided your landscape.

_______Score for entire landscape

21. On average, how often are cars washed at home?

☐ Never [0]	☐ Once a month [2]	☐ Once a week [4]
☐ Less than once a month [1]	☐ Twice a month [3]	☐ More than once a week [5]
		☐ Don't know [99]

22. On average, how often is a hose used to clean the sidewalks or driveways around your residence?

☐ Never [0]	☐ Once a month [2]	☐ Once a week [4]
☐ Less than once a month [1]	☐ Twice a month [3]	☐ More than once a week [5]
		☐ Don't know [99]

23. If your home has a swimming pool, please estimate the pool dimensions in feet.

☐ No swimming pool [0] _______Length _______Width _______Average depth

24. On a scale of 1 to 5, with 5 being "most important", how important do you believe it is for everyone in your community to conserve water on a regular basis?

_______Score

25. In the last several years, has your household taken any action to conserve water?

☐ No ☐ Yes ☐ Don't know

25a. If yes, what types of action have you taken to conserve water? (*Please check all that apply.*) [0/1]

☐ Take shorter showers
☐ Installed low-flow showerheads
☐ Installed water savers (inserts) in toilet
☐ Installed ultra-low-flush toilet
☐ Use garbage disposal less often
☐ Use dishwasher less/use fuller loads
☐ Use washing machine less/use fuller loads
☐ Repaired leaks in faucet/toilet
☐ Use greywater/reuse household water
☐ Washing car less often
☐ Water lawn and shrubs less often
☐ Water lawn and shrubs at night
☐ Install low-water-use landscaping
☐ Changed run-times on automatic sprinklers
☐ Installed water efficient irrigation system
☐ Cycle irrigate lawns (e.g., 5 min. on, 1 hour off, repeated several times or similar arrangement)
☐ Had a home water audit done

☐ Other (*please specify*)____

____

26. At the present time, would you say that your community is experiencing:

☐ No drought [0]
☐ Mild drought [1]
☐ Moderate drought [2]
☐ Severe drought [3]
☐ Don't know [99]

Now, we would like to ask you a few questions about your house and household characteristics. This information will only be used for statistical purposes.

27. Please indicate the type of residence you live in.

☐ Single-family detached house [1]
☐ Single-family detached house with separate <u>detached</u> apartment [2]
☐ Single-family detached house with separate <u>attached</u> apartment unit [3]
☐ Duplex [4]
☐ Triplex [5]
☐ Townhouse [6]
☐ Attached apartment [7]
☐ Mobile home [8]
☐ Other (please specify) [9] ____

28. Does your residence have two water meters - one to measure inside use and the other for measuring outside use?

☐ No ☐ Yes ☐ Don't know

29. Is your household responsible for paying the water bill or is it paid by a landlord or homeowners' association?

☐ Household pays [1]
☐ Landlord/homeowner's association [2]
☐ Don't know [99]

30. How many people reside full-time at this address during the winter months of the year (generally December -February)? *(Enter the number of individuals in each age group.)* [0 or #]

_____ Adults (18+) _____ Teenagers (13 - 17) _____ Children (under 13)

31. How many people reside full-time at this address during the summer months of the year (generally June - August)? *(Enter the number of individuals in each age group.)* [0 or #]

_____ Adults (18+) _____ Teenagers (13 - 17) _____ Children (under 13)

32. What number of adults living at the residence are employed full-time **OUTSIDE** the home?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 or more

33. Approximately, what year was your residence built?

☐ Before 1960 [1]	☐ 1975 - 1979 [4]	☐ 1990 - 1992 [7]
☐ 1960 - 1969 [2]	☐ 1980 - 1984 [5]	☐ 1993 - 1994 [8]
☐ 1970 - 1974 [3]	☐ 1985 - 1989 [6]	☐ Since 1994 [9]
		☐ Don't know [99]

34. In what year did you move to your current address? ___________year

35. Please give your best estimate of the total number of square feet of living space in your home (including enclosed garage area).

☐ Less than 800 sq. ft.[1]	☐ 1800 - 1999 sq. ft.[7]	☐ 3000 - 3199 sq. ft.[13]
☐ 800 - 999 sq. ft.[2]	☐ 2000 - 2199 sq. ft.[8]	☐ 3200 - 3399 sq. ft.[14]
☐ 1000 - 1199 sq. ft.[3]	☐ 2200 - 2399 sq. ft.[9]	☐ 3400 - 3599 sq. ft.[15]
☐ 1200 - 1399 sq. ft.[4]	☐ 2400 - 2599 sq. ft.[10]	☐ 3600 - 3799 sq. ft.[16]
☐ 1400 - 1599 sq. ft.[5]	☐ 2600 - 2799 sq. ft.[11]	☐ More than 3,800 sq. ft.[17]
☐ 1600 - 1799 sq. ft.[6]	☐ 2800 - 2999 sq. ft.[12]	☐ Don't know [99]

36. How many floors of living space are in your home (including a finished basement area)?

☐ 1 ☐ 2 ☐ 3 or more

37. Do you rent or own your residence? ☐ Rent [0] ☐ Own [1]

38. If you rent your home, what is your monthly rent payment?

☐ Do not rent [0]	☐ $700 - 799/month [6]	☐ $1750 - 1999/month [12]
☐ Less than $300/month [1]	☐ $800 - 899/month [7]	☐ $2000 - 2249/month [13]
☐ $300 - 399/month [2]	☐ $900 - 999/month [8]	☐ $2500/month or more [14]
☐ $400 - 499/month [3]	☐ $1000 - 1249/month [9]	
☐ $500 - 599/month [4]	☐ $1250 - 1499/month [10]	
☐ $600 - 699/month [5]	☐ $1500 - 1749/month [11]	☐ Don't know [99]

39. If you own your home, what is the approximate market value of your home?

☐ Do not own [0]	☐ $150,000 - 174,999 [7]	☐ $350,000 - 399,999 [14]
☐ Less than $25,000 [1]	☐ $175,000 - 199,999 [8]	☐ $400,000 - 449,000 [15]
☐ $25,000 - 49,000 [2]	☐ $200,000 - 224,999 [9]	☐ $450,000 - 499,000 [16]
☐ $50,000 - 74,999 [3]	☐ $225,000 - 249,999 [10]	☐ $500,000 - 749,000 [17]
☐ $75,000 - 99,999 [4]	☐ $250,000 - 274,999 [11]	☐ $750,000 - 999,999 [18]
☐ $100,000 - 124,999 [5]	☐ $275,000 - 299,999 [12]	☐ $1,000,000 or more [19]
☐ $125,000 - 149,999 [6]	☐ $300,000 - 349,999 [13]	☐ Don't know [99]

40. What is the last grade of formal education the primary wage earner has completed? (*Check one category only*)

☐ Less than High School [1]	☐ Bachelor's degree [4]
☐ High School graduate [2]	☐ Master's degree [5]
☐ Some College [3]	☐ Doctoral degree [6]

41. What is your gross annual <u>household</u> income?

☐ Less than $10,000 [1]	☐ $ 70,000 - 79,999 [8]	☐ $140,000 - 149,999 [15]
☐ $ 10,000 - 19,999 [2]	☐ $ 80,000 - 89,999 [9]	☐ $150,000 - 159,999 [16]
☐ $ 20,000 - 29,999 [3]	☐ $ 90,000 - 99,999 [10]	☐ $160,000 - 169,999 [17]
☐ $ 30,000 - 39,999 [4]	☐ $100,000 - 109,999 [11]	☐ $170,000 - 179,999 [18]
☐ $ 40,000 - 49,999 [5]	☐ $110,000 - 119,999 [12]	☐ $180,000 - 189,999 [19]
☐ $ 50,000 - 59,999 [6]	☐ $120,000 - 129,999 [13]	☐ $190,000 - 199,999 [20]
☐ $ 60,000 - 69,999 [7]	☐ $130,000 - 139,999 [14]	☐ $200,000 or more [21]
		☐ Don't know [99]

Thank you very much for taking your time to provide this research information.

Please use this space for any comments or suggestions you would like to include regarding the topics of this questionnaire. Your ideas will help us serve you better in the future.

COMMENTS?

PLEASE SEE BACK OF THIS PAGE FOR INSTRUCTIONS ABOUT RETURNING THIS QUESTIONNAIRE.

When you have completed the survey, please fold along the lines indicated on this page and staple shut with a single staple or seal shut with a single tab of tape. Please be sure the address shows and then mail the survey to the return address shown below. Thank you.

SURVEY FOLLOW-UP POSTCARD

The following postcard text was provided to all participating utilities to be sent to all survey recipients four to seven days after the survey instrument itself. The postcard was intended to be a reminder to the resident to return the survey. Not all participating utilities chose to send the follow-up postcard.

Mail to all 1,000 customers that Survey was mailed to:

Place City/Utility Logo on reverse side with address stick-on label and postage.

Dear Valued Water Customer: <*Date*>

One week ago, you should have received a very important water use survey we mailed to you. If you have not already mailed the survey back, it would be very appreciated if you could take 15 minutes to fill it out and return it today or tomorrow.

Because you home was scientifically selected to be part of a small group of residential customers, who together represent the consumption pattern of all our residential customers, it is most important and would be a real service to your fellow residential water customers and the <*City/Utility*> if you would return the survey. All information you share with us will only be used for planning purposes.

Should you prefer to have someone go over the survey with you, please call <*phone # of designate staff person*>. Arrangements can also be made for our staff expert to call you back in the evening if that would be more convenient for you. We urge that you call. We would be very grateful to hear from you.

Thank you for your co-operation. It is deeply appreciated.

_______________ General Manager

In Spanish.

[Notice! If you are a Spanish speaking person and have difficulty reading this notice, it is most important you call <i*nsert phone number of knowledgeable Spanish speaking staff person*> as soon as possible and the contents of this notice will be carefully read to you. Thank you.]

SURVEY FOLLOW-UP LETTER TO NON-RESPONDENTS

The following letter was provided to all participating utilities to use as a follow-up for customers who did not return the water survey.

<*Utility's Letterhead and Logo*>

<*Month and day Survey with cover letter is posted*>, 199_

Dear Valued Water Customer:

Two weeks ago we mailed a water use survey to you and asked that you fill it out. As of this date, we have not received your response which is very important to the success of the study of water use that we have embarked on. In case you mislaid or threw the previous form away, thinking your input was unimportant, we enclose another copy.

Your home was selected out of approximately <*number of homes*> homes in the <*Utility/City*> urban water service area. When added to a small carefully selected statistical sample group, the group makes up a representative sample of all single-family home water use. A lot of calculations and effort has gone into figuring out which homes to mail the survey to. I know it may sound ludicrous to you that your participation could be so important but the science of statistical sampling says that it is. Please appreciate how important it is that you take 15 minutes and this very evening and fill out the form.

Should you have any questions or should you wish to have a person go through the form with you, please call <*designated phone #*> and ask for <*name of designated staff contact person*>. We would be most grateful to hear from you and are ready, willing and able to assist you. We can even arrange to call you back in the evening if that would be more convenient for you.

The information you provide will be used solely for planning purposes..

On behalf of <*name of City of Utility*> and residential water customers throughout our service area, thank you for responding to this urgent request and helping us plan the best possible and most sensible water future that we can.

Type in Spanish:
[Notice! If you are a Spanish speaking person and have difficulty reading this letter, it is very important you call <*insert phone number of knowledgeable Spanish speaking staff person*> within the next three days and the contents of the letter and questions on the form will be carefully read to you. We can take the information right over the phone. We will gladly call you back if your call to us is not within the free calling area so that the cost of the phone call while going over the form is on us. Your participation in this survey is very important and we wish to help you in any way that we can. We welcome your call. Thank you.]

Sincerely yours;
________________, <*General Mgr., Pres. of Board, Mayor or other appropriate high official*>

Enclosure: Residential Water Use Survey

SURVEY IMPLEMENTATION SCHEDULE

Each participating utility was asked to adhere to the following survey implementation schedule:

Day 1 – 60:	Utility to provide historic water use records and to follow instructions to identify the Q1000 sample.
Day 60 – 65:	Print the Q1000 service address labels and corresponding CUSTID labels.
Day 1 – 67:	Prepare and print survey form, cover letter and follow-up postcard and on (about) the 67th day posts to Q1000 list. Commencing with posting date, designated utility staff person remains available to answer inquires from Q1000 customers for about 30 days.
Day 71 – 73:	Post follow-up postcard.
Day 77 – 107:	Survey responses loaded into Access database
Day 108 – 113:	Survey database combined with historic water use database and summarizes water use and survey response records.
Day 110 – 115:	Utility receives summary of survey responses, copy of comments received and information on net response rate (based on usable responses).
Day 114 – 128:	Representative sample for end use monitoring (Q150) is identified.
Day 130 – 132:	Utility mails notice (passive consent) letter to Q150 informing them of intended end use monitoring.
Day 153 – 155:	Data loggers installed at 100 of the Q150 sites.
Day 167 – 170:	Data loggers removed by utility and shipped to next study site. (A repeat two weeks of logging is then done about six months later)

SAMPLE WATER SURVEY INPUT FORM

The form shown in Figure A.1 is a portion of a survey input form used to “code” the returned water surveys. Responses to each question were entered into this form which then stored the answers is a Microsoft Access database table.

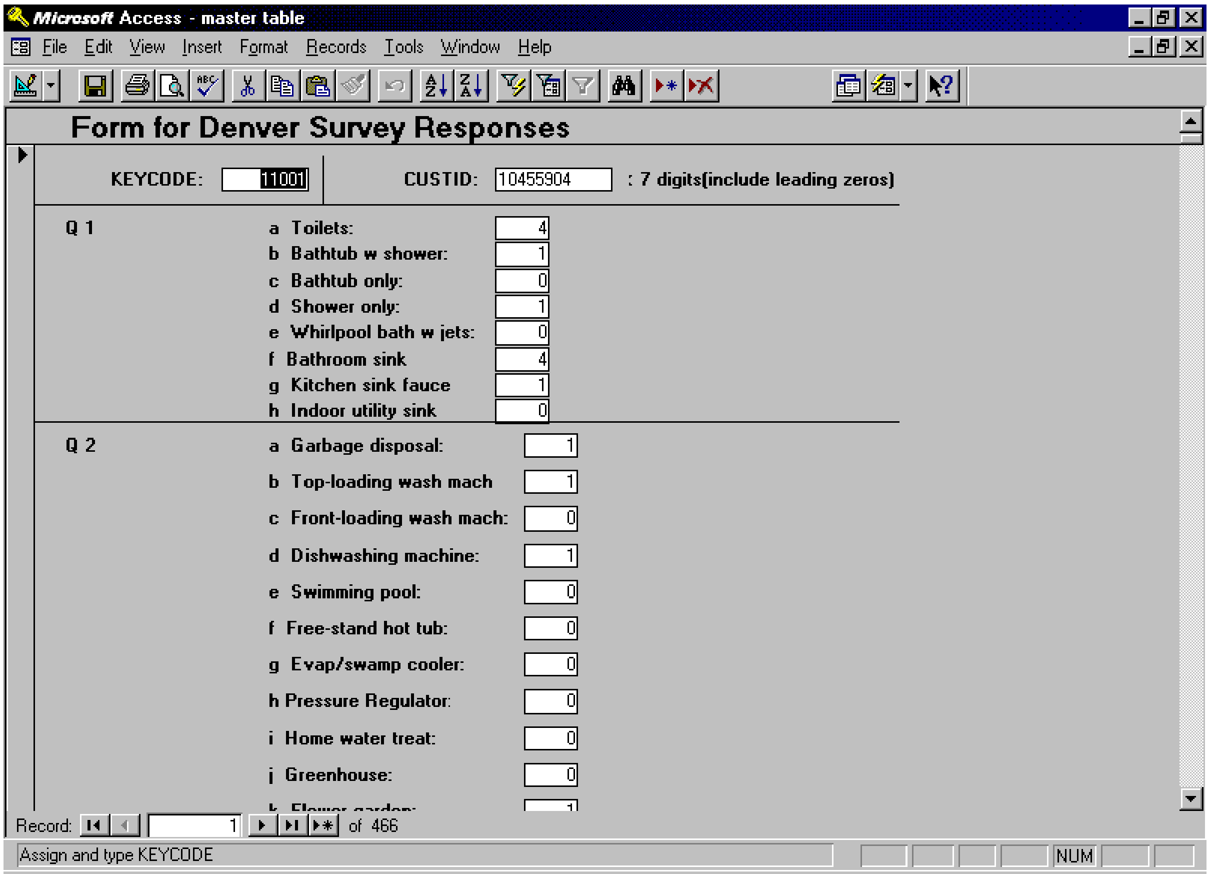

Figure A.1 Sample survey input form

DRAFT OF NOTICE (CONSENT) LETTER

The following draft letter was provided to all participating utilities to use as a consent letter for participating in the data logging portion of the study.

<*Utility Letterhead*>

_______ __, 199_

<*Address of Customer Jones who is one of the 150 customers selected for potential installation of a data logger*>

Dear <*Mr. Jones*>,

Did you ever wonder how much water is used by a clothes washer or how much water we put on our lawns? Where do we use most of our water? The <*name of City/Utility*> is conducting a study and hopes to answer these and other water use questions for the purpose of making our water conservation programs more responsive to our residential customer's needs and more effective.

Your home is one of 100 single family residences, which taken together, use water in a pattern that is representative of all the single family residences in our service area. Your residence was randomly selected following a painstaking scientific process involving analysis of the water use of all single family residences and the water use survey you received some weeks ago and were kind enough to fill out and return. It is most important to us that your residence be included in our study. The <*City/Utility*> appreciates your cooperation, but we want you to understand that participation is voluntary. If you have any questions or you do not wish to participate, please call <*phone number of key and knowledgeable City/Utility contact person armed with polite, respectful, and persuasive reasons why customer should agree to participate*> as soon as possible.

The study techniques we plan to use have been designed to be non-intrusive and will in no way interfere with your use of water as normal. In fact it is important you use water just like you normally would. The study will work like this. During the course of the next two or three weeks, our field service technician will attach a data logging device to your water meter. It will be located inside the water meter box and hence be out-of-sight. There will be no water service outage. The logger will be in place for only a two week period and will monitor water flowing through the meter at short intervals of time. It will then be removed - again there will be no water service outage. About 6 months later, the logger will again be installed for another two week period and then removed for good.

Your participation in the study will not impact your water service or your water bill in any way.

The use of the data will be limited to planning purposes and any resultant databases created will be secretly coded and not contain any information that would allow the data to be traced back to your name, home address or even your water account number.

The study is being sponsored jointly by the <*City/Utility*> and the American Water Works Association Research Foundation.

Thank you very much for your cooperation with this study. Once again, please don't hesitate to call if you have any questions about the study or your participation.

Sincerely,

<*Name/Title of highest official possible in City/Utility*>

If Spanish speaking population is significant, add following notice in Spanish.
[Notice! If you are a Spanish speaking person and have any difficulty reading this letter, it is most important you call <insert phone number of knowledgeable Spanish speaking staff person> at your earliest convenience and the contents of the letter will be carefully read to you. Thank you.]

COMPLETE MAIL SURVEY RESPONSES

Table A.1 presents summary responses from the mail questionnaire for all 14 study cities. Survey responses in Tempe, Scottsdale, Waterloo, and Cambridge were kept separate so that officials in those cities could have results that pertained directly to their own population. Please refer to the questionnaire in Appendix A for a complete listing of each survey question. Table A.1 continues for the next 45 pages.

Table A.1 Complete survey response summary, 14 study cities

Study city	**Question 1: Count of water using appliances fixtures in each home**								
	Q1a Toilets			**Q1b Bathtubs w/shower**			**Q1c Bathtub only**		
	Mean	**Mode**	**Median**	**Mean**	**Mode**	**Median**	**Mean**	**Mode**	**Median**
Boulder, Colorado	2.48	2	2	1.32	1	1	0.15	0	0
Denver, Colorado	2.33	2	2	1.16	1	1	0.2	0	0
Eugene, Oregon	1.91	2	2	1.05	1	1	0.16	0	0
Seattle, Washington	2.20	2	2	1.21	1	1	0.13	0	0
San Diego, California	2.18	2	2	1.15	1	1	0.20	0	0
Tampa, Florida	1.76	2	2	1.15	1	1	0.11	0	0
Phoenix, Arizona	2.19	2	2	1.30	1	1	0.24	0	0
Tempe, Arizona	2.13	2	2	1.18	1	1	0.19	0	0
Scottsdale, Arizona	2.45	2	2	1.32	1	1	0.36	0	0
Waterloo, Ontario	2.40	2	2	1.07	1	1	0.14	0	0
Cambridge, Ontario	2.00	2	2	1.09	1	1	0.15	0	0
Walnut Valley WD	2.51	2	2	1.40	1	1	0.30	0	0
Las Virgenes Valley WD	3.23	3	3	1.56	1	1	0.48	1	0
Lompoc, California	2.04	2	2	1.01	1	1	0.21	0	0
14 Study Cities	2.27	2	2	1.21	1	1	0.22	0	0

(continued)

Table A.1 (Continued)

Study city	Question 1 (continued): Count of water using appliances fixtures in each home								
	Q1d Shower only			Q1e Whirlpool tubs			Q1f Bathroom sinks		
	Mean	Mode	Median	Mean	Mode	Median	Mean	Mode	Median
Boulder, Colorado	0.73	1	1	0.07	0	0	2.65	2	3
Denver, Colorado	0.73	1	1	0.06	0	0	2.41	2	2
Eugene, Oregon	0.57	1	1	0.04	0	0	1.97	2	2
Seattle, Washington	0.62	1	1	0.06	0	0	2.29	2	2
San Diego, California	0.75	1	1	0.04	0	0	2.34	2	2
Tampa, Florida	0.46	0	0	0.03	0	0	1.79	1	2
Phoenix, Arizona	0.75	1	1	0.07	0	0	2.51	2	2
Tempe, Arizona	0.79	1	1	0.06	0	0	2.56	2	2
Scottsdale, Arizona	0.90	1	1	0.15	0	0	3.10	2	3
Waterloo, Ontario	0.69	1	1	0.17	0	0	2.47	2	2
Cambridge, Ontario	0.42	0	0	0.14	0	0	2.01	2	2
Walnut Valley WD	0.93	1	1	0.05	0	0	2.89	2	3
Las Virgenes Valley WD	1.25	1	1	0.23	0	0	3.89	3	4
Lompoc, California	0.77	1	1	0.02	0	0	2.17	2	2
14 Study Cities	0.74	1	1	0.09	0	0	2.50	2	2

(continued)

Table A.1 (Continued)

Study city	Question 1 (continued): Count of water using fixtures in each home						Question 2		
	Q1g Number of kitchen sinks			Q1h Indoor utility/garage sink			Q2a Garbage disposal		
	Mean	Mode	Median	Mean	Mode	Median	Yes	No	NR[1]
Boulder, Colorado	1.09	1	1	0.29	0	0	92.8%	6.7%	0.2%
Denver, Colorado	1.08	1	1	0.37	0	0	87.1%	12.7%	0.2%
Eugene, Oregon	1.05	1	1	0.34	0	0	63.5%	34.7%	1.8%
Seattle, Washington	1.09	1	1	0.51	1	0	61.4%	36.4%	2.2%
San Diego, California	1.05	1	1	0.44	0	0	84.2%	14.5%	1.2%
Tampa, Florida	1.07	1	1	0.23	0	0	36.3%	58.2%	5.5%
Phoenix, Arizona	1.07	1	1	0.24	0	0	73.5%	26.3%	0.2%
Tempe, Arizona	1.06	1	1	0.19	0	0	84.1%	15.5%	0.5%
Scottsdale, Arizona	1.08	1	1	0.38	0	0	90.4%	8.7%	0.9%
Waterloo, Ontario	1.26	1	1	0.78	1	1	5.8%	89.2%	5.0%
Cambridge, Ontario	1.16	1	1	0.56	1	1	2.6%	90.2%	7.2%
Walnut Valley WD	1.07	1	1	0.24	0	0	92.5%	6.1%	1.3%
Las Virgenes Valley WD	1.17	1	1	0.44	0	0	93.4%	5.4%	1.2%
Lompoc, California	1.03	1	1	0.17	0	0	80.9%	17.1%	1.9%
14 Study Cities	1.09	1	1	0.37	0	0	67.8%	30.1%	2.1%

(continued)

[1]NR = Non response

Table A.1 (Continued)

Study city	Question 2 (continued): Do you have these water-using appliances or fixtures in your home?								
	Q2b Top loading washer			Q2c Front loading washer			Q2d Dishwasher		
	Yes	No	NR	Yes	No	NR	Yes	No	NR
Boulder, Colorado	96.3%	3.5%	0.0%	2.4%	87.4%	10.0%	86.3%	12.0%	1.5%
Denver, Colorado	94.6%	4.7%	0.6%	2.6%	86.5%	10.9%	75.1%	22.5%	2.4%
Eugene, Oregon	96.1%	3.1%	0.8%	2.5%	84.3%	13.1%	80.6%	16.9%	2.5%
Seattle, Washington	96.6%	3.0%	0.4%	1.6%	84.5%	13.9%	80.5%	16.9%	2.6%
San Diego, California	94.4%	4.8%	0.8%	2.9%	86.3%	10.8%	67.6%	30.7%	1.7%
Tampa, Florida	89.9%	9.6%	0.5%	2.7%	84.7%	12.6%	44.0%	50.5%	5.5%
Phoenix, Arizona	96.9%	2.8%	0.2%	1.2%	89.0%	9.9%	77.0%	22.3%	0.7%
Tempe, Arizona	95.5%	4.1%	0.5%	0.5%	95.0%	4.5%	85.0%	13.6%	1.4%
Scottsdale, Arizona	98.8%	0.9%	0.3%	1.5%	85.6%	12.9%	93.4%	5.7%	0.9%
Waterloo, Ontario	96.1%	3.1%	0.8%	2.7%	86.9%	10.4%	60.2%	36.7%	3.1%
Cambridge, Ontario	94.1%	4.2%	1.6%	3.9%	84.3%	11.8%	50.7%	44.4%	4.9%
Walnut Valley WD	97.1%	2.4%	0.5%	3.2%	74.3%	22.5%	89.3%	8.3%	2.4%
Las Virgenes Valley WD	96.3%	2.4%	1.2%	2.4%	84.8%	12.7%	94.4%	4.6%	1.0%
Lompoc, California	96.8%	1.9%	1.3%	2.1%	84.2%	13.7%	70.2%	25.7%	4.1%
14 Study Cities	95.7%	3.6%	0.7%	2.3%	85.6%	12.1%	75.3%	22.2%	2.5%

(continued)

Table A.1 (Continued)

Study city	Question 2 (continued): Do you have these water-using appliances, fixtures or purposes in your home?								
	Q2e Swimming pool			Q2f Hot tub			Q2g Evap./swamp cooler		
	Yes	No	NR	Yes	No	NR	Yes	No	NR
Boulder, Colorado	1.3%	91.1%	7.4%	5.9%	86.7%	7.2%	9.4%	82.8%	7.6%
Denver, Colorado	1.5%	90.8%	7.7%	4.7%	87.3%	7.9%	18.7%	75.3%	6.0%
Eugene, Oregon	2.9%	87.3%	9.8%	13.3%	77.5%	9.2%	0.2%	89.6%	10.2%
Seattle, Washington	3.0%	87.3%	9.7%	8.9%	82.7%	8.5%	0.0%	89.9%	10.1%
San Diego, California	11.4%	82.0%	6.6%	7.9%	85.3%	6.8%	1.2%	91.7%	7.1%
Tampa, Florida	16.1%	76.2%	7.7%	3.8%	88.5%	7.7%	0.3%	90.7%	9.0%
Phoenix, Arizona	37.8%	59.6%	2.6%	6.6%	89.0%	4.5%	37.8%	58.9%	3.3%
Tempe, Arizona	40.9%	57.3%	1.8%	9.1%	87.7%	3.2%	37.7%	59.5%	2.7%
Scottsdale, Arizona	53.2%	42.6%	4.2%	16.5%	76.3%	7.2%	17.4%	75.4%	7.2%
Waterloo, Ontario	7.3%	86.1%	6.6%	2.7%	90.7%	6.6%	0.4%	92.7%	6.9%
Cambridge, Ontario	9.8%	82.4%	7.8%	2.3%	90.2%	7.5%	0.7%	90.8%	8.5%
Walnut Valley WD	28.6%	58.8%	12.6%	15.0%	70.6%	14.4%	1.6%	81.6%	16.8%
Las Virgenes Valley WD	48.4%	46.9%	4.6%	17.1%	75.6%	7.3%	2.4%	89.7%	7.8%
Lompoc, California	0.9%	89.5%	9.6%	11.6%	79.4%	9.0%	0.2%	89.9%	9.9%
14 Study Cities	18.8%	74.1%	7.1%	9.0%	83.4%	7.6%	9.1%	82.8%	8.1%

(continued)

Table A.1 (Continued)

Study city	**Question 2 (continued): Do you have these water-using appliances or purposes in your home?**								
	Q2h Pressure regulator			**Q2i Water treatment system**			**Q2j Greenhouse**		
	Yes	**No**	**NR**	**Yes**	**No**	**NR**	**Yes**	**No**	**NR**
Boulder, Colorado	35.2%	42.2%	22.4%	8.3%	84.1%	7.4%	2.2%	91.1%	6.5%
Denver, Colorado	7.3%	69.3%	23.4%	7.1%	85.2%	7.7%	1.3%	90.8%	7.9%
Eugene, Oregon	10.8%	66.9%	22.4%	2.2%	87.6%	10.2%	2.5%	88.0%	9.4%
Seattle, Washington	10.1%	70.8%	19.1%	5.6%	85.7%	8.7%	1.8%	88.9%	9.3%
San Diego, California	36.7%	50.0%	13.3%	25.3%	69.3%	5.4%	1.7%	91.3%	7.1%
Tampa, Florida	2.7%	78.7%	18.6%	13.7%	77.9%	8.5%	0.5%	91.5%	7.9%
Phoenix, Arizona	15.3%	70.0%	14.8%	21.4%	75.6%	3.1%	0.2%	96.5%	3.3%
Tempe, Arizona	9.1%	75.5%	15.5%	25.0%	73.2%	1.8%	0.5%	97.7%	1.8%
Scottsdale, Arizona	24.3%	56.2%	19.5%	36.6%	59.8%	3.6%	0.6%	92.8%	6.6%
Waterloo, Ontario	5.4%	79.2%	15.4%	73.0%	23.2%	3.9%	0.0%	93.8%	6.2%
Cambridge, Ontario	4.9%	77.1%	18.0%	55.9%	39.2%	4.9%	0.0%	92.2%	7.8%
Walnut Valley WD	41.4%	40.6%	17.9%	29.4%	58.0%	12.6%	0.5%	83.2%	16.3%
Las Virgenes Valley WD	59.9%	25.4%	14.7%	26.2%	67.7%	6.1%	2.0%	91.4%	6.6%
Lompoc, California	49.3%	32.1%	18.6%	22.3%	70.9%	6.9%	1.1%	90.4%	8.6%
14 Study Cities	22.3%	59.6%	18.1%	25.1%	68.4%	6.5%	1.1%	91.4%	7.5%

(continued)

Table A.1 (Continued)

Study city	Question 2 (continued)						Question 4			Question 5		
	Q2k Flower garden			Q2l Vegetable garden			Year of purchase of clothes washer			Year of purchase of dishwasher		
	Yes	No	NR	Yes	No	NR	Mean	Mode	Median	Mean	Mode	Median
Boulder, Colorado	75.2%	21.7%	2.8%	43.9%	51.7%	4.1%	1986	1990	1987	1987	1993	1989
Denver, Colorado	63.1%	34.1%	2.8%	35.6%	59.7%	4.7%	1988	1990	1989	1988	1995	1990
Eugene, Oregon	70.8%	25.7%	3.5%	41.6%	51.6%	6.9%	1988	1994	1988	1988	1990	1990
Seattle, Washington	70.8%	26.4%	2.8%	35.2%	58.1%	6.6%	1988	1990	1988	1988	1990	1990
San Diego, California	58.9%	39.4%	1.7%	26.8%	67.8%	5.4%	1988	1990	1989	1988	1995	1989
Tampa, Florida	28.7%	65.6%	5.7%	7.9%	83.6%	8.5%	1988	1994	1990	1988	1993	1990
Phoenix, Arizona	40.1%	57.5%	2.3%	15.3%	81.7%	3.1%	1988	1994	1991	1988	1995	1990
Tempe, Arizona	40.5%	57.7%	1.8%	16.8%	80.0%	3.2%	1990	1995	1990	1990	1995	1991
Scottsdale, Arizona	47.4%	48.6%	3.9%	12.9%	79.9%	7.2%	1990	1995	1990	1990	1995	1992
Waterloo, Ontario	78.8%	18.9%	2.3%	30.1%	64.5%	5.4%	1988	1985	1988	1988	1990	1990
Cambridge, Ontario	72.9%	22.5%	4.6%	33.3%	58.5%	8.2%	1989	1994	1990	1991	1996	1991
Walnut Valley WD	61.0%	32.6%	6.4%	25.1%	62.8%	12.0%	1989	1995	1990	1989	1989	1989
Las Virgenes Valley WD	71.6%	26.7%	1.7%	24.9%	69.9%	5.1%	1988	1995	1990	1988	1990	1990
Lompoc, California	67.7%	27.6%	4.7%	36.6%	57.0%	6.4%	1988	1990	1990	1990	1995	1990
14 Study Cities	60.5%	36.1%	3.4%	27.6%	66.2%	6.2%	1988	1992	1989	1989	1993	1990

(continued)

Table A.1 (Continued)

Study city	Question 6: How many times per week is a load of dishes had washed in your home?										
	0	**1-2**	**3-4**	**5-6**	**7-8**	**9-10**	**11-12**	**13-14**	**>14**	**D.Know**	**NR**
Boulder, Colorado	24.6%	25.3%	14.8%	9.4%	10.7%	3.3%	2.4%	2.4%	3.9%	0.9%	2.4%
Denver, Colorado	18.9%	29.0%	16.7%	9.0%	9.9%	3.2%	1.9%	4.5%	2.2%	1.3%	3.4%
Eugene, Oregon	22.0%	25.7%	15.1%	8.2%	10.0%	4.1%	2.9%	3.1%	2.9%	0.6%	5.3%
Seattle, Washington	22.3%	27.6%	17.1%	6.0%	10.3%	2.8%	1.8%	2.4%	4.2%	1.4%	4.0%
San Diego, California	16.2%	20.7%	13.1%	8.3%	12.9%	5.0%	3.7%	6.6%	7.5%	2.5%	3.5%
Tampa, Florida	14.5%	14.8%	12.6%	6.3%	19.7%	7.1%	3.6%	7.9%	7.7%	2.5%	3.6%
Phoenix, Arizona	15.5%	23.7%	18.5%	9.6%	12.2%	4.5%	1.9%	2.8%	8.0%	1.6%	1.6%
Tempe, Arizona	20.0%	25.5%	18.6%	10.5%	7.3%	3.6%	3.6%	2.3%	6.4%	0.9%	1.4%
Scottsdale, Arizona	18.9%	28.2%	17.4%	12.3%	7.8%	2.1%	2.1%	2.7%	2.7%	0.9%	4.8%
Waterloo, Ontario	6.6%	17.8%	13.1%	7.3%	18.9%	5.8%	3.9%	6.9%	14.3%	0.0%	5.4%
Cambridge, Ontario	7.5%	14.4%	11.1%	5.9%	21.2%	9.2%	5.6%	7.5%	14.1%	0.7%	2.9%
Walnut Valley WD	12.8%	17.1%	15.8%	9.1%	12.3%	5.3%	3.5%	5.9%	10.4%	2.1%	5.6%
Las Virgenes Valley WD	22.0%	22.2%	15.2%	7.8%	12.7%	2.9%	2.9%	3.7%	6.8%	1.0%	2.7%
Lompoc, California	12.8%	20.3%	16.7%	10.3%	14.1%	6.4%	1.1%	5.8%	7.7%	0.9%	3.9%
14 Study Cities	16.8%	22.3%	15.4%	8.6%	12.9%	4.7%	2.9%	4.6%	7.1%	1.2%	3.6%

(continued)

Table A.1 (Continued)

Study city	Question 7: How many showers in your home have low-flow shower heads?							Question 8: How many of the toilets in your home are ultra-low-flush toilets?						
	0	**1**	**2**	**3**	**>4**	**D.Know**	**NR**	**0**	**1**	**2**	**3**	**>4**	**D.Know**	**NR**
Boulder, Colorado	32.2%	28.8%	24.2%	5.9%	4.4%	7.4%	1.1%	63.4%	11.6%	10.7%	4.1%	0.9%	9.4%	0.0%
Denver, Colorado	33.3%	29.6%	20.6%	4.9%	0.3%	8.4%	2.6%	53.7%	21.5%	9.7%	3.2%	0.6%	9.7%	1.7%
Eugene, Oregon	12.7%	43.3%	33.7%	4.5%	0.0%	2.5%	3.1%	58.6%	15.9%	9.2%	2.2%	0.2%	10.4%	3.5%
Seattle, Washington	23.9%	36.6%	29.8%	4.6%	1.0%	3.6%	0.4%	57.7%	18.9%	10.1%	4.2%	0.8%	7.4%	0.8%
San Diego, California	15.4%	33.0%	37.3%	7.5%	1.5%	4.1%	1.2%	35.9%	18.5%	28.6%	8.9%	0.8%	6.8%	0.4%
Tampa, Florida	27.0%	39.9%	20.5%	1.9%	0.8%	6.8%	3.0%	47.8%	26.8%	9.0%	3.8%	0.8%	9.8%	1.9%
Phoenix, Arizona	26.1%	24.9%	35.2%	3.5%	0.9%	8.2%	1.2%	45.1%	14.1%	19.0%	5.4%	0.7%	14.8%	0.9%
Tempe, Arizona	30.5%	26.8%	32.3%	3.2%	0.5%	5.9%	0.9%	51.4%	13.6%	19.1%	2.3%	0.9%	10.5%	2.3%
Scottsdale, Arizona	27.6%	17.1%	36.0%	7.2%	3.0%	5.4%	3.6%	42.9%	10.8%	18.9%	10.5%	4.5%	9.0%	3.3%
Waterloo, Ontario	23.2%	44.0%	22.8%	2.7%	0.0%	3.1%	4.2%	53.7%	18.9%	9.7%	4.2%	1.2%	10.0%	2.3%
Cambridge, Ontario	24.8%	49.0%	17.0%	2.0%	0.3%	3.6%	3.3%	53.3%	20.3%	12.7%	2.0%	0.7%	9.5%	1.6%
Walnut Valley WD	23.8%	15.8%	40.4%	10.4%	0.5%	5.1%	4.0%	39.3%	13.4%	21.1%	9.6%	0.5%	11.5%	4.5%
Las Virgenes Valley WD	16.1%	14.2%	34.0%	16.9%	11.2%	7.1%	0.5%	31.5%	13.0%	15.4%	16.9%	12.0%	10.3%	1.0%
Lompoc, California	20.8%	27.8%	40.7%	3.2%	0.2%	5.8%	1.5%	40.3%	11.1%	34.5%	4.9%	0.2%	7.5%	1.5%
14 Study Cities	24.1%	30.8%	30.3%	5.6%	1.8%	5.5%	2.2%	48.2%	16.3%	16.3%	5.9%	1.8%	9.8%	1.8%

(continued)

Table A.1 (Continued)

Study city	Question 9: Indicate the approximate total lot (parcel) area of your residence.								
	<2000	**2-3999**	**4-5999**	**6-7999**	**8-9999**	**10-11999**	**12-13999**	**14-15999**	**16-17999**
Boulder, Colorado	1.5%	9.4%	12.4%	16.3%	13.5%	14.4%	4.4%	3.1%	2.0%
Denver, Colorado	7.7%	11.2%	9.7%	13.5%	7.5%	11.2%	2.4%	2.4%	0.4%
Eugene, Oregon	4.9%	9.4%	9.2%	9.8%	15.7%	12.7%	3.7%	2.0%	0.8%
Seattle, Washington	2.2%	6.8%	14.1%	15.7%	12.3%	15.9%	2.8%	3.0%	2.0%
San Diego, California	10.2%	8.7%	16.6%	14.3%	6.8%	8.7%	1.7%	2.7%	0.8%
Tampa, Florida	9.3%	6.6%	9.0%	9.8%	7.9%	12.3%	2.7%	3.3%	1.4%
Phoenix, Arizona	6.3%	10.1%	3.5%	9.2%	12.2%	15.3%	2.8%	3.1%	1.2%
Tempe, Arizona	8.2%	5.5%	11.4%	11.8%	9.5%	15.5%	4.1%	1.8%	1.8%
Scottsdale, Arizona	5.4%	7.5%	7.8%	8.7%	8.4%	14.7%	3.0%	4.5%	0.9%
Waterloo, Ontario	5.4%	10.4%	18.1%	17.0%	12.7%	9.3%	1.5%	2.3%	1.2%
Cambridge, Ontario	6.5%	14.4%	17.3%	14.4%	6.5%	7.2%	2.0%	1.0%	1.3%
Walnut Valley WD	3.5%	6.4%	6.4%	13.6%	11.8%	12.8%	6.1%	3.5%	1.3%
Las Virgenes Valley WD	3.7%	5.9%	6.6%	9.5%	6.4%	15.9%	6.1%	4.9%	2.0%
Lompoc, California	6.2%	9.2%	9.2%	18.8%	9.2%	11.1%	2.1%	2.1%	0.4%
14 Study Cities	5.8%	8.7%	10.8%	13.0%	10.0%	12.6%	3.2%	2.8%	1.2%

(continued)

Table A.1 (Continued)

Study city	18-19999	20-24999	25-29999	30-34999	35-39999	>40000	D.Know	NR
	Question 9 (continued): Indicate the approximate total lot (parcel) area of your residence.							
Boulder, Colorado	1.5%	3.3%	0.7%	0.4%	0.4%	1.7%	11.1%	3.9%
Denver, Colorado	1.5%	4.7%	0.2%	1.5%	0.4%	4.7%	15.9%	8.2%
Eugene, Oregon	2.0%	4.3%	1.6%	2.0%	0.2%	2.0%	13.1%	6.7%
Seattle, Washington	0.6%	3.8%	0.6%	2.2%	0.4%	1.2%	12.5%	3.6%
San Diego, California	1.0%	4.4%	0.6%	1.5%	0.2%	0.8%	16.2%	4.8%
Tampa, Florida	2.5%	3.6%	0.5%	1.1%	0.0%	1.6%	21.3%	7.1%
Phoenix, Arizona	1.4%	5.4%	0.2%	1.6%	0.2%	4.2%	19.2%	4.0%
Tempe, Arizona	2.3%	2.3%	0.5%	1.8%	0.0%	0.5%	16.8%	6.4%
Scottsdale, Arizona	1.8%	5.7%	0.9%	1.8%	1.8%	8.1%	10.8%	8.1%
Waterloo, Ontario	0.8%	2.3%	0.8%	1.2%	0.4%	0.0%	12.4%	4.2%
Cambridge, Ontario	0.3%	1.6%	1.0%	0.0%	0.0%	1.3%	18.3%	6.9%
Walnut Valley WD	1.6%	4.5%	1.3%	1.6%	0.5%	4.0%	13.9%	7.0%
Las Virgenes Valley WD	2.9%	6.6%	1.0%	2.0%	0.7%	11.7%	11.2%	2.9%
Lompoc, California	1.1%	0.9%	0.6%	0.6%	0.0%	0.2%	21.2%	6.9%
14 Study Cities	1.5%	3.8%	0.8%	1.4%	0.4%	3.0%	15.3%	5.8%

(continued)

Table A.1 (Continued)

Study city	**Question 10: Approximately what percent of your total lot area is landscape?**					
	Mean	**Mode**	**Median**	**0%**	**D.Know**	**Non Response**
Boulder, Colorado	55.7%	50.0%	50.0%	0.7%	8.7%	1.7%
Denver, Colorado	19.6%	5.0%	6.0%	0.9%	17.4%	2.8%
Eugene, Oregon	49.8%	50.0%	50.0%	1.6%	18.8%	4.1%
Seattle, Washington	55.8%	50.0%	50.0%	1.6%	18.8%	4.1%
San Diego, California	45.9%	99.0%	40.0%	1.6%	18.8%	4.1%
Tampa, Florida	41.6%	50.0%	40.0%	4.9%	26.5%	3.0%
Phoenix, Arizona	38.4%	50.0%	35.0%	2.6%	17.4%	2.3%
Tempe, Arizona	37.2%	50.0%	30.0%	2.3%	16.4%	2.3%
Scottsdale, Arizona	36.7%	50.0%	30.0%	1.6%	14.1%	3.4%
Waterloo, Ontario	54.1%	60.0%	60.0%	0.4%	17.0%	3.1%
Cambridge, Ontario	49.7%	50.0%	50.0%	1.6%	21.9%	4.2%
Walnut Valley WD	14.4%	5.0%	5.0%	0.5%	13.6%	0.0%
Las Virgenes Valley WD	39.4%	50.0%	39.0%	1.5%	17.4%	1.0%
Lompoc, California	42.1%	50.0%	40.0%	1.1%	19.9%	3.0%
14 Study Cities	41.4%	47.8%	37.5%	1.6%	17.6%	2.8%

(continued)

Table A.1 (Continued)

Study city	Question 11: What portion of your landscape area is the lawn area?											
	0	**1-10%**	**11-20%**	**21-30%**	**31-40%**	**41-50%**	**51-60%**	**61-70%**	**71-80%**	**81-90%**	**91-100%**	**D.Know**	**NR**
Boulder, Colorado	2.6%	2.6%	5.2%	8.5%	7.8%	11.8%	8.7%	14.4%	16.3%	9.6%	6.1%	4.4%	2.0%
Denver, Colorado	0.4%	5.4%	5.4%	7.3%	10.3%	11.4%	8.6%	9.7%	14.8%	8.2%	7.3%	8.2%	3.2%
Eugene, Oregon	9.2%	8.4%	8.4%	9.8%	7.6%	10.6%	8.6%	9.2%	9.0%	5.7%	1.0%	8.0%	4.3%
Seattle, Washington	7.0%	11.1%	9.9%	10.5%	9.3%	11.9%	7.8%	9.3%	8.7%	4.8%	2.6%	5.4%	1.8%
San Diego, California	16.2%	18.3%	13.9%	8.7%	6.8%	8.5%	5.2%	3.9%	5.2%	3.3%	2.3%	6.0%	1.7%
Tampa, Florida	2.7%	10.7%	7.7%	10.9%	9.0%	7.1%	5.2%	7.9%	7.4%	6.3%	5.2%	14.8%	5.2%
Phoenix, Arizona	18.1%	14.1%	11.5%	7.5%	6.6%	8.7%	3.8%	4.7%	7.7%	3.8%	5.6%	5.6%	2.3%
Tempe, Arizona	17.3%	9.1%	9.5%	10.0%	5.0%	10.5%	2.3%	4.1%	10.0%	6.4%	8.2%	5.0%	2.7%
Scottsdale, Arizona	30.6%	17.4%	9.3%	6.9%	5.4%	6.3%	4.8%	3.0%	1.8%	2.1%	4.2%	2.7%	5.4%
Waterloo, Ontario	0.8%	1.5%	3.1%	8.9%	6.2%	9.3%	7.3%	15.8%	14.3%	10.0%	10.0%	8.1%	4.6%
Cambridge, Ontario	0.3%	4.2%	5.2%	7.8%	9.5%	11.1%	8.8%	9.8%	11.8%	9.8%	6.5%	10.5%	4.6%
Walnut Valley WD	4.3%	11.8%	15.0%	9.6%	8.8%	9.1%	5.1%	11.0%	7.2%	5.1%	2.7%	5.1%	5.3%
Las Virgenes Valley WD	12.5%	11.7%	14.9%	11.7%	8.8%	10.5%	6.6%	6.1%	6.4%	2.4%	1.7%	5.6%	1.0%
Lompoc, California	7.9%	12.0%	10.5%	10.9%	8.8%	9.6%	4.5%	7.3%	8.6%	4.7%	3.0%	9.0%	3.2%
14 Study Cities	9.3%	9.9%	9.2%	9.2%	7.9%	9.7%	6.2%	8.3%	9.2%	5.9%	4.7%	7.0%	3.4%

(continued)

Table A.1 (Continued)

Study city	Question 12: What percent of your landscape area do you typically tend to water?												
	0	**1-10%**	**11-20%**	**21-30%**	**31-40%**	**41-50%**	**51-60%**	**61-70%**	**71-80%**	**81-90%**	**91-100%**	**D.Know**	**NR**
Boulder, Colorado	2.8%	3.1%	5.5%	5.2%	5.9%	5.9%	5.2%	7.6%	13.9%	10.5%	28.1%	3.9%	2.4%
Denver, Colorado	0.6%	4.9%	4.1%	4.3%	6.7%	9.0%	5.8%	7.5%	9.2%	9.4%	27.7%	7.5%	3.2%
Eugene, Oregon	5.7%	11.2%	7.1%	6.9%	4.3%	8.0%	4.5%	5.9%	8.4%	7.8%	18.2%	6.5%	5.5%
Seattle, Washington	6.2%	14.7%	12.9%	11.3%	7.2%	8.0%	5.6%	5.2%	5.6%	3.6%	11.9%	4.8%	2.8%
San Diego, California	3.9%	13.9%	12.2%	7.3%	4.4%	7.9%	5.2%	5.0%	5.2%	5.8%	21.4%	5.2%	2.7%
Tampa, Florida	19.4%	18.3%	10.7%	5.5%	4.1%	6.8%	2.7%	2.7%	2.7%	3.3%	13.1%	7.7%	3.0%
Phoenix, Arizona	5.2%	16.2%	11.0%	9.2%	6.1%	10.3%	3.1%	3.5%	5.9%	3.5%	16.4%	6.3%	3.3%
Tempe, Arizona	5.0%	13.6%	9.1%	7.3%	7.7%	8.6%	3.6%	2.3%	7.7%	6.4%	21.4%	4.5%	2.7%
Scottsdale, Arizona	2.7%	19.8%	10.8%	8.4%	5.1%	9.0%	3.6%	3.6%	4.2%	3.3%	18.0%	4.5%	6.9%
Waterloo, Ontario	11.6%	14.7%	11.6%	10.4%	6.9%	6.6%	6.2%	3.5%	4.6%	4.2%	10.0%	6.2%	3.5%
Cambridge, Ontario	9.2%	14.7%	11.8%	11.4%	6.2%	7.8%	5.9%	5.9%	3.3%	3.9%	9.2%	7.8%	2.9%
Walnut Valley WD	1.1%	6.4%	5.9%	7.8%	6.7%	7.8%	4.8%	7.8%	7.5%	7.2%	26.5%	5.3%	5.3%
Las Virgenes Valley WD	1.2%	5.9%	4.4%	5.1%	2.2%	4.9%	3.7%	3.2%	7.1%	7.3%	49.1%	3.9%	2.0%
Lompoc, California	4.5%	12.8%	9.2%	9.2%	8.6%	8.4%	3.6%	5.6%	7.9%	5.8%	16.5%	5.4%	2.6%
14 Study Cities	5.7%	12.2%	9.0%	7.8%	5.9%	7.8%	4.5%	4.9%	6.7%	5.9%	20.5%	5.7%	3.5%

(continued)

Table A.1 (Continued)

Study city	Question 13: During the winter months how many days each week to you typically water any part of your landscape?											
	0	<2/ month	few/ month	<1/wee k	1/week	2/week	3/week	4/week	5/week	6/week	7/week	D.Kno w	NR
Boulder, Colorado	68.2%	28.3%	2.4%	0.0%	0.4%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%
Denver, Colorado	75.5%	19.3%	2.4%	0.0%	0.4%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.4%	1.5%
Eugene, Oregon	91.4%	3.3%	1.0%	1.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	2.4%
Seattle, Washington	93.8%	4.2%	0.6%	0.2%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%
San Diego, California	13.7%	16.2%	16.6%	6.4%	17.0%	14.7%	8.7%	1.5%	0.8%	0.0%	0.6%	2.7%	1.0%
Tampa, Florida	33.6%	18.6%	12.0%	7.1%	9.0%	15.0%	0.3%	0.0%	0.3%	0.0%	0.0%	2.7%	1.4%
Phoenix, Arizona	16.2%	22.8%	13.1%	7.5%	10.6%	13.8%	8.7%	2.3%	0.2%	0.5%	2.6%	0.9%	0.7%
Tempe, Arizona	16.8%	24.5%	12.3%	5.5%	12.7%	11.8%	7.3%	2.3%	0.5%	0.0%	2.3%	2.3%	1.8%
Scottsdale, Arizona	6.9%	12.6%	14.4%	5.4%	17.4%	17.1%	11.1%	2.4%	2.1%	0.6%	5.7%	0.9%	3.3%
Waterloo, Ontario	98.1%	0.4%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%
Cambridge, Ontario	97.1%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.3%	0.3%	0.3%	0.0%	0.3%	1.3%
Walnut Valley WD	9.1%	15.5%	13.9%	4.8%	14.2%	14.7%	14.2%	2.7%	1.1%	0.5%	3.5%	1.6%	4.3%
Las Virgenes Valley WD	7.8%	7.3%	12.5%	4.4%	16.6%	24.4%	19.8%	2.9%	0.5%	0.0%	0.5%	2.2%	1.0%
Lompoc, California	32.1%	18.4%	16.5%	5.8%	10.9%	8.1%	3.2%	0.2%	0.0%	0.2%	0.2%	2.1%	2.1%
14 Study Cities	47.2%	13.7%	8.4%	3.4%	7.9%	8.6%	5.3%	1.0%	0.4%	0.2%	1.1%	1.2%	1.6%

(continued)

Table A.1 (Continued)

Study city	Question 14: During the summer months how many days each week to you typically water any part of your landscape?												
	0	**<2/ month**	**few/ month**	**<1/wee k**	**1/week**	**2/week**	**3/week**	**4/week**	**5/week**	**6/week**	**7/week**	**D.Kno w**	**NR**
Boulder, Colorado	2.2%	2.0%	2.2%	1.7%	8.3%	25.1%	37.5%	9.6%	4.8%	0.7%	4.4%	1.5%	0.2%
Denver, Colorado	0.2%	0.6%	2.4%	1.3%	6.9%	30.9%	41.6%	8.2%	3.0%	0.2%	1.9%	0.9%	1.9%
Eugene, Oregon	4.3%	2.5%	5.5%	2.2%	14.5%	21.4%	24.9%	9.0%	4.5%	1.6%	4.9%	1.8%	2.9%
Seattle, Washington	5.6%	4.0%	10.5%	5.0%	15.5%	24.7%	21.7%	5.8%	3.2%	0.6%	1.8%	0.6%	0.8%
San Diego, California	3.5%	3.1%	4.1%	2.3%	7.9%	21.0%	28.2%	10.8%	6.2%	2.7%	7.1%	2.9%	0.2%
Tampa, Florida	19.9%	11.2%	10.7%	5.7%	13.9%	29.8%	2.7%	1.9%	0.8%	0.3%	0.5%	1.4%	1.1%
Phoenix, Arizona	4.7%	3.5%	4.7%	1.4%	8.9%	16.4%	30.3%	10.8%	6.8%	1.9%	8.5%	1.2%	0.9%
Tempe, Arizona	2.7%	3.6%	4.5%	1.4%	12.3%	14.5%	20.0%	10.9%	7.3%	5.5%	12.7%	2.7%	1.8%
Scottsdale, Arizona	1.8%	0.9%	3.3%	3.0%	6.9%	18.0%	20.4%	13.5%	9.9%	1.8%	16.5%	0.3%	3.6%
Waterloo, Ontario	8.9%	12.4%	16.2%	6.6%	16.6%	17.0%	12.7%	4.6%	0.8%	0.0%	0.0%	1.9%	2.3%
Cambridge, Ontario	7.5%	12.7%	12.1%	3.9%	18.6%	19.3%	15.7%	4.6%	2.0%	1.0%	0.7%	0.7%	1.3%
Walnut Valley WD	0.8%	1.6%	2.1%	0.8%	5.6%	12.0%	20.3%	11.5%	10.2%	3.7%	27.3%	0.0%	4.0%
Las Virgenes Valley WD	0.7%	1.0%	1.0%	1.2%	3.4%	7.1%	18.8%	17.1%	10.8%	9.8%	27.9%	0.7%	0.5%
Lompoc, California	2.8%	4.5%	8.8%	5.1%	15.6%	22.3%	23.1%	6.6%	3.2%	1.9%	2.8%	1.5%	1.7%
14 Study Cities	4.7%	4.6%	6.3%	3.0%	11.1%	20.0%	22.7%	8.9%	5.2%	2.3%	8.3%	1.3%	1.7%

(continued)

Table A.1 (Continued)

Study city	**Question 15: In addition to the water purchased from your water utility, do you use water from any of the following sources for outdoor water needs?**						
	None	**Canal**	**Cistern**	**Well**	**Stream**	**Other**	**NR**
Boulder, Colorado	93.7%	0.7%	0.4%	1.7%	0.0%	1.7%	1.7%
Denver, Colorado	93.8%	0.2%	0.2%	0.4%	0.0%	1.1%	3.7%
Eugene, Oregon	83.1%	0.0%	0.2%	11.4%	0.0%	1.2%	3.9%
Seattle, Washington	92.2%	0.0%	0.6%	0.2%	0.2%	4.2%	2.6%
San Diego, California	94.6%	0.0%	0.0%	0.4%	0.0%	2.9%	2.1%
Tampa, Florida	81.7%	0.0%	0.3%	10.7%	0.0%	4.4%	3.0%
Phoenix, Arizona	89.0%	4.7%	0.0%	0.5%	0.0%	3.1%	2.6%
Tempe, Arizona	91.4%	0.9%	0.0%	0.0%	0.0%	0.0%	3.6%
Scottsdale, Arizona	92.5%	0.9%	0.0%	0.3%	0.0%	1.2%	5.1%
Waterloo, Ontario	87.6%	0.0%	0.4%	0.4%	0.4%	4.2%	6.9%
Cambridge, Ontario	85.9%	0.0%	0.0%	1.3%	0.7%	0.0%	5.2%
Walnut Valley WD	90.6%	0.3%	0.0%	0.0%	0.0%	1.3%	7.8%
Las Virgenes Valley WD	93.9%	0.0%	0.0%	0.5%	0.0%	1.5%	4.2%
Lompoc, California	92.7%	0.0%	0.0%	0.2%	0.0%	1.7%	5.4%
14 Study Cities	90.2%	0.5%	0.2%	2.0%	0.1%	2.0%	4.1%

(continued)

Table A.1 (Continued)

Study city	Question 16: Characterize your sprinkling system. (check all that apply)											
	No sprinkling system		In-ground (front yard)		In-ground (back yard)		Drip or bubbler system		Soaker hose		Hose and sprinkler	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Boulder, Colorado	7.4%	92.6%	47.1%	52.9%	43.6%	56.4%	1.1%	88.7%	12.0%	88.0%	52.5%	47.5%
Denver, Colorado	9.7%	90.1%	47.2%	52.8%	44.2%	55.8%	5.2%	94.9%	8.8%	91.2%	45.1%	54.9%
Eugene, Oregon	9.4%	90.6%	27.8%	72.2%	24.7%	75.3%	4.9%	95.1%	20.2%	79.8%	58.0%	42.0%
Seattle, Washington	14.7%	85.3%	12.5%	87.5%	10.3%	89.7%	5.0%	95.0%	17.3%	82.7%	59.8%	40.2%
San Diego, California	10.6%	89.4%	53.7%	46.3%	46.7%	53.3%	15.8%	84.2%	8.5%	91.5%	27.2%	72.8%
Tampa, Florida	23.5%	76.5%	31.7%	68.3%	23.0%	77.0%	2.2%	97.8%	3.3%	96.7%	24.9%	75.1%
Phoenix, Arizona	14.1%	85.9%	35.4%	64.6%	41.5%	58.5%	31.7%	68.3%	5.9%	94.1%	21.6%	78.4%
Tempe, Arizona	8.6%	91.4%	44.5%	55.5%	51.8%	48.2%	36.8%	63.2%	4.5%	95.5%	24.1%	75.9%
Scottsdale, Arizona	5.7%	94.3%	46.5%	53.5%	50.8%	49.2%	52.3%	47.7%	5.4%	94.6%	15.0%	85.0%
Waterloo, Ontario	13.1%	86.9%	3.1%	96.9%	2.7%	97.3%	0.4%	99.6%	8.9%	91.1%	58.7%	41.3%
Cambridge, Ontario	14.1%	85.9%	2.6%	97.4%	1.6%	98.4%	0.7%	99.3%	7.8%	92.2%	63.1%	36.9%
Walnut Valley WD	5.1%	94.9%	79.9%	20.1%	70.1%	29.9%	11.5%	88.5%	4.3%	95.7%	18.4%	81.6%
Las Virgenes Valley WD	4.9%	95.1%	85.8%	14.2%	80.0%	20.0%	22.5%	77.5%	7.6%	92.4%	13.2%	86.8%
Lompoc, California	13.7%	86.3%	49.9%	50.1%	35.5%	64.5%	15.8%	84.2%	6.0%	94.0%	37.5%	62.5%
14 Study Cities	11.0%	88.9%	40.6%	59.4%	37.6%	62.4%	14.7%	84.6%	8.6%	91.4%	37.1%	62.9%

(continued)

Table A.1 (Continued)

Study city	Question 16 (continued)				Question 17: How is front yard in-ground sprinkler operated?				
	Hand held garden hose		Other						
	Yes	No	Yes	No	None	Hand	Timer	D.Know	NR
Boulder, Colorado	27.7%	72.3%	1.5%	98.5%	45.8%	12.2%	36.2%	0.0%	5.9%
Denver, Colorado	25.1%	74.9%	0.6%	99.4%	48.3%	4.9%	42.7%	0.4%	3.7%
Eugene, Oregon	35.5%	64.5%	1.4%	98.6%	63.7%	10.4%	18.0%	0.4%	7.5%
Seattle, Washington	48.7%	51.3%	2.4%	97.6%	79.9%	3.2%	9.3%	0.0%	7.6%
San Diego, California	42.1%	57.9%	2.7%	97.3%	40.7%	21.6%	35.1%	0.4%	2.3%
Tampa, Florida	36.1%	63.9%	1.1%	98.9%	63.7%	14.2%	17.8%	1.1%	3.3%
Phoenix, Arizona	30.3%	69.7%	1.6%	98.4%	52.8%	11.3%	31.2%	0.7%	4.0%
Tempe, Arizona	23.6%	76.4%	2.3%	97.7%	45.0%	14.5%	35.5%	0.5%	4.5%
Scottsdale, Arizona	26.4%	73.6%	0.6%	99.4%	29.1%	9.3%	57.1%	0.9%	3.6%
Waterloo, Ontario	49.8%	50.2%	3.1%	96.9%	83.4%	0.4%	2.7%	0.4%	13.1%
Cambridge, Ontario	48.7%	51.3%	1.6%	98.4%	87.6%	1.6%	1.0%	0.3%	9.5%
Walnut Valley WD	35.3%	64.7%	0.5%	99.5%	13.1%	28.1%	57.0%	0.0%	1.9%
Las Virgenes Valley WD	35.0%	65.0%	1.5%	98.5%	10.5%	11.5%	76.0%	0.5%	1.5%
Lompoc, California	42.8%	57.2%	1.9%	98.1%	44.1%	27.0%	25.7%	0.4%	2.8%
14 Study Cities	36.2%	63.8%	1.6%	98.4%	50.5%	12.2%	31.8%	0.4%	5.1%

(continued)

Table A.1 (Continued)

Study city	Question 18: How is back yard in-ground sprinkler operated?					Question 19: Is any in-ground sprinkler system fitted with a moisture sensor or rain shut-off device (SOD)?						
	None	**Hand**	**Timer**	**D.Know**	**NR**	**No Spklr.**	**No SOD**	**Soil Sensor**	**Rain Sensor**	**Soil +Rain**	**D.Know**	**NR**
Boulder, Colorado	48.2%	10.2%	34.4%	0.2%	7.0%	47.7%	39.4%	0.4%	6.5%	0.4%	3.1%	8.3%
Denver, Colorado	49.4%	3.9%	41.0%	0.4%	5.4%	50.2%	36.5%	0.6%	1.1%	0.0%	5.4%	6.2%
Eugene, Oregon	67.3%	8.8%	16.3%	0.2%	7.5%	67.6%	16.1%	0.0%	0.4%	0.4%	2.0%	13.5%
Seattle, Washington	79.9%	3.0%	8.5%	0.0%	8.7%	80.1%	8.0%	0.0%	0.6%	0.2%	1.2%	9.9%
San Diego, California	48.8%	18.5%	30.5%	0.8%	1.5%	53.3%	30.9%	0.2%	2.3%	0.8%	5.6%	6.8%
Tampa, Florida	72.4%	9.3%	14.5%	0.8%	3.0%	73.5%	12.0%	0.0%	4.6%	0.0%	3.6%	6.3%
Phoenix, Arizona	49.8%	9.9%	36.4%	0.2%	3.8%	52.6%	34.3%	0.9%	0.5%	0.2%	4.5%	7.0%
Tempe, Arizona	41.4%	12.7%	42.3%	0.9%	2.7%	48.6%	35.0%	0.9%	1.8%	0.0%	5.0%	8.6%
Scottsdale, Arizona	28.2%	7.2%	61.0%	0.3%	3.3%	30.6%	50.8%	1.2%	2.1%	0.6%	8.7%	6.0%
Waterloo, Ontario	83.4%	0.0%	2.7%	0.8%	13.1%	82.2%	1.2%	0.4%	1.2%	0.0%	0.4%	14.7%
Cambridge, Ontario	88.6%	0.7%	1.0%	0.0%	9.8%	88.2%	0.7%	0.0%	0.3%	0.0%	0.3%	10.5%
Walnut Valley WD	22.2%	22.7%	51.9%	0.0%	3.2%	31.3%	47.3%	0.5%	2.7%	1.3%	5.9%	11.0%
Las Virgenes Valley WD	14.4%	10.8%	72.1%	0.2%	2.4%	25.2%	58.4%	0.2%	4.2%	0.7%	4.9%	6.4%
Lompoc, California	57.6%	19.3%	19.7%	0.4%	3.0%	56.7%	24.0%	0.2%	1.1%	0.4%	4.3%	13.3%
14 Study Cities	53.7%	9.8%	30.9%	0.4%	5.3%	56.3%	28.2%	0.4%	2.1%	0.4%	3.9%	9.2%

(continued)

Table A.1 (Continued)

Study city	Question 20: On a scale of 1 to 5, with 5 being best, judge the overall appearance, level of care, and maintenance provided your landscape.				
	1	**2**	**3**	**4**	**5**	**NR**
Boulder, Colorado	3.7%	11.6%	30.5%	38.6%	13.1%	2.6%
Denver, Colorado	2.2%	6.9%	32.8%	39.9%	13.1%	5.2%
Eugene, Oregon	3.9%	11.6%	29.2%	32.7%	17.1%	5.1%
Seattle, Washington	4.2%	13.9%	33.4%	32.0%	13.1%	3.0%
San Diego, California	5.4%	13.9%	26.6%	32.2%	16.8%	4.4%
Tampa, Florida	10.4%	14.2%	31.7%	21.6%	11.2%	9.6%
Phoenix, Arizona	4.5%	13.6%	27.5%	31.5%	19.0%	3.5%
Tempe, Arizona	4.1%	7.3%	25.9%	36.4%	19.5%	6.8%
Scottsdale, Arizona	2.4%	4.8%	19.2%	36.9%	33.3%	3.3%
Waterloo, Ontario	2.7%	9.7%	31.7%	42.1%	8.1%	5.8%
Cambridge, Ontario	3.9%	10.5%	39.9%	28.8%	8.5%	8.5%
Walnut Valley WD	0.8%	5.9%	30.5%	40.4%	19.5%	2.9%
Las Virgenes Valley WD	2.7%	4.6%	15.9%	38.9%	34.2%	3.7%
Lompoc, California	2.8%	10.9%	27.2%	31.5%	22.7%	4.9%
14 Study Cities	3.8%	9.9%	28.7%	34.5%	17.8%	4.9%

(continued)

Table A.1 (Continued)

Study city	**Question 21: On average how often are cars washed at home?**							
	Never	**<1/month**	**1/month**	**2/month**	**1/week**	**>1/week**	**Don't Know**	**NR**
Boulder, Colorado	44.2%	37.9%	8.3%	5.9%	2.4%	0.0%	1.1%	0.2%
Denver, Colorado	42.5%	33.5%	12.0%	9.4%	2.2%	0.0%	0.0%	0.4%
Eugene, Oregon	20.8%	36.9%	16.1%	16.5%	7.3%	0.4%	1.0%	1.2%
Seattle, Washington	26.0%	42.3%	14.9%	11.9%	3.6%	0.2%	0.8%	0.4%
San Diego, California	36.3%	29.5%	15.4%	12.4%	5.4%	0.0%	0.6%	0.4%
Tampa, Florida	32.8%	32.8%	14.5%	11.5%	6.3%	0.5%	0.5%	1.1%
Phoenix, Arizona	35.9%	31.9%	15.3%	11.7%	3.8%	0.2%	1.2%	0.0%
Tempe, Arizona	26.4%	36.4%	17.7%	8.6%	7.7%	0.5%	0.9%	1.8%
Scottsdale, Arizona	42.9%	28.2%	13.8%	9.6%	4.5%	0.0%	0.6%	0.3%
Waterloo, Ontario	22.0%	34.7%	22.8%	11.2%	5.0%	0.8%	0.8%	2.7%
Cambridge, Ontario	25.2%	29.7%	17.0%	13.4%	11.1%	0.0%	1.3%	2.3%
Walnut Valley WD	20.3%	30.5%	16.3%	21.7%	9.6%	0.0%	0.3%	1.3%
Las Virgenes Valley WD	40.8%	25.7%	13.0%	13.4%	5.6%	0.5%	0.0%	1.0%
Lompoc, California	26.1%	27.6%	18.8%	18.0%	7.5%	0.0%	0.9%	1.1%
14 Study Cities	31.6%	32.7%	15.4%	12.5%	5.9%	0.2%	0.7%	1.0%

(continued)

Table A.1 (Continued)

Study city	Question 22: On average how often is a hose used to clean the sidewalks or driveways?							
	Never	**<1/month**	**1/month**	**2/month**	**1/week**	**>1/week**	**Don't Know**	**NR**
Boulder, Colorado	53.4%	35.3%	7.2%	1.5%	1.3%	0.0%	1.1%	0.2%
Denver, Colorado	36.7%	41.9%	10.7%	4.5%	4.5%	0.2%	0.9%	0.6%
Eugene, Oregon	27.6%	46.7%	13.7%	5.9%	2.4%	0.6%	1.6%	1.6%
Seattle, Washington	49.7%	40.0%	5.6%	2.0%	1.0%	0.2%	1.4%	0.0%
San Diego, California	50.0%	30.3%	9.5%	3.7%	4.4%	0.6%	0.6%	0.8%
Tampa, Florida	49.5%	31.7%	7.9%	4.4%	3.3%	0.3%	2.2%	0.8%
Phoenix, Arizona	23.2%	44.1%	16.0%	9.9%	4.5%	0.9%	1.2%	0.2%
Tempe, Arizona	28.6%	39.1%	15.5%	9.1%	5.5%	0.5%	0.5%	1.4%
Scottsdale, Arizona	23.1%	42.0%	18.6%	9.3%	5.4%	1.2%	0.0%	0.3%
Waterloo, Ontario	49.0%	38.2%	7.3%	2.7%	1.2%	0.0%	0.0%	1.5%
Cambridge, Ontario	45.8%	35.0%	9.8%	4.6%	2.3%	0.0%	1.0%	1.6%
Walnut Valley WD	24.6%	40.4%	15.0%	10.4%	5.6%	1.9%	0.5%	1.6%
Las Virgenes Valley WD	32.0%	33.5%	12.2%	8.6%	12.0%	1.2%	0.2%	0.2%
Lompoc, California	50.3%	33.6%	7.9%	3.0%	2.6%	0.2%	1.1%	1.3%
14 Study Cities	38.8%	38.0%	11.2%	5.7%	4.0%	0.6%	0.9%	0.9%

(continued)

Table A.1 (Continued)

Study city	Question 23: If you home has a swimming pool, please estimate the pool dimensions in feet.										
	No pool	# of pools	Length Mean	Length Mode	Length Median	Width Mean	Width Mode	Width Median	Length Mean	Length Mode	Length Median
Boulder, Colorado	88.5%	5	39.2	40.0	40.0	16.4	20.0	16.0	5.0	4.0	5.0
Denver, Colorado	88.8%	7	29.3	NA	27.0	16.4	10.0	17.0	4.57	5.0	5.0
Eugene, Oregon	87.5%	12	14.7	12.0	12.0	12.4	12.0	12.0	3.6	3.0	3.0
Seattle, Washington	89.5%	12	26.6	32.0	32.0	14.1	16.0	15.5	4.9	5.0	5.0
San Diego, California	84.9%	46	30.8	30.0	30.0	15.3	12.0	15.0	5.4	5.0	5.0
Tampa, Florida	80.0%	50	26.9	30.0	30.0	15.2	15.0	15.0	5.2	4.0	5.0
Phoenix, Arizona	58.7%	146	29.3	30.0	30.0	15.5	15.0	15.0	5.6	4.0	5.0
Tempe, Arizona	57.3%	72	30.5	30.0	30.0	15.8	15.0	15.0	5.7	5.0	5.0
Scottsdale, Arizona	42.6%	148	29.7	30.0	30.0	15.1	15.0	15.0	5.3	5.0	5.0
Waterloo, Ontario	92.7%	19	32.0	32.0	32.0	16.4	16.0	16.0	5.1	5.0	5.0
Cambridge, Ontario	91.5%	26	29.0	32.0	32.0	17.8	16.0	16.0	5.4	4.0	5.0
Walnut Valley WD	73.8%	98	29.7	30.0	30.0	16.0	15.0	15.0	6.1	6.0	6.0
Las Virgenes Valley WD	45.5%	223	32.4	30.0	33.0	16.2	20.0	16.0	5.7	6.0	5.0
Lompoc, California	91.4%	4	32.8	30.0	33.0	15.0	NA	16.0	4.8	4.0	4.5
14 Study Cities	76.6%	66	28.7	30.0	30.0	15.4	15.0	15.0	5.2	5.0	5.0

(continued)

Table A.1 (Continued)

Study city	Question 24: On a scale of 1 to 5, rate the importance of conservation.						Question 25: Has household taken any action to conserve water?			
	1	**2**	**3**	**4**	**5**	**NR**	**Yes**	**No**	**D.Know**	**NR**
Boulder, Colorado	2.0%	5.9%	17.4%	26.8%	43.1%	4.6%	85.4%	10.9%	2.8%	0.4%
Denver, Colorado	2.4%	3.0%	18.0%	28.1%	42.5%	6.0%	88.4%	7.5%	2.8%	1.3%
Eugene, Oregon	2.4%	4.3%	15.9%	22.4%	51.0%	4.1%	87.6%	8.8%	2.4%	1.2%
Seattle, Washington	0.8%	2.2%	9.9%	24.5%	61.2%	1.4%	93.2%	4.6%	2.2%	0.0%
San Diego, California	0.6%	1.5%	5.0%	22.6%	68.9%	1.5%	96.1%	1.9%	1.7%	0.4%
Tampa, Florida	1.1%	2.2%	3.0%	14.5%	76.5%	2.7%	88.8%	6.8%	3.6%	0.8%
Phoenix, Arizona	1.6%	1.9%	7.3%	17.6%	69.7%	1.9%	87.6%	9.2%	2.6%	0.7%
Tempe, Arizona	0.5%	1.4%	11.8%	15.9%	68.2%	2.3%	84.5%	10.0%	2.3%	3.2%
Scottsdale, Arizona	0.9%	2.7%	7.2%	20.1%	65.5%	3.6%	86.5%	10.2%	2.1%	1.2%
Waterloo, Ontario	0.4%	2.7%	6.9%	21.6%	63.7%	4.6%	81.9%	6.6%	2.7%	8.9%
Cambridge, Ontario	1.6%	1.3%	7.5%	19.6%	64.4%	5.6%	83.3%	5.9%	4.6%	6.2%
Walnut Valley WD	0.3%	0.8%	9.6%	21.9%	65.2%	2.1%	91.4%	4.0%	1.1%	3.5%
Las Virgenes Valley WD	0.7%	1.2%	8.6%	21.0%	66.5%	2.0%	91.9%	3.4%	1.7%	2.9%
Lompoc, California	1.5%	1.5%	7.9%	21.6%	65.5%	1.9%	86.9%	6.2%	1.7%	5.1%
14 Study Cities	1.2%	2.3%	9.7%	21.3%	62.3%	3.2%	88.1%	6.9%	2.4%	2.6%

(continued)

Table A.1 (Continued)

Study city	Question 25a: Please indicate all actions you have taken to conserve water. (Check all that apply)											
	Take shorter showers		Install LF showerheads		Install toilet inserts		Install ULF toilet		Use garbage disposal less		Fuller dishwasher	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Boulder, Colorado	35.3%	64.7%	37.0%	63.0%	14.8%	85.2%	16.3%	83.7%	28.3%	71.7%	56.6%	43.4%
Denver, Colorado	38.2%	61.8%	37.7%	62.2%	20.2%	79.8%	20.2%	79.8%	34.1%	65.9%	55.2%	44.9%
Eugene, Oregon	36.3%	63.7%	71.4%	28.6%	14.1%	85.9%	11.2%	88.8%	22.7%	77.3%	51.0%	49.0%
Seattle, Washington	47.9%	52.1%	57.7%	42.3%	28.0%	72.0%	20.3%	79.7%	20.5%	79.5%	60.4%	39.6%
San Diego, California	60.4%	39.6%	64.3%	35.7%	32.8%	67.2%	43.2%	56.8%	36.5%	63.5%	51.5%	48.5%
Tampa, Florida	45.1%	54.9%	43.7%	56.3%	24.6%	75.4%	20.5%	79.5%	16.1%	83.9%	33.6%	66.4%
Phoenix, Arizona	41.8%	58.2%	44.8%	55.2%	24.6%	75.4%	17.8%	82.2%	29.3%	70.7%	54.2%	45.8%
Tempe, Arizona	34.1%	65.9%	38.2%	61.8%	21.4%	78.6%	15.5%	84.5%	32.3%	67.7%	63.6%	36.4%
Scottsdale, Arizona	45.3%	54.7%	42.9%	57.1%	16.5%	83.5%	23.1%	76.9%	36.0%	64.0%	66.7%	33.3%
Waterloo, Ontario	35.5%	64.5%	54.1%	45.9%	36.7%	63.3%	16.2%	83.8%	3.9%	96.1%	40.2%	59.8%
Cambridge, Ontario	38.2%	61.8%	55.9%	43.8%	32.0%	68.0%	19.3%	80.7%	2.3%	97.7%	37.3%	62.7%
Walnut Valley WD	54.3%	45.7%	51.6%	48.4%	29.7%	70.3%	26.5%	73.5%	40.4%	59.6%	64.4%	35.6%
Las Virgenes Valley WD	55.0%	45.0%	57.0%	43.0%	33.0%	67.0%	37.7%	62.3%	38.1%	61.9%	69.9%	30.1%
Lompoc, California	53.7%	46.3%	52.7%	47.3%	19.5%	80.5%	31.3%	68.7%	34.9%	65.1%	54.8%	45.2%
14 Study Cities	44.4%	55.6%	50.6%	49.3%	24.8%	75.2%	22.8%	77.2%	26.8%	73.2%	54.2%	45.8%

(continued)

Table A.1 (Continued)

Study city	Question 25a (continued): Please indicate all actions you have taken to conserve water.											
	Fuller clothes washer loads		Repaired leaks		Greywater or reuse		Wash car less often		Water lawn less often		Water lawn at night	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Boulder, Colorado	44.4%	55.6%	51.2%	48.8%	7.4%	92.6%	21.4%	78.7%	34.9%	65.1%	50.1%	49.9%
Denver, Colorado	49.8%	50.2%	48.9%	50.9%	4.3%	95.7%	25.1%	74.9%	29.2%	70.8%	51.3%	48.7%
Eugene, Oregon	44.9%	55.1%	42.0%	58.0%	4.7%	95.3%	28.4%	71.6%	30.4%	69.6%	36.1%	63.9%
Seattle, Washington	54.5%	45.5%	44.5%	55.5%	7.0%	93.0%	34.8%	65.2%	50.7%	49.3%	45.1%	54.9%
San Diego, California	60.6%	39.4%	52.9%	47.1%	14.1%	85.9%	43.6%	56.4%	45.4%	54.6%	42.1%	57.9%
Tampa, Florida	51.9%	48.1%	55.5%	44.5%	3.0%	97.0%	38.0%	62.0%	44.0%	56.0%	40.4%	59.6%
Phoenix, Arizona	52.6%	47.2%	58.0%	42.0%	3.8%	96.0%	36.2%	63.8%	35.7%	64.3%	53.1%	46.9%
Tempe, Arizona	51.4%	48.6%	49.1%	50.9%	3.2%	96.4%	30.5%	69.5%	22.3%	77.7%	47.7%	52.3%
Scottsdale, Arizona	52.9%	47.1%	56.2%	43.8%	2.4%	97.6%	30.9%	69.1%	25.2%	74.8%	40.2%	59.8%
Waterloo, Ontario	40.2%	59.8%	42.9%	57.1%	6.6%	93.4%	29.7%	70.3%	45.6%	54.4%	42.5%	57.5%
Cambridge, Ontario	48.4%	51.6%	39.2%	60.8%	5.2%	94.8%	32.0%	68.0%	40.5%	59.5%	46.7%	53.3%
Walnut Valley WD	49.2%	50.8%	57.5%	42.5%	3.5%	96.5%	46.8%	53.2%	39.8%	60.2%	48.7%	51.3%
Las Virgenes Valley WD	56.5%	43.5%	52.8%	47.2%	5.1%	94.9%	33.3%	66.7%	36.4%	63.6%	47.4%	52.6%
Lompoc, California	57.2%	42.8%	52.7%	47.3%	7.9%	92.1%	39.8%	60.2%	41.1%	58.9%	43.5%	56.5%
14 Study Cities	51.0%	49.0%	50.2%	49.8%	5.6%	94.4%	33.6%	66.4%	37.2%	62.8%	45.3%	54.7%

(continued)

Table A.1 (Continued)

Study city	Question 25a (continued): Please indicate all actions you have taken to conserve water.											
	Low-water-use landscaping		Adjust auto sprinkler timing		New efficient sprinkler system		Cycle irrigate lawn		Home water audit		Other	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Boulder, Colorado	21.4%	78.7%	20.3%	79.7%	5.7%	94.3%	4.6%	95.4%	0.0%	100.0%	9.8%	90.2%
Denver, Colorado	10.9%	89.1%	21.2%	78.8%	2.2%	97.9%	3.2%	96.8%	3.7%	96.4%	6.0%	93.8%
Eugene, Oregon	7.5%	92.5%	7.8%	92.2%	3.7%	96.3%	2.2%	97.8%	1.0%	99.0%	8.2%	91.8%
Seattle, Washington	9.7%	90.3%	5.6%	94.4%	3.6%	96.4%	1.0%	99.0%	0.0%	100.0%	8.2%	91.8%
San Diego, California	20.3%	79.7%	21.0%	79.0%	9.3%	90.7%	3.3%	96.7%	4.4%	95.6%	6.0%	94.0%
Tampa, Florida	9.8%	90.2%	7.9%	92.1%	1.6%	98.4%	0.5%	99.5%	0.3%	99.7%	8.7%	91.3%
Phoenix, Arizona	21.4%	78.6%	25.4%	74.6%	6.6%	93.4%	2.1%	97.9%	0.7%	99.3%	7.3%	92.7%
Tempe, Arizona	22.3%	77.7%	21.4%	78.6%	6.4%	93.6%	1.8%	97.7%	0.9%	99.1%	4.5%	95.5%
Scottsdale, Arizona	25.2%	74.8%	33.0%	67.0%	12.6%	87.4%	2.7%	97.3%	0.6%	99.4%	5.1%	94.9%
Waterloo, Ontario	7.7%	92.3%	1.9%	98.1%	0.0%	100.0%	0.4%	99.6%	0.8%	99.2%	3.5%	96.5%
Cambridge, Ontario	2.9%	97.1%	1.0%	99.0%	0.7%	99.3%	1.3%	98.7%	0.3%	99.7%	5.6%	94.4%
Walnut Valley WD	12.3%	87.7%	37.2%	62.8%	5.9%	94.1%	3.5%	96.5%	5.1%	94.9%	2.4%	97.6%
Las Virgenes Valley WD	12.2%	87.8%	51.1%	48.9%	11.5%	88.5%	5.1%	94.9%	3.4%	96.6%	2.2%	97.8%
Lompoc, California	18.4%	81.6%	18.0%	82.0%	9.0%	91.0%	4.1%	95.9%	2.6%	97.4%	3.0%	97.0%
14 Study Cities	14.4%	85.6%	19.5%	80.5%	5.6%	94.4%	2.6%	97.4%	1.7%	98.3%	5.8%	94.2%

(continued)

Table A.1 (Continued)

Study city	**Question 26: At the present time would you say that your community is experiencing:**					
	No drought	**Mild drought**	**Moderate drought**	**Severe drought**	**Don't Know**	**NR**
Boulder, Colorado	36.2%	25.5%	14.6%	0.2%	22.7%	0.9%
Denver, Colorado	36.5%	21.5%	14.2%	0.6%	25.5%	1.5%
Eugene, Oregon	75.7%	7.1%	2.0%	0.0%	12.9%	2.4%
Seattle, Washington	71.6%	8.5%	2.2%	0.0%	17.5%	0.2%
San Diego, California	16.6%	30.3%	28.6%	3.7%	19.3%	1.5%
Tampa, Florida	13.1%	30.9%	28.7%	3.8%	22.4%	1.1%
Phoenix, Arizona	21.6%	21.4%	22.5%	4.0%	30.3%	0.2%
Tempe, Arizona	19.1%	25.9%	16.8%	2.7%	33.2%	2.3%
Scottsdale, Arizona	26.1%	22.8%	21.9%	2.1%	26.4%	0.6%
Waterloo, Ontario	54.8%	13.9%	8.9%	0.4%	18.5%	3.5%
Cambridge, Ontario	55.2%	10.1%	7.2%	0.0%	23.2%	4.2%
Walnut Valley WD	36.4%	21.7%	12.0%	1.1%	26.7%	2.1%
Las Virgenes Valley WD	36.2%	26.4%	17.4%	0.7%	18.1%	1.2%
Lompoc, California	18.4%	34.0%	23.3%	4.1%	18.0%	2.1%
14 Study Cities	37.0%	21.4%	15.7%	1.7%	22.5%	1.7%

(continued)

Table A.1 (Continued)

Study city	Question 27: Please indicate the type of residence you live in.									
	Single-family detached	SF w/ detached apartment	SF w/ attached apartment	Duplex	Triplex	Town-house	Attached apart.	Mobile home	Other	NR
Boulder, Colorado	96.3%	0.2%	1.7%	0.2%	0.2%	0.2%	0.0%	0.0%	0.2%	0.4%
Denver, Colorado	94.9%	0.4%	1.5%	1.1%	0.2%	6.4%	0.0%	0.0%	0.4%	0.9%
Eugene, Oregon	83.3%	1.2%	1.6%	4.9%	0.0%	2.2%	0.4%	4.5%	0.6%	0.9%
Seattle, Washington	96.0%	0.2%	1.2%	0.4%	0.0%	0.4%	0.2%	0.6%	0.8%	0.9%
San Diego, California	90.9%	1.7%	0.2%	1.5%	0.0%	2.9%	0.4%	0.0%	2.1%	0.9%
Tampa, Florida	90.7%	1.9%	1.1%	1.9%	0.3%	3.6%	0.0%	0.0%	0.0%	0.9%
Phoenix, Arizona	89.9%	1.6%	1.2%	1.2%	0.0%	2.3%	0.2%	2.6%	0.5%	0.9%
Tempe, Arizona	91.8%	0.9%	0.0%	1.4%	0.0%	2.3%	0.9%	0.0%	0.9%	0.9%
Scottsdale, Arizona	85.6%	1.5%	0.9%	1.2%	0.3%	6.3%	0.0%	0.0%	3.6%	0.9%
Waterloo, Ontario	88.0%	0.0%	1.2%	3.9%	0.4%	1.2%	0.0%	0.0%	2.3%	0.9%
Cambridge, Ontario	81.0%	0.0%	1.0%	5.2%	0.3%	2.9%	0.7%	0.0%	2.9%	0.9%
Walnut Valley WD	96.3%	0.0%	0.3%	0.0%	0.0%	1.1%	0.0%	0.0%	0.3%	0.9%
Las Virgenes Valley WD	90.0%	1.0%	0.2%	0.0%	0.2%	5.4%	0.0%	0.2%	0.7%	0.9%
Lompoc, California	91.6%	0.6%	0.4%	2.6%	0.0%	0.6%	0.2%	0.0%	1.3%	0.9%
14 Study Cities	90.5%	0.8%	0.9%	1.8%	0.1%	2.7%	0.2%	0.6%	1.2%	0.8%

(continued)

Table A.1 (Continued)

Study city	Question 28: Does your residence have a separate irrigation meter?				Question 29: Who pays the water bill in your home?			
	Yes	No	D.Know	NR	Household	Landlord	D.Know	NR
Boulder, Colorado	21.1%	68.6%	9.4%	0.7%	96.5%	2.6%	0.0%	0.7%
Denver, Colorado	30.0%	55.2%	13.7%	0.9%	96.6%	2.8%	0.4%	0.2%
Eugene, Oregon	2.0%	84.1%	13.1%	0.8%	98.6%	1.0%	0.2%	0.2%
Seattle, Washington	1.8%	88.5%	9.3%	0.4%	98.0%	2.0%	0.0%	0.0%
San Diego, California	2.3%	84.4%	13.1%	0.2%	97.7%	1.7%	0.0%	0.6%
Tampa, Florida	2.5%	86.9%	10.1%	0.5%	98.6%	0.3%	0.0%	1.1%
Phoenix, Arizona	0.5%	89.9%	9.4%	0.2%	99.8%	0.0%	0.2%	0.0%
Tempe, Arizona	0.9%	84.5%	12.7%	1.8%	97.7%	0.9%	0.0%	1.4%
Scottsdale, Arizona	0.9%	86.2%	12.3%	0.6%	98.5%	0.6%	0.3%	0.6%
Waterloo, Ontario	7.3%	81.9%	9.3%	1.5%	97.7%	0.8%	0.0%	1.5%
Cambridge, Ontario	7.2%	82.4%	7.8%	2.6%	95.8%	1.3%	0.3%	2.6%
Walnut Valley WD	1.1%	85.0%	12.8%	1.1%	99.2%	0.0%	0.0%	0.8%
Las Virgenes Valley WD	1.2%	84.1%	13.9%	0.7%	98.0%	1.2%	0.0%	0.7%
Lompoc, California	0.6%	87.2%	11.1%	1.1%	97.2%	1.5%	0.0%	1.3%
14 Study Cities	5.7%	82.1%	11.3%	0.9%	97.9%	1.2%	0.1%	0.8%

(continued)

Table A.1 (Continued)

Study city	Question 30: How many people reside full-time at this address during the winter months?											
	Adults (18 years +)				Teenagers (13 – 17 years)				Children (under 13 years)			
	Mean	**Mode**	**Median**	**NR**	**Mean**	**Mode**	**Median**	**NR**	**Mean**	**Mode**	**Median**	**NR**
Boulder, Colorado	2.00	2	2	0.4%	0.17	0	0	73.0%	0.4	0	0	62.8%
Denver, Colorado	1.92	2	2	2.2%	0.21	0	0	73.0%	0.47	0	0	62.2%
Eugene, Oregon	1.95	2	2	2.0%	0.23	0	0	75.1%	0.39	0	0	68.4%
Seattle, Washington	2.04	2	2	2.0%	0.16	0	0	75.1%	0.36	0	0	68.4%
San Diego, California	2.10	2	2	1.2%	0.17	0	0	75.9%	0.34	0	0	70.3%
Tampa, Florida	2.06	2	2	1.2%	0.20	0	0	75.9%	0.34	0	0	70.3%
Phoenix, Arizona	2.08	2	2	1.6%	0.22	0	0	75.1%	0.48	0	0	64.1%
Tempe, Arizona	2.10	2	2	3.6%	0.15	0	0	78.6%	0.50	0	0	62.7%
Scottsdale, Arizona	2.02	2	2	2.5%	0.11	0	0	80.7%	0.29	0	0	69.1%
Waterloo, Ontario	2.22	2	2	0.8%	0.22	0	0	76.1%	0.48	0	0	66.0%
Cambridge, Ontario	2.14	2	2	3.6%	0.31	0	0	69.9%	0.52	0	0	64.1%
Walnut Valley WD	2.42	2	2	0.0%	0.26	0	0	0.0%	0.54	0	0	0.0%
Las Virgenes Valley WD	2.17	2	2	0.0%	0.21	0	0	75.1%	0.45	0	0	64.1%
Lompoc, California	1.95	2	2	2.6%	0.21	0	0	84.8%	0.46	0	0	75.2%
14 Study Cities	2.08	2	2	1.7%	0.20	0	0	70.6%	0.43	0	0	62.0%

(continued)

Table A.1 (Continued)

Study city	**Question 31: How many people reside full-time at this address during the summer months?**											
	Adults (18 years +)				**Teenagers (13 – 17 years)**				**Children (under 13 years)**			
	Mean	**Mode**	**Median**	**NR**	**Mean**	**Mode**	**Median**	**NR**	**Mean**	**Mode**	**Median**	**NR**
Boulder, Colorado	2.03	2	2	0.7%	0.18	0	0	72.8%	0.39	0	0	63.4%
Denver, Colorado	1.95	2	2	2.8%	0.22	0	0	73.2%	0.48	0	0	36.1%
Eugene, Oregon	1.97	2	2	1.2%	0.23	0	0	75.5%	0.39	0	0	69.0%
Seattle, Washington	2.07	2	2	1.2%	0.18	0	0	75.5%	0.37	0	0	69.0%
San Diego, California	2.09	2	2	1.7%	0.17	0	0	76.6%	0.34	0	0	70.7%
Tampa, Florida	2.06	2	2	1.7%	0.20	0	0	76.6%	0.34	0	0	70.7%
Phoenix, Arizona	2.05	2	2	1.6%	0.23	0	0	74.9%	0.46	0	0	65.5%
Tempe, Arizona	2.07	2	2	3.2%	0.17	0	0	78.2%	0.52	0	0	63.6%
Scottsdale, Arizona	1.83	2	2	2.5%	0.13	0	0	79.8%	0.29	0	0	69.6%
Waterloo, Ontario	2.15	2	2	1.5%	0.20	0	0	76.8%	0.47	0	0	66.0%
Cambridge, Ontario	2.17	2	2	3.9%	0.30	0	0	71.6%	0.52	0	0	65.0%
Walnut Valley WD	2.44	2	2	0.0%	0.27	0	0	0.0%	0.55	0	0	0.0%
Las Virgenes Valley WD	2.20	2	2	0.0%	0.22	0	0	74.9%	0.46	0	0	65.5%
Lompoc, California	1.91	2	2	4.1%	0.20	0	0	85.7%	0.45	0	0	75.2%
14 Study Cities	2.07	2	2	1.9%	0.21	0	0	70.8%	0.43	0	0	60.7%

(continued)

Table A.1 (Continued)

Study city	**Question 32: How many adults living at the residence are employed full-time outside the home?**						
	0	**1**	**2**	**3**	**4**	**>=5**	**NR**
Boulder, Colorado	26.8%	42.7%	26.8%	5.0%	0.9%	0.0%	0.9%
Denver, Colorado	27.7%	37.1%	28.8%	3.9%	0.4%	0.2%	1.9%
Eugene, Oregon	32.2%	36.1%	27.8%	2.2%	0.8%	0.2%	0.8%
Seattle, Washington	27.4%	35.6%	31.6%	1.8%	1.8%	0.0%	1.8%
San Diego, California	35.1%	33.2%	23.2%	6.0%	0.6%	0.2%	1.7%
Tampa, Florida	28.1%	33.1%	30.9%	4.6%	0.8%	0.3%	2.2%
Phoenix, Arizona	22.5%	37.1%	34.3%	4.2%	1.2%	0.0%	0.7%
Tempe, Arizona	13.2%	37.7%	38.2%	6.4%	0.5%	0.9%	3.2%
Scottsdale, Arizona	34.2%	34.8%	21.9%	4.8%	0.3%	0.6%	3.3%
Waterloo, Ontario	22.8%	39.8%	33.6%	1.5%	0.8%	0.0%	1.5%
Cambridge, Ontario	18.0%	37.3%	36.3%	3.9%	1.0%	0.0%	3.6%
Walnut Valley WD	13.1%	32.4%	43.6%	7.5%	1.9%	0.5%	1.1%
Las Virgenes Valley WD	22.5%	40.3%	27.9%	5.6%	0.7%	0.0%	2.9%
Lompoc, California	36.2%	28.9%	28.9%	1.9%	0.9%	0.0%	3.2%
14 Study Cities	25.7%	36.1%	31.0%	4.2%	0.9%	0.2%	2.1%

(continued)

Table A.1 (Continued)

Study city	Question 33: Approximately what year was your residence built?										
	<1960	**1960-69**	**1970-74**	**1975-79**	**1980-84**	**1985-89**	**1990-92**	**1993-94**	**>1994**	**D.Know**	**NR**
Boulder, Colorado	32.7%	32.5%	10.9%	6.8%	3.7%	7.0%	3.3%	1.7%	0.0%	1.3%	0.2%
Denver, Colorado	50.9%	12.7%	8.6%	10.3%	6.4%	3.2%	1.7%	1.1%	0.4%	2.6%	1.5%
Eugene, Oregon	35.1%	22.5%	8.4%	13.1%	3.9%	5.1%	5.7%	1.4%	0.6%	3.7%	0.4%
Seattle, Washington	55.5%	15.3%	5.4%	6.4%	3.2%	3.8%	3.4%	1.6%	0.6%	4.0%	0.6%
San Diego, California	43.8%	18.0%	9.5%	7.9%	4.1%	7.1%	1.9%	2.1%	0.4%	3.9%	1.2%
Tampa, Florida	43.4%	17.5%	7.4%	5.5%	5.7%	5.2%	1.6%	1.4%	1.6%	8.2%	2.5%
Phoenix, Arizona	24.2%	10.6%	13.6%	12.2%	9.9%	12.9%	4.7%	4.0%	3.5%	3.5%	0.9%
Tempe, Arizona	7.3%	27.7%	18.6%	14.1%	8.6%	8.6%	2.7%	3.2%	3.6%	4.1%	1.4%
Scottsdale, Arizona	10.5%	19.5%	7.5%	8.1%	12.0%	15.0%	6.9%	7.2%	10.5%	1.2%	1.5%
Waterloo, Ontario	23.2%	16.6%	7.3%	10.4%	12.4%	18.5%	6.6%	1.9%	2.3%	0.4%	0.4%
Cambridge, Ontario	27.8%	14.1%	10.8%	11.1%	2.0%	15.4%	7.2%	3.9%	2.0%	3.6%	2.3%
Walnut Valley WD	3.2%	31.6%	10.7%	16.0%	8.8%	24.9%	1.1%	0.5%	0.5%	2.4%	0.3%
Las Virgenes Valley WD	6.4%	22.5%	13.2%	9.3%	10.3%	23.2%	9.0%	1.5%	2.0%	1.2%	1.5%
Lompoc, California	22.3%	33.6%	2.6%	5.1%	9.4%	13.5%	5.4%	0.6%	1.9%	4.1%	1.5%
14 Study Cities	27.6%	21.0%	9.6%	9.7%	7.2%	11.7%	4.4%	2.3%	2.1%	3.2%	1.2%

(continued)

Table A.1 (Continued)

Study city	Question 34: When did you move to your current address?				Question 35: Give best estimate of total square feet of living space in your home.							
	Mean	**Mode**	**Median**	**NR**	**<800**	**800-999**	**<1199**	**<1399**	**<1599**	**<1799**	**<1999**	**<2199**
Boulder, Colorado	1983	1995	1987	1.1%	0.4%	1.3%	5.9%	8.6%	7.2%	5.2%	8.1%	8.7%
Denver, Colorado	1981	1994	1987	2.8%	2.2%	6.7%	7.7%	8.2%	5.8%	5.6%	6.7%	7.3%
Eugene, Oregon	1981	1994	1987	1.0%	1.4%	5.3%	12.4%	14.1%	13.5%	11.4%	9.0%	6.3%
Seattle, Washington	1981	1992	1981	1.0%	1.2%	4.6%	5.6%	8.9%	5.6%	7.2%	8.9%	9.3%
San Diego, California	1981	1994	1983	2.1%	1.5%	5.2%	7.7%	12.2%	12.2%	10.2%	10.0%	8.7%
Tampa, Florida	1981	1995	1985	4.1%	4.1%	7.9%	11.5%	10.9%	9.0%	8.7%	6.8%	5.5%
Phoenix, Arizona	1981	1994	1989	1.6%	0.9%	3.3%	8.2%	8.7%	9.2%	12.4%	12.4%	7.0%
Tempe, Arizona	1986	1995	1989	2.3%	0.5%	0.9%	3.2%	11.8%	13.6%	10.0%	12.7%	13.6%
Scottsdale, Arizona	1987	1995	1990	1.6%	0.0%	1.2%	0.9%	3.9%	11.7%	11.7%	9.6%	13.8%
Waterloo, Ontario	1981	1993	1986	2.7%	0.0%	2.3%	11.2%	12.7%	5.4%	6.9%	8.9%	9.3%
Cambridge, Ontario	1977	1995	1988	4.2%	1.0%	3.9%	15.4%	14.4%	8.8%	4.9%	8.8%	8.8%
Walnut Valley WD	1979	1986	1986	0.0%	0.3%	0.5%	1.1%	7.2%	11.2%	12.8%	15.0%	13.1%
Las Virgenes Valley WD	1981	1991	1987	1.0%	0.2%	1.2%	0.7%	1.5%	5.4%	5.4%	4.6%	6.6%
Lompoc, California	1981	1987	1986	1.0%	0.6%	2.6%	5.1%	12.6%	14.3%	10.9%	13.7%	7.5%
14 Study Cities	1981	1993	1986	1.9%	1.0%	3.4%	6.9%	9.7%	9.5%	8.8%	9.7%	9.0%

(continued)

Table A.1 (Continued)

Study city	Question 35 (continued): Give best estimate of total square feet of living space in your home.										
	<2399	**<2599**	**<2799**	**<2999**	**<3199**	**<3399**	**<3599**	**<3799**	**>3800**	**D.Know**	**NR**
Boulder, Colorado	10.2%	9.2%	5.7%	3.7%	5.2%	3.9%	3.1%	2.4%	6.1%	5.5%	2.4%
Denver, Colorado	7.1%	7.1%	5.4%	3.9%	3.4%	2.4%	1.9%	0.3%	4.9%	9.9%	3.4%
Eugene, Oregon	5.3%	4.7%	2.2%	1.8%	2.2%	0.4%	0.6%	0.6%	0.6%	6.9%	1.6%
Seattle, Washington	8.0%	5.2%	5.2%	3.2%	4.2%	1.8%	2.8%	1.6%	5.0%	8.9%	2.6%
San Diego, California	6.6%	5.4%	2.1%	3.3%	1.9%	0.2%	0.6%	0.6%	1.2%	7.7%	2.7%
Tampa, Florida	3.6%	2.5%	2.2%	1.4%	1.9%	0.5%	0.3%	0.3%	1.6%	16.9%	4.4%
Phoenix, Arizona	8.5%	5.4%	2.6%	2.8%	2.1%	1.4%	1.6%	0.9%	3.1%	7.0%	2.3%
Tempe, Arizona	5.0%	8.2%	3.6%	2.3%	2.3%	1.8%	0.9%	0.5%	1.4%	5.9%	1.8%
Scottsdale, Arizona	7.5%	7.5%	4.2%	6.0%	5.1%	2.1%	2.4%	2.1%	6.3%	2.4%	1.5%
Waterloo, Ontario	4.6%	6.9%	3.5%	7.3%	4.6%	2.3%	0.8%	0.4%	3.1%	6.9%	2.7%
Cambridge, Ontario	3.6%	3.3%	3.9%	1.3%	1.6%	1.0%	1.6%	0.3%	1.6%	9.8%	5.9%
Walnut Valley WD	7.8%	8.8%	5.6%	4.5%	1.9%	1.6%	1.3%	0.5%	1.1%	4.5%	1.1%
Las Virgenes Valley WD	8.1%	8.1%	7.1%	4.9%	9.5%	6.4%	4.9%	3.2%	19.1%	1.7%	1.5%
Lompoc, California	7.1%	2.4%	1.5%	1.1%	1.1%	0.0%	0.0%	0.4%	0.4%	13.9%	4.7%
14 Study Cities	6.6%	6.0%	3.9%	3.4%	3.4%	1.8%	1.6%	1.0%	4.0%	7.7%	2.8%

(continued)

Table A.1 (Continued)

Study city	Question 36: How many floors of living space are in your home (including finished basement)?				Question 37: Do you rent or own your residence?		
	1	**2**	**>=3**	**NR**	**Rent**	**Own**	**NR**
Boulder, Colorado	23.3%	49.9%	26.1%	0.7%	11.8%	87.8%	0.4%
Denver, Colorado	22.3%	52.2%	24.9%	0.6%	5.6%	93.8%	0.6%
Eugene, Oregon	67.6%	26.7%	5.3%	0.4%	12.5%	87.1%	0.4%
Seattle, Washington	29.2%	54.1%	16.1%	0.6%	10.1%	89.1%	0.8%
San Diego, California	67.8%	27.0%	3.9%	1.2%	10.4%	88.4%	1.2%
Tampa, Florida	82.2%	10.4%	4.6%	2.7%	10.4%	89.1%	0.5%
Phoenix, Arizona	85.0%	10.1%	3.5%	1.4%	5.6%	91.5%	2.8%
Tempe, Arizona	88.2%	8.2%	2.7%	0.9%	9.5%	89.1%	1.4%
Scottsdale, Arizona	82.9%	13.5%	2.4%	1.2%	5.4%	92.8%	1.8%
Waterloo, Ontario	3.1%	49.8%	46.3%	0.8%	1.9%	96.1%	1.9%
Cambridge, Ontario	8.2%	48.4%	39.5%	3.9%	5.6%	89.5%	4.9%
Walnut Valley WD	46.8%	47.6%	4.8%	0.8%	5.3%	94.7%	0.0%
Las Virgenes Valley WD	32.0%	60.9%	5.9%	1.2%	4.4%	94.1%	1.5%
Lompoc, California	82.4%	9.9%	6.2%	1.5%	12.2%	85.7%	2.1%
14 Study Cities	51.5%	33.5%	13.7%	1.3%	7.9%	90.6%	1.5%

(continued)

Table A.1 (Continued)

Study city	Question 38: If you rent your home, what is your monthly rent payment?							
	Don't Rent	**<300**	**<399**	**<499**	**<599**	**<699**	**<799**	**<899**
Boulder, Colorado	46.8%	0.0%	0.2%	0.0%	0.2%	0.7%	0.9%	0.7%
Denver, Colorado	55.8%	0.6%	0.4%	0.6%	0.6%	0.6%	0.6%	0.4%
Eugene, Oregon	55.5%	1.0%	1.0%	1.6%	3.5%	2.5%	2.2%	0.8%
Seattle, Washington	54.9%	0.4%	0.4%	1.0%	0.2%	1.4%	1.6%	2.2%
San Diego, California	48.8%	1.0%	0.2%	0.4%	0.6%	0.6%	1.5%	1.5%
Tampa, Florida	52.5%	3.6%	0.8%	1.6%	3.6%	1.6%	0.3%	0.0%
Phoenix, Arizona	53.1%	0.9%	0.9%	1.2%	0.7%	0.9%	0.7%	0.0%
Tempe, Arizona	42.7%	0.9%	0.0%	0.9%	0.0%	1.8%	2.7%	1.4%
Scottsdale, Arizona	36.3%	1.2%	0.3%	0.0%	0.6%	1.5%	0.6%	0.3%
Waterloo, Ontario	55.6%	0.0%	0.0%	0.0%	0.0%	0.4%	0.8%	0.0%
Cambridge, Ontario	52.3%	0.3%	0.7%	0.3%	1.3%	1.0%	1.3%	0.3%
Walnut Valley WD	36.9%	0.3%	0.3%	0.3%	0.3%	0.3%	0.5%	0.3%
Las Virgenes Valley WD	37.4%	0.5%	0.0%	0.0%	0.0%	0.2%	0.0%	0.2%
Lompoc, California	44.8%	1.1%	0.6%	0.9%	2.4%	1.7%	2.1%	3.0%
14 Study Cities	48.1%	0.8%	0.4%	0.6%	1.0%	1.1%	1.1%	0.8%

(continued)

Table A.1 (Continued)

Study city	**Question 38 (continued): If you rent your home, what is your monthly rent payment?.**								
	<999	**<1249**	**<1499**	**<1749**	**<1999**	**<2249**	**>=2500**	**D.Know**	**NR**
Boulder, Colorado	0.7%	5.0%	2.4%	0.9%	0.2%	0.0%	0.0%	0.0%	41.4%
Denver, Colorado	0.4%	0.9%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	38.6%
Eugene, Oregon	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	31.4%	0.0%
Seattle, Washington	0.2%	0.8%	0.2%	0.0%	0.0%	0.0%	0.0%	34.6%	0.0%
San Diego, California	2.1%	0.8%	0.2%	0.0%	0.0%	0.2%	0.0%	39.6%	0.0%
Tampa, Florida	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	35.8%	0.0%
Phoenix, Arizona	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	40.6%	0.0%
Tempe, Arizona	0.9%	0.0%	0.0%	0.9%	0.0%	0.5%	0.0%	0.5%	44.5%
Scottsdale, Arizona	0.6%	0.3%	0.6%	0.0%	0.0%	0.3%	0.0%	56.5%	0.0%
Waterloo, Ontario	0.8%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	42.1%	0.0%
Cambridge, Ontario	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	41.2%
Walnut Valley WD	1.1%	2.7%	1.3%	0.5%	0.0%	0.5%	0.0%	50.8%	0.0%
Las Virgenes Valley WD	0.0%	0.7%	1.5%	0.7%	1.0%	1.2%	0.0%	55.3%	0.0%
Lompoc, California	1.3%	0.2%	0.4%	0.0%	0.0%	0.0%	0.0%	0.6%	38.8%
14 Study Cities	0.7%	0.9%	0.5%	0.2%	0.1%	0.2%	0.0%	27.7%	14.6%

(continued)

Table A.1 (Continued)

Study city	Question 39: If you own your home, what is the approximate market value of your home?										
	Don't own	<25000	<49000	<74999	<99999	<124999	<149999	<174999	<199999	<224999	<249999
Boulder, Colorado	6.4%	0.0%	0.0%	0.0%	0.2%	0.2%	3.9%	6.5%	12.2%	12.2%	11.6%
Denver, Colorado	2.8%	0.0%	2.2%	7.5%	13.7%	16.7%	10.1%	10.5%	8.8%	6.7%	2.2%
Eugene, Oregon	7.6%	0.8%	2.0%	5.3%	17.6%	19.8%	14.1%	10.0%	5.3%	2.7%	1.8%
Seattle, Washington	6.6%	0.0%	0.0%	0.2%	2.6%	6.8%	10.5%	12.9%	12.7%	8.9%	7.0%
San Diego, California	5.0%	0.2%	0.0%	0.2%	2.3%	6.0%	10.4%	16.2%	10.4%	7.1%	7.9%
Tampa, Florida	6.3%	2.7%	14.8%	24.9%	15.3%	7.1%	4.6%	2.2%	3.6%	0.5%	1.1%
Phoenix, Arizona	4.7%	0.5%	6.1%	20.4%	20.4%	11.0%	11.7%	3.8%	2.6%	2.3%	2.3%
Tempe, Arizona	6.4%	0.0%	0.5%	7.7%	24.5%	24.5%	14.5%	4.1%	3.2%	1.8%	0.9%
Scottsdale, Arizona	2.4%	0.0%	0.0%	1.8%	9.3%	12.3%	12.3%	10.2%	6.0%	5.4%	5.7%
Waterloo, Ontario	1.5%	0.0%	0.0%	0.0%	1.2%	9.3%	23.2%	15.8%	13.1%	8.1%	5.8%
Cambridge, Ontario	2.9%	0.0%	0.3%	0.3%	4.2%	17.3%	27.1%	12.4%	10.8%	5.6%	0.7%
Walnut Valley WD	2.1%	0.3%	0.3%	0.0%	0.0%	0.5%	1.6%	9.4%	16.3%	14.7%	11.5%
Las Virgenes Valley WD	1.2%	0.0%	0.0%	0.5%	0.2%	0.5%	0.5%	0.2%	2.0%	4.4%	3.9%
Lompoc, California	8.1%	0.0%	0.4%	0.6%	1.5%	13.7%	32.8%	16.3%	10.3%	2.4%	1.1%
14 Study Cities	4.6%	0.3%	1.9%	5.0%	8.1%	10.4%	12.7%	9.3%	8.4%	5.9%	4.5%

(continued)

Table A.1 (Continued)

Study city	**Question 39 (continued): If you own your home, what is the approximate market value of your home?**										
	<274999	**<299999**	**<349999**	**<399999**	**<449999**	**<499999**	**<749999**	**<999999**	**>=1000000**	**D.Know**	**NR**
Boulder, Colorado	7.8%	4.4%	10.5%	6.3%	3.1%	2.0%	2.0%	0.2%	0.2%	4.6%	5.8%
Denver, Colorado	1.9%	2.2%	2.2%	0.6%	1.1%	0.0%	1.3%	0.0%	0.2%	5.6%	3.9%
Eugene, Oregon	0.8%	0.6%	1.2%	0.4%	0.2%	0.0%	0.0%	0.0%	0.0%	3.3%	6.5%
Seattle, Washington	5.8%	2.2%	4.2%	3.6%	1.0%	0.8%	0.0%	1.2%	0.6%	6.0%	6.2%
San Diego, California	3.9%	3.5%	5.0%	4.4%	2.1%	1.7%	0.0%	0.2%	0.4%	5.0%	8.3%
Tampa, Florida	0.8%	0.5%	0.5%	0.0%	0.0%	0.0%	0.0%	0.5%	0.3%	7.4%	6.8%
Phoenix, Arizona	1.2%	0.7%	1.4%	0.9%	0.5%	0.0%	0.0%	0.2%	0.2%	2.8%	6.1%
Tempe, Arizona	0.9%	0.5%	0.9%	0.5%	0.0%	0.0%	0.5%	0.0%	0.0%	2.7%	5.9%
Scottsdale, Arizona	5.4%	2.7%	6.0%	2.1%	1.2%	0.9%	0.0%	2.1%	0.6%	2.7%	10.8%
Waterloo, Ontario	3.9%	3.5%	3.9%	2.3%	0.0%	0.0%	0.0%	0.4%	0.0%	4.2%	3.9%
Cambridge, Ontario	1.3%	1.0%	1.6%	0.0%	0.0%	0.3%	0.0%	0.3%	0.3%	6.5%	6.9%
Walnut Valley WD	10.2%	6.1%	8.0%	4.3%	1.9%	1.1%	0.0%	0.3%	0.8%	3.7%	7.0%
Las Virgenes Valley WD	4.2%	4.9%	10.3%	9.0%	9.5%	6.6%	0.0%	8.8%	5.1%	6.4%	21.8%
Lompoc, California	1.1%	0.6%	0.4%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	5.6%	4.9%
14 Study Cities	3.5%	2.4%	4.0%	2.5%	1.5%	1.0%	0.3%	1.0%	0.6%	4.8%	7.5%

(continued)

Table A.1 (Continued)

Study city	Question 40: What is the last grade of formal education the primary wage earner has completed?						
	Less than high school	**High school graduate**	**Some college**	**Bachelor's degree**	**Master's degree**	**Doctoral degree**	**NR**
Boulder, Colorado	0.7%	6.1%	NA*	44.7%	27.0%	19.4%	2.2%
Denver, Colorado	5.6%	17.2%	24.5%	27.9%	16.3%	5.4%	3.2%
Eugene, Oregon	4.7%	21.2%	29.0%	23.1%	12.9%	6.9%	2.2%
Seattle, Washington	4.2%	14.3%	22.3%	34.2%	14.5%	8.2%	2.2%
San Diego, California	5.6%	13.7%	30.5%	24.7%	14.3%	8.3%	2.9%
Tampa, Florida	12.6%	25.1%	24.3%	19.4%	9.3%	3.8%	5.5%
Phoenix, Arizona	7.7%	18.1%	34.7%	20.9%	8.9%	6.3%	3.3%
Tempe, Arizona	2.7%	11.4%	25.0%	30.9%	15.9%	8.6%	5.5%
Scottsdale, Arizona	2.1%	10.8%	24.3%	37.8%	15.6%	6.3%	3.0%
Waterloo, Ontario	10.8%	18.5%	23.2%	27.8%	6.6%	6.9%	6.2%
Cambridge, Ontario	20.3%	25.5%	24.2%	16.3%	3.3%	2.0%	8.5%
Walnut Valley WD	2.9%	14.7%	29.7%	33.4%	14.2%	2.7%	2.4%
Las Virgenes Valley WD	0.7%	7.6%	22.2%	31.5%	18.3%	14.4%	5.1%
Lompoc, California	5.8%	19.3%	36.2%	21.4%	8.8%	2.6%	6.0%
14 Study Cities	6.2%	16.0%	26.9%	28.2%	13.3%	7.3%	4.1%

* This option was not on the Boulder mail questionnaire, but was added to subsequent questionnaires.

(continued)

Table A.1 (Continued)

Study city	Question 41: What is your gross annual household income?										
	<10000	**<19999**	**<29999**	**<39999**	**<49999**	**<59999**	**<69999**	**<79999**	**<89999**	**<99999**	**<119999**
Boulder, Colorado	1.3%	4.4%	6.5%	7.8%	11.3%	8.5%	8.5%	8.7%	6.3%	4.6%	8.3%
Denver, Colorado	4.9%	9.2%	9.7%	10.7%	11.4%	7.5%	9.0%	7.5%	3.4%	3.7%	3.0%
Eugene, Oregon	5.3%	10.8%	16.3%	12.0%	11.4%	9.2%	6.9%	6.7%	2.5%	2.0%	2.0%
Seattle, Washington	1.6%	6.0%	9.1%	10.5%	11.3%	8.9%	9.1%	7.2%	4.4%	2.8%	2.8%
San Diego, California	3.3%	10.4%	9.3%	12.4%	8.7%	8.5%	7.9%	3.5%	5.0%	3.3%	4.1%
Tampa, Florida	8.5%	16.7%	11.2%	11.2%	9.3%	7.9%	3.3%	3.0%	2.7%	2.2%	1.1%
Phoenix, Arizona	2.6%	9.2%	11.5%	12.7%	11.5%	10.3%	6.6%	3.3%	3.8%	2.1%	3.3%
Tempe, Arizona	0.9%	2.3%	9.1%	7.7%	9.5%	12.7%	10.0%	7.3%	7.7%	4.1%	3.6%
Scottsdale, Arizona	0.3%	2.7%	4.2%	8.1%	8.7%	6.9%	6.3%	9.0%	3.0%	3.3%	6.0%
Waterloo, Ontario	0.0%	3.1%	3.9%	8.9%	6.6%	10.0%	8.5%	7.7%	5.4%	3.9%	3.5%
Cambridge, Ontario	0.7%	6.2%	4.2%	7.8%	11.8%	11.8%	10.5%	7.8%	2.9%	3.9%	3.9%
Walnut Valley WD	0.5%	1.9%	4.8%	5.9%	7.8%	9.9%	12.8%	10.7%	5.3%	5.3%	7.2%
Las Virgenes Valley WD	1.7%	1.2%	1.5%	3.4%	4.2%	3.4%	3.4%	5.9%	4.2%	10.80%	5.13%
Lompoc, California	4.1%	7.9%	11.3%	12.8%	9.6%	10.7%	8.1%	6.6%	3.4%	2.8%	2.1%
14 Study Cities	2.55%	6.56%	8.04%	9.43%	9.50%	9.02%	7.92%	6.79%	4.30%	3.91%	4.01%

(continued)

Table A.1 (Continued)

Study city	Question 41 (continued): What is your gross annual household income?									
	<129999	**<139999**	**<149999**	**<159999**	**<169999**	**<179999**	**<189999**	**<199999**	**>=200000**	**D.Know**	**NR**
Boulder, Colorado	1.7%	1.1%	0.7%	2.0%	0.7%	0.2%	0.0%	0.4%	1.3%	5.7%	10.0%
Denver, Colorado	0.6%	0.2%	0.9%	0.4%	0.4%	0.4%	0.0%	0.6%	1.7%	5.4%	9.2%
Eugene, Oregon	0.4%	0.6%	0.6%	0.0%	0.4%	0.0%	0.0%	0.0%	0.2%	3.1%	9.8%
Seattle, Washington	2.2%	1.6%	1.0%	0.2%	0.8%	0.4%	0.2%	0.8%	0.0%	4.2%	14.9%
San Diego, California	1.5%	0.6%	0.4%	1.0%	0.2%	0.2%	0.2%	0.0%	0.0%	5.6%	13.7%
Tampa, Florida	0.8%	0.3%	0.0%	0.8%	1.1%	0.0%	0.3%	0.0%	0.0%	7.1%	12.6%
Phoenix, Arizona	0.7%	1.6%	0.5%	0.0%	0.2%	0.0%	0.2%	0.0%	0.2%	4.2%	15.5%
Tempe, Arizona	1.4%	1.4%	1.4%	0.5%	0.0%	0.0%	0.5%	0.0%	0.0%	0.5%	19.5%
Scottsdale, Arizona	1.5%	2.7%	1.5%	1.5%	2.1%	0.9%	0.0%	0.6%	0.3%	7.5%	22.8%
Waterloo, Ontario	1.9%	3.1%	2.7%	0.4%	0.8%	0.0%	0.0%	0.0%	2.7%	9.7%	17.4%
Cambridge, Ontario	0.3%	1.3%	1.3%	0.0%	0.3%	0.3%	0.0%	0.0%	0.0%	0.7%	24.2%
Walnut Valley WD	2.4%	2.4%	2.7%	1.3%	1.1%	0.3%	0.3%	0.3%	1.9%	5.9%	9.4%
Las Virgenes Valley WD	3.42%	3.67%	1.22%	2.93%	2.20%	1.47%	1.71%	0.49%	18.1%	6.8%	13.2%
Lompoc, California	0.2%	0.6%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.4%	4.9%	13.9%
14 Study Cities	1.37%	1.52%	1.05%	0.79%	0.73%	0.32%	0.24%	0.23%	1.92%	5.09%	14.72%

APPENDIX B

QUALITY ASSURANCE AND QUALITY CONTROL

DESCRIPTION OF EIGHT MAJOR QUALITY ASSURANCE TESTS

The eight major quality assurance tests are described below. Included is identification of the risk that the test is designed to address, the test itself, when the test is to be done, who is responsible for seeing that the test is done, allowable tolerances, remedy to follow if test is out of tolerance, and the form to report the test results on. All tests were sent to Aquacraft and were included in the seven periodic reports made to AWWARF during the course of the research work.

QA Test 1 - Test Validity of Service Address

Risk: That the 1,000 sample addresses pulled from the utility's billing database are not service addresses but account billing addresses. They often are the same, but not always, such as in the case of renters whose landlord pays the water bill. Also since the entire single (SF) database is first screened for accounts closed in the last 12 months and then sorted in order of recent annual water consumption, an error of some sort could corrupt the order and hence accuracy of records.

Test: Obtain CUSTID for random sample of 20 records (2%) taken from list of 1,000 extracted records (stratified random sample for Survey mailing) and compare address in database given to consultants (Peter Mayer) by utility to address obtained by giving utility billing clerk CUSTID and having her/him look-up service address on billing system customer screen.

When: Perform as soon as sample group of 1.000 records is drawn for a given utility site.

By: Peter Mayer, Aquacraft

Tolerance: There must be a 100% match. If not, database must be considered corrupt until further investigation clears.

Remedy: Have utility investigate whole database, screening, sorting and extraction process. Peter Mayer to coordinate.

Form: QATest1

QA Test 2 - Test to See if 1,000 Sample is Representative

Risk: That the distribution of water use in the 1,000 sample is not statistically representative of the entire population of SF customers.

Test: For all SF customers, after screening out accounts closed in the last year (or annual time frame used), obtain annual and monthly (in some cases bimonthly) means and standard deviations of water use for both the entire population and the 1,000 sample. Then determine the *Z-score*.

When: Perform as soon as sample group of 1000 records is drawn and summary statistics are available for a given utility site.

By: Peter Mayer, Aquacraft

Tolerance: Varies, depending on population distribution but generally (+1.96 > *Z-score*> -1.96).

Remedy: Discuss variance in means with PMCL and determine whether to increase sample size and draw another systematic sample or in some other way improve representative.

Form: None - Aquacraft (Peter Mayer) will maintain results of this test.

Note: The above is a very brief description of this test. It was so important to have a representative sample that a very detailed procedure was designed and followed by each of the participating utilities. A description of this procedure is contained in the next section.

QA Test 3 - Check Accuracy of Survey Response Data Entry Process

Risk: That data entry person doesn't understand entry form and makes errors.

Test: Select first 10 survey responses entered by any new data entry person. Thereafter perform random check of approximately 10% of survey responses entered.

When: Perform these random checks periodically after entry of about every 100 records.

By: John Nelson, Water Resources Mgt.

Tolerance: Should achieve virtually a 100% accuracy.

Remedy: Correct record and randomly select another 10% and continue until 100% accuracy observed. If accuracy is less than 90%, review all records back to last test.

Form: QATest3

QA Test 4 - Test if Water Use of Survey Respondents is Representative

Risk: That the response to the survey is biased and not representative of customers comprising the sample of 1,000.

Test: The mail survey is sent to a sample of 1,000 customers. At the completion of the mail survey, the sample of 1,000 customers are designated as survey respondents or survey non-respondents. The average annual water use of the survey respondents is compared to the annual water use of the survey non-respondents in order to determine if there is a significant bias between the respondents and the non-respondents. The mean and standard deviation are calculated on the *annual* water use of both respondents and non-respondents. Given these statistics, a *t-test,* assuming unequal variances, is conducted at an alpha level of 0.05 to determine if there is a significant difference in the mean annual water use of respondents versus non-respondents. Also, if monthly water use statistics are available, a *t-test* is conducted to determine if there is a significant difference between the average *monthly* water use of respondents and non-respondents. When possible, the respondent characteristics will be compared with population socioeconomic characteristics from Census data.

When: These tests will be conducted upon receipt of both: (1) the data base containing water billing records for the sample of 1,000 accounts and (2) the data base containing the survey responses.

By: Eva Opitz, PMCL

Tolerance: *t-test* accepted at an alpha level of 0.05

Remedy: Recognition of problem of bias between survey respondents and non-respondents and consideration of problem in QA Test 5.

Form: None - PMCL will maintain results of study site tests

QA Test 5 - Test if 150 Sites Selected for Logging are Representative

Risk: That the sites selected for logging are not representative of mean water use of typical household and other characteristics determined by the survey.

Test: A random sample of 150 accounts selected for logging is selected from the total mail survey respondents. The sample of 150 sites is selected using the random number generation of Microsoft EXCEL, Version 5.0. *T-test*s are conducted to determine if the mean annual water use of the logging sample (n=150) is significantly different from the mean annual water use of (1) the total population of single-family detached units from which the mail survey sample was selected, (2) those receiving the mail survey (n = 1000), and (3) the mail survey respondents. The above three groups are listed in order of priority; that is, the primary objective is to assure that the sample of 150 accounts is representative of the population. Additional consideration will be given when QA Test 4 determines that significant differences in water use exist between survey respondents and non-respondents.

From the 150 accounts designated as the logging sample, 25 are randomly removed on the basis of home value quartile delineation and are designated to be used for replacement purposes. Thus, the remaining 100 accounts are the selected logging sample for the study area. A *t-test* is conducted to determine if there is a significant difference between the mean annual water of the logging sample (n = 100 accounts) and the mean annual water use of: (1) the total population of single-family detached units from which the mail survey sample was selected, (2) those receiving the mail survey (n = 1000), and (3) the mail survey respondents.

When: These tests will be conducted upon receipt of both: (1) the data base containing water billing records for the sample of 1,000 accounts and (2) the data base containing the survey responses.

By: Eva Opitz, PMCL

Tolerance: *t-test* accepted at an alpha level of 0.05

Remedy: Repeat procedure until acceptable sample is obtained

Form: None - PMCL will maintain results of study site tests

QA Test 6 - Test Data Logger to See that it is Recording Properly

Risk: The sensor may not be properly in place and the logger may not be recording..

Test: For each data logger, once recording has begun, run a small amount of water though an outside tap and look for the flashing light on the logger which indicates that flow is being recorded. Make sure the make and model of the meter are properly recorded.

When: Upon installation of data logger at each new site.

By: Peter Mayer and Bill DeOreo, Aquacraft

Tolerance: 100% - All loggers will be verified to be recording properly when the lid of the meter pit is replaced.

Remedy: Adjust sensor and logger until the system is operating properly.

Form: QATest6

QA Test 7 - Check Accuracy of Data Logger vs. Meter

Risk: The data logger inaccurately records flow through the meter doing the recording period of 2 weeks.

Test: Take initial and final reading of water meter, calculate consumption and compare to volume determined by logger.

When: Upon installation and again on removal of data logger at each site.

By: Peter Mayer and Bill DeOreo, Aquacraft.

Tolerance: Variance in volume shall be less than 15%

Remedy: Ultimately our flow traces are only as good as the meters they are recorded from. Cities are encouraged to replace old meters prior to the start of data logging. However, this is not a requirement. Flow traces within tolerance levels will be modified to align with meter volumes. Flow trace records exceeding tolerance levels or which appear suspect for other reasons will be discarded and not included in the database.

Form: QATest7

QA Test 8 - Check Accuracy of Event Database

Risk: The event database is created by analyzing the logged data per site with Trace Wizard. This process is not entirely automatic and requires some trial and error applications and judgement on the part of the computer analyst. The risk is that the operator adopts a bias in interpreting the log data or makes errors in using Trace Wizard.

Test: Have supervisor check the 10% of the work of each computer analyst.

When: Upon completion of about every 20 records.

By: Peter Mayer, Aquacraft.

Tolerance: Sum of the absolute value of the variance in all categorized volumes divided by the total volume in the trace shall be less than 15%

Remedy: Further flow traces disaggregated by the computer analyst will be examined and additional training provided to the analyst. Corrected flow traces will be re-submitted to the event database.

Form: QATest8

QA TEST FORMS

QA Test 1 - Test Validity of Service Address

City/Utility: ____

Name of Person filling out this form: ____

Phone Number of Person filling out this form: _____ _____ - ____________ x _____

Date that Column 3 data was obtained from Clerk in Billing Department from Customer Records Screen: ____________

Col. 1	Col. 2	Col. 3
CUSTID#(1)	Address from Survey Database(2)	Address Reported by Billing Dept.(3)

Notes:

(1) From Survey Database (the file used to generate the address and CUSTID* stick-on labels) select at random 20 records (if Database is sorted in any way, select every 20th record) and record CUSTID# and Address for that record in Columns 1 and 2 respectively.

(2) Call Billing Dept. (or give them this sheet) and have Billing Clerk pull up customer screen that goes with given CUSTID# and record the ***Service Address*** that appears on the screen in Column 3 (Entering "Same" is ok if it matches Column 2).

(3) The result should be a 100% match. If there is not a 100% match, research and determine why not and explain on an attached sheet for the CUSTID# in question.

(4) Please, as soon as QATest is completed, Fax this sheet and any attachment to:

John Olaf Nelson Water Resources Management, 1709 Alhambra Ct., Petaluma, CA 94954

Ph: 707 778-8620, Fx: 707 778-3566, Email: jonolaf@crl.com

QATest 3 - Check Accuracy of Survey Response Data Entry Process

City/Utility: ____
Name of Person filling out this form: ____
Name of data entry person being checked: ____
Phone Number of Person filling out this form: _____ _____ - ____________ x _____

Col. 1 Date	Col. 2 KEYCODE	Col. 3 Errors?	Col.1 Date	Col. 2 KEYCODE	Col. 3 Errors?

Notes:

(1) Double check first 10 forms for if new data entry person.
(2) Then after about every 100 forms loaded into Access, check 10% at random.
(3) Their should be no errors or at most 1 per form.
(4) If error is found, note field name from master printed form above correct it, then draw another 10% until no errors are found.

John Olaf Nelson Water Resources Management, 1709 Alhambra Ct., Petaluma, CA 94954
Ph: 707 778-8620, Fx: 707 778-3566, Email: jonolaf@crl.com

QA Test 6 -- Data Logger Installation and Removal

City/Utility: ____
Name of Person(s) filling out this form: ____

Logger #	Address	Meter Type and Model	Date and Time	Starting Meter Read	Ending Meter Read	Logge r on?

QA Test 7 -- Check Logger vs. Meter Volumes

City/Utility: ____
Name of Person filling out this form: ____

Logger # Keycode Logger Volume (Gal.) Meter Volume (Gal.) % Difference
Log Vol. - Meter Vol/Meter Volume

Logger #	Keycode	Logger Volume (Gal.)	Meter Volume (Gal.)	%Difference (Log. Vol. – Meter Vol.)/Meter Volume

QA Test 8 -- Check Accuracy of Event Database

City/Utility: ____
Name of Person filling out this form: ____
Name of Computer Analyst:____
Trace Address:____
KEYCODE:________________________

Water Use Category	Analyst Total (gallons)	Supervisor Total (gallons)	Absolute Difference
Toilets			
Showers			
Dishwashers			
Clothes washers			
Faucets			
Baths			
Leaks			
Other			
TOTALS			

Total Absolute Difference/Total Trace Volume = _______________________%

QA TEST RESULTS

Table B.1 QA test 1 results

Study site	Test validity of service address
Boulder, Colorado	100% match
Denver, Colorado	100% match
Eugene, Oregon	100% match
Seattle, Washington	100% match
San Diego, California	100% match
Tampa, Florida	100% match
Phoenix, Arizona	100% match
Tempe & Scottsdale, Arizona	100% match
Waterloo & Cambridge, Ontario	100% match
Walnut Valley WD, Calif.	100% match
Las Virgenes MWD, Calif	100% match
Lompoc, California	100% match
All 12 study sites	100% match

Table B.2 QA test 2 results

Study city	Test to see if 1,000 sample is representative		
	Total single-family (SF) accounts	Targets for survey (Q1000)	Statistically significant difference between survey targets and total SF accounts?
Boulder, Colorado	16,904	1,000	No
Denver, Colorado	174,688	1,000	No
Eugene, Oregon	27,523	983	No*
Seattle, Washington	303,000	985	NA†
San Diego, California	171,952	1,007	No
Tampa, Florida	60,830	1,017	No
Phoenix, Arizona	254,781	1,000	No
Scottsdale, Arizona	42,811	600	No
Tempe, Arizona	29,700	401	Yes‡
Cambridge, Ontario	23,614	600	No
Waterloo, Ontario	14,972	400	No
Walnut Valley WD, Calif.	18,307	1,000	No
Las Virgenes MWD, Calif	12,740	1,062	No
Lompoc, California	5,740	1,000	No

Footnotes:

* No significant differences after outliers removed.

† Population mean and standard deviation could not be calculated so test was not performed.

‡ Because of smaller sample size, t-test indicated statistically significant difference.

Table B.3 QA test 3 results

Study site	Check accuracy of survey response data entry		
	Total completed surveys loaded	Completed surveys checked	Errors found in checked surveys
Boulder, Colorado	459	21	1 (Q1a)
Denver, Colorado	466	41	1 (Q16)
Eugene, Oregon	510	50	1 (Q38)
Seattle, Washington	497	50	0
San Diego, California	482	48	0
Tampa, Florida	366	33	0
Phoenix, Arizona	426	42	0
Scottsdale & Tempe, Arizona	553	53	0
Cambridge and Waterloo, Ontario	565	54	0
Walnut Valley WD, Calif.	374	39	0
Las Virgenes MWD, Calif	409	42	0
Lompoc, California	467	45	0

Footnotes:
Any errors found during random survey checks were corrected in the final survey database.

Table B.4 QA test 4 results

Study city	Test if water use of survey respondents is representative			
	Targets for survey (Q1000)	Survey respondents	Statistically significant difference between: Survey targets and respondents?	Survey respondents and non-respondents?
Boulder, Colorado	1,000	459	No	No
Denver, Colorado	1,000	466	No	No
Eugene, Oregon	983	510	No	No
Seattle, Washington	985	497	No	No
San Diego, California	1,007	482	Yes*	Yes*
Tampa, Florida	1,017	366	No	No
Phoenix, Arizona	1,000	426	No	No
Scottsdale, Arizona	600	333	No	No
Tempe, Arizona	401	220	No	No
Cambridge, Ontario	600	306	No	No
Waterloo, Ontario	400	259	No	No
Walnut Valley WD	1,000	374	No	No
Las Virgenes MWD	1,062	409	No[2]	No†
Lompoc, California	1,000	467	No	Yes‡

Footnotes:
* Survey respondents were found to have significantly different (i.e., lower) water use than mail survey targets. Corrective action taken in subsequent steps.
† Initial tests showed significant differences in water use. However, after 5 outliers were removed, no significant differences were found.
‡ Significant differences in water use were found between survey respondents and non-respondents. However, other comparisons showed no significant differences.

Table B.5 QA test 5 results

Study city	Test if sites selected for data logging are representative		
	Data logging sample size	Statistically significant difference between logging sample and survey respondents?	Statistically significant difference between logging sample and survey targets?
Boulder, Colorado	125	No	No
Denver, Colorado	125	No	No
Eugene, Oregon	125	No	No
Seattle, Washington	150	No	No
San Diego, California	125	No*	No[1]
Tampa, Florida	150	No	No
Phoenix, Arizona	150	No	No
Scottsdale, Arizona	90	No	No
Tempe, Arizona	60	No	No
Cambridge, Ontario	90	No	No
Waterloo, Ontario	60	No	No
Walnut Valley WD	150	No	No
Las Virgenes MWD	150	No	No
Lompoc, California	150	No	No

Footnotes:

* Because significant differences were found between survey respondents and non-respondents and survey respondents and mail survey targets, a matching sample approach was used to select the data logging sample.

Table B.6 QA test 6 results

Study site	Test data logger to see that it is recording
Boulder, Colorado	100%
Denver, Colorado	100%
Eugene, Oregon	100%
Seattle, Washington	100%
San Diego, California	100%
Tampa, Florida	100%
Phoenix, Arizona	100%
Tempe & Scottsdale, Arizona	100%
Waterloo & Cambridge, Ontario	100%
Walnut Valley WD, Calif.	100%
Las Virgenes MWD, Calif	100%
Lompoc, California	100%
All 12 study sites	100%

Table B.7 QA test 7 results

Study site	Check accuracy of data logger vs. water meter				
	Logging period	**Loggers installed**	**Flow traces accepted as accurate**	**Flow traces rejected (due to inaccuracy or logger failure)**	**Success rate**
Boulder, Colorado	1	100	88	12	88.0%
	2	100	88	12	88.0%
Denver, Colorado	1	99	92	7	92.9%
	2	99	91	8	91.9%
Eugene, Oregon	1	100	87	13	87.0%
	2	100	89	11	89.0%
Seattle, Washington	1	100	92	8	92.0%
	2	97	88	9	90.7%
San Diego, California	1	100	97	3	97.0%
	2	100	84	16	84.0%
Tampa, Florida	1	100	92	8	92.0%
	2	100	93	7	93.0%
Phoenix, Arizona	1	100	96	4	96.0%
	2	100	97	3	97.0%
Tempe & Scottsdale, Arizona	1	100	93	7	93.0%
	2	100	92	8	92.0%
Cambridge & Waterloo, Ontario	1	97	90	7	92.8%
	2	88	78	10	88.6%
Walnut Valley WD	1	100	97	3	97.0%
	2	100	86	14	86.0%
Las Virgenes MWD	1	100	98	2	98.0%
	2	99	89	10	89.9%
Lompoc, California	1	100	95	5	95.0%
	2	100	92	8	92.0%
All study sites	All 24	2379	2184	195	91.8%

Table B.8 QA test 8 results

Study site	**Check accuracy of event database**			
	Logging period	**Flow traces accepted as accurate**	**Flow traces selected for re-analysis**	**Mean percent difference between analyst and checker***
Boulder, Colorado	1	88	15	7.6%
	2	88	6	2.9%
Denver, Colorado	1	92	15	5.2%
	2	91	7	3.2%
Eugene, Oregon	1	87	15	4.8%
	2	89	5	13.0%
Seattle, Washington	1	92	6	5.0%
	2	88	6	4.3%
San Diego, California	1	97	7	4.6%
	2	84	7	6.8%
Tampa, Florida	1	92	6	4.7%
	2	93	7	3.1%
Phoenix, Arizona	1	96	6	4.5%
	2	97	7	5.0%
Tempe & Scottsdale,	1	93	6	3.0%
Arizona	2	92	6	6.0%
Cambridge &	1	90	6	10.8%
Waterloo, Ontario	2	78	6	9.0%
Walnut Valley WD	1	97	7	4.0%
	2	86	6	7.0%
Las Virgenes MWD	1	98	7	8.0%
	2	89	6	9.0%
Lompoc, California	1	95	6	8.0%
	2	92	6	7.0%
All study sites	All 24	2184	177	6.0%

Footnote:
* Any re-analyzed flow trace which differed from the original by more than 15% was re-submitted and re-checked by the project engineer and only the corrected flow trace was included in the final database. However, the uncorrected percent error is included in this column.

APPENDIX C

THE RESIDENTIAL END USES OF WATER STUDY DATABASE

INTRODUCTION

One of the products of the *Residential End Uses of Water Study* is the extensive database developed over the entire research effort. This database, which is in Microsoft Access format, contains all of the end use water events recorded during the study along with the survey response data, historic billing data, and weather data obtained for each study site. It was always the intention of the project team to make the REUWS database available to utilities, academic institutions, and other researchers so that additional and more extensive analysis can be performed. This is a tremendously rich data resource, and the analysis presented in this report can be seen as a jumping off point for further research which can utilize this database.

The purpose of this appendix is to provide a general introduction to the database and to some of the types of analysis which are possible. It is assumed that the reader is familiar with a few database fundamentals including a basic understanding of the following terms: field, record, table, and query.

DATABASE STRUCTURE

The REUWS database is a relational database in Microsoft Access format in which a number of tables are related or linked to each other via a common field. Specifically, the KEYCODE field is used to link different tables such as the survey response data table and the end use data table. The KEYCODE is the unique number assigned at the time when each mail questionnaire was loaded into the database. The KEYCODE is a five digit number and the first two digits identify the study site. For example, a KEYCODE beginning with 10 indicates a record from a residence in Boulder, Colorado. The KEYCODE is the only piece of information which can be used to distinguish different study participants. All specific information which might identify a specific household or account such as an address or name has been stripped from the database. The only identifying information which can be gleaned is the study site to which the record pertains.

Another unique identifier field is used to link several tables of weather data. This field help link specific study houses to the nearest available weather station.

The REUWS database also contains a number of pre-developed queries. These queries can be used to summarize data or to extract data meeting specific criteria from the database.

The database is approximately 230 Mb in size.

DATABASE TABLES

The following are description of tables of data found in the REUWS database.

1) DAILY USE Table – Contains summed water use by fixture for each of the 1,188 home in the data logger portion of the study for each day that the logger was in place. 28,015 records. Fields in the table include: KEYCODE, date, and each recorded end use (toilet, shower, clothes washer, irrigation, faucet, leak, etc.)
2) DAILY WEATHER Table – Contains daily minimum and maximum temperature and total precipitation from weather stations in all participating cities. The weather station identification field, STATID relates these data to specific houses in the study group. 38701 records. Fields include: STATID, date, minimum temp., maximum temp., and daily precipitation.
3) LOGGING DATA Table – Contains each individual water use event recorded during the two year study and all available information about each water use event. Leakage has been summarized into total daily leakage. Logging data is related to survey responses via the KEYCODE field. 1,959,817 records. Fields include: KEYCODE, event type (toilet, shower, clothes washer, etc.), date, start time, stop time, duration, volume, peak flow rate, mode flow rate, and count of the mode occurrence.
4) SURVEY_RESPONSES Table – Contains each coded survey response from all 12 study sites. Also includes the KEYCODE and STATID fields to link water use and survey data with weather data. 5928 records. Fields include: KEYCODE, STATID, and more than 100 individual survey questions.
5) WEATHER STATIONS Table – Contains the location and station identification for all weather stations found in conjunction with this study. Includes the latitude and longitude of

each weather station. 39 records. Fields include: STATID, station code, station name, city, state, county, agency, latitude, longitude, and elevation.

6) Q1000 Tables – These 12 tables contain the historic billing data obtained from the systematic random sample of approximately 1,000 homes per study site. A KEYCODE is included for homes which responded to the survey. Fields in these tables vary depending upon the billing system of each participating utility.

DATA CONSIDERATIONS

The data contained in the REUWS database ranges from numerical survey responses to annual water use consumption to average daily water use to measured daily water use and specific end use data. There are a number of database idiosyncrasies which must be understood in order to understand and work with the REUWS data. This section describes some of the specific details about the data contained in the database including details about the assignment of KEYCODES to specific study sites, and the disaggregated end use categories.

Keycodes

The following KEYCODES were assigned for each study site. For example, the KEYCODE numbers for Boulder, Colorado begin with 10001 and do not exceed 10999. The first two digits identify the study site, and the next three numbers distinguish the individual survey respondent. Study sites can be distinguished by KEYCODE using Table C.1.

Table C.1 Keycode definitions

Study site	**KEYCODE range**
Boulder, Colorado	10001 – 10999
Denver, Colorado	11001 – 11999
Eugene, Oregon	12001 – 12999
Seattle, Washington	13001 – 13999
San Diego, California	14001 – 14999
Tampa, Florida	15001 – 15999
Phoenix, Arizona	16001 – 16999
Tempe and Scottsdale, Arizona	17001 – 17999
Waterloo and Cambridge, Arizona	18001 – 18999
Walnut Valley WD, California	19001 – 19999
Las Virgenes MWD, California	20001 – 20999
Lompoc, California	21001 – 21999

Logging Data

The Logging Data table contains the name, date, and specific statistics about each water use event recorded during the data logging portion of the study. These water use events include individual toilet flushes, showers, faucet uses, clothes washer and dishwasher cycles, irrigation uses, etc. Each record also contains a KEYCODE assignment so that each specific water use can be associated with a specific study house and study site.

Listed below are the specific categories of disaggregated end uses that have been identified through flow trace analysis. These 17 names are the only descriptors used in the Logging Data table to distinguish water use events. The 17 categories are:

BATH, CLOTHESWASHER, CLOTHESWASHER1, COOLER, DISHWASHER, DISHWASHER1, FAUCET, HOT TUB, HUMIDIFIER, IRRIGATION, LEAK, SHOWER, SWIMMING POOL, TOILET, TOILET@, TREATMENT, UNKNOWN

CLOTHESWASHER1 and DISHWASHER1 names are assigned to the *first cycle* in each multi-cycle use of these machines. This was done to facilitate the count of uses per day, because clothes washers and dishwashers all have multiple cycles which then appear in the database as separate water use events. By designating the first cycle with a different name it is possible to calculate the number of loads of clothes or dishes washed by any household on any given logged day.

Leaks have been summarized on a daily basis. The LEAK category appears in the database with only a KEYCODE, data, and volume attached. None of the other statistics about leakage apply because the leaks for that day have all been summed.

TOILET@ is a special category of toilet flush which refers to partial or double toilet flushes) which should be included in any count of daily uses or summed daily volume, but should not be used to calculate any statistics related to actual flush volumes. A partial flush occurs then the toilet flush lever is not depressed completed and only a portion of toilet tank water is used to clean the bowl. The resulting toilet fill cycle, which is what appears in the flow trace, is much briefer than a regular flush and the volume is much less. A double flush occurs where the flush handle has been held down for an extended period so the fill volume in increased or when the toilet is flushed a second time while in the midst of a fill cycle. In these cases the toilet flush appears as longer in duration and higher in volume than a regular toilet flush. These TOILET@ events are evident as toilet flushes because of the flow rate which is identical to the fill rate of a standard flush. Certainly the volume of water in a TOILET@ event must be included in the calculation of total daily toilet use. However, because these flushes are either low or high volume, they are not appropriate to use in the calculation of the average flush volume of toilets in a given household or study site. These events would distort this calculation.

TREATMENT refers to home water treatment systems and water softeners.

UNKNOWN refers to water use which could not be positively assigned a fixture designation. It is not known if these events occurred indoors or outdoors.

Split Events

Occasionally during flow trace analysis, some single water use events such as a shower, or a bath, or a clothes washer cycle may be split into several pieces. This happened from time to time in the REUWS when the Trace Wizard software's analysis algorithm incorrectly identified a simultaneous usage when none existed, or when people split the events themselves (e.g. by taking Navy showers). Care must be taken when evaluating the average volume or flow rate for showers, or the frequency of use.

Daily Use

In the Daily Use data table, in addition to the identified end uses, daily sums of indoor use and total use are also included for each record. The indoor field is equal to the sum of all daily uses *except* for irrigation, swimming pools, and unknowns. The total daily use field is the sum of all recorded water uses for that given day.

Survey Responses

When a survey question was left unanswered it was described as a "non response". Non responses to questions were entered into the database using a default setting of "-1". Because Access treats this as a numeric response, the –1 can dramatically effect analysis and summaries of survey responses (e.g. the average number of residents). Care must be taken when working with the survey data to make sure that these negative one values are handled properly.

Q1000 Tables

The Q1000 tables include all available historic consumption for approximately 1000 single family accounts in each of 12 logging sites for a total of approximately 12,000 accounts. There are a total of 12 Q1000 tables, one for each of the 12 REUWS study sites. In most cases these tables also include number of days in the billing cycle or the billing year and a calculation of average daily use for each household based on the billing data and the number of days. In some cases this information was not available.

All customers that returned a survey were assigned a KEYCODE which appears in the KEYCODE filed in each of the 12 Q1000 tables. To obtain the billing data for just the data logged groups it is possible Q1000 tables with the logging data table or to the daily use table in a query using the KEYCODE field. If done properly, this will exclude all homes which were not participants in the data logging portion of the study.

Q1000 water use consumption is in units of thousand gallons (K gal) unless otherwise noted in the table.

USING THE REUWS DATABASE

The REUWS database can provide a wide variety of information about residential water use in the 12 participating study sites and across all study sites. All of the analyses found in this report including the tables and figures are based on data from this source. This section describes in general terms how the database can be used to extract information.

In Microsoft Access, database queries are used to summarize data, perform statistical calculations, or to select specific records from the data set. A familiarity with developing simple queries in Access is a pre-requisite for working with the REUWS database.

Billing data

The historic billing data found in the Q1000 tables can be used to calculate annual use statistics such as mean, median, standard deviation, etc. These billing data can also be linked with the survey response data to obtain information about different groups of customers. This link is accomplished with the KEYCODE field.

For example, it is possible to obtain annual water use information on all survey respondents from household with a combined annual income greater than $100,000. Or annual water use information could be obtained from all survey respondents who reported owning a swimming pool. The measures of central tendencies around these billing data could then be compared with those of households which do not own a swimming pool.

The survey data provides a way to separate the nearly 6,000 survey respondents into different groups in a wide variety of ways. The historic billing data permits comparison of the annual water consumption or average daily consumption of these different groups.

Another use of the billing data is for analysis of seasonal water use. Once again the combination of survey data and billing data provides a myriad of ways to examine seasonal water use. For example, seasonal and non-seasonal water use for homes with and without automatic sprinkler systems can be compared. In many cases it may be desirable to perform Access queries and the copy the resulting dynaset into a spreadsheet program such as Excel or a statistical analysis package for further analysis and for development of charts and graphs.

End Use Data

A tremendous variety of analysis can be performed using the specific end use data collected during the data logging portion of the REUWS. Examples of these analyses include: examination of specific end uses such as toilets and showers and their duration, volume, flow rates, and frequency of use; hourly use analysis such as those presented in Chapter 5; and analysis of the distribution of daily water use.

When combined with the survey data it is possible to separate the 1,188 data logged homes into a variety of groups (based on survey responses) and compare daily water use or by fixture between these groups. It is also simple to calculate per capita daily consumption for any end use and compare groups on this basis. These data provide a way to examine existing efficiencies in a wide variety of single-family groups. This information is critical when planning conservation programs.

The outdoor use information in the end use database and the weather data provide an opportunity to examine how people responded to different weather events including extreme heat and rain. It is also possible to compare homes outdoor use in households with manual and automatic sprinkler systems.

Because data were collected in two logging sessions (usually in the summer and winter) it is also possible to examine seasonal variations in indoor water use. Are certain end uses more frequent in the winter or in the summer? Does the timing of water use change with the season? Any number of analysis are possible.

Because the end use data table contains more than 1.3 million records, a fast computer is a benefit when working with the database. This is particularly true when performing a query which requires extracting data from the entire end use data table. It is often advisable to extract portions of this table, such as all of the shower events, and work with these data in another platform such as Excel or Quattro Pro.

The end use data may be particularly useful for calibrating water use models which attempt to disaggregate residential water use. It can also be used to examine flow rates through residential meters. This is an important issue for metering. The database could be used to answer question like: What percentage of flow is less than 0.25 gpm or 4.0 gpm? This is an area of research not touched on in this report.

Survey Response Data

Another rich source of information is the survey response table. This table contains the individual responses to each survey question - more than 5,500 records. A wide variety of questions relating to hardware, behavior, conservation, and demography were included in the survey and the responses can be compared by region or by study site or by income group or by household size or by any number of ways. A copy of the survey questionnaire is printed in Appendix A along with summarized responses to each survey question from each study city.

The survey response data is useful in identifying groups of households so that their water use behavior can be compared. For example, homes with and without automatic irrigation systems or homes with and without dishwashers. Do homes without dishwashers tend to use more water for faucets? This type of analysis is possible.

HOW TO OBTAIN THE REUWS DATABASE

To obtain a copy of the REUWS database please contact Aquacraft, Inc. or AWWARF.

Aquacraft. Inc.
2709 Pine St.
Boulder, CO 80302
303-786-9691
303-786-8696
www.aquacraft.com

AWWARF
6666 Quincy
Denver, CO 80235
303-347-6103
303-730-0851

APPENDIX D

RESIDENTIAL END USE MODELS

STATISTICAL MODEL OF AVERAGE TOTAL HOUSEHOLD USE

Introduction

The contemporary approach to evaluating water conservation programs and forecasting water demand normally involves the development of water use models that seek to explain the variation in total household use. The more sophisticated analyses combine survey information on household characteristics, with weather, price, and other information, to model water use within a multivariate framework. This technique is intended to account for as many factors as necessary to distinguish the independent impacts on water use of such factors as participation in conservation programs, the presence of particular end uses of water, and many other cross-sectional and time-series phenomena.

A model of average daily billing period use is constructed below, using the wealth of survey, price, weather, and water use data collected as part of the Residential End Uses of Water Study. The model that is presented is one of many possible models that can be constructed using the data that are available. The purpose of the model is to provide a reference point for the end use models of Chapter 6 and to highlight the advantages of the end use logging approach for understanding water use relationships.

Model Estimation Procedure

Multiple regression analysis is used to estimate the water use relationship displayed below. Multiple regression is commonly used to estimate a direct and quantifiable numeric relationship between a variable of interest (the dependent variable) and a set of independent variables that are hypothesized to affect or *explain* changes in the variable of interest. The general linear regression model may be expressed as:

$$Y_{i,t} = \beta_0 + \sum_m \beta_m X_{m,i,t} + \varepsilon_{i,t} \qquad \text{(D.1)}$$

where Y = the dependent variable of interest (e.g., water use in toilets per logging period)

X = the *m*th explanatory or independent variable (e.g., household size, temperature)

β_0 = an estimated model intercept term

β_m = estimated model parameters that measure the relationship between Y and a set of *m* explanatory variables, X

ε = a random error term that denotes the difference between actual Y, and Y as estimated from the model

i = index for household (i=1,2,…,n; where n denotes the number of cross sections present in any particular end use model)

t = index for logging period (t=1,2)

Observations on Y and the vector of X's are assembled to estimate the regression equation. Generally, regression models select values for β_0 and β_m that best explain changes in Y, or in statistical terms those estimates of β_0 and β_m that minimize the sum of squared errors (also known as ordinary least squares (OLS) regression). Oftentimes, the regression relationship uses natural logarithmic transformations of data such that equation D.1 can be written as:

$$\ln Y_{i,t} = \beta_0 + \sum_m \beta_m \ln X_{m,i,t} + \varepsilon_{i,t} \qquad \text{(D.2)}$$

where the term *ln* denotes the natural logarithmic transformation. Upon estimating this type of transformed equation, the relationship would retain the following mathematical form after it is re-transformed from the logarithmic to raw scale:

$$Y_{i,t} = e^{\beta_0} \prod_m X_{m,i,t}^{\beta_m} \qquad \text{(D.3)}$$

If some variables are left untransformed in this type of formulation, then the model is said to be estimated in log-partial-log form, in which untransformed variables and their estimated coefficients become part of the exponent of the base of the natural logarithm, *e*, where the index u in D.4 denotes the set of untransformed variables:

$$Y_{i,t} = e^{\beta_0 + \sum_u \beta_u X} \prod_m X_{m,i,t}^{\beta_m} \qquad \text{(D.4)}$$

In the log-transformed model, the estimated exponents, β_m, can be interpreted directly as elasticities. Elasticity measures the effect on the dependent variable of a one percent change in the value of an independent variable.

Scale Correction for Interpreting Coefficients of Binary Variables

Given a natural logarithmic transformation of water use, the estimated coefficients of binary (0/1) variables gives the median percentage difference in water use between particular the groups of households or time periods that are categorized by the binary variable (Chesnutt and McSpadden 1992). In order to translate the coefficient estimates into expected percent change, a small-scale correction must be made. An unbiased estimate of the expected percent change can be derived as:

$$e^{\beta - .5\sigma_\beta^2} - 1 \times 100 \qquad \text{(D.5)}$$

where β is the coefficient estimate of the binary variable, and σ_β is the standard error of the coefficient estimate (Chesnutt and McSpadden 1991). Although the interpretation of the model below does not go to this level of detail, one should take into account this correction for his or her own closer look at the results.

Interpretation of Total Household Use Model

Table D.1 presents an estimated model of total average daily water use. A total of 20,551 observations on monthly average water use, survey, price, and weather data were used in the estimation process. As shown, the model contains a group of binary variables indicating the month of the billing period. The coefficients show the common distinct seasonal trend in average single-family water use. Among the sample, the month of July was on average the month of highest average use, while February was generally the month of lowest average daily use. As expected, water use is shown to increase with temperature and decrease with precipitation, which similar to the seasonal component is related to the outdoor component of total use—a component of use that cannot be precisely differentiated from total use without the aid of data logging.

Average daily use increases with the number of persons in a household, which is certainly related to the indoor/domestic component of total use. Generally, however, the model indicates that children and teenagers add incrementally less to average daily use than adults. Further, the greater the number of persons employed outside the home, the less water use that occurs. The strength of the end use-level models of Chapter 6 (with estimation results shown later in this appendix) is that one may differentiate the effects of household composition on the particular components of indoor use. Similarly, the end use models can differentiate the effects of household income and other proxies for standard of living and ability to pay at the end use level. As shown in Table D.1, total average use is estimated to increase with income and the size of the home.

Household water use is shown to increase with the number of toilets and showers in the home, but as should be expected, is shown to decrease with the number of toilets that have been retrofitted with the conserving/ultra-conserving variety. However, converse to expectations, the model estimates suggest that water use actually rises with the number of showerheads that have retrofitted. This finding is reversed in the shower end use model, likely because of the degree of resolution that is obtained by looking solely at shower use.

The indicator variable for the presence of a dishwasher shows little significance and retains a negative sign, which is contrary to expectations. The clothes washer indicator suggests that households with clothes washers use about 10 percent more water, on average, than their counterparts. Similarly, households who have evaporative coolers, pools, and/or irrigation systems use substantially more, on average, than households that do not have these end uses. As expected, households that have access to other non-utility sources of water display lower billed water use than those that rely solely on utility-supplied water, everything else held constant. As demonstrated in the Chapter 6 and later in this appendix, the power of the end use modeling approach is that one can go beyond analyzing the mere presence of an end use and relate the amount of water used via the various indoor and outdoor end uses of water to specific factors that create variation in both total water use and water use at the end use level.

Table D.1 OLS model of household billing data water use

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	0.267	0.226	1.18	0.24
Indicator that billing period is January (0/1)	-0.063	0.020	-3.09	0.00
Indicator that billing period is February (0/1)	-0.134	0.020	-6.57	0.00
Indicator that billing period is March (0/1)	-0.090	0.021	-4.26	0.00
Indicator that billing period is April (0/1)	0.082	0.024	3.48	0.00
Indicator that billing period is May (0/1)	0.201	0.027	7.52	0.00
Indicator that billing period is June (0/1)	0.325	0.028	11.42	0.00
Indicator that billing period is July (0/1)	0.387	0.030	12.97	0.00
Indicator that billing period is August (0/1)	0.324	0.029	11.33	0.00
Indicator that billing period is September (0/1)	0.170	0.027	6.24	0.00
Indicator that billing period is October (0/1)	0.086	0.022	3.82	0.00
Indicator that billing period is November (0/1)	-0.037	0.021	-1.81	0.07
Ln(water marginal price[2nd block]+1)	-0.102	0.047	-2.18	0.03
Ln(average maximum temperature)	0.568	0.045	12.76	0.00
Ln(total precipitation(in.)+1)	-0.159	0.009	-18.50	0.00
Ln(household size)	0.465	0.015	31.17	0.00
Ln(number of children+1, ages 0-12)	-0.136	0.013	-10.54	0.00
Ln(number of teenagers+1, ages 13-17)	-0.025	0.015	-1.63	0.10
Ln(adults employed full time outside of home)	-0.030	0.011	-2.61	0.01
Ln(household income, midpoints of intervals)	0.035	0.008	4.25	0.00
Ln(home living space (sf)), midpoints of intervals	0.158	0.017	9.22	0.00
Ln(lotsize(sf)), midpoints of intervals	0.065	0.006	11.15	0.00
Indicator of rented house (0/1)	0.009	0.019	0.49	0.62
Indicator that household wasn't responsible for paying water bill (0/1)	-0.125	0.047	-2.68	0.01
Indicator house was built before 1960 (0/1)	-0.050	0.014	-3.57	0.00
Indicator house was built between 1960-1969 (0/1)	0.019	0.014	1.42	0.16
Indicator house was built between 1970-1979 (0/1)	0.018	0.013	1.37	0.17
Indicator house was built between 1990-present (0/1)	-0.072	0.017	-4.21	0.00
Number of toilets	0.005	0.010	0.54	0.59
Household ultra-low-flush toilet ratio	-0.034	0.011	-3.13	0.00
Indicator house retrofitted all usable toilets (0/1)	-0.147	0.033	-4.40	0.00
Number of showers	0.043	0.008	5.53	0.00
Household ultra-low-flow showerhead ratio	0.027	0.010	2.62	0.01
Indicator of whirlpool bathtub (0/1)	0.062	0.015	4.02	0.00
Indicator of hot-tub (0/1)	0.024	0.014	1.74	0.08
Number of sinks(bathroom, kitchen, indoor utility)	0.005	0.005	0.95	0.34
Indicator of home water treatment system (0/1)	0.038	0.011	3.35	0.00

(continued)

Table D.1 (Continued)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Indicator of garbage disposal (0/1)	-0.003	0.013	-0.22	0.82
Indicator of dishwasher (0/1)	-0.011	0.014	-0.78	0.44
Indicator of clothes washer (0/1)	0.090	0.019	4.63	0.00
Indicator of evaporative/swamp cooler (0/1)	0.111	0.016	7.02	0.00
Indicator that the household irrigates (0/1)	0.159	0.027	5.96	0.00
Percentage of lawn among landscape	0.002	0.000	9.83	0.00
Indicator of in-ground sprinkler system (0/1)	0.147	0.013	11.41	0.00
Indicator of automatic timer sprinkler (0/1)	0.168	0.013	12.52	0.00
Indicator of drip irrigation system (0/1)	0.017	0.012	1.40	0.16
Indicator of garden hose w/ attached sprinkler (0/1)	0.044	0.011	4.20	0.00
Indicator for flower and/or vegetable garden (0/1)	0.104	0.010	10.83	0.00
Indicator of swimming pool (0/1)	0.257	0.013	19.64	0.00
Indicator of additional water sources for outdoor use (example - well) (0/1)	-0.243	0.019	-13.06	0.00
Indicator for Boulder (0/1)	-0.127	0.023	-5.55	0.00
Indicator for Denver (0/1)	0.075	0.032	2.35	0.02
Indicator for Eugene (0/1)	-0.083	0.037	-2.23	0.03
Indicator for Las Virgenes (0/1)	0.120	0.024	4.98	0.00
Indicator for Phoenix (0/1)	0.173	0.024	7.24	0.00
Indicator for San Diego (0/1)	0.049	0.021	2.34	0.02
Indicator for Scottsdale/Tempe (0/1)	-0.211	0.025	-8.48	0.00
Indicator for Seattle (0/1)	0.144	0.027	5.35	0.00
Indicator for Tampa (0/1)	-0.141	0.030	-4.75	0.00
Indicator for Walnut Valley (0/1)	0.059	0.026	2.23	0.03
Indicator for Waterloo/Cambridge (0/1)	-0.139	0.036	-3.87	0.00

Dependent variable:	Ln(Logged Total Daily Use in GPD)
Observations:	20551
Root Mean Square Error(RMSE):	0.589
Mean Square Error:	0.347
R-Square:	0.479

DEVELOPMENT OF INFERENTIAL MODELS

Estimation Procedure for Inferential Models

Multiple regression analysis was used to estimate each of eight end use models (see previous section for a discussion of the make-up of the classical multiple regression model). Each regression model was estimated using an estimated generalized least-squares (EGLS) procedure, which is a variant of Ordinary Least Squares (OLS). A *variance components* formulation is used, in which the model error term is assumed to be composed of two elements. One error component is unique to each household and another error component represents the classical error term (or white noise):

$$\varepsilon_{i,t} = \mu_i + \omega_{i,t} \qquad \text{(D.6)}$$

The term μ_i is the error associated with a particular household *i* (which varies cross-sectionally, but not in time), while the term $\omega_{,i,t}$ denotes the error that varies in time for every household. Under the assumptions that (1) μ is a random variable distributed normally (with mean α and variance σ_μ^2) and (2) μ_i and $\omega_{,i,t}$ are independent from one another, the one-way *random effects* model is born..[15] The random effects procedure was enacted using both SAS® (version 6.12) and LIMDEP (version 7.0) statistical software.

Model Specification and Selection

The specification of the individual end use models involved tests for nonlinearity and selection of appropriate functional forms. More specifically, the Box-Cox procedure was used to study appropriate transformations for water use and other continuous variables that were candidates for incorporation into the models.[16] Generally, the Box-Cox procedure suggested the

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[15] Note that a *two-way* random effects model can also be specified, which divides the error term into both household and time components. The error structure in the two-way model may be written as $\varepsilon^* = \mu_i + \nu_t + \omega_{it}$, where μ_i is the household variance component, ν_t is the time variance component, and ω_{it} is the classical error term associated with each observation. Estimation of two-way RE models was attempted for all models reported in this appendix. Only the outdoor use model displayed a substantial (i.e., non-zero) and non-negative time variance component.

[16] The Box-Cox procedure attempts to correct for nonnormal errors and other common model violations by selecting an exponent to transform the dependent variable, Y, so to maximize some measure of model fit (e.g., R-square). Computational details are available in general statistical reference books like Neter et al. (1996).

use of a natural logarithmic transformation of the left and right-hand side variables of the model that assumed or could assume continuous or integer values. However, because of problems with interpretation, certain ratios, namely those pertaining to the fraction of toilets and showers retrofitted to the low-flow variety, were left untransformed in the raw scale. Many binary (0/1) variables are also specified among the models in order to study differences in mean end usage between various groups of households and time periods. Therefore, the models were estimated in what can be termed log-partial-log form (see the first section of this appendix for the general mathematical form of a log-partial-log model). The coefficients of logarithmically transformed variables may be interpreted as elasticities, where elasticity measures the impact on water use of a one-percent change in the value of particular variable (everything else kept constant). Finally, because of the natural logarithmic transformation of water use, the estimated coefficients of the binary variables gives the median percentage difference in water use between particular the groups of households or time periods that are categorized by the binary variable (Chesnutt and McSpadden 1992). In order to translate the coefficient estimates into expected percent change, a small-scale correction must be made. An unbiased estimate of the expected percent change can be derived as:

$$e^{\beta - .5\sigma_\beta^2} - 1 \times 100 \qquad \text{(D.7)}$$

where β is the coefficient estimate of the binary variable, and σ_β is the standard error of the coefficient estimate (Chesnutt and McSpadden 1991). This correction is taken into account in the interpretation of the inferential models provided in the text of Chapter 6.

The tables below present the parameter estimates and related statistical output for the set of eight inferential end use models:

Table D.2: Toilet Water Use Model

Table D.3: Shower/Bath Water Use Model

Table D.4: Faucet Water Use Model

Table D.5: Dishwasher Water Use Model

Table D.6: Clothes Washer Water Use Model

Table D.7: Leak Water Use Model

Table D.8: Outdoor Water Use Model

Table D.9: Other/Unknown Water Use Model

Table D.2 Toilet water use model

Variable Definition	**Coefficient**	**Std. Error**	**T Statistic**	**P-Value**
Intercept	3.012	0.314	9.59	0.00
Ln(water marginal price[2nd block]+1)	-0.158	0.084	-1.88	0.06
Ln(household size)	0.699	0.055	12.74	0.00
Ln(number of children+1, ages 0-12)	-0.241	0.050	-4.80	0.00
Ln(number of teenagers+1, ages 13-17)	-0.115	0.059	-1.97	0.05
Ln(number of adults employed full time outside of home)	-0.180	0.039	-4.65	0.00
Ln(home living space(sf)), midpoints of intervals	0.068	0.042	1.62	0.11
Indicator that house was built before 1960 (0/1)	-0.054	0.037	-1.44	0.15
Indicator that house was built between 1990-present (0/1)	-0.098	0.061	-1.62	0.11
Household ultra-low-flush toilet ratio	-0.107	0.040	-2.69	0.01
Indicator that house has retrofitted all usable toilets (0/1)	-0.509	0.063	-8.09	0.00

Dependent variable:	Ln(logged toilet use in GPD)
Observations:	1530
Root Mean Square Error (RMSE):	0.342
Cross sectional (765 houses) variance component:	0.135
Model error variance component:	0.117
R-Square:	0.200

Table D.3 Shower and bath water use model

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	1.863	0.388	4.81	0.00
Ln(water marginal price[2nd block]+1)	-0.403	0.132	-3.05	0.00
Ln(household size)	0.498	0.083	5.97	0.00
Ln(number of children+1, ages 0-12)	0.154	0.074	2.07	0.04
Ln(number of teenagers+1, ages 13-17)	0.244	0.089	2.74	0.01
Ln(number of adults employed full time outside of home)	0.269	0.064	4.21	0.00
Ln(household income, midpoints of intervals)	0.111	0.037	2.96	0.00
Indicator of rented house (0/1)	0.212	0.096	2.21	0.03
Household ultra-low-flow showerhead ratio	-0.105	0.060	-1.74	0.08

Dependent variable:	Ln(logged shower/bath use in GPD)
Observations:	1158
Root Mean Square Error (RMSE):	0.506
Cross sectional (579 Houses) variance component:	0.221
Model error variance component:	0.256
R-Square:	0.208

Table D.4 Faucet water use model

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	2.144	0.498	4.30	0.00
Ln(water marginal price[2nd block]+1)	0.082	0.122	0.67	0.50
Ln(household size)	0.734	0.074	9.96	0.00
Ln(number of children+1, ages 0-12)	-0.210	0.070	-2.99	0.00
Ln(number of adults employed full time outside of home)	-0.262	0.058	-4.48	0.00
Ln(home living space(sf)), midpoints of intervals	0.078	0.070	1.11	0.27
Indicator of rented house (0/1)	-0.189	0.096	-1.97	0.05
Indicator of home water treatment system (0/1)	0.277	0.056	4.93	0.00
Household ultra-low-flow showerhead ratio	-0.073	0.058	-1.26	0.21
Indicator of dishwasher (0/1)	-0.109	0.067	-1.64	0.10

Dependent variable:	Ln(Logged Faucet/Treatment Use in GPD)
Observations:	906
Root Mean Square Error (RMSE):	0.473
Cross sectional (453 houses) variance component:	0.138
Model error variance component:	0.224
R-Square:	0.179

Table D.5 Dishwasher water use model

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	0.070	0.407	0.17	0.86
Ln(water marginal price [2nd block]+1)	-0.265	0.126	-2.10	0.04
Ln(household size)	0.250	0.057	4.42	0.00
Ln(number of adults employed full time outside of home)	-0.079	0.063	-1.26	0.21
Ln(household income, midpoints of intervals)	0.110	0.039	2.82	0.00
Indicator for indoor conserving behavior (e.g. using fuller loads) (0/1)	-0.069	0.061	-1.14	0.25

Dependent variable:	Ln(logged dishwasher use in GPD)
Observations:	1214
Root Mean Square Error(RMSE):	0.503
Cross sectional (607 houses) variance component:	0.227
Model error variance component:	0.253
R-Square:	0.031

Table D.6 Clothes washer water use model

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	2.021	0.469	4.31	0.00
Ln(water marginal price [2nd block]+1)	0.073	0.154	0.48	0.63
Ln(household size)	0.784	0.071	10.98	0.00
Ln(number of teenagers+1, ages 13-17)	0.131	0.098	1.34	0.18
Ln(number of adults employed full time outside of home)	0.113	0.075	1.52	0.13
Ln(household income, midpoints of intervals)	0.043	0.045	0.95	0.34

Dependent variable:	Ln(logged clothes washer use in GPD)
Observations:	1324
Root Mean Square Error(RMSE):	0.674
Cross sectional (662 houses) variance component:	0.331
Model error variance component:	0.455
R-Square:	0.152

Table D.7 Leak water use model

Variable Definition	**Coefficient**	**Std. Error**	**T Statistic**	**P-Value**
Intercept	1.143	0.934	1.22	0.22
Ln(water marginal price [2nd block]+1)	-0.451	0.208	-2.17	0.03
Ln(sewer marginal price+1)	-0.250	0.068	-3.66	0.00
Ln(household size)	0.337	0.081	4.17	0.00
Ln(home living space(sf)), midpoints of intervals	0.148	0.136	1.08	0.28
Indicator of rented house (0/1)	-0.250	0.150	-1.67	0.10
Indicator that house was built between 1970-1979 (0/1)	0.125	0.093	3.12	0.00
Number of toilets	0.071	0.061	1.15	0.25
Indicator of home water treatment system (0/1)	0.293	0.094	3.11	0.00
Indicator of dishwasher (0/1)	-0.320	0.107	-2.98	0.00
Indicator of evaporative/swamp cooler (0/1)	0.273	0.133	2.05	0.04
Indicator of swimming pool (0/1)	0.446	0.106	4.19	0.00
Indicator of drip irrigation system (0/1)	-0.195	0.109	-1.79	0.07
Indicator of hand-held garden hose (0/1)	-0.118	0.081	-1.46	0.14

Dependent variable:	Ln(logged leak use in GPD)
Observations:	1526
Root Mean Square Error (RMSE):	1.001
Cross sectional (763 houses) variance component:	0.579
Model error variance component:	1.006
R-Square:	0.077

Table D.8 Outdoor water use model

Variable Definition	**Coefficient**	**Std. Error**	**T Statistic**	**P-Value**
Intercept	-1.140	1.356	-0.84	0.40
Ln(water marginal price [2nd block]+1)	-0.818	0.125	-2.80	0.01
Ln(home living space (sf)), midpoints of intervals	0.566	0.153	3.68	0.00
Ln(home lotsize (sf)), midpoints of intervals	0.147	0.063	2.32	0.02
Percentage of lawn among landscape	0.003	0.002	1.73	0.08
Indicator of in-ground sprinkler system (0/1)	0.310	0.143	2.17	0.03
Indicator of automatic timer sprinkler (0/1)	0.394	0.141	2.79	0.01
Indicator of drip irrigation system (0/1)	0.158	0.128	1.23	0.22
Indicator of hand-held garden hose (0/1)	-0.400	0.109	-3.66	0.00
Indicator for flower and/or vegetable garden (0/1)	0.268	0.106	2.53	0.01
Indicator of swimming pool (0/1)	0.813	0.125	6.48	0.00
Indicator of additional water sources for outdoor use (e.g. well or canal) (0/1)	-0.271	0.206	-1.31	0.19

Dependent variable:	Ln(Logged Outdoor Use in GPD)
Observations:	894
Root Mean Square Error (RMSE):	1.450
Cross sectional (447 houses) variance component:	0.000
Time Series (logging periods) variance component:	1.322
Model error variance component:	2.116
R-Square:	0.215

Table D.9 Other/Unknown water use model

Variable Definition	**Coefficient**	**Std. Error**	**T Statistic**	**P-Value**
Intercept	0.819	0.437	1.87	0.06
Ln(logged outdoor use in GPD)	0.064	0.012	5.59	0.01
Ln(logged clothes washer use in GPD)	-0.110	0.035	-3.14	0.00
Ln(logged shower/bathtub use in GPD)	0.106	0.043	2.48	0.01
Ln(logged faucet/treatment use in GPD)	0.309	0.050	6.22	0.00
Ln(logged leak use in GPD)	0.047	0.020	2.31	0.02
Ln(household size)	0.142	0.067	2.14	0.03
Ln(household income, midpoints of intervals)	-0.095	0.040	-2.39	0.02
Indicator of hot-tub	0.208	0.093	2.25	0.02
Indicator of evaporative/swamp cooler	0.447	0.090	4.98	0.00

Dependent variable:	Ln(Logged Other Use in GPD)
Observations:	1052
Root Mean Square Error (RMSE):	0.776
Cross sectional (526 houses) variance component:	0.102
Model error variance component:	0.602
R-Square:	0.137

DEVELOPMENT OF PREDICTIVE SYSTEM OF END USE EQUATIONS

Estimation Approach

One distinguishing feature between the inferential end use models of Chapter 6 and the previous section of Appendix D and the predictive models presented below is that the predictive models contain fewer data inputs, which should make the end use models more conducive for application. The predictive models are in essence "reduced-form" versions of the inferential models. Another distinctive feature relates to the approach that was used to estimate the predictive models. Unlike the inferential models that were estimated one by one for the purpose of revealing (or inferring) relationships among the survey data and end usage, a systems approach was adopted for the predictive versions of the end use models.

While studying each individual end use model has its benefits, a systems approach takes advantage of the connections among end use models, since water use of each end use must sum to a total daily water use for a household. One such approach is seemingly unrelated regression (SUR), which extends OLS regression from one to multiple equations. SUR is intended to create more efficient estimates of model coefficients by comparing the errors between models for a given set of observations and then making appropriate adjustments. For example, errors in predicting toilet use may associated with errors in predicting faucet use, which may in turn, be associated with errors in predicting shower use. The SUR method estimates this type of correlation and uses the information to simultaneously adjust end use model estimates and increase the efficiency of the parameter estimates.

The Seemingly Unrelated Regression (SUR) Procedure

Seemingly Unrelated Regression (SUR) amounts to estimating a set of individual equations as one large equation (Kennedy, 1996). The simplest way to portray the SUR estimation process is to write the a system of equations in matrix form:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{bmatrix} = \begin{bmatrix} x_1 & 0 & \cdots & 0 \\ 0 & x_2 & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & \cdots & x_M \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_M \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_M \end{bmatrix} \qquad \text{D.8}$$

The terms of this matrix expression complement the discussion of the multiple regression model given earlier in this appendix. The terms x_m denote a data matrix of observations on the set of explanatory variables, X, that is contained in each individual equation, where x_M may vary among the individual equations. The β_M now reflect vectors of parameters that explain the relationship between the dependent and independent variables of each individual (end use) relationship. Similarly the ε_M are vectors of error terms that measure the difference between observed and predicted values of the dependent variables (y_M).

To account for correlation among the error terms in each equation, the SUR procedure first uses OLS regression to compute the residuals for each equation separately. These errors are then used to estimate the cross-equation covariance matrix. With this information, the procedure produces generalized least-squares (EGLS) estimates of the parameters (β) of each individual equation.[17]

Table D.10 - 18 below presents the SUR estimates for the system of end use models. Table D.10 describes the correlation among the end use models, while the remaining eight tables present estimation results for each model separately. The interpretation guidelines defined in the first two sections of this appendix apply uniformly.

Table D.10 Seemingly unrelated regression end use model – cross model correlation between end uses

End Use Models	Toilet	Faucet	Shower	Dish-washer	Clothes-washer	Leaks	Outdoor	Other
Toilet	1.00	0.51	0.47	0.30	0.47	0.11	0.09	0.02
Faucet/Treatment	0.51	1.00	0.39	0.26	0.41	0.18	0.08	0.00
Shower/Bath	0.47	0.39	1.00	0.30	0.48	0.03	0.09	0.00
Dishwasher	0.30	0.26	0.30	1.00	0.32	-0.03	0.05	0.01
Clothes washer	0.47	0.41	0.48	0.32	1.00	0.07	0.08	0.00
Leaks	0.11	0.18	0.03	-0.03	0.07	1.00	0.01	0.00
Outdoor	0.09	0.08	0.09	0.05	0.08	0.01	1.00	0.00
Other/Unknown	0.02	0.00	0.00	0.01	0.00	0.00	0.00	1.00

SUR Model Observations:	System Weighted R-Square:	System Weighted MSE:
894	0.141	0.999

[17] See Kmenta (1986) for a mathematical exposition on the SUR procedure.

Table D.11 Seemingly unrelated regression end use model – dependent variable: Ln (logged toilet use in gallons per day)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	2.673	0.328	8.15	0.00
Ln(water marginal price [2nd block]+1)	-0.225	0.084	-2.69	0.01
Ln(household size)	0.509	0.040	12.84	0.00
Ln(home living space(sf)), midpoints of intervals	0.117	0.044	2.66	0.01
Indicator that house was built before 1960 (0/1)	-0.091	0.035	-2.62	0.01
Indicator house was built from 1990-present (0/1)	-0.164	0.051	-3.20	0.00
Household ultra-low-flush toilet ratio	-0.076	0.038	-2.02	0.04
Indicator house has retrofitted all usable toilets (0/1)	-0.539	0.058	-9.33	0.00

Table D.12 Seemingly unrelated regression end use model – dependent variable: Ln(logged faucet/treatment use in gallons per day)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	2.076	0.377	5.51	0.00
Ln(household size)	0.498	0.043	11.45	0.00
Ln(home living space(sf)), midpoints of intervals	0.077	0.050	1.54	0.12
Indicator of rented house (0/1)	-0.254	0.083	-3.05	0.00
Indicator of home water treatment system (0/1)	0.238	0.040	5.93	0.00

Table D.13 Seemingly unrelated regression end use model – dependent variable: Ln(logged shower/bath use in gallons per day)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	1.179	0.367	3.21	0.00
Ln(water marginal price [2nd block]+1)	-0.514	0.120	-4.27	0.00
Ln(household size)	0.885	0.056	15.91	0.00
Ln(household income, midpoints of intervals)	0.171	0.034	4.95	0.00
Indicator of rented house (0/1)	0.349	0.101	3.44	0.00
Household ultra-low-flow showerhead ratio	-0.116	0.052	-2.23	0.03

Table D.14 Seemingly unrelated regression end use model – dependent variable: Ln(logged dishwasher use in gallons per day)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	-0.894	0.367	-2.44	0.02
Ln(water marginal price [2nd block]+1)	-0.517	0.124	-4.15	0.00
Ln(household size)	0.345	0.052	6.62	0.00
Ln(household income, midpoints of intervals)	0.193	0.035	5.54	0.00

Table D.15 Seemingly unrelated regression end use model – dependent variable: Ln(logged clothes washer use in gallons per day)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	0.830	0.416	2.00	0.05
Ln(household size)	0.852	0.063	13.48	0.00
Ln(household income, midpoints of intervals)	0.162	0.039	4.19	0.00

Table D.16 Seemingly unrelated regression end use model – dependent variable: Ln(logged leak use in gallons per day)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	0.378	0.876	0.43	0.67
Ln(water marginal price [2nd block]+1)	-0.485	0.225	-2.16	0.03
Ln(sewer marginal price+1)	-0.160	0.071	-2.25	0.02
Ln(household size)	0.392	0.088	4.43	0.00
Ln(home living space(sf)), midpoints of intervals	0.217	0.118	1.84	0.07
Indicator of rented house (0/1)	-0.264	0.198	-1.33	0.18
Indicator of swimming pool (0/1)	0.712	0.107	6.63	0.00

Table D.17 Seemingly unrelated regression end use model – dependent variable: Ln(logged outdoor use in gallons per day)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	-3.087	1.521	-2.03	0.04
Ln(water marginal price [2nd block]+1)	-0.887	0.386	-2.30	0.02
Ln(home living space(sf)), midpoints of intervals	0.634	0.220	2.88	0.00
Ln(home lotsize (sf)), midpoints of intervals	0.237	0.093	2.55	0.01
Indicator of in-ground sprinkler system (0/1)	1.116	0.151	7.37	0.00
Indicator of swimming pool (0/1)	1.039	0.190	5.47	0.00

Table D.18 Seemingly unrelated regression end use model – dependent variable: Ln(logged other/unknown use in gallons per day)

Variable Definition	**Coefficient**	**Std. Error**	**T Statistic**	**P-Value**
Intercept	0.024	0.477	0.05	0.96
Ln(logged shower/bath use in GPD)	0.117	0.042	2.77	0.01
Ln(logged faucet/treatment use in GPD)	0.253	0.052	4.90	0.00
Ln(logged clothes washer use in GPD)	-0.054	0.038	-1.43	0.15
Ln(logged leak use in GPD)	0.083	0.013	6.62	0.00
Ln(logged outdoor use in GPD)	0.086	0.023	3.78	0.00
Ln(household size)	0.162	0.071	2.28	0.02
Ln(household income, midpoints of intervals)	-0.058	0.044	-1.32	0.19
Indicator of hot-tub (0/1)	0.507	0.101	5.01	0.00
Indicator of evaporative/swamp cooler (0/1)	0.263	0.098	2.68	0.01

EXTENDING END USE MODELS TO PREDICT TOTAL MONTHLY USE

Estimation Process and Results

In order to adjust the system of predictive end use models for the effects of weather and time of year, water use billing data and weather data were combined with predictions from the SUR models of the previous section to develop a model that is capable of producing better estimates of total average daily water use in any given monthly/bimonthly billing period. In this context, predictions from the end use models were arrayed with billing period water use and weather conditions to estimate the model. The model was estimated using Ordinary Least Squares regression in log-partial-log form, using 4,559 observations on billing data for the logging sample. Because the process broadens the use of the SUR predictions to billing data, the model is termed the "extended" model for predicting billing period use. The model provides estimates of average total single family household water in any given billing period and location in terms of gallons per day (gpd).

The parameter estimates of the extended model are presented in Table D.18. As shown, binary variables are included to indicate the month of the billing period, so that the model accounts for systematic seasonal variations related to normal weather conditions. Predictions obtained from the system of end use models are incorporated in natural-logarithmic form. The predictions for dishwashing, clothes washing, and outdoor use are *interacted* with binary (0/1) variables denoting the presence of these end uses in any home (e.g., the outdoor coefficient is set to 0 in the log scale if a particular household does not irrigate).[18] Though, technically, the coefficients for these variables can be interpreted as elasticities, no real interpretation should be assigned to their meaning, perhaps aside from the fact that these parameters adjust the predictive inputs in a way as to explain total average use.

Because different parts of the North American continent have different normal climate characteristics, one may expect different seasonal patterns of outdoor water use depending on location. Therefore, the model contains terms relating total average use to three-way interactions of month, location, and the outdoor water use prediction from the SUR model. Given that the

[18] An interaction term reflects a product of two or more variables. For example, one interaction in the model of Table D.18 represents the product of a binary (0/1) variable indicating the presence of a dishwasher with the prediction for dishwashing use obtained from the SUR model of the previous section. The coefficient of this

billing month indicators serve to account for systematic fluctuations in use related to normal climate, weather variables are introduced into the model in departure from normal form. Specifically, the weather variables are formulated as:

$$Maximum\ Temperature\ Departure = \ln(Max\ Temp)_m - \ln(\overline{Max\ Temp})_m \qquad \text{(D.9)}$$

$$Precipitation\ Departure = \ln(Precip + 1)_m - \ln(\overline{Precip} + 1)_m \qquad \text{(D.10)}$$

where the bar over the second term on the right-hand side of each equation denotes the long-term average. To calculate these departures, daily observations on maximum temperature and precipitation were processed to match the exact billing periods for all water use observations in the sample. Long-term normal monthly values were obtained from various weather sources, and the monthly values were weighted to reflect the billing periods as precisely as possible. As shown in Table D.18, lagged values of the weather departures are specified to capture remnant variations in water use attributable to the billing cycle, as well as actual effects from past weather conditions (a.k.a. short-term memory in water use). The weather variables are interacted with the indicator for outdoor use, so that weather is assigned exclusively with the outdoor component of the model.

Developing Estimates of Total Average Water Use

The estimated model of Table D.18 may be expressed in generalized form as:

$$q_M = e^{(3.004+\beta_M)} \cdot \hat{T}^{0.372} \cdot \hat{S}^{0.012} \cdot \hat{F}^{0.124} \cdot \hat{D}^{0.066(DW)} \cdot \hat{C}^{-0.020(CW)} \cdot \hat{L}^{0.085} \cdot \hat{U}^{0.006} \cdot \hat{O}^{(\beta_{L,M})OUT} \cdot e^{(0.919(TD)+1.108(TD1)+1.026(TD2)-0.140(PD)-0.011(PD1))OUT} \qquad \text{(D.11)}$$

where q_m = average daily household water use in billing month M (expressed in gallons per day)

e = the base of the natural logarithm (approximately = 2.718282)

$\hat{T}$ = prediction of toilet use from SUR (predictive system) model

$\hat{S}$ = prediction of shower/bath use from SUR (predictive system) model

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interaction term measures the relationship (or slope) between the dishwashing prediction and total average water use, if a household has a dishwasher.

$\hat{F}$ = prediction of faucet/treatment use from SUR (predictive system) model

$\hat{D}$ = prediction of dishwasher use from SUR (predictive system) model

$\hat{C}$ = prediction of clothes washer use from SUR (predictive system) model

$\hat{L}$ = prediction of leaks from SUR (predictive system) model

$\hat{U}$ = prediction of other/unknown use from SUR (predictive system) model

$\hat{O}$ = prediction of outdoor use from SUR (predictive system) model

DW = binary (0/1) variable denoting the presence of a dishwasher

CW = binary (0/1) variable denoting the presence of a clothes washer

OUT = binary (0/1) variable denoting the presence of a outdoor use

TD = maximum temperature departure (see equation D.9)

TD1 = 1 billing period lag of temperature departure

TD2 = 2 billing period lag of temperature departure

PD = precipitation departure (see equation D.9)

PD1 = 1 billing period lag of precipitation departure

β_M = adjustment for billing month

$\beta_{M,L}$ = adjustment for billing month and location (outdoor component only)

To use derive estimates of total average daily water use using equation D.11, one must gather the necessary model input data. Because the extended model relies on inputs from the system of end use models, this requires first that the user derive end use predictions from the system of equations presented in the previous section of Appendix D. Therefore, values for explanatory variables contained in the predictive system are required. Values for the weather departure variables are also required. The necessary values for the parameters β_M and $\beta_{M,L}$ are found in Table D.19, which provides a handy means of looking-up values for month and location. To develop estimates for average total use for any particular month and location follow the four steps below:

Step 1: Obtain/Derive Inputs for System of Predictive End Use Model

As highlighted in Chapter 6, the system of predictive models require certain data inputs related to the explanatory variables. These data should be obtained from certain secondary sources or derived through appropriate assumptions.

Step 2: Substitute Inputs into Predictive System and Obtain Predictions

As shown in the example in Chapter 6, the substitution of data for explanatory variables into the predictive system results in water use predictions at the end use level.

Step 3: Look-up Appropriate Extended Model Parameters from Table D.19

The extended model is dependent on location and time of year. Use the look-up table of Table D.19 to tailor the model for your location and the month of interest. (If your location is not listed, use the default parameters for starters and then try parameters for other locations following Step 4 if they seem to portray your service area more appropriately.)

Step 4: Substitute Predictions of End Usage into Equation D.3

To develop an estimate of average total water use for the month and location defined in Step 3, substitute the end use predictions into Equation D.11. The resultant prediction will be in terms of gallons per day.

Example Application of End Use Model

To illustrate the use of the extended model and the look-up table, consider that you are interested in predicting total average use in Denver for the month of October. Suppose you have the following information, some of which has been derived from the application of the system of end use models from the previous section of Appendix D.

Location: Denver
Month of interest: October
Unit: Single-family home
Prediction for toilet use: 40 gallons per day
Prediction for shower use: 25 gallons per day
Prediction for faucet use: 25 gallons per day
Prediction for dishwasher use: 2.8 gallons per day
Prediction for clothes washer use: 27 gallons per day
Prediction for leaks: 5 gallons per day
Prediction for other/unknown use: 3 gallons per day
Prediction for outdoor use: 40 gallons per day

Fraction of households with dishwashers (DW): 0.75

Fraction of households with clothes washers (CW): 0.85

Fraction of households that have a pool or practice irrigation (OUT): 0.90

Temperature departure: 0.75

Lag 1 temperature departure: 0

Lag 2 temperature departure: 0

Precipitation departure: 0

Lag 1 precipitation departure: 1

Substitution of this information into equation D.11 yields an estimate of average use in Denver for October:

$$q_{october} = e^{(3.004-0.162)} \cdot 40^{0.372} \cdot 25^{0.012} \cdot 25^{0.124} \cdot 2^{0.066(0.75)} \cdot 27^{-0.020(0.85)} \cdot 5^{0.085} \cdot 3^{0.006} \cdot 40^{(0.208)0.90} \cdot e^{(0.919(0.75)+1.108(0)+1.026(0)-0.140(0)-0.011(1.0))0.90}$$

$$= 378 \; gallons \; per \; day$$

Developing Predictions of Indoor and Outdoor Use

Equation D.11 may be used to develop estimates of indoor and outdoor use. Assuming that no outdoor use is present (i.e., OUT=0 in the equation), equation D.11 collapses to the following and may be taken as a model of indoor use:

$$q_{m,indoor} = e^{(3.004+\beta_m)} \cdot \hat{T}^{0.372} \cdot \hat{S}^{0.012} \cdot \hat{F}^{0.124} \cdot \hat{D}^{0.066(DW)} \cdot \hat{C}^{-0.020(CW)} \cdot \hat{L}^{0.085} \cdot \hat{U}^{0.006} \qquad \text{(D.12)}$$

An estimate of outdoor use is obtained by subtracting the indoor use estimate from the estimate of total average use:

$$q_{m,outdoor} = q_m - q_{m,indoor} \qquad \text{(D.13)}$$

Applying this procedure to the example above, one obtains estimates of indoor and outdoor use for Denver in the month of October:

$$q_{october,indoor} = e^{(3.004-0.162)} \cdot 40^{0.372} \cdot 25^{0.012} \cdot 25^{0.124} \cdot 2^{0.066(0.75)} \cdot 27^{-0.020(0.85)} \cdot 5^{0.085} \cdot 3^{0.006}$$

$$= 103 \; gallons \; per \; day$$

$$q_{october,outdoor} = 378 - 103$$

$$= 275 \; gallons \; per \; day$$

Table D.19 Adjusted billing model of household water use

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Intercept	3.004	0.183	16.43	0.00
Indicator of January billing period	-0.170	0.161	-1.06	0.29
Indicator of February billing period	-0.177	0.161	-1.10	0.27
Indicator of March billing period	-0.211	0.153	-1.38	0.17
Indicator of April billing period	-0.031	0.162	-0.19	0.85
Indicator of May billing period	-0.160	0.154	-1.04	0.30
Indicator of June billing period	0.106	0.163	0.65	0.51
Indicator of July billing period	0.108	0.157	0.68	0.49
Indicator of August billing period	0.166	0.159	1.04	0.30
Indicator of September billing period	-0.108	0.158	-0.68	0.50
Indicator of October billing period	-0.162	0.162	-1.00	0.32
Indicator of November billing period	-0.156	0.160	-0.98	0.33
Ln(SUR toilet end use prediction)	0.372	0.046	8.11	0.00
Ln(SUR shower/bath end use prediction)	0.012	0.040	0.31	0.75
Ln(SUR faucet/treatment end use prediction)	0.124	0.066	1.89	0.06
Ln(SUR dishwasher end use prediction (only if end use presence exists)	0.066	0.024	2.69	0.01
Ln(SUR clothes washer end use prediction (only if end use presence exists)	-0.020	0.012	-1.74	0.08
Ln(SUR leaks end use prediction)	0.085	0.041	2.10	0.04
Ln(SUR other (cooler, hot-tub, humidifier, unknown) end use prediction)	0.206	0.047	4.40	0.00
Ln(SUR outdoor (irrigation/pool) end use prediction (if any end use presence exist)	0.144	0.039	3.66	0.00
Interaction of outdoor prediction and January indicator	0.006	0.055	0.11	0.91
Interaction of outdoor prediction and February indicator	0.026	0.057	0.45	0.66
Interaction of outdoor prediction and March indicator	0.022	0.054	0.40	0.69
Interaction of outdoor prediction and April indicator	0.045	0.058	0.79	0.43
Interaction of outdoor prediction and May indicator	0.146	0.055	2.66	0.01
Interaction of outdoor prediction and June indicator	0.054	0.057	0.95	0.34
Interaction of outdoor prediction and July indicator	0.109	0.055	1.99	0.05
Interaction of outdoor prediction and August indicator	0.084	0.055	1.53	0.13
Interaction of outdoor prediction and September indicator	0.106	0.055	1.93	0.05
Interaction of outdoor prediction and October indicator	0.114	0.055	2.06	0.04
Interaction of outdoor prediction and November indicator	0.033	0.054	0.60	0.55
Interaction of outdoor prediction and Boulder indicator	-0.099	0.035	-2.80	0.01
Interactions of outdoor prediction and January/Boulder indicators	0.013	0.048	0.27	0.79
Interactions of outdoor prediction and February/Boulder indicators	-0.002	0.054	-0.04	0.97
Interactions of outdoor prediction and March/Boulder indicators	-0.072	0.049	-1.49	0.14

(continued)

Table D.19 (Continued)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Interactions of outdoor prediction and April/Boulder indicators	-0.030	0.053	-0.57	0.57
Interactions of outdoor prediction and May/Boulder indicators	-0.042	0.049	-0.85	0.40
Interactions of outdoor prediction and June/Boulder indicators	0.090	0.048	1.88	0.06
Interactions of outdoor prediction and July/Boulder indicators	0.134	0.050	2.66	0.01
Interactions of outdoor prediction and August/Boulder indicators	0.160	0.050	3.19	0.00
Interactions of outdoor prediction and September/Boulder indicators	0.154	0.046	3.32	0.00
Interactions of outdoor prediction and October/Boulder indicators	0.062	0.049	1.27	0.20
Interactions of outdoor prediction and November/Boulder indicators	0.050	0.050	1.01	0.31
Interaction of outdoor prediction and Eugene indicator	-0.157	0.034	-4.61	0.00
Interactions of outdoor prediction and January/Eugene indicators	0.027	0.047	0.57	0.57
Interactions of outdoor prediction and February/Eugene indicators	-0.074	0.049	-1.50	0.13
Interactions of outdoor prediction and March/Eugene indicators	-0.029	0.050	-0.59	0.56
Interactions of outdoor prediction and April/Eugene indicators	-0.050	0.054	-0.92	0.36
Interactions of outdoor prediction and May/Eugene indicators	0.003	0.052	0.07	0.95
Interactions of outdoor prediction and June/Eugene indicators	0.103	0.048	2.13	0.03
Interactions of outdoor prediction and July/Eugene indicators	0.119	0.048	2.47	0.01
Interactions of outdoor prediction and August/Eugene indicators	0.096	0.049	1.99	0.05
Interactions of outdoor prediction and September/Eugene indicators	0.076	0.048	1.59	0.11
Interactions of outdoor prediction and October/Eugene indicators	0.001	0.048	0.01	0.99
Interactions of outdoor prediction and November/Eugene indicators	-0.006	0.048	-0.12	0.90
Interaction of outdoor prediction and Seattle indicator	-0.044	0.046	-0.95	0.34
Interactions of outdoor prediction and January/Seattle indicators	-0.015	0.065	-0.23	0.82
Interactions of outdoor prediction and February/Seattle indicators	0.009	0.064	0.13	0.89
Interactions of outdoor prediction and March/Seattle indicators	0.061	0.065	0.93	0.35
Interactions of outdoor prediction and April/Seattle indicators	-0.037	0.062	-0.60	0.55
Interactions of outdoor prediction and May/Seattle indicators	0.033	0.067	0.49	0.62
Interactions of outdoor prediction and June/Seattle indicators	0.059	0.064	0.91	0.36
Interactions of outdoor prediction and July/Seattle indicators	0.108	0.066	1.63	0.10
Interactions of outdoor prediction and August/Seattle indicators	-0.008	0.064	-0.13	0.90
Interactions of outdoor prediction and September/Seattle indicators	0.040	0.066	0.61	0.54
Interactions of outdoor prediction and October/Seattle indicators	-0.073	0.062	-1.18	0.24
Interactions of outdoor prediction and November/Seattle indicators	0.016	0.065	0.24	0.81
Interaction of outdoor prediction and Tampa indicator	0.011	0.046	0.24	0.81
Interactions of outdoor prediction and January/Tampa indicators	0.015	0.063	0.24	0.81
Interactions of outdoor prediction and February/Tampa indicators	0.009	0.067	0.13	0.90
Interactions of outdoor prediction and March/Tampa indicators	0.048	0.059	0.81	0.42
Interactions of outdoor prediction and April/Tampa indicators	-0.086	0.062	-1.38	0.17
Interactions of outdoor prediction and May/Tampa indicators	-0.081	0.062	-1.30	0.19
Interactions of outdoor prediction and June/Tampa indicators	-0.128	0.064	-1.98	0.05
Interactions of outdoor prediction and July/Tampa indicators	-0.208	0.064	-3.23	0.00
Interactions of outdoor prediction and August/Tampa indicators	-0.226	0.070	-3.22	0.00
Interactions of outdoor prediction and September/Tampa indicators	-0.154	0.063	-2.43	0.02
Interactions of outdoor prediction and October/Tampa indicators	-0.165	0.068	-2.45	0.01
Interactions of outdoor prediction and November/Tampa indicators	-0.010	0.063	-0.15	0.88
Interaction of outdoor prediction and San Diego indicator	0.006	0.038	0.16	0.87
Interactions of outdoor prediction and January/San Diego indicators	0.010	0.054	0.19	0.85
Interactions of outdoor prediction and February/San Diego indicators	-0.016	0.055	-0.30	0.77
Interactions of outdoor prediction and March/San Diego indicators	0.052	0.054	0.95	0.34

(continued)

Table D.19 (Continued)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Interactions of outdoor prediction and April/San Diego indicators	0.036	0.060	0.59	0.55
Interactions of outdoor prediction and May/San Diego indicators	-0.037	0.058	-0.64	0.53
Interactions of outdoor prediction and June/San Diego indicators	0.053	0.059	0.89	0.37
Interactions of outdoor prediction and July/San Diego indicators	-0.006	0.057	-0.11	0.92
Interactions of outdoor prediction and August/San Diego indicators	0.004	0.055	0.08	0.94
Interactions of outdoor prediction and September/San Diego indicators	0.049	0.055	0.88	0.38
Interactions of outdoor prediction and October/San Diego indicators	-0.065	0.054	-1.20	0.23
Interactions of outdoor prediction and November/San Diego indicators	0.031	0.053	0.58	0.56
Interaction of outdoor prediction and Phoenix indicator	-0.005	0.032	-0.16	0.87
Interactions of outdoor prediction and January/Phoenix indicators	0.009	0.044	0.21	0.84
Interactions of outdoor prediction and February/Phoenix indicators	-0.007	0.047	-0.15	0.88
Interactions of outdoor prediction and March/Phoenix indicators	0.050	0.046	1.10	0.27
Interactions of outdoor prediction and April/Phoenix indicators	0.070	0.047	1.48	0.14
Interactions of outdoor prediction and May/Phoenix indicators	0.050	0.046	1.09	0.28
Interactions of outdoor prediction and June/Phoenix indicators	0.103	0.046	2.22	0.03
Interactions of outdoor prediction and July/Phoenix indicators	0.053	0.047	1.12	0.26
Interactions of outdoor prediction and August/Phoenix indicators	0.048	0.045	1.06	0.29
Interactions of outdoor prediction and September/Phoenix indicators	0.030	0.046	0.65	0.52
Interactions of outdoor prediction and October/Phoenix indicators	0.004	0.045	0.10	0.92
Interactions of outdoor prediction and November/Phoenix indicators	0.053	0.044	1.20	0.23
Interaction of outdoor prediction and Scottsdale/Tempe indicator	-0.012	0.034	-0.37	0.71
Interactions of outdoor prediction and January/(Scottsdale/Tempe) indicators	0.015	0.045	0.33	0.74
Interactions of outdoor prediction and February/(Scottsdale/Tempe) indicators	-0.031	0.049	-0.63	0.53
Interactions of outdoor prediction and March/(Scottsdale/Tempe) indicators	0.019	0.047	0.41	0.68
Interactions of outdoor prediction and April/(Scottsdale/Tempe) indicators	0.055	0.048	1.15	0.25
Interactions of outdoor prediction and May/(Scottsdale/Tempe) indicators	-0.005	0.046	-0.11	0.91
Interactions of outdoor prediction and June/(Scottsdale/Tempe) indicators	0.016	0.046	0.35	0.73
Interactions of outdoor prediction and July/(Scottsdale/Tempe) indicators	-0.033	0.046	-0.71	0.48
Interactions of outdoor prediction and August/(Scottsdale/Tempe) indicators	-0.075	0.046	-1.63	0.10
Interactions of outdoor prediction and September/(Scottsdale/Tempe) indicators	-0.067	0.046	-1.46	0.14
Interactions of outdoor prediction and October/(Scottsdale/Tempe) indicators	-0.071	0.045	-1.59	0.11
Interactions of outdoor prediction and November/(Scottsdale/Tempe) indicators	0.010	0.044	0.23	0.82
Interaction of outdoor prediction and Las Virgenes indicator	0.011	0.031	0.35	0.73
Interactions of outdoor prediction and January/Las Virgenes indicators	-0.034	0.050	-0.69	0.49
Interactions of outdoor prediction and February/Las Virgenes indicators	-0.040	0.048	-0.84	0.40
Interactions of outdoor prediction and March/Las Virgenes indicators	0.045	0.049	0.91	0.36
Interactions of outdoor prediction and April/Las Virgenes indicators	0.055	0.049	1.13	0.26
Interactions of outdoor prediction and May/Las Virgenes indicators	0.032	0.048	0.66	0.51
Interactions of outdoor prediction and June/Las Virgenes indicators	0.089	0.046	1.94	0.05

(continued)

Table D.19 (Continued)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Interactions of outdoor prediction and July/Las Virgenes indicators	0.016	0.048	0.33	0.74
Interactions of outdoor prediction and August/Las Virgenes indicators	0.036	0.045	0.80	0.43
Interactions of outdoor prediction and September/Las Virgenes indicators	0.011	0.052	0.21	0.84
Interactions of outdoor prediction and October/Las Virgenes indicators	0.029	0.046	0.63	0.53
Interactions of outdoor prediction and November/Las Virgenes indicators	0.021	0.047	0.44	0.66
Interaction of outdoor prediction and (Waterloo/Cambridge) indicator	-0.145	0.046	-3.12	0.00
Interactions of outdoor prediction and January/(Waterloo/Cambridge) indicators	0.129	0.066	1.94	0.05
Interactions of outdoor prediction and February/(Waterloo/Cambridge) indicators	0.063	0.067	0.94	0.35
Interactions of outdoor prediction and March/(Waterloo/Cambridge) indicators	0.149	0.068	2.17	0.03
Interactions of outdoor prediction and April/(Waterloo/Cambridge) indicators	0.064	0.070	0.90	0.37
Interactions of outdoor prediction and May/(Waterloo/Cambridge) indicators	0.000	0.070	0.00	1.00
Interactions of outdoor prediction and June/(Waterloo/Cambridge) indicators	0.014	0.071	0.20	0.84
Interactions of outdoor prediction and July/(Waterloo/Cambridge) indicators	-0.033	0.070	-0.48	0.63
Interactions of outdoor prediction and August/(Waterloo/Cambridge) indicators	-0.062	0.068	-0.92	0.36
Interactions of outdoor prediction and September/(Waterloo/Cambridge) indicators	-0.048	0.069	-0.69	0.49
Interactions of outdoor prediction and October/(Waterloo/Cambridge) indicators	-0.053	0.067	-0.79	0.43
Interactions of outdoor prediction and November/(Waterloo/Cambridge) indicators	0.058	0.064	0.90	0.37
Interaction of outdoor prediction and Walnut Valley indicator	-0.031	0.038	-0.81	0.42
Interactions of outdoor prediction and January/Walnut Valley indicators	0.001	0.064	0.02	0.98
Interactions of outdoor prediction and February/Walnut Valley indicators	0.011	0.055	0.20	0.84
Interactions of outdoor prediction and March/Walnut Valley indicators	0.085	0.065	1.30	0.19
Interactions of outdoor prediction and April/Walnut Valley indicators	0.073	0.054	1.36	0.17
Interactions of outdoor prediction and May/Walnut Valley indicators	0.008	0.064	0.13	0.89
Interactions of outdoor prediction and June/Walnut Valley indicators	0.059	0.055	1.07	0.28
Interactions of outdoor prediction and July/Walnut Valley indicators	0.016	0.064	0.25	0.80
Interactions of outdoor prediction and August/Walnut Valley indicators	0.000	0.053	0.01	1.00
Interactions of outdoor prediction and September/Walnut Valley indicators	0.015	0.064	0.23	0.82
Interactions of outdoor prediction and October/Walnut Valley indicators	0.001	0.053	0.02	0.98
Interactions of outdoor prediction and November/Walnut Valley indicators	0.019	0.067	0.28	0.78
Interaction of outdoor prediction and Denver indicator	-0.138	0.055	-2.53	0.01
Interactions of outdoor prediction and January/Denver indicators	0.041	0.067	0.61	0.54
Interactions of outdoor prediction and February/Denver indicators	-0.043	0.070	-0.61	0.54
Interactions of outdoor prediction and March/Denver indicators	0.061	0.067	0.91	0.36

(continued)

Table D.19 (Continued)

Variable Definition	Coefficient	Std. Error	T Statistic	P-Value
Interactions of outdoor prediction and April/Denver indicators	0.198	0.072	2.76	0.01
Interactions of outdoor prediction and May/Denver indicators	0.199	0.068	2.92	0.00
Interactions of outdoor prediction and June/Denver indicators	0.270	0.071	3.82	0.00
Interactions of outdoor prediction and July/Denver indicators	0.167	0.066	2.52	0.01
Interactions of outdoor prediction and August/Denver indicators	0.137	0.072	1.91	0.06
Interactions of outdoor prediction and September/Denver indicators	0.090	0.066	1.36	0.17
Interactions of outdoor prediction and October/Denver indicators	-0.049	0.085	-0.58	0.56
Interactions of outdoor prediction and November/Denver indicators	-0.054	0.065	-0.83	0.40
Interaction of outdoor presence and max temperature departure	0.919	0.392	2.35	0.02
Interaction of outdoor presence and one lag of max temperature departure	1.108	0.420	2.64	0.01
Interaction of outdoor presence and two lags of max temperature departure	1.026	0.461	2.23	0.03
Interaction of outdoor presence and rainfall departure	-0.140	0.043	-3.28	0.00
Interaction of outdoor presence and one period lag of rainfall departure	-0.011	0.043	-0.26	0.80

Dependent variable:	Ln(logged total daily use in GPD)
Dependent variable mean:	5.825
Observations:	4599
Mean square error:	0.314
R-square:	0.537

Table D.20 Adjusted billing Table D.20 (Continued) model look-up table

	Site Specifics				Site Specifics		
Location (L)	**Month (M)**	β_L	$\beta_{L,M}$	**Location (L)**	**Month (M)**	β_L	$\beta_{L,M}$
Lompoc (and also default parameter values)	January	-0.170	0.150	**San Diego**	January	-0.170	0.160
	February	-0.177	0.169		February	-0.177	0.153
	March	-0.211	0.166		March	-0.211	0.217
	April	-0.031	0.189		April	-0.031	0.225
	May	-0.160	0.290		May	-0.160	0.253
	June	0.106	0.198		June	0.106	0.251
	July	0.108	0.253		July	0.108	0.247
	August	0.166	0.228		August	0.166	0.232
	September	-0.108	0.250		September	-0.108	0.299
	October	-0.162	0.258		October	-0.162	0.193
	November	-0.156	0.176		November	-0.156	0.207
	December	0.000	0.144		December	0.000	0.150
Boulder	January	-0.170	0.163	**Scottsdale**	January	-0.170	0.165
	February	-0.177	0.167		February	-0.177	0.139
	March	-0.211	0.093		March	-0.211	0.185
	April	-0.031	0.159		April	-0.031	0.244
	May	-0.160	0.248		May	-0.160	0.285
	June	0.106	0.287		June	0.106	0.214
	July	0.108	0.387		July	0.108	0.220
	August	0.166	0.387		August	0.166	0.153
	September	-0.108	0.404		September	-0.108	0.183
	October	-0.162	0.320		October	-0.162	0.187
	November	-0.156	0.227		November	-0.156	0.187
	December	0.000	0.045		December	0.000	0.131
Denver	January	-0.170	0.191	**Seattle**	January	-0.170	0.135
	February	-0.177	0.126		February	-0.177	0.178
	March	-0.211	0.227		March	-0.211	0.226
	April	-0.031	0.387		April	-0.031	0.152
	May	-0.160	0.489		May	-0.160	0.323
	June	0.106	0.468		June	0.106	0.256
	July	0.108	0.419		July	0.108	0.361
	August	0.166	0.365		August	0.166	0.219
	September	-0.108	0.340		September	-0.108	0.291
	October	-0.162	0.208		October	-0.162	0.185
	November	-0.156	0.122		November	-0.156	0.192
	December	0.000	0.006		December	0.000	0.100
Eugene	January	-0.170	0.177	**Tampa**	January	-0.170	0.165
	February	-0.177	0.095		February	-0.177	0.178
	March	-0.211	0.136		March	-0.211	0.213
	April	-0.031	0.139		April	-0.031	0.104
	May	-0.160	0.294		May	-0.160	0.209

(continued)

Location (L)	Site Specifics Month (M)	β_L	$\beta_{L,M}$	Location (L)	Site Specifics Month (M)	β_L	$\beta_{L,M}$
	June	0.106	0.300		June	0.106	0.070
	July	0.108	0.372		July	0.108	0.045
	August	0.166	0.324		August	0.166	0.001
	September	-0.108	0.327		September	-0.108	0.096
	October	-0.162	0.259		October	-0.162	0.092
	November	-0.156	0.170		November	-0.156	0.167
	December	0.000	-0.014		December	0.000	0.155
Las Virgenes	January	-0.170	0.116	**Walnut Valley**	January	-0.170	0.151
	February	-0.177	0.129		February	-0.177	0.181
	March	-0.211	0.210		March	-0.211	0.250
	April	-0.031	0.244		April	-0.031	0.262
	May	-0.160	0.322		May	-0.160	0.299
	June	0.106	0.287		June	0.106	0.257
	July	0.108	0.268		July	0.108	0.269
	August	0.166	0.263		August	0.166	0.228
	September	-0.108	0.261		September	-0.108	0.265
	October	-0.162	0.287		October	-0.162	0.259
	November	-0.156	0.197		November	-0.156	0.195
	December	0.000	0.155		December	0.000	0.113
Phoenix	January	-0.170	0.159	**Waterloo**	January	-0.170	0.279
	February	-0.177	0.162		February	-0.177	0.232
	March	-0.211	0.216		March	-0.211	0.314
	April	-0.031	0.260		April	-0.031	0.253
	May	-0.160	0.340		May	-0.160	0.290
	June	0.106	0.301		June	0.106	0.212
	July	0.108	0.305		July	0.108	0.219
	August	0.166	0.276		August	0.166	0.165
	September	-0.108	0.280		September	-0.108	0.203
	October	-0.162	0.262		October	-0.162	0.205
	November	-0.156	0.229		November	-0.156	0.234
	December	0.000	0.139		December	0.000	-0.001

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ABBREVIATIONS

ANOVA	analysis of variance
ATTN.	Attention:
Ave.	avenue
AWC	average winter consumption
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
Blvd.	boulevard
CCF	hundred cubic feet
CDM	conditional demand model
CF	cubic feet
CIS	customer information system
CUSTID	customer identification number
e.g.	for example
EBMUD	East Bay Municipal Utility District
EGLS	estimated generalized least-squares
ET	evapotranspiration
EWEB	Eugene Water and Electric Board
gal.	gallon
gpcd	gallons per capita per day
gpd	gallons per day
gpf	gallons per flush
gpm	gallons per minute

gpsf	gallons per square foot
HCF	hundred cubic feet
HUD	U.S. Department of Housing and Urban Development
i.e.	for example
Inc.	incorporated
IWR-MAIN	Institute for Water Resources – Municipal and Industrial Needs
JONWRN	John Olaf Nelson Water Resources Management
KEYCODE	unique identifying number for survey respondents
kgal	thousand gallons
l.	liter
LF	Low-flow
LITEBILL	Pasadena Residential Water and Energy Conservation Program
lpf	liters per flush
min.	minute
MWD	Municipal Water District
OLS	ordinary least squares
PAC	Project Advisory Committee
PC	personal computer
PMCL	Planning and Management Consultants, Limited

pop.	population
Q1000	systematic random sample of 1000 single family accounts
Q125	sample of 125 accounts for data logging
Q150	sample of 150 accounts for data logging
QA	quality assurance
QAQC	quality assurance and quality control
R^2	coefficient of determination
Rd.	road
RE	random effects
REUWS	Residential End Uses of Water Study
RMSE	root mean square error
SCS	Soil Conservation Service
sf	square foot
St.	street
St. Dev.	Standard deviation
Std. Dev.	Standard deviation
SUR	Seemingly unrelated regression
TW	Trace Wizard
ULF	Ultra-low-flush
ULFT	Ultra-low-flush toilet
UPS	United Parcel Service
WD	Water District