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Quantification of Exposure-Related Water Uses for Various U.S. Subpopulations

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Quantification of Exposure-Related Water Uses for Various U.S. Subpopulations

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Notice

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Abstract

Personal exposure to water-borne contaminants in the home results from three possible routes of exposure: ingestion, inhalation, and dermal contact. To assess realistic exposure estimates for specific population groups, it is vital to understand population water-use behavior for indoor water-use activities as a function of demographic characteristics. In this report, frequencies and durations of use of showers, baths, clothes washers, dishwashers, toilets and faucets are presented and compared for various demographic groups derived from analyses of the National Human Activities Pattern Survey (NHAPS) database, the Residential End Uses of Water Study (REUWS) database, the Residential Energy Consumption Survey (RECS) as well as from current literature and manufacturer information. Volumes and flow rates are also analyzed from REUWS for the various water uses. Furthermore, tap water ingestion data are analyzed for various population groups derived from the Continuing Survey of Food Intake by Individuals (CSFII) as well as from NHAPS and current literature**.** Typical parameters of indoor water-uses are presented and recommended for use in human exposure modeling.

Keywords: Water Use, Showers, Baths, Dishwashers, Clothes Washers, Toilets, Faucets, Drinking Water, Ingestion, NHAPS, REUWS, RECS, CSFII, Activity Patterns, Water Contaminants

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Section 1

Executive Summary

A realistic assessment of exposure and risk to water-borne contaminants requires accurate summaries of water usage patterns. This report examines population water-use behavior for showers, baths, clothes washers, dishwashers, toilets and faucets derived from a review of current literature as well as analyses of the National Human Activity Pattern Survey (NHAPS), the Residential End Uses of Water Study (REUWS), and the Residential Energy Consumption Survey (RECS), and ingestion behavior derived from analyses of the Continuing Survey of Food Intake by Individuals (CSFII). The NHAPS database was compiled as a result of an EPA supported survey, conducted between October 1992 and September 1994, with the goal of collecting a rich set of exposure-related behavioral data. Detailed analysis of NHAPS has been completed for some exposure assessment purposes (Tsang and Klepeis, 1996), but the water-use behavior with respect to exposure to water-borne contaminants has not been thoroughly analyzed. The REUWS database was compiled through an American Water Works Association Research Foundation project (AWWARF Project# 241) conducted between May 1996 and March 1998 with the goal of understanding how water is used and to identify potential for water conservation (Mayer et al., 1998). As such, this database also has not been analyzed for water-use behavior with respect to exposure to water-borne contaminants. In this paper, NHAPS and REUWS (and to a lesser extent, RECS) are extensively analyzed as a function of a variety of demographic characteristics for the purpose of using this behavioral information in assessing exposure. CSFII is analyzed to quantify ingestion of drinking water as a function of demographic characteristics.

Linking the use of contaminated water with exposure and potential risk can be accomplished using an exposure model that characterizes the release of, and contact with, the contaminant. Such a model must represent the physical environment, the emission characteristics of the water appliances during their use, and the water-use and location behavior of the occupants. Subsequently, the model must account for the principal routes of exposure: inhalation, dermal contact, and ingestion. The water-use characteristics and distributions discussed and presented in this report are analyzed such that the data can effectively be utilized by an exposure model (such as the Total Exposure Model (TEM)) when simulating realistic occupant water-use behaviors of various populations.

NHAPS contains responses to questionnaires and 24-hour time-location-activity diaries from over nine thousand U.S. residents who recalled the frequencies and durations of the previous day’s activities. NHAPS is analyzed in this report to quantify characteristics of various household water uses, including the use of showers, baths, clothes washers, dishwashers, faucets, and drinking water intake. REUWS holds water-use data (duration, volume and flow rates of water-use events) for 1,188 households acquired using a magnetic data logger attached to the household water supply pipe. The REUWS data is analyzed in this report to quantify frequency, duration, volume and flow rate characteristics for various water uses, including the use of showers, toilets, faucets, and clothes washers. RECS contains energy related water-usage information obtained from questionnaires from 5,900 residential housing units. The RECS database is analyzed in this report to quantify estimates on household clothes washer and dishwasher usage. CSFII contains tap water consumption data collected through dietary recall interviews with approximately 15,300 people. The CSFII data are analyzed in this report to quantify estimates of per capita water ingestion for both direct water (plain water consumed as a beverage) and indirect water (water used to prepare foods and beverages).

When applicable, the frequencies and duration data from NHAPS, REUWS and RECS, segregated by demographic characteristics (such as gender, age, race, education, housing-type, and employment status), are analyzed and compared for each type of water use. After comparing the databases, it is concluded that databases based on recall surveys, like NHAPS and RECS, are reliable sources for frequency information of occasional events such as showers, baths, and dishwasher and clothes-washer use, but are unreliable in reflecting more frequent events such as faucet use. In regard to all frequency questions asked in the surveys, it is very clear that the way the questions were asked had a large impact on the quality of the data. REUWS, which is based on analysis of waterflow signatures through household water meters, is an excellent source for water-use duration information.

Overall, NHAPS data are more reliable than REUWS for frequency information, while REUWS data are more reliable than NHAPS for duration information. The reasons for this lie within the manner in which the databases were compiled. NHAPS was compiled from a recall telephone survey of the respondents' activities of the previous 24 hours. Respondents were able to remember how many showers and baths they took, while they had difficulty estimating the durations of the events, as the duration values appeared to be overestimated and clustered around 5-minute intervals. In contrast, REUWS was compiled from direct mechanical measurements of water usage logged at household water meters and subsequent waterflow disaggregation by a software program, Trace Wizard©, to determine individual water uses. REUWS contains measured values of duration, volume, and flow rates of the water-use events in its database. For this reason, REUWS provides very accurate duration data. However, REUWS has a few integral limitations that make it less reliable in reference to frequency data, such as the inability to discern which person is performing the water uses in question, and at times Trace Wizard mislabeled events as they were clearly unrealistic. In regard to the frequency of clothes-washer and dishwasher use, the RECS database was the most reliable source as the survey questions were more straightforward than those asked for NHAPS. Dishwasher and clothes-washer durations and volumes are best characterized using a combination of data from REUWS, data provided by the manufacturers, and data from field experiments. Only REUWS provides usable information on faucet and toilet use.

1.1 Showers and Baths

1.1.1 Shower and Bath Frequency

The frequency statistics for various demographic groups resulting from the NHAPS analysis are believed to most appropriately represent the population frequency-of-use behavior. NHAPS analysis revealed that the overall frequency of shower use for the surveyed population was 0.98 showers per person per day, and the overall frequency of bath use was 0.32 baths per person per day. Although the impact is believed to be relatively small, potential biases must be recognized including the ability to recall events and biases due to perceived societal expectations.

1.1.2 Shower Duration

The shower duration data are fitted to lognormal distributions, and the geometric mean and standard deviation, and arithmetic mean are presented for the various demographic groups. The shower duration statistics resulting from the REUWS analysis are believed to most appropriately represent the length of showers for the given population. The shower duration data for the overall population represented in our analysis of the REUWS database fit a lognormal distribution with a geometric mean of 6.8 minutes, and the data have an arithmetic mean of 7.65 minutes. Shower and bath duration behavior was analyzed as a function of the various demographic variables. It was revealed that there are significant differences in durations given differences in age, race, education level, and housing type. The other demographic variables analyzed, such as gender, employment status, income, or number of adults in the household, were found to not significantly affect the duration of the showers or baths.

1.1.3 Bath Duration

NHAPS contains the best available dataset for bath durations, since surveys like REUWS contain only the amount of water used to fill the bathtub not the bath duration. Although there are significant biases in the dataset, the NHAPS duration statistics are recommended until a more definitive study provides better information. The durations reported in NHAPS are biased by a multitude of factors, mostly resulting from inaccurate memory recall and perception by the survey respondents. Examples of these include the round-off error (the vast majority reported durations at a five-minute interval), estimation errors (based on the comparison between NHAPS, REUWS and other shower duration studies, it appears that people overestimated the duration), and ambiguous questions (from the question, it is unclear whether respondents were asked to give the amount of time in the bathtub, or the time for all bath related activities including filling the tub and drying off). The bath duration data for the overall population represented in our analysis of NHAPS database fit a lognormal distribution with a geometric mean of 17.6 minutes, and the data have an arithmetic mean of 20.9 minutes.

1.1.4 Shower Volume and Flow Rate

REUWS shower volume and flow rate data were analyzed and fit to lognormal distributions. For the given population, the average shower volume was 18.6 gallons (arithmetic mean), and the geometric mean was 15.8 gallons per shower. The average flow rate per shower was 2.4 gallons per minute (arithmetic mean), and the geometric mean was 2.0 gallons per minute. However, as with the other REUWS data, this data may be impacted by misclassification and single events reported as multiple events.

1.1.5 Bath Fill Flow Rate

From an analysis of the REUWS data, the average flow rate for filling the bathtub was 4.9 gallons per minute, with a geometric mean of 4.4 gallons per minute. The bath fill volume is not well enough understood to make a recommendation based on our analysis of the REUWS data. However, the general dimensions of the standard bathtubs are well understood, holding approximately 50 gallons of water, when filled to the overflow, though this is likely to be reduced by approximately 20-30% due to the bather’s body volume.

1.1.6 Comparison with Other Studies

In general, the frequency of showering and bathing reported in NHAPS agreed reasonably well with previous studies; however, durations of these events were found to be significantly longer. NHAPS data indicates that, overall, 78% of the population took at least one shower in the given day, while Brown and Caldwell (1984) and Konen and Anderson (1993) report that, respectively, 74% and 70% of the population take a shower in a given day. The frequency of showering reported in REUWS was slightly less than that reported for NHAPS, (REUWS reported that only 56% of the population took at least one shower on a given day), though this may be due to NHAPS reflecting all showers taken during the day including those taken at work or at health clubs, while REUWS only recorded showers taken at home. The overall-population arithmetic and geometric mean durations of showers reported in REUWS (7.65 minutes and 6.8 minutes, respectively) were consistent with other studies (Brown and Caldwell, 1984; Konen and Anderson, 1993; and Aher et al., 1991), reporting approximate mean shower durations between 6 to 10.4 minutes. However, shower duration data in NHAPS were found to be less consistent with other studies, with an arithmetic mean of 13.2 minutes and a geometric mean of 11.3 minutes.

1.2 Clothes Washers

1.2.1 Clothes-Washer Use Frequency

The RECS database proved to be the most reliable resource for clothes-washer use frequency data, as its data directly reflects the number of loads of clothes washed in the household per week. In contrast, the NHAPS data was not useful for two major reasons: the data reflected only the washing done by the survey respondent, and it was not clear whether the answer reflected the number of loads washed per week or the number of days per week the wash was done regardless of the number of loads done each day. Based on an analysis of RECS data, the number of loads of laundry washed per household per week increases as the number of occupants in the household increases. The average household of the analyzed population washed 6.1 loads of laundry a week, or 2.3 loads of laundry per week per person.

1.2.2 Clothes-Washer Duration and Volume

In regard to duration, REUWS provides data on the durations of the individual cycles (wash and rinses), which can be combined to determine the time it takes from the start of the first fill until the end of the last fill. However, REUWS does not provide data on the duration of the entire event, which would include the time to complete the final agitation and spin. In order to characterize the entire clothes-washer duration, various sources are analyzed. For individual cycle duration information (wash fill, rinse fill), the REUWS data is used. For information on the agitation and spin durations, data from timed experiments are used, as well as information from published literature and characteristic information supplied by the clothes-washer machine manufacturers. According to the REUWS data, the fill (1st cycle) and first rinse (2nd cycle) are 100% likely to occur. The second (3rd cycle) and third rinses (4th cycle) are 18.7% and 0.8% likely to occur. Weighting the duration values for these additional rinses, the total duration of the washing event in this configuration would be 43 minutes (from the first fill to the time the machine turns off). Based on information presented in Consumer Reports (July 1998, July 1999, August 2000), if a top-loaded clothes-washer machine was manufactured around 1998, a load is estimated to use approximately 41 gallons and last for 43 minutes. If the top-loaded machine is more modern, a load is estimated to use approximately 33 gallons per load and last for 45 minutes. If the machine is front-loaded and manufactured around 2000, each load is estimated to use approximately 27 gallons and last for 64 minutes.

1.3 Dishwashers

As compared to other water sources in a household, dishwasher uses represent a relatively small source because of the infrequent usage, small water volume, and the relatively sealed washing compartments. As such, the exposure resulting from dishwasher use can be expected to be a very small portion of an occupant’s overall exposure to water borne contaminants.

1.3.1 Dishwasher-Use Frequency

To represent the frequency of dishwasher use, the most reliable data was judged to be from the RECS analysis. RECS was chosen as more reliable over NHAPS because the RECS survey question reflected household use, while the NHAPS survey question reflected dishwasher use of the respondent. However, the RECS data did not capture the lower frequencies of use, as the data lumped all frequencies of “less than 4 loads per week” into one category. Considering that 56.3% of the respondents answered “less than 4 loads per week”, this data is clearly lacking definition. From the analysis of RECS, it is estimated that the dishwasher is used approximately 3.7 times per week in the average household, or 1.4 times per person per week.

1.3.2 Dishwasher Duration and Volume

Based on the information available from dishwasher manufacturers and data reported in various Consumer Reports issues, the typical dishwasher event is comprised of approximately 5 small wash and rinse fills. The entire dishwasher event lasts an average of 100 minutes and uses a total of approximately 8 gallons of water.

1.4 Toilets

The analysis of the REUWS data provides reliable information for toilet flush frequency, and toilet tank fill duration, volume and flow rate. From the data analysis, it is estimated that, on average, a person flushes 5.5 times per day. The amount of water that toilets use to flush has dramatically decreased due to conservation efforts and mandated plumbing codes. Early models used about 5-7 gallons per flush, while newer toilets manufactured after 1992 are required by U.S. law to use only 1.6 gallons per flush. The analysis of the REUWS database found that the toilets used by the studied population used an average of 3.5 gallons of water and took 71 seconds to refill a toilet tank after each flush. The tanks were filled at a mean flow rate of 3.9 gallons per minute. It is safe to assume that as years go by, the average volume of water used per flush in any given U.S. population will decrease as older toilets are replaced with newer 1.6 gallon/flush toilets.

1.5 Faucets

Faucet usage is probably the most difficult household water use to characterize in general terms because each water use may differ greatly from the next in its duration, volume, flow rate and temperature. The REUWS database is the best available source of frequency, volume, duration, and flow rate information regarding faucet use. It is shown that frequency of faucet use is dependent on the number of occupants in the household, as the mean faucet uses per person per day decreases as the household size increases. This results from the many faucet uses that are house-related, not individual-related, such as for cooking or cleaning. From the analysis of REUWS, the mean faucet use overall is 17.4 uses per person per day. The mean volume used per faucet use is 0.7 gallons per event, with mean duration of 33.9 seconds, and a mean mode flow rate of 1.2 gallons per minute.

1.6 Drinking Water Consumption

The 1994-1996 Continuing Survey of Food Intake by Individuals (CSFII) database provides comprehensive and reliable data on drinking water intake by individuals residing in the United States. Data are provided for direct ingestion of tap water (plain water consumed as a beverage), indirect ingestion of tap water (water ingested from beverages or foods that are prepared with water, such as tea, coffee, baby formula, juices from concentrate, and soups). Intrinsic water (water contained in foods and beverages prior to purchase before home or restaurant preparation) is also provided in the CSFII data, but not analyzed for purposes of this report. Overall, men consume approximately 728 ml/day of direct tap water and 521 ml/day of indirect tap water. Women consume approximately 677 ml/day of direct tap water and 459 ml/day of indirect tap water. Children between the ages of 4 to 6 consume approximately 378 ml/day of direct tap water and 172 ml/day of indirect tap water, while children between the ages of 11 to 14 consume approximately 535 ml/day direct tap water and 228 ml/day of indirect tap water.

Section 2

Introduction

Tap water in homes is often contaminated with chemicals that pose potential risks to public health. These chemicals often originate in a ground water or surface water supply that is contaminated as a result of industrial activity, agricultural runoff, or a spill, or they may be a result of the disinfection process implemented at the water treatment plant. When contaminants are introduced into the home through the water supply, the occupants are exposed to the contaminants via three primary routes: inhalation, ingestion, and dermal absorption. The contaminants can enter the bloodstream through the ingestion route when people drink water; the contaminant can cross the skin into the bloodstream when contaminated water contacts the skin; and the contaminant can be inhaled when chemicals are volatilized during household water use. A realistic assessment of exposure and risk requires reasonable understanding of usage patterns. This paper examines population water-use behavior for showers, baths, clothes washers, dishwashers, toilets and faucets derived from a review of current literature as well as analyses of the National Human Activity Pattern Survey (NHAPS), the Residential End Uses of Water Study (REUWS), and the Residential Energy Consumption Survey (RECS), and ingestion behavior derived from analyses of the Continuing Survey of Food Intake by Individuals (CSFII). The NHAPS database was compiled as a result of an EPA supported survey conducted between October 1992 and September 1994, with the goal of collecting a rich set of exposure-related behavioral data. Detailed analysis of NHAPS has been completed for some exposure assessment purposes (Tsang and Klepeis, 1996), but the water-use behavior with respect to exposure to water-borne contaminants has not been thoroughly analyzed. The REUWS database was compiled as a result of an American Water Works Association Research Foundation project (AWWARF Project# 241) conducted between May 1996 and March 1998 with the goal of understanding how water is used and to identify potential for water conservation (Mayer et al., 1998). As such, this database also has not been analyzed for water-use behavior with respect to exposure to water-borne contaminants. In this paper, NHAPS and REUWS (and to a lesser extent, RECS) are extensively analyzed as a function of a variety of demographic characteristics for the purpose of using this behavioral information in assessing exposure. CSFII is also analyzed to quantify ingestion of drinking water as a function of demographic characteristics.

Linking the use of contaminated water with exposure and potential risk can be accomplished using an exposure model that represents the factors leading to the release of and contact with the contaminant. To provide realistic estimates, such a model must represent the physical environment, the emission characteristics of the water appliances during their use, and the water-use and location behavior of the occupants; and the model must account for the principal routes of exposure.

Modeling ingestion exposure is the most straightforward, as the exposure depends primarily on how much water the persons consume in their drinks or food. Modeling dermal exposure is more complex as it depends on how long the persons are in contact with the water, what parts and how much of their bodies are in contact with the water, the contaminant concentration in the water, and the temperature of the water. Modeling the inhalation route is potentially the most complex as it deals with a multitude of factors. If the contaminant is non-volatile, the inhalation route is of small consequence, since only minimal exposure occurs due to aerosolization (Wilkes, 1999). However, if the contaminant is volatile, the model must represent all the water-use activities in the home; simulate the chemicals' release from the water sources; represent the chemicals' transport throughout the home; and represent the locations of the individuals throughout the day. The water-use characteristics and distributions discussed and presented in this paper are analyzed such that the data can effectively be utilized by an exposure model (Total Exposure Model (TEM)) when simulating realistic occupant water-use behaviors of various populations.

Section 3

Evolution of Water-Using Fixtures

The use of water has received increasing attention as areas of the United States have received less than normal rainfall and/or the population has increased, putting a greater burden on ground water aquifers and surface-water sources. Municipalities and water utilities have responded to the need for water conservation with educational programs, mandatory and voluntary reductions in water use including programs to encourage the retrofit of conservation-type appliances and mandatory use of water-conserving appliances in new construction. Many research efforts have also been initiated, which have resulted in a better understanding of how water is consumed.

The evolution of water-use appliances toward lower water use has been occurring for many years, but more recently, the changes have been accelerated by mandatory standards, such as plumbing codes requiring 1.6 gallons per flush toilets, and low-flow rate showerheads and faucets.

Prior to the 1970's, showerheads typically delivered water at a flow rate, depending on the pipeline pressure, in excess of 3 gallons per minute (gpm). For a five-minute shower, this resulted in a use of more than 15 gallons. According to a 1984 U.S. Department of Housing and Urban Development (HUD) study (Brown and Caldwell, 1984) households using non-conserving showerheads consumed approximately 16 gallons per person per day (gppd) for showering. Varieties of lower-flow showerheads were introduced prior to the mid-1980's, whose flow ranged from a minimum of approximately 1.3 gpm (Turbojector, Model 501) to a maximum of approximately 2.1 gpm (Brown and Caldwell, 1984). Although a wide range of showerheads is currently in use, the most efficient modern day showerheads deliver water at approximately 1.5 gpm. Aquacraft (Mayer et al., 1998) reports a current average consumption rate for showers of 11.1 gppd in homes that use showerheads with a maximum flow rate of 2.5 gpm and an average consumption rate of 13.3 gallons per person-day (gppd) for showerheads with a maximum flow rate greater than 2.5 gpm (Mayer et al., 1998). Shower and bath water-use characteristics are further discussed in the following Section 6.

Clothes washers and dishwashers have also undergone redesign to reduce water consumption. Consumer Reports, August 1983 (Brown and Caldwell, 1984) reported that clothes washers in the early 1980s varied from 42 to 55 gallons per load. Typical clothes washers manufactured in the late 1990’s varied between 34 and 47 gallons per load (Consumer Reports, July 1998 and July 1999), while typical models manufactured around 2000 use an average of approximately 33 gallons, varying from 30 to 37 gallons per load depending on the size of the machine (Consumer Reports, August 2000). The recently introduced front-loading models use even less water, averaging approximately 27 gallons per load, ranging from 16 to 30 gallons based on the size and model (Consumer Reports, July 1998 and August 2000). These clothes-washer characteristics are presented for comparison in Section 7. Clearly there has been a significant decrease in the amount of water used in washing machines.

Similarly, dishwashers have also evolved to use less water. Machines made prior to 1980 used around 14 gallons per load, machines manufactured in the early 1980s used from 8.5 to 12 gallons per load (Consumer Reports, August 1983, reported in Brown and Caldwell, 1984), and typical modern dishwashers manufactured after 1997 use approximately 8 gallons per load, though the volume can vary from 4.8 to 11.5 gallons depending on the type of wash cycle selected (Consumer Reports, March 1998 and manufacturer-supplied data from Whirlpool, Maytag, and General Electric). Dishwashers are discussed in Section 8.

Toilet flush volumes also dramatically reduced over recent years resulting from the implementation of municipality-based conservation incentives and mandated plumbing codes. Toilets installed prior to 1980 typically used 5 - 7 gallons per flush, accounting for approximately 28% of the total water use in the home and an average of 22 gallons per person per day (gppd) (Brown and Caldwell, 1984). The advent of the low-flow toilet, nominally specified as 3.5 gallon per flush, occurred in the mid 1970's. Kohler introduced the "Wellworth Water-Guard" 3.5 gallon per flush toilet in 1974 (www.kohler.com/files/y1974.htm, no longer accessible). Other companies introduced similar models during the same time period. The introduction of the 3.5-gallon per flush toilet led to a significant reduction in toilet water use, with an average of 19.2 gppd (Brown and Caldwell, 1984).

The ultra-low flush toilets, nominally specified as 1.6 gallon per flush toilets, were introduced in the late 1980's and early 1990's. In 1992, Congress passed the National Energy Policy Act (PL102-486), which required toilets and other appliances to meet a variety of energy and water-efficiency standards. This act established the requirement of 1.6 gallon per flush for new toilets, and led to an even greater reduction of water use by toilets. Toilet-use characteristics are further discussed in the following Section 9.

Section 4

Data Sources

In any water-related exposure scenario, an understanding of people's water-use behavior is fundamental to estimating their exposures. As a basis for understanding water-use behavior, a variety of resources are analyzed and used. These include a number of studies focused strictly on water-use behavior and other studies conducted by water utilities aimed at understanding the impacts of water conserving services such as low-volume toilets and low-flow showerheads.

Databases compiled from several recent surveys have provided a wealth of new information on water-use behavior. An analysis of these databases can provide valuable insight into water-use behavior and can be utilized as inputs for exposure modeling. In this report, water-use data from the NHAPS, REUWS, RECS and CSFII databases are analyzed (see below for brief descriptions).

4.1 NHAPS

The National Human Activity Pattern Survey (NHAPS) database contains the results from a two-year, nationwide, activity pattern survey. The NHAPS study was commissioned by the EPA National Exposure Research Laboratory. During the period from October 1992 through September 1994, 9,386 persons residing in the 48 contiguous United States were interviewed over the phone. The households were chosen using a telephone random-digit dial (RDD) method such that the database would statistically represent the U.S. population. The interview was composed of two parts, which will hereafter be referred to as the "Diary" and the "Main Questionnaire."

In the "Diary" section, all respondents of the NHAPS survey were asked to recall their activities and locations for the previous 24 hours. This was recorded in a sequential timeline, where the time spent in each activity and location was recorded for the entire previous day. The locations and activities were recorded as codes chosen from a list of 83 possible locations and 91 possible activities. In cases where the exact location or activity was not on the list, the most similar choice was selected. The only activity on the list of choices that specifically pertains to water-use is "bathing." All of the other activities are more generally defined; however, some of the activities nearly always involve water use, such as "food preparation," "food clean-up," and "plant care," while other activities may or may not involve water use, such as "clothes care," "animal care," "personal care," etc.

In the second part of the survey, called the "Main Questionnaire" section of the interview, the respondents were asked a series of multiple-choice questions. Every respondent was asked for specific demographic information, including date of birth, gender, race, geographical region, level of education, etc. The other questions in the survey covered a wide range of specific activities, most relating to possible exposure to contaminants in the air and water, such as "Do you use a kerosene space heater?" "How many cigarettes did you smoke yesterday?" or "How long did you spend in the shower?" or "When you showered, was there a window open or an exhaust fan on?"

Apparently in an effort to shorten the length of questioning, one half of the respondents were asked one set of questions (Version A) and the other half were asked another set of questions (Version B). Both versions asked very general water-use questions; such as, "Was a dishwasher used yesterday when you were home?" However, the more detailed, and therefore more useful, water-use questions were included in Version B. The respondents to Version B recalled the frequency and durations of their showers and baths, and the frequency of dishwasher, laundry machine, and humidifier use. However, NHAPS contains no information on toilet use, and only limited information on faucet use.

NHAPS is especially useful because the data can be paired with corresponding demographic information, as the survey recorded age, gender, race, employment status, and educational level. NHAPS is analyzed in the following Sections 6, 7, and 8 to quantify the reported usage of showers, baths, clothes washers, and dishwashers. NHAPS is also analyzed in Section 11 to quantify the amount of water people reported drinking on the survey day.

4.2 REUWS

The Residential End Uses of Water Study (REUWS) database contains water-use data obtained from 1,188 volunteer households throughout North America. The REUWS study was funded by the American Water Works Association Research Foundation (AWWARF). During the period from May 1996 through March 1998, approximately 100 single-family detached homes in each of 12 different municipalities (located in California, Colorado, Oregon, Washington, Florida, Arizona, and Ontario) were outfitted with a data-logging device (Meter-Master® 100EL, manufactured by F.S. Brainard and Co.[1]) attached to their household water meter (on only magnetic-driven water meters). The data logger recorded the water quantities at 10-second intervals for a total of four weeks (two in warm weather and two in cool weather) at each household. Following the study, the data were retrieved and analyzed by a flow-trace analysis software program, called Trace Wizard, developed by Aquacraft Engineering, Inc.[2], (DeOreo, 1996), which disaggregated the total water volumes into individual end uses (i.e., toilet, shower, faucet, dishwasher, clothes washer, etc.) (Mayer et al. 1998). In addition to identifying the type of water use (e.g., shower, faucet, toilet), Trace Wizard identified the event durations, volumes, peakflows, and mode measurements for each water-using event.

The REUWS database includes demographic information collected for each household based on a mail-in survey. This information includes employment status (unemployed, part-time, full-time), education level of the primary wage earner (less than high school, high school graduate, some college, Bachelor’s, Master’s, Doctoral), and household income.

Though REUWS offers a tremendous amount of useful information, the database is not a statistically representative sample of our nation’s population (as is NHAPS). The sampled households were located within only six U.S. states (five of which are in the western U.S.) and one Canadian province, and the participants were all volunteers who may not be representative of the entire population.

The REUWS database is analyzed in the following Sections 6, 7, 8, 9, and 10 to quantify the frequencies and water-use characteristics of household appliances and fixtures including showers, baths, clothes washers, dishwashers, toilets, and faucets. The following sections discuss how and when REUWS is used in the various analyses (e.g., REUWS can be used for determining durations of most water usages, but not for baths, as REUWS contains the data on how long it took to fill the bathtub, not how long the person bathed.)

The REUWS database presents a potentially significant data source toward the understanding of household water-use behavior. However, the quality of the data relies heavily on the disaggregation algorithms employed by the Trace Wizard software. In a recent small, evaluation study of Trace Wizard (see Appendix A), we have uncovered flaws in Trace Wizard’s analysis techniques. Though fairly acceptable in classifying single, non-overlapping water-uses, the software quite often misclassified water-

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[1] F.S. Brainard and Company, P.O. Box 366, Burlington, NH 08016

[2] Aquacraft Engineering, Inc., 2709 Pine Street, Boulder, CO 80304

uses when two or more water uses overlapped. In the evaluation study, over 83% of single water uses were classified correctly, and less than 25% of multiple, overlapping water-uses were classified correctly. The performance of Trace Wizard would benefit from improvements in correctly linking water uses that consist of multiple water draws, such as the numerous sequential fills comprising a dishwasher or clothes-washer use. Although the program attempts to identify the initial dishwasher or clothes-washer fill (labeled as DISHWASHER1 or CLOTHESWASHER1), some of the subsequent fills are labeled DISHWASHER1 or CLOTHESWASHER1 or mislabeled as another type of water use, affecting the apparent frequencies and volumes of these events. This makes it difficult to use the database when analyzing these types of appliances. In addition, in the REUWS database, which included 1,959,817 water-use events, Trace Wizard identified 1.40% (27,587) of the water-use events as "leaks" when in reality, many of those events were probably small faucet uses. There were also 1.42% (27,883) of the events labeled as "unknown."

4.3 RECS

The Residential Energy Consumption Survey (RECS) is a nationwide survey conducted in 1997 to obtain household energy-use information. The resultant RECS database contains energy-usage characteristics of 5,900 residential housing units. The information was acquired through on-site personal interviews with residents; telephone interviews with rental agents of units where energy use was included in the rent; and mail questionnaires to energy suppliers to the units. The database contains information on physical characteristics of the housing units, demographic information of the residents, heating and cooling appliances used, clothes washer and dishwasher-use frequency information, fuel types, and energy consumption. The RECS database is analyzed in the following Sections 7 and 8 in order to quantify estimates on household clothes-washer and dishwasher usage.

4.4 CSFII

The 1994-96 USDA's Continuing Survey of Food Intake by Individuals (CSFII) is the most recent and comprehensive consumption database available. CSFII was conducted over the three-year period between January 1994 and January 1997. A nationally representative total of 15,303 persons in the United States were interviewed on two non-consecutive days with questions about what drinks and foods they consumed in the previous 24 hours. The dietary recall information was collected by an interviewer who came to the participants' homes and provided instructions and standard measuring cups and spoons to assist in recalling consumption quantities. The EPA report, "Estimated Per Capita Water Ingestion in the United States" (Jacobs et al., 2000), explains the details of the study and presents the results. The CSFII data are analyzed in the following Section 11 for purposes of quantifying estimates of per capita water ingestion for both direct water (plain water consumed as a beverage) and indirect water (water used to prepare foods and beverages).

Section 5

Data-Analysis Techniques

5.1 Introduction

This report analyzes data from a variety of sources for water-use behavioral characteristics. This report addresses four primary types of water-use behavior: (1) frequency of appliance use, (2) duration of appliance use, (3) water flow rate, and (4) water volume. As described in Section 4, four primary data sources are analyzed: (1) NHAPS, (2) REUWS, (3) RECS, and (4) CSFII. The survey conducted to compile NHAPS (Tsang and Klepeis, 1996) was designed to gather exposure-related information, and as such, quantifying duration and frequency of appliance use was a goal of the survey. REUWS (Mayer et al., 1998) and RECS (USDOE, 1995) were gathered for other purposes, but also contain useful information. REUWS was conducted to better understand how much water is used by the various household appliances and issues related to water conservation. RECS was conducted with a primary focus on energy consumption. CSFII (Jacobs et al., 2000) is a study of food intake, which is analyzed for tap-water consumption. The analyzed variables and their data sources are summarized in Table 5-1.

Table 5-1. Summary of Data Types and Data Analysis Techniques

Variable	Data Source*	Data Description
Shower Duration	NHAPS	Dataset compiled from telephone survey results. Duration in minutes, truncated at > 60 minutes recorded as 61. In addition, records with multiple events per day were lumped. Multiple events were averaged. Also found clustering around 5 min intervals.
Shower Duration	REUWS	Dataset compiled from meter monitoring program. Actual duration in minutes. Removed events of less than 60 seconds from analysis. Also, very likely there were some misclassifications.
Shower Frequency	NHAPS	Dataset compiled from telephone survey results. Event occurrence. In cases where the shower frequency was reported as “greater than 10,” 11 was assumed in the frequency calculation.
Shower Frequency	REUWS	Dataset compiled from meter monitoring program. Event occurrence. Removed events of less than 60 seconds from analysis. Also, very likely there were some misclassifications.
Shower Volume and Flow Rate	REUWS	Dataset compiled from meter monitoring program. Average flow rate and event volumes for the same events analyzed for duration and frequency.
Bath Duration	NHAPS	Dataset compiled from telephone survey results. Duration in minutes, truncated at > 60 minutes recorded as 61. In addition, records with multiple events per day are lumped. Multiple events were averaged. Also found clustering around 5 min intervals.
Bath Duration	REUWS	Not Analyzed. Dataset compiled from meter monitoring program. Duration of actual bath was not available, only time of water flow.
Bath Frequency	NHAPS	Dataset compiled from telephone survey results. Event occurrence.

Table 5-1. *(Continued)*

Variable	Data Source*	Data Description
Bath Frequency	REUWS	Not Analyzed – shortcomings in dataset.
Bath Volume	REUWS	Not Analyzed – shortcomings in dataset.
Clothes-Washer Use Frequency	NHAPS	Dataset compiled from telephone survey results. Responses to questions that were both vague and across a range (3-5 times/week; 1-2 times/week; less often).
Clothes-Washer Use Frequency	RECS	Dataset compiled from telephone and personal interview survey results. Better quality of questions (<1/wk; 2-4/wk; 5-9/wk; 10-15/wk; >15/wk).
Clothes-Washer Duration and Volume	REUWS	Dataset compiled from meter monitoring program. Dataset has many questionable records. Applied criteria to raw dataset to yield a “reasonable” representative dataset. Criteria: 2, 3, or 4 fills between 6 and 23 gal; 1st fill must be <23 and >6 gal; maximum 6 cycles; 1st and 2nd fill between 4 and 26 minutes apart; Subsequent fills between 2 and 16 min apart; Ratio of mode flows between 0.25 and 4.
Toilet Frequency	REUWS	Dataset compiled from meter monitoring program. Fairly reliable dataset of event occurrence.
Toilet Volume	REUWS	Dataset compiled from meter monitoring program. Fairly reliable dataset of event volume.
Tap Water Consumption	CSFII	Tap water consumption data reported as consumption volume vs. percentile of population.

* REUWS = Residential End Use Water Survey (Mayer et al., 1998)
NHAPS = National Human Activity Pattern Survey (Tsang and Klepeis, 1996)
RECS = Residential Energy Consumption Survey (USDOE, 1995)
CSFII = Continuing Survey of Food Intakes by Individuals (Jacobs et al., 2000)

5.2 Frequency Data

The frequency of appliance use is calculated by taking the number of occurrences and dividing by the period over which the occurrences took place. For NHAPS, the frequency was calculated in one of two ways, depending upon how the data were gathered. Some of the frequency data is in the form of a range of values, while others give a specific number of events over a given time period, and in some cases, the frequency range is truncated. For example, the clothes-washer frequency data was provided as daily, 3-5 times per week, 1-2 times per week or less than once per week, and showers, where the frequencies of 10 and greater reported as “greater than 10.” For binned data, the midpoint of the range was assumed in the calculation. For truncated data, the calculation for overall frequency assumed the first number in the truncated range (i.e, 11 was assumed for the truncated range “greater than 10”).

5.3 Analysis of Duration, Volume, Flow Rate, and Tap Water Intake Data

The durations, volumes and flow rates of water uses are extremely important for estimating exposure to waterborne contaminants. These parameters are most useful when they can be approximated as continuous distributions that can be sampled as inputs for exposure, dose and uptake estimates. For this reason, the parameters for a representative continuous distribution are approximated for the various data where this could be reasonably accomplished. Several continuous distributions were considered, including the Normal, Lognormal, Weibull, and Gamma distributions. However, because of the considerable number of variables and data sets, the normal and lognormal distributions were chosen for primary consideration. The lognormal distribution often provides good representation of non-negative, positively skewed physical quantities (Small, 1990). Because variables such as duration fit these characteristics, and because other studies have had considerable success in approximating similar variables as a lognormal (Roseberry and Burmaster, 1992, Burmaster, 1998A, Burmaster, 1998B, Burmaster Crouch, 1997), the lognormal distribution was chosen for primary consideration for duration of water-use activities. Random variables that are not constrained by zero have been observed to have distributions that are approximately normal. For this reason, the normal distribution will be considered for variables such as flow rate.

5.3.1 Techniques for Approximating a Lognormal Distribution

Several techniques can be used to estimate the parameters to a lognormal distribution representative of the data set depending upon the form of the data. As described in Table 5-1, for some of the parameters a representative sample of the data is available. For other parameters, a limited data set is available. For example, the data for showering duration are truncated at 60 minutes, with the events over 60 minutes recorded as 61. For another variable, volume of consumed tap water, the raw data set is not available, but rather consumption values for various percentiles of the population are available. Each of these limited data sets poses a specific set of constraints and alternative methods are required to estimate the parameters for a representative lognormal distribution.

Two types of lognormal fitting techniques are utilized for estimating the parameters to a representative lognormal distribution, as follows:

(1) MLE TECHNIQUE: This technique involves using maximum likelihood estimators (MLE) for the lognormal distribution. The MLE technique is the preferable technique, however, to implement this technique, the data values are needed.

The maximum likelihood estimator for the geometric mean of the lognormal distribution is given by Equation 1 (Crow and Shimizu, 1988).

$$\mu_g = \exp\left(\frac{1}{N}\sum_{i=1}^{N} \mathrm{In}(x_i)\right) \tag{5-1}$$

Where μ_g = geometric mean
x_i = values in distribution
N = total # of values in distribution

The MLE for the geometric standard deviation, σ_g, is given by Equation 2 (Crow and Shimizu, 1988).

$$\sigma_g = \exp\left(\left(\frac{1}{N}\sum_{i=1}^{N} (\mathrm{In}\, x_i - \mathrm{In}\, \mu_g)^2\right)^{\frac{1}{2}}\right) \tag{5-2}$$

The fitted lognormal distribution resulting from this technique approximates the continuous shape of the clustered data. Therefore, this technique is useful for adjusting both the clustering problem as well as the truncation problem.

(2) LOG PROBIT TECHNIQUE: The log-probit graphical technique (Travis and Land, 1990) or a numerical probit technique (Crow and Shimizu, 1988) involve ranking the data and fitting them using a probit technique.

The graphical version involves plotting them on log-probit paper, and then fitting a straight line to the data, taking advantage of the knowledge that a distribution forms a straight line when the cumulative value is plotted against the standard deviations. This subsequently gives you the parameters to the lognormal distribution. This technique, applied by Travis and Land to fit lognormal distributions to datasets with values below the detection limit, allows you to account for truncated values at one end of the distribution through the ranking of the data.

The numerical version of this technique involves minimizing the squared difference between the representative lognormal cumulative distribution function (cdf) and the value at the corresponding percentile of the population. This is accomplished by transforming the cdf and percentiles into probits using a standard probit table or a standard normal distribution function area table. For example, the probit for a given percentile is calculated as follows:

$$p_i = 5 + \xi_i \qquad \textbf{(5-3)}$$

where: $F_i = \phi(\xi_i)$ = desired probability level
ϕ represents the cumulative standard normal distribution function
ξ_i = standard normal quantile of the i^{th} observation
p_i = probit value corresponding to the i^{th} observation
5 = constant, the probit is defined as 5 for the geometric mean

For example, the probit value for the 86th percentile is calculated as follows:

$F_i = 0.86$
$\phi(\xi_i)$ (as the desired probability level) = 0.86 => $\xi_i = 1.08$
(as the desired standard normal quantile with a probability level of 0.86; taken from Table of the Standard Normal Distribution Function)
$p_i = 5 + \xi_i = 6.08$

Following the conversion of the known percentile values to probit values, the parameters for the representative lognormal distribution are estimated by taking advantage of the knowledge that the equation to the lognormal is linear in log-probit space, as represented by the following equation:

$$\hat{y}_i = m * p_i + b \qquad \textbf{(5-4)}$$

y_i = natural log of the i^{th} observation
$\hat{y}_i$ = natural log of the fitted distribution corresponding with the i^{th} observation
m = slope of the fitted log-probit linear relationship
p_i = probit value associated with i^{th} observation
b = intercept; geometric standard deviation for the representative lognormal distribution

Minimizing the squared difference between the y_i values from the data set and the corresponding values from the representative lognormal distribution provides the parameter estimates for the distribution. Once the fitted linear log-probit relationship is estimated, the fitted geometric standard deviation is the intercept, b, and the fitted geometric mean is calculated by setting p_i in equation 5.4 to 5, as follows:

$$\textit{Geometric Mean} = m * 5 + b$$

Example of the Log-Probit Fitting Technique: The following is an example of the calculations for the numerical version of the log-probit parameter estimation technique. In this example, the parameters for the representative lognormal for direct consumption are estimated. Table 5-2 provides the data from the CSFII survey data, as described in Section 11. The squared residuals between the representative lognormal and the data are calculated and minimized. The resultant fitted lognormal is presented in Figures 5-1 and 5-2.

Table 5-2. Sample Calculation for Least Square Log-Probit Parameter Estimation

Percentile	Probit Corresponding to Percentile p_i	Values from CSFII Survey Data		Representative Lognormal Distribution	
		Direct Consumption, All Ages	*ln*(Consumption) y_i	*ln*(Consumption) y_i	$(\text{Residual})^2$
50	5	290	5.6699	5.7727	0.010579
75	5.68	707	6.5610	6.4643	0.009358
90	6.28	1270	7.1468	7.0841	0.003924
95	6.65	1769	7.4782	7.4581	0.000403
99	7.33	3240	8.0833	8.1599	0.005862

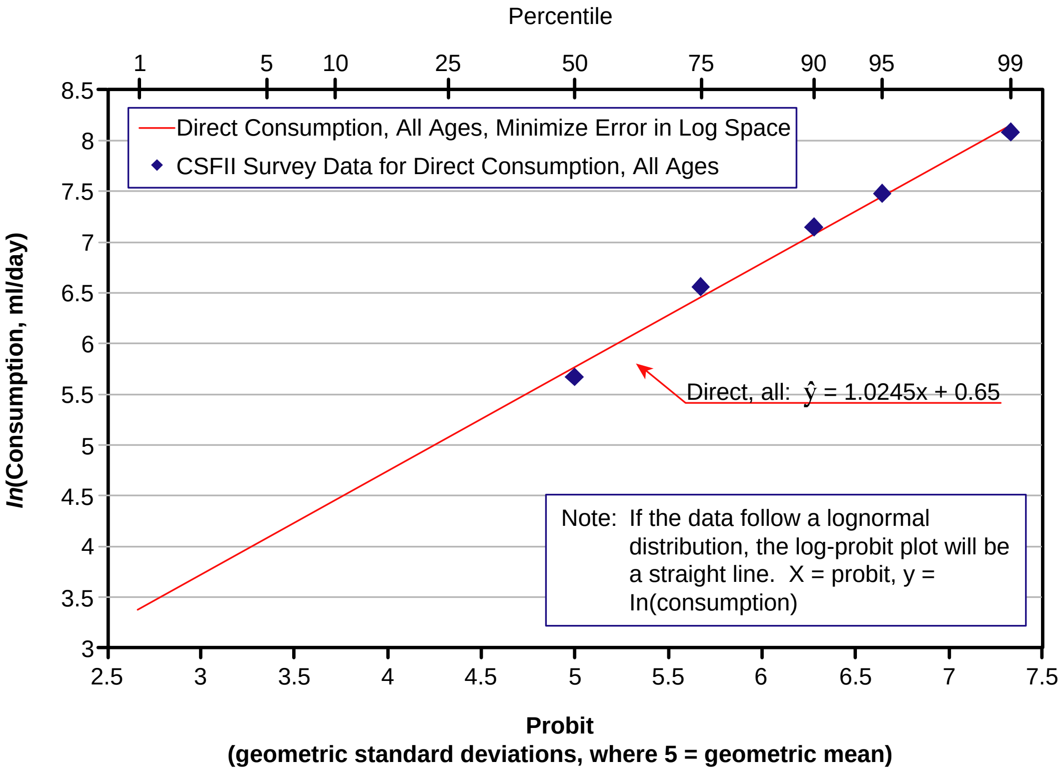
Sum = 0.030126

Minimized {Sum of $(\text{Residuals})^2$} = 0.030126

<u>Summary of Fitted Parameters</u>:

m = 1.024529 Geometric Mean = 321.4 ml/day

b = 0.65009 Geometric Standard Deviation = 0.65009



Direct, all: $\hat{y} = 1.0245x + 0.65$

Note: If the data follow a lognormal distribution, the log-probit plot will be a straight line. X = probit, y = ln(consumption)

Figure 5-1. Example of Log-Probit Fit to Direct Consumption Data: Log-Probit Plot.

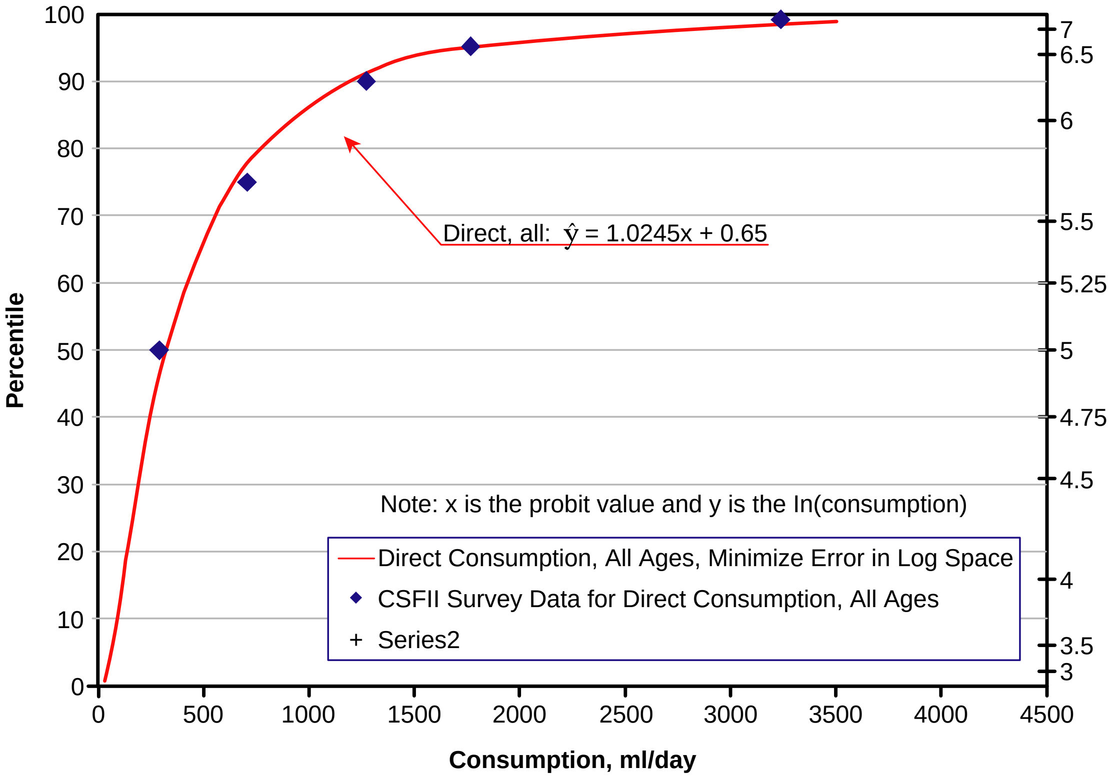


Figure 5-2. Example of Log-Probit Fit to Direct Consumption Data: Cumulative Distribution Function.

5.4 Summary of Data and Analysis Techniques Used for the Analysis of Duration, Volume and Flow Rate Data

The various analyzed duration, volume and flow rate variables along with the analyzed data sources and the analysis techniques used for analyzing the variables are summarized in Table 5-3.

Table 5-3. Summary of Data Types and Data Analysis Techniques

Variable	Data Source	Analysis Technique
Shower Duration	NHAPS	**MLE:** Analysis indicated that the actual value of the truncated data did not have a large impact on the final parameters, and that assuming 61 minutes for the NHAPS values over one hour was adequate. Therefore, each of the distributions was fitted using MLE techniques.
Shower Duration	REUWS	MLE
Shower Volume and Flow Rate	REUWS	MLE
Bath Duration	NHAPS	**MLE:** Analysis indicated that the actual value of the truncated data did not have a large impact on the final parameters, and that assuming 61 minutes for the NHAPS values over one hour was adequate. Therefore, each of the distributions was fitted using MLE techniques.
Bath Duration	REUWS	Not Analyzed

Table 5-3. *(Continued)*

Variable	**Data Source**	**Analysis Technique**
Bath Volume	REUWS	NA
Clothes-Washer Duration and Volume	REUWS	Volume is analyzed as a function of fill, for mean and standard deviation, minimum and maximum. Mode flow rate is analyzed as a function of fill for mean, standard deviation, minimum and maximum. Time between fills is analyzed as a function of fill for mean, standard deviation, minimum and maximum.
Toilet Volume	REUWS	Minimum, Maximum, and Empirical CDF
Consumption Volume	CSFII	Log-Probit

Section 6

Showers and Baths

6.1 Introduction

In this chapter, residential shower and bath use is analyzed with the objective of developing a set of general shower and bath use characteristics that adequately reflect how often people take showers or baths, and the duration and volume of water used per event. Bathing and showering require the user to initiate and end the use, and typically require the user's presence for the duration of the activity. These bathroom-type water uses have been shown to dominate personal exposure routes (Wilkes et al., 1996), particularly for volatile compounds. The results presented herein are intended for use in modeling human behavior and related exposure in respect to household water use. This chapter will review published literature on showers and baths, and analyze the shower and bath use data in the NHAPS, RECS and REUWS databases.

6.2 Previous Shower-Use Studies

Many studies have been conducted throughout the United States to determine typical shower durations, frequencies, and volumes. Several studies contrasted the water-use characteristics of homes before and after retrofitting the homes with water-conserving showerheads. The results from the various studies on showers are presented in Table 6-1. The Brown and Caldwell study (June 1984) monitored shower use in 162 households across the nation, containing a variety of showerheads. In the group of people who only showered (did not bathe), the average person took a 10.4-minute shower, 5.2 times a week. The researchers also studied smaller groups of households that used particular showerheads. In these smaller samples, however, they did not gather duration data on individual showers, but instead they divided the total shower water-use time over the course of the study by the number of days and by the number of occupants in the household. The study reported average shower water use durations ranging from 4.8 minutes to 6.0 minutes per person per day (see Table 6-1). The average water temperature ranged from 103ºF to 106ºF.

In a study of 25 homes in Tampa, Florida (Konen, 1993), households with non-conserving showerheads (2.5 gpm) took about 6.3 minute showers, 4.9 times per week. After the showerheads were replaced with low-flow rate showerheads (1.5 gpm), the mean duration was 6.0 minutes. In a study of 25 homes in Oakland, California (Aher et al., 1991), the households with non-conserving showerheads (2.3 gpm) took 6-minute showers and the homes with low-flow rate showerheads (1.6 gpm) took 6.6-minute showers.

Two larger water-use studies, NHAPS and REUWS add a plethora of information to the previous studies. A comprehensive analysis of these data sets, presented in the following sections of this report, examines these studies for shower durations and frequencies based on various demographic groups.

Table 6-1. Summary of Reported Shower-Use Characteristics from Literature

Type of Showerhead	Frequency	Duration (min/shower)	Miscellaneous Information	Water Temp.	Population/ Sample Size	Reference
Variety	5.2 eppw[1] (0.74 eppd[1])	10.4		Unknown	CA, CO, VA, WA, D.C., 345 people who shower only	Brown and Caldwell, 1984
Conventional (max > 3 gpm[2])		4.8 min/pers/day[3]	Flow Rate = 3.4 gpm	103˚F	CA, CO, D.C., VA, WA, 87 households	Brown and Caldwell, 1984
Low Flow (max <=3 gpm)		4.8 min/pers/day[3]	Flow Rate = 1.9 gpm	104˚F	CA, CO, D.C., VA, WA, 48 households	Brown and Caldwell, 1984
Conventional with Restrictor (max<=3 gpm)		6.0 min/pers/day[3]	Flow Rate = 2.1 gpm	103˚F	CA, CO, D.C., VA, WA, 27 households	Brown and Caldwell, 1984
Zinplas Model (rated 3 gpm)		4.5 min/pers/day[3]	Flow Rate = 1.8 gpm	106˚F	CA, CO, D.C., VA, WA, 103 households	Brown and Caldwell, 1984
Turbojector Model (rated 1.5 gpm)		4.9 min/pers/day[3]	Flow Rate = 1.3 gpm	104˚F	CA, CO, D.C., VA, WA, 21 households	Brown and Caldwell, 1984
Comparison Studies of Homes with Nonconserving Showerheads Retrofitted with Low flow Showerheads						
Nonconserving	4.9 eppw (0.7 eppd)	Mean = 6.3 Min = 2.9 Max = 13.2	Mean Min Max **Max Flows**[4] (gpm) 3.8 1.9 6.5 **Actual Flows**[5] (gpm) 2.5 0.9 4.0 **Actual Vol** (gal/shw)[2] 14.7 5.5 33.2	Unknown	Tampa, Florida 25 single family homes	Konen and Anderson, 1993
Low-flow		Mean = 6.0 Min = 3.5 Max = 9.2	Mean Min Max **Max Flows** (gpm) 2.5 **Actual Flows** (gpm) 1.5 0.9 2.1 **Actual Vol** (gal/shw) 8.9 4.8 18.6	Unknown	Tampa, Florida 25 single family homes	Konen and Anderson, 1993
Conventional		Mean = 6	Average actual flow (gpm) = 2.3 Average volume (gal/shw) = 13.5	101˚F	Oakland, Calif., 25 single family homes	Aher et al., 1991
Low-flow		Mean = 6.6	Ave. actual flow (gpm) = 1.6 Average volume (gal/shw) = 10.7	104˚F	Oakland, Calif., 25 single family homes	Aher et al., 1991

[1] eppw = events per person per week; eppd = events per person per day
[2] gpm = gallons per minute; gal/shw = gallons per shower
[3] Cumulative shower time during study divided by # persons and # days per household
[4] Measured flow rates of these fixtures with faucets in full-on position
[5] Flows measured at the household, actual use settings

6.3 Previous Bath Use Studies

Relatively few studies have been conducted throughout the United States to determine typical bath durations, frequencies, and volumes. One study that examined bath use was the Brown and Caldwell (1984) study for HUD. The data, collected from 1981-1983 and summarized in Table 6-2, indicate that the average bath frequency among individuals that only bathe (do not shower) is about 2.9 baths per week. NHAPS contains a significant amount of information on bath duration and frequency, which is analyzed in the following sections of this report. The REUWS database could not be analyzed for bathing frequency or duration because the bathing frequency could not be determined from the REUWS data due to problems in the records, where single events often appear to be represented as many events, probably due to individual user's fill behavior, such as repeatedly using the faucet to adjust the water temperature. Additionally, REUWS could not be analyzed for bath duration because only the actual fill activity is recorded, not the duration of the time spent in the tub. These shortcomings inherent in the REUWS database are further discussed in the following sections.

Table 6-2. Summary of Reported Bath-Use Characteristics in Literature

Frequency	Volume	Population/ Sample Size	Reference
2.9 baths/person/week*	50 gallons/bath (estimated)	CA, CO, D.C., VA, WA, 162 households, 168 people who took baths	Brown and Caldwell, June 1984

* This value is taken from only those individuals who exclusively took baths.

6.4 Demographic Variables

Understanding shower and bath water use as a function of various demographic characteristics, such as age, gender, race, education, employment, and income, is valuable to properly represent people's behavior and to estimate their resultant exposures. Both NHAPS and REUWS collected a variety of basic demographic information for the individual participants. NHAPS collected information on age, gender, race, education, housing type, number of adults and number of children living at the residence, employment status and EPA region. REUWS was more limited and only collected information on education, full-time employment outside the home, income, housing type and the location (city or water utility). The demographic variables fall into two categories: (1) quantitative variables, where the magnitude of the value reflects the status of the variable (e.g., income, age, education, employment, and number of occupants living in residence); and (2) qualitative variables, where the value is sometimes arbitrarily assigned (e.g., gender and race). For qualitative variables, often referred to as "indicator" variables (Lapin, 1983; Larson, 1982), the analysis is conducted by separating the observations into two classifications (e.g., male or female), and analyzing the data for each classification category. The NHAPS and REUWS data are analyzed for the influence of the demographic variables on shower and bath water-use behavior (frequency and duration of use). The EPA region was not used in our analysis as a general demographic variable; because of the large size of the regions and the large variation in population characteristics across a region, this analysis was not considered to provide meaningful results.

6.5 NHAPS Correlation Analysis

An analysis of the NHAPS database seeks to determine the differences in showering and bathing characteristics between various population groups. The variables describing basic attributes, such as age and gender, were analyzed for their predictive ability. Each considered demographic variable, given in Table 6-3 and each analyzed water-use variable, given in Table 6-4, are identified as "quantitative" or "indicator" variables. As described above, the "indicator" variables were binary, containing two distinctive outcomes, and therefore the value of the variable does not have predictive value in a correlation analysis. In the case of quantitative variables, the numeric value does have a predictive value, as shown by the results of the correlation analysis presented in Table 6-5 (Note: the number of “adults only” was analyzed, not the number of occupants). The impact of the indicator variables will be analyzed below by comparing the summary statistics and fitted distributions for the populations represented by each of the indicator variables. The analysis presented in Table 6-5 indicates that education may have a strong influence, but it is unclear whether other variables are important. The influence of these variables will be further examined below.

Table 6-3. Demographic Variables Considered in the Analysis, NHAPS

NHAPS Variable	Type	Definition
EDUC	Quantitative	Grade or level of education completed. A value of 0-12 represents level of primary school education, values greater than 12 represent level of college completed.
ADULT	Quantitative	Number of adults (18 years of age and older) residing in the household. Less than 11 is actual number of adults, 11 indicates more than 10 adults.
YOB	Quantitative	Year of Birth. Indicates actual year of birth in the 1900’s; if birth occurred on or before 1900, a value of 0 is recorded.
RSEX	Indicator	Gender of respondent. Males are assigned a value of 1, females 2.
HOUSING	Indicator	Type of housing. Apartments are assigned a value of 1, detached single-family homes are assigned 2, townhouses are assigned 3.
EMP	Indicator	Employment status. A value of 1 is assigned to full-time, 2 is assigned to part-time, and 3 is assigned to unemployed.
RACE	Indicator	Race of respondent. A value of 1 is assigned to White, 2 is assigned to Black, 3 is assigned to Asian, 5 is assigned to Hispanic, and 4 is assigned to Other.

Table 6-4. Water-Use Variables Considered in the Analysis, NHAPS

Variable	Type	Definition
SHOWER	Indicator	Occurrence of a shower. A value of 0 represents no, a value of 1 represents yes.
SHOWER#	Quantitative	Number of showers taken by respondent. Less than 11 indicates the actual number of showers; 11 indicates more than 10 showers.
SHTIME	Quantitative	Total duration of all showers taken by respondent. Less than 61 indicates the actual number of minutes in the shower; 61 indicates more than 60 minutes.
BATH	Indicator	Occurrence of a bath (adult). A value of 0 represents no, a value of 1 represents yes.
BATHP	Indicator	Occurrence of a bath (child). A value of 0 represents no, a value of 1 represents yes.
BATH#	Quantitative	Number of baths taken by respondent. Less than 21 indicates the actual number of baths; 21 indicates more than 20 baths.
BATIME	Quantitative	Total duration of all baths by respondent. Less than 61 indicates the actual number of minutes in the bath; 61 indicates more than 60 minutes.

Table 6-5. Ranking of Correlation of Quantitative Demographic Variables, NHAPS

Rank	Demographic Variable (Correlation Coefficient)				
	SHOWER	SHOWER#	SHTIME	BATH#	BATIME
1	EDUC (0.185)	EDUC (0.248)	EDUC (0.120)	EDUC (0.270)	EDUC (0.168)
2	ADULT (0.081)	ADULT (0.101)	ADULT (0.026)	ADULT (0.149)	YOB (0.110)
3	YOB (-0.077)	YOB (0.026)	YOB (-0.010)	YOB (0.008)	ADULT (0.080)

6.6 Frequency Analysis

6.6.1 NHAPS Shower Frequency

NHAPS contains two variables with information about shower frequency: (1) SHOWER and (2) SHOWER#. SHOWER indicates whether a respondent engaged in a showering activity during the 24-hour survey period (yes, no, or don’t know) and SHOWER# indicates the number of showers taken during that period.

One of the issues of concern identified during the analysis was the large number of showers per day recorded by a few respondents. Of the 3587 respondents who reported taking a shower, 4 respondents reported instances of taking more than 10 showers, another 4 reported taking between 4 and 10 showers, and 30 respondents reported taking 3 showers. These reported frequencies may be valid, but it is also possible they resulted from miscommunication or other errors. In any case, because of the relatively small fraction of the total samples, these values were found to have a relatively minor impact on the resulting distributions and were included in the analysis.

Other problems encountered with the NHAPS database involved the presence of invalid records. For example, a record would not be valid if the respondent answered “Don’t know” for frequency, or answered they did not shower, but responded that they took one or more showers. For each respective demographic variable, records that contained invalid responses or records of people who refused to provide information about the given demographic variable were removed. For the age analysis, the year of birth (YOB) was collected, however, the actual birth date and month were not recorded. For all individuals, the age of the respondent was estimated by assuming a birth date in the middle of the reported YOB (July 1) and calculating the age based on this birth date and the date of the survey.

6.6.2 NHAPS Shower Frequency Analysis and Results

The database was fine-tuned by removing the invalid entries as well as estimating a birth date for each respondent based on their given “year of birth” as described above. The analysis based on the employment status of the individual was conducted only on individuals 18 years of age or older to avoid the children’s impact on the unemployed category. The “employed” category in our analyses includes both part-time and full-time workers. All individuals who recorded they had “some college” education were combined with “high school graduates”, and all respondents who had their Bachelor’s degree, Master’s degree, or PhD were combined into the category of “college graduates.” For each of the demographic variables, only records with valid responses for that demographic characteristic were used.

The shower frequency characteristics for each of the demographic variables in Table 6-3 are analyzed and tabulated in Table 6-6. The table lists the number of persons per demographic group who took each of 0 through 10 (and over 10) showers during the survey day. The table also lists the overall frequency of showers per person-day (spd) for each demographic group.

Table 6-6. Shower Frequency Analysis as a Function of Demographic Group, NHAPS

Population Group	Number[1] of Person-Days	Number of persons who took this number of showers												Overall[3,4] Frequency Showers per person-Day
		0	1	2	3	4	5	6	7	8	9	10	>10	
OVERALL	4608	1021 (22%)	2747 (60%)	802 (17%)	30	1	1	0	0	1	0	1	4	0.98
GENDER														
Male	2141	423 (20%)	1259 (59%)	436 (20%)	21	1	0	0	0	0	0	0	1	1.03
Female	2465	598 (24%)	1486 (60%)	366 (15%)	9	0	1	0	0	1	0	1	3	0.93
AGE[2]														
0-5 yrs	299	254 (85%)	34 (11%)	10 (3%)	1	0	0	0	0	0	0	0	0	0.19
5-12 yrs	329	180 (55%)	118 (36%)	30 (9%)	1	0	0	0	0	0	0	0	0	0.55
12-18 yrs	335	47 (14%)	209 (62%)	72 (21%)	7	0	0	0	0	0	0	0	0	1.12
18-33 yrs	1033	73 (7%)	685 (66%)	266 (26%)	8	0	0	0	0	0	0	0	1	1.21
33-48 yrs	1076	101 (9%)	728 (68%)	235 (22%)	9	1	0	0	0	0	0	0	2	1.16
48-63 yrs	744	114 (15%)	508 (68%)	116 (16%)	3	0	1	0	0	1	0	0	1	1.04
> 63 yrs	718	243 (34%)	417 (58%)	56 (8%)	1	0	0	0	0	0	0	1	0	0.76
RACE														
White	3744	837 (22%)	2323 (62%)	562 (15%)	17	0	1	0	0	0	0	0	4	0.95
Black	456	108 (24%)	199 (44%)	140 (31%)	7	1	0	0	0	1	0	0	0	1.12
Asian	76	12 (16%)	49 (64%)	14 (18%)	1	0	0	0	0	0	0	0	0	1.05
Hispanic	192	30 (16%)	103 (54%)	56 (29%)	2	0	0	0	0	0	0	1	0	1.20

[1] The number of person-days equals the number of households. This number does not include individuals who answered “Don’t Know” or did not give the number of showers.

[2] The year of birth is recorded in the database, however the actual birth month and day are not given. To calculate the actual age, the birth date is assumed to be July 1 of the year of birth.

[3] In calculating the number of showers, shower frequencies recorded as greater than 10 were assumed to be equal to 11.

[4] Overall frequency is defined as the total number of showers (including multiple showers) taken by everyone divided by the number of people in the population.

[5] Analyzed only respondents >=18 years of age.

Table 6-6. *(Continued)*

Population Group	Number[1] of Person-Days	Number of persons who took this number of showers												Overall[3,4] Frequency Showers per person-Day
		0	1	2	3	4	5	6	7	8	9	10	>10	
EDUCATION														
Pre High School	397	100 (25%)	240 (60%)	54 (14%)	2	0	0	0	0	0	0	0	1	0.92
High School Grad	2129	319 (15%)	1378 (65%)	419 (20%)	9	0	1	0	0	1	0	1	1	1.07
College Grad	1084	116 (11%)	747 (69%)	208 (19%)	10	1	0	0	0	0	0	0	2	1.12
HOUSING														
Single-Family	3122	733 (23%)	1855 (59%)	511 (16%)	18	1	0	0	0	1	0	1	2	0.95
Apartment	975	176 (18%)	592 (61%)	196 (20%)	10	0	0	0	0	0	0	0	1	1.05
Townhouse	234	44 (19%)	141 (60%)	45 (19%)	2	0	1	0	0	0	0	0	1	1.08
ADULTS														
1 – 2 adults	3801	893 (23%)	2252 (59%)	632 (17%)	20	0	0	0	0	1	0	1	2	0.95
3 – 4 adults	745	110 (15%)	463 (62%)	159 (21%)	9	1	1	0	0	0	0	0	2	1.13
> 4 adults	41	13 (32%)	19 (46%)	8 (20%)	1	0	0	0	0	0	0	0	0	0.93
EMPLOYMENT[5]														
Full-time	2001	166 (8%)	1361 (68%)	454 (23%)	17	0	0	0	0	0	0	1	2	1.17
Part-time	378	51 (13%)	261 (69%)	65 (17%)	0	0	1	0	0	0	0	0	0	1.05
Unemployed	1287	321 (25%)	780 (61%)	177 (14%)	5	1	0	0	0	1	0	0	1	0.92

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[1] The number of person-days equals the number of households. This number does not include individuals who answered “Don’t Know” or did not give the number of showers.

[2] The year of birth is recorded in the database, however the actual birth month and day are not given. To calculate the actual age, the birth date is assumed to be July 1 of the year of birth.

[3] In calculating the number of showers, shower frequencies recorded as greater than 10 were assumed to be equal to 11.

[4] Overall frequency is defined as the total number of showers (including multiple showers) taken by everyone divided by the number of people in the population.

[5] Analyzed only respondents >=18 years of age.

The frequency data demonstrated the greatest variation with respect to age. For this reason, the age demographic variable was chosen for a further in-depth analysis. The NHAPS data for the number of showers taken per person per day by the entire population, as a function of age, is plotted in Figure 6-1.

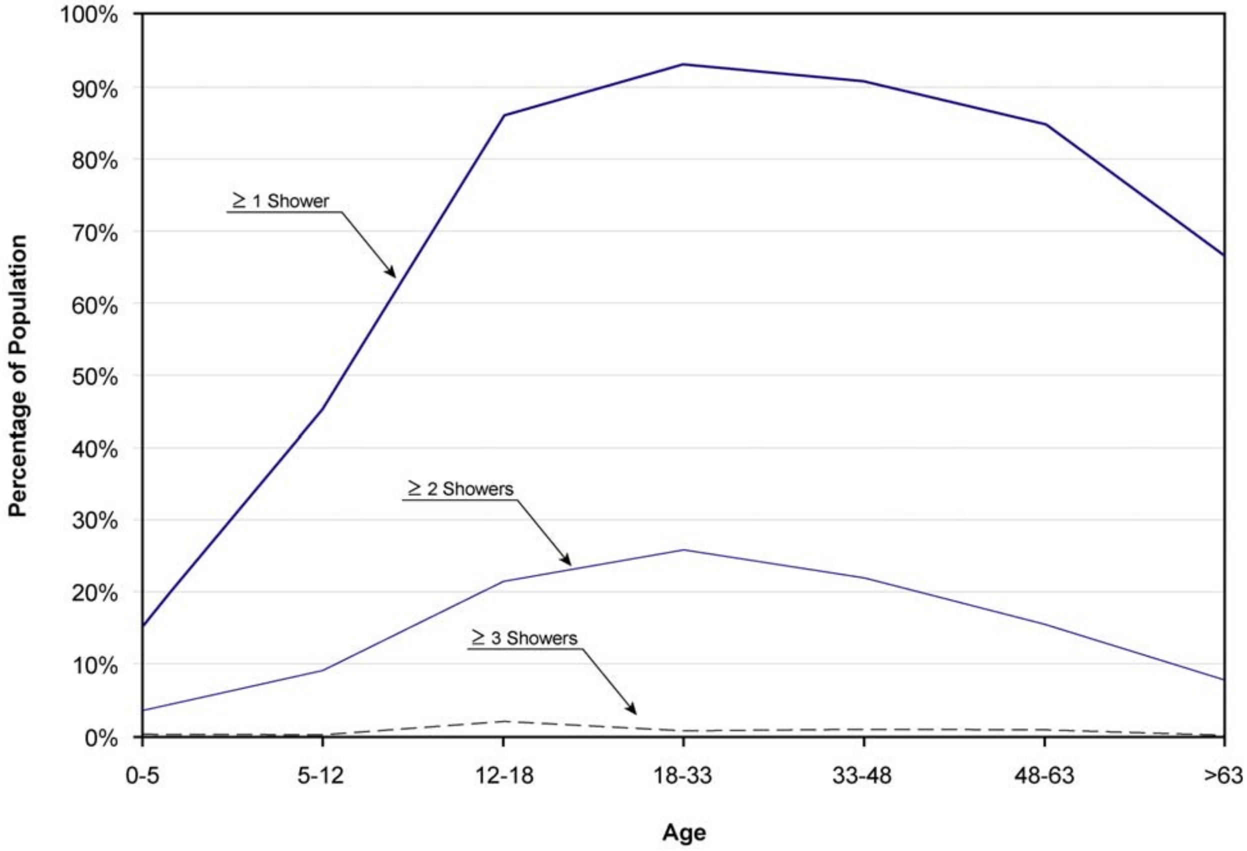


Figure 6-1. Comparison of Mean Showering Frequency (showers/person/day) as a Function of Age, NHAPS.

6.6.3 REUWS Shower Frequency

The REUWS database contains a continuous water-use record for each household in the study, recorded via a device placed on the household water meter and analyzed by a software program that defined each water-use type, duration, volume, flow rate and mode. The record for each house covers two approximately 2-week periods, one in the spring and the other in the fall.

There are various problems with the REUWS database in regard to analyzing for frequency of daily water-use events. First, REUWS accounts for only water uses occurring at the home. Therefore, the frequency of shower use may not be accurate for determining daily human behavior patterns, as it does not reflect showers an individual may take at a health club, gym, or at work.

Second, the REUWS survey did not gather data on gender, age, or race, and therefore its utility in water-use activity pattern analysis, based on demographic parameters, is limited. However, the survey did acquire information on education, income, and the number of individuals employed full-time outside of the home. However, this information is useful only for those homes with one occupant. In cases where households have multiple residents, discerning which particular individual performs which water-use event is not possible. Consequently, water-use data from households with multiple residents cannot be used to analyze activity patterns for various sub-populations based on individual demographics.

Therefore, since we are concerned with identifying shower and bath usage for various sub-populations, the analysis that follows is performed on only those households occupied by one adult (with no children in the house), for whom the personal demographics are known. Although limiting the database to one-adult households works well, it is not known whether these households had houseguests during the time of the monitoring or whether single occupants have different water-use behaviors than residents in multiple occupant households. The REUWS survey asked for the number of full-time residents, and did not include information on part-time residents or visitors. Part-time occupants would likely produce an apparent, but not real, increase in the frequencies of showering or bathing events.

Third, the accuracy of REUWS is limited by the capabilities of the Trace Wizard analysis technique. The accuracy of event frequencies (and durations) depends on Trace Wizard's ability to correctly isolate and identify the individual water uses and types. Trace Wizard software has been shown to have difficulty disaggregating the total water use into its individual contributing appliances when more than one water use occurs simultaneously. A recent small-scale study (see Appendix A) comparing field data to the Trace Wizard analysis, found that during multiple-water-use events (when two or more events overlap), Trace Wizard often failed to disaggregate the total flow into its respective individual water uses, or Trace Wizard incorrectly identified the types of appliances in use. However, this study found that Trace Wizard was significantly more accurate when discerning single (non-overlapping) water uses. Therefore, focusing our analysis on only the homes with one occupant helps to reduce these errors of incorrect disaggregation, as one person only infrequently uses multiple water appliances simultaneously. In these cases, multiple uses likely only occur when automatic appliances, such as the dishwasher, clothes washer, or toilet, are running during the shower, or (presumably infrequently) when a visitor is present.

In regard to the REUWS database, there are a few anomalies that required attention. For example, in residences documented to have only one occupant, there were numerous cases where two showers occurred simultaneously, or one shower followed directly after another. In the cases of simultaneous showers, it is possible that other water usages were mislabeled as showers, the survey data were incorrect and the households had more than one occupant, or visitors were present. In the cases of subsequent showers, it is possible that numerous "related" small shower events were actually part of one larger shower event, as the person turned on and off the water at various times during the shower. These anomalous entries are responsible for, in general, less than 10% of the single adult shower events in the database. In order to minimize the effect of overlapped showers, or multiple showers separated by very short durations on the resultant analysis, shower events that overlapped or were separated by less than five minutes were combined into a single event. There was a significant difference between the number of showers in the raw data compared with the number of showers after the "related" events were combined.

6.6.4 REUWS Shower Frequency Analysis and Results

An analysis of the REUWS database was performed to determine the differences in shower frequency between various population groups. The analysis was limited to only those households occupied by one person, most specifically because it is not possible to discern who is using the water in homes of multiple residents. In the database, there are 151 households (3241 shower events) containing only one adult. This population was analyzed to determine the differences in shower frequency between individuals differentiated by education level, employment status, and income. As mentioned above, the REUWS survey did not include information on age, gender, or race.

The database was tailored to eliminate invalid entries, to combine shower events that were separated by less than a five-minute interval into a single shower event, and to remove days when the occupants were not home. All days with three or less water uses (including leaks) were removed from the dataset. These days with little to no water usage indicate that the household residents were not home. Their inclusion in the dataset would have been represented by a zero shower frequency and unrealistically affect the shower frequency distribution.

In order to calculate the shower frequency per day, the two to four weeks of continuous data per household had to be separated into individual days. The first day was determined to begin at midnight, and the last day end at midnight. In turn, all data during the partial days at the beginning and end of the dataset were discarded.

The results from the REUWS shower frequency analysis for each available demographic group are presented in Table 6-7. The table lists the number of persons per demographic group who took each of 0 through 10 (and over 10) showers during the survey day. The table also lists the overall frequency of showers per person-day for each demographic group.

6.6.5 NHAPS Bath Frequency

NHAPS contains four variables with information about bath frequency: (1) BATH, (2) KBATH, (3) BATHP, and (4) BATH#. BATH indicates whether an adult respondent took or gave a bath during the 24-hour survey period (yes, no, or don't know). KBATH and BATHP indicate whether a child took a bath, as ascertained either by direct questioning of the child or asking the guardian adult (proxy). BATH# indicates the number of baths taken or given during that period.

This dataset presents a significant problem with respect to exposure to waterborne contaminants. Because the survey asked the respondent if he/she took or gave a bath to another individual, an answer in the affirmative does not indicate whether the person took the shower him or herself or gave a bath to someone else. This shortcoming has important implications on the ability to estimate skin contact and potential for dermal exposure, as immersing oneself in a bath creates much higher levels of dermal exposure.

6.6.6 NHAPS Bath Frequency Analysis and Results

The frequency analysis for bathing as a function of each demographic variable was conducted in much the same manner as described for showers, by first sorting and condensing to include only the valid records for the variables indicating whether an individual bathes and the number of baths taken. Refer to the discussion in the NHAPS Shower Frequency Analysis section, above, for a description of the process for sorting and condensing the database for each demographic variable. The frequency characteristics for bathing for each of the demographic variables in Table 6-3 are analyzed and presented in Table 6-8. As with showers, the frequency data for the various age groups demonstrated the greatest variation as a function of age. Young children (under 12) bathe more frequently, and adults tend to shower more frequently. Figure 6-2 presents the relationship between age and number of baths (using the NHAPS data).

6.6.7 REUWS Bath Frequency

It is extremely difficult to get reliable results from a bath frequency analysis on REUWS. Due to the nature of bathing, often times people add small amounts of water at various times during the event in order to adjust the temperature or volume. As opposed to showers, these water additions can be separated by long time intervals. Therefore, a bathing frequency analysis was not performed on the REUWS data.

Table 6-7. Shower Frequency Analysis as a Function of Demographic Group, REUWS

Population Group	Number* of Person-Days	Number of Households	Number of persons-days who took this number of showers												Overall Frequency Showers per person-Day
			0	1	2	3	4	5	6	7	8	9	10	>10	
OVERALL	2947	151	1311 (44%)	1103 (37%)	368 (12%)	113	27	21	4	0	0	0	0	0	0.82
EDUCATION															
Pre High School	250	13	135 (54%)	69 (28%)	24 (10%)	10	5	6	1	0	0	0	0	0	0.81
High School Grad	1412	74	607 (43%)	532 (38%)	201 (14%)	57	11	4	0	0	0	0	0	0	0.83
College Grad	1007	51	427 (42%)	410 (41%)	110 (11%)	36	10	11	3	0	0	0	0	0	0.85
INCOME															
< $30K	1120	58	523 (47%)	369 (33%)	151 (13%)	52	15	9	1	0	0	0	0	0	0.84
$30K - $50K	744	39	302 (41%)	318 (43%)	84 (11%)	25	7	5	3	0	0	0	0	0	0.85
$50K - $100K	384	20	153 (40%)	174 (45%)	45 (12%)	12	0	0	0	0	0	0	0	0	0.78
> $100K	352	4	168 (48%)	111 (32%)	54 (15%)	11	3	5	0	0	0	0	0	0	0.82
HOUSING															
Single-Family	2483	127	1168 (47%)	919 (37%)	281 (11%)	83	19	13	0	0	0	0	0	0	0.75
Townhouse	301	15	83 (28%)	112 (37%)	67 (22%)	21	7	7	4	0	0	0	0	0	1.32
EMPLOYMENT**															
Employed	1198	61	422 (35%)	485 (40%)	189 (16%)	62	20	16	4	0	0	0	0	0	1.03
Unemployed	1613	83	816 (51%)	590 (37%)	157 (10%)	40	6	4	0	0	0	0	0	0	0.66

* Data derived from only households with one adult and no children.

** For REUWS, “employed” are those occupants who worked full-time outside of the house; all others are classified as “unemployed.”

Table 6-8. Bathing Frequency Analysis as a Function of Demographic Group, NHAPS

Population Group	Number[1] of Person-Days	Number of persons who took this number of baths												Overall[3] Frequency Baths per person-Day
		0	1	2	3	4	5	6	7	8	9	10	>10	
OVERALL	4591	3556 (77%)	800 (17%)	189 (4%)	22	9	4	2	1	0	0	2	6	0.32
GENDER														
Male	2138	1778 (83%)	297 (14%)	53 (2%)	5	1	0	1	1	0	0	1	1	0.22
Female	2451	1776 (72%)	503 (21%)	136 (6%)	17	8	4	1	0	0	0	1	5	0.40
AGE[2]														
0-5 yrs	209	14 (7%)	165 (79%)	26 (12%)	1	0	0	0	0	0	0	1	2	1.31
5-12 yrs	336	189 (56%)	135 (40%)	11 (3%)	1	0	0	0	0	0	0	0	0	0.48
12-18 yrs	327	282 (86%)	38 (12%)	7 (2%)	0	0	0	0	0	0	0	0	0	0.16
18-33 yrs	1019	835 (82%)	109 (11%)	55 (5%)	11	3	4	1	0	0	0	1	0	0.30
33-48 yrs	1077	888 (82%)	117 (11%)	55 (5%)	9	4	0	1	1	0	0	0	2	0.29
48-63 yrs	756	648 (86%)	88 (12%)	17 (2%)	2	0	0	0	0	0	0	0	1	0.19
> 63 yrs	730	574 (79%)	138 (19%)	17 (2%)	0	0	0	0	0	0	0	0	1	0.26
RACE														
White	3730	2958 (79%)	631 (17%)	113 (3%)	13	7	2	1	0	0	0	1	4	0.27
Black	455	293 (64%)	109 (24%)	43 (9%)	5	1	0	1	1	0	0	1	1	0.57
Asian	76	59 (78%)	10 (13%)	5 (7%)	0	1	0	0	0	0	0	0	1	0.51
Hispanic	192	143 (74%)	23 (12%)	21 (11%)	3	0	2	0	0	0	0	0	0	0.44

[1] The number of person-days equals the number of households. This number does not include individuals who answered "Don't Know" or did not give the number of baths.

[2] The year of birth is recorded in the database, however the actual birth month and day are not given. To calculate the actual age, the birth date is assumed to be July 1 of the year of birth.

[3] Overall frequency is defined as the total number of baths (including multiple showers) taken by everyone divided by the number of people in the population. In calculating the number of baths, bath frequencies recorded as greater than 10 were assumed equal to 11.

[4] Analyzed only respondents >=18 years of age.

Table 6-8. *(Continued)*

Population Group	Number[1] of Person-Days	Number of persons who took this number of baths												Overall[3] Frequency Baths per person-Day
		0	1	2	3	4	5	6	7	8	9	10	>10	
EDUCATION														
Pre High School	392	299 (76%)	66 (17%)	19 (5%)	3	2	2	0	0	0	0	0	1	0.37
High School Grad	2120	1724 (81%)	279 (13%)	92 (4%)	14	4	2	2	1	0	0	0	2	0.27
College Grad	1084	933 (86%)	110 (10%)	33 (3%)	3	3	0	0	0	0	0	1	1	0.21
HOUSING														
Single-Family	3109	2394 (77%)	554 (18%)	130 (4%)	16	7	1	1	1	1	0	1	4	0.32
Apartment	972	781 (80%)	149 (15%)	30 (3%)	5	1	3	1	0	0	0	1	1	0.29
Townhouse	233	172 (74%)	46 (20%)	14 (6%)	1	0	0	0	0	0	0	0	0	0.33
ADULTS														
1 – 2 adults	3787	2887 (76%)	714 (19%)	148 (4%)	17	9	2	2	1	0	0	1	6	0.33
3 – 4 adults	743	620 (83%)	79 (11%)	36 (5%)	5	0	2	0	0	0	0	1	0	0.26
> 4 adults	61	49 (80%)	7 (11%)	5 (8%)	0	0	0	0	0	0	0	0	0	0.28
EMPLOYMENT[4]														
Full-time	1967	1686 (86%)	182 (9%)	76 (4%)	12	5	0	2	1	0	0	1	2	0.23
Part-time	358	283 (79%)	56 (16%)	16 (4%)	1	1	1	0	0	0	0	0	0	0.28
Unemployed	1239	960 (77%)	212 (17%)	52 (4%)	7	3	3	0	0	0	0	0	2	0.32

[1] The number of person-days equals the number of households. This number does not include individuals who answered “Don’t Know” or did not give the number of baths.

[2] The year of birth is recorded in the database, however the actual birth month and day are not given. To calculate the actual age, the birth date is assumed to be July 1 of the year of birth.

[3] Overall frequency is defined as the total number of baths (including multiple showers) taken by everyone divided by the number of people in the population. In calculating the number of baths, bath frequencies recorded as greater than 10 were assumed equal to 11.

[4] Analyzed only respondents >=18 years of age.

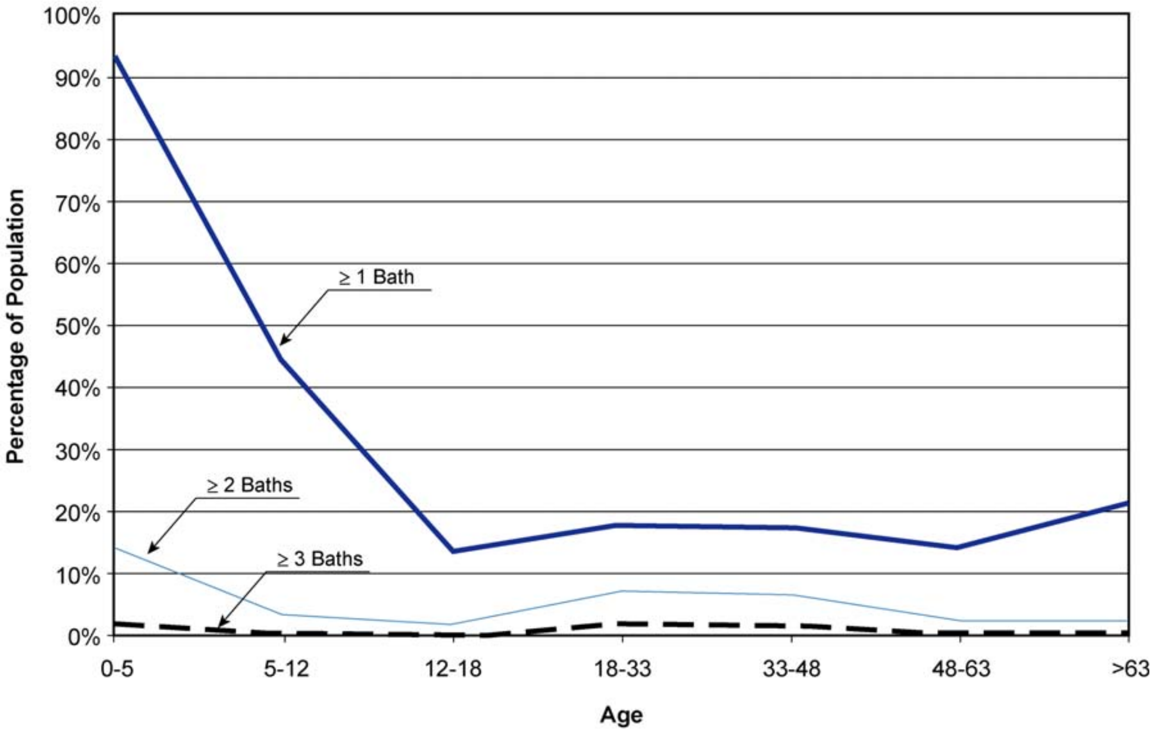


Figure 6-2. Comparison of Mean Bathing Frequency (baths/person/day) (self-taken or given to another) as a Function of Age, NHAPS.

6.7 Duration Analysis

6.7.1 NHAPS Shower Duration

NHAPS recorded information about shower duration in the variable SHTIME. The respondents were asked, “How long did you spend taking the shower(s) in total?”

Although the NHAPS database contains valuable information on showers, there are a few major difficulties with the data that may limit their usefulness for exposure modeling, or may dictate the need for alternative approaches to simulating the activity patterns. There are three major obstacles encountered in analyzing the NHAPS database. The first problem involves truncation of the data. The actual shower duration response was recorded provided the duration was 60 minutes or less. The respondents who reported a total duration of more than 60 minutes were counted as “greater than one hour.” For the purposes of evaluating the exposure to waterborne contaminants, individuals with long showers are likely to comprise the highly exposed tail portion of the exposure distribution, and therefore are an important segment of the population. Various means were examined to address this problem. It was discovered that defining showers recorded as “over one hour” as 61 minutes in duration did not significantly impact the results. Therefore, all showers over one minute in length were assumed to be 61 minutes in the analysis.

The second difficulty with NHAPS involves the manner in which the shower duration was recorded. The respondents were asked to estimate how much total (collective) time was spent in the shower the previous day. For people who took more than one shower, the duration of each individual shower was not given. After analysis, it was decided that the duration distribution should be based on only those individuals who reported one shower (discarding those who reported multiple showers) for the following reasons. In the case of multiple showers, if the total shower duration was divided by the number of showers to get an average shower length, this would apply inappropriate weight to the distribution. Furthermore, many multiple shower durations totaled over 60 minutes, meaning they were recorded as "greater than one hour." Because the actual total is unknown, it would be impossible to properly estimate the average shower lengths. Therefore, the individuals who reported taking multiple showers during the day were taken out of the analysis dataset.

The third problem with the data is revealed by the histogram of the shower durations for the entire population of individuals in the NHAPS database who took a shower, presented in Figure 6-3. The data, shown in Figure 6-3, exhibited clustering around 5, 10, 15, 20, and 30 minutes. In the analysis, 89% of the reported showers have durations reported at a 5-minute interval. The clustered values are most likely a result of a tendency of the respondents to round to the nearest 5 minutes. It is hypothesized that the actual values for those reported at a given 5 minute increment are distributed in some unknown manner around the 5-minute increment. The objective is to fit the data to a continuous distribution, thereby, in effect, redistributing the data.

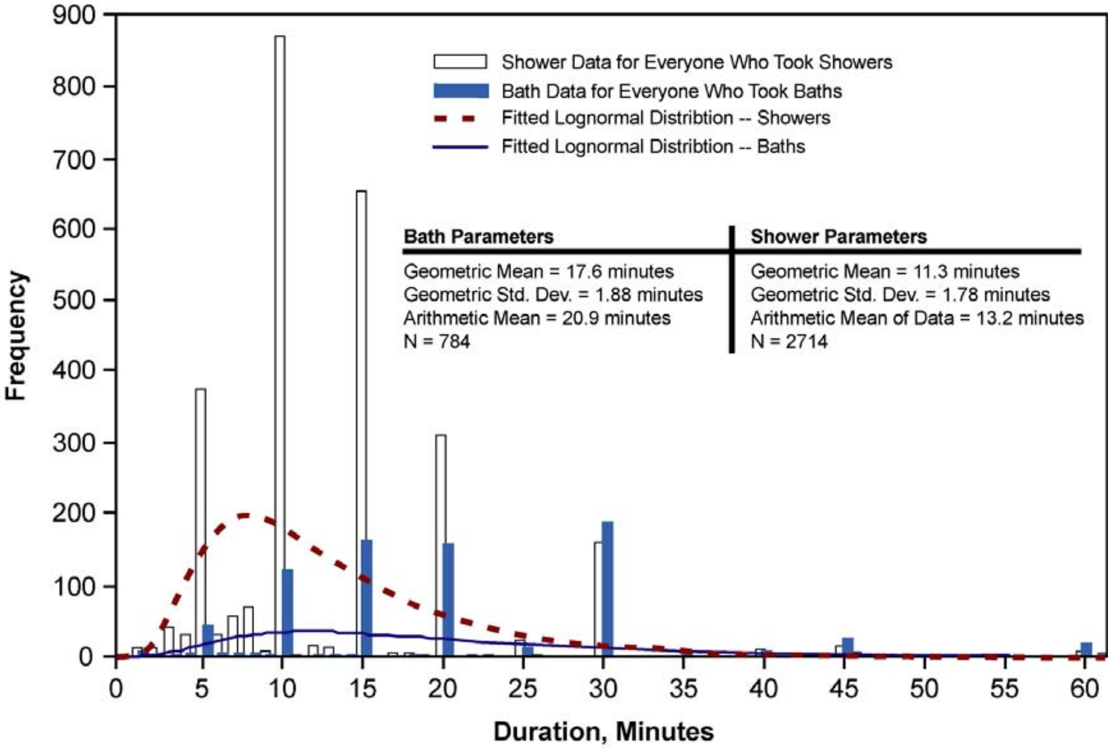


Figure 6-3. Histogram of Shower and Bath Duration and Fitted Lognormal Distribution for Entire Population, NHAPS.

6.7.2 REUWS Shower Duration

The REUWS database provides useful duration information based on actual water usage measured by the household water meter (unlike NHAPS, where water-use durations are based on personal memory recall, often rounded to the nearest five minutes). The REUWS database contains shower duration data derived from disaggregating the household continuous flow traces (through the household water meter) into individual appliance-usage events and determining which of these events are showers.

In addition to the issues discussed in the earlier section on REUWS shower frequency analysis, another anomaly of the REUWS data set was the presence of showers of implausibly short durations. Approximately 1.2% (40 out of 3281 events) of the single adult user shower events were one minute or less in duration, with 0.3% (10 events) lasting 30 seconds or less. Although some of these events may be due to the usage of the shower faucet for purposes other than showering, it is likely that most of these unusually short shower events are mislabeled. We have therefore opted to truncate this dataset to include only those events whose duration is greater than 60 seconds. The remaining dataset used in the following analyses includes 3241 events.

6.7.3 NHAPS Shower Duration Analysis and Results

The shower duration for the entire population was analyzed for all individuals who took one shower. This subset are those individuals who reported taking a shower (SHOWER variable), who also reported a shower frequency of 1 shower (SHOWER# variable), and reported a shower duration (SHTIME variable) greater than 0. There were 2747 individuals who reported taking one shower, (presented in Table 6-6), but only 2714 of these persons also reported a valid duration. Therefore, the dataset analyzed for shower duration contained 2714 persons (presented in Table 6-9). The resulting dataset was ranked and fitted to a lognormal distribution using the MLE technique described in Section 5. Because of the truncation issue described above, the log-probit technique was considered. However, an analysis of the impact of the truncated records on the parameters estimated by the MLE technique showed that, because of the relatively small number of truncated events, the impact was negligible.

Figure 6-4 presents the lognormal distribution fitted to the data for shower duration. In Figure 6-4, the data are normalized and agglomerated in five-minute increments to smooth the clustered data in order to better evaluate the fit of the lognormal distribution. Although there were 840 individuals who reported taking multiple showers, they were not included in the duration analysis for reasons discussed above.

This procedure was repeated for each demographic variable presented in Table 6-3. In each case, the dataset was sorted and condensed to include only the valid records for each respective demographic variable, removing records that contained invalid responses or records of people who refused to provide information about the given demographic variable. The results for the analysis as a function of gender are shown in Figure 6-5. Similarly, the results of the analysis as a function of Employment Status and Education are shown in Figures 6-6 and 6-7, respectively. The parameters of the fitted lognormal distribution resulting from the analysis of each demographic variable have been tabulated in Table 6-9.

6.7.4 REUWS Shower Duration Analysis and Results

The shower duration analysis was performed on the entire population in the REUWS dataset using the analysis technique described above for estimating the lognormal distribution parameters using the MLE. This distribution is presented in Figure 6-4. The REUWS shower duration distributions as functions of the various sub-categories of Employment Status, Education, and Income are presented in Figures 6-6, 6-7, and 6-8, respectively. The collective results from the analysis are tabulated in Table 6-9. (Note: this table is labeled as “Preliminary” because it is refined with significance testing and finalized in Table 6-18.)

6.7.5 NHAPS Bath Duration

NHAPS contains the variable BATIME with information on bath duration. The bath data in NHAPS has all the same problems as discussed in the NHAPS shower duration problems section above, including truncation of the data, clustering of the responses, and combined durations. In summary, the respondents were asked to give the total amount of time spent in the bath (or giving a bath) on the previous day. If someone took multiple baths that day, it was not possible to identify the duration of each separate bath. Therefore, as with the shower duration analysis, only those persons who took one bath and gave a valid duration were used in the analysis.

Table 6-9. Preliminary Summary of Parameters of Fitted Lognormal Distributions as Function of Demographic Group for Shower Durations, NHAPS and REUWS

	No. of Persons			Lognormal Distribution Parameters				Arithmetic Mean[3] (minutes)	
		REUWS[2]		Geometric Mean (minutes)		Geometric Std. Dev.			
Population Group	**NHAPS[1]**	**Events**	**Users**	**NHAPS**	**REUWS**	**NHAPS**	**REUWS**	**NHAPS[3]**	**REUWS**
OVERALL	2714	3241	151	11.3	6.8	1.78	1.64	13.2	7.7
GENDER									
Male	1250	—	—	11.1	—	1.79	—	13.1	—
Female	1462	—	—	11.4	—	1.78	—	13.3	—
AGE[4]									
0-5 yrs.	33	—	—	15.1	—	1.79	—	17.4	—
5-12 yrs.	117	—	—	12.4	—	1.75	—	14.5	—
12-18 yrs.	208	—	—	13.6	—	1.79	—	16.1	—
18-33 yrs.	685	—	—	11.8	—	1.70	—	13.6	—
33-48 yrs.	725	—	—	11.1	—	1.80	—	13.0	—
48-63 yrs.	503	—	—	10.2	—	1.78	—	11.9	—
>63 yrs.	398	—	—	10.5	—	1.86	—	12.5	—
RACE									
White	2295	—	—	11.0	—	1.77	—	12.9	—
Black	197	—	—	12.5	—	1.80	—	14.8	—
Other	191	—	—	12.8	—	1.87	—	15.4	—
EDUCATION[5]									
Pre-High School	234	270	13	14.1	7.2	1.75	1.65	16.4	8.2
High School Grad	1362	1545	74	11.3	6.4	1.77	1.64	13.1	7.2
College Grad	743	1146	51	9.7	7.3	1.74	1.63	11.1	8.2

[1] This number includes only those people who took only one shower and also provided an estimate of its duration.

[2] If the space is left blank, the data source did not contain information for these variables.

[3] Assumes data over 60 minutes are 61 minutes.

[4] Year of birth is recorded in the database, however actual birth month and day are not given. To calculate the actual age, the birth date is assumed to be July 1 of the year of birth.

[5] Analyzed only respondents >=18 years of age.

Table 6-9. *Continued*

	No. of Persons			Lognormal Distribution Parameters				Arithmetic Mean[3] (minutes)	
		REUWS[2]		Geometric Mean (minutes)		Geometric Std. Dev.			
Population Group	**NHAPS[1]**	**Events**	**Users**	**NHAPS**	**REUWS**	**NHAPS**	**REUWS**	**NHAPS[3]**	**REUWS**
HOUSING									
Single Family	1832	2495	126	11.1	6.8	1.79	1.63	13.0	7.7
Apartment[6]	586	270	7	11.6	6.8	1.76	1.73	13.5	7.9
Townhouse	140	262	8	10.7	6.9	1.78	1.60	12.6	7.7
ADULTS									
1-2 adults	2223	—	—	11.1	—	1.78	—	13.0	—
3-4 adults	459			11.9		1.80		14.1	
>4 adults	19	—	—	13.4	—	1.68	—	15.3	—
EMPLOYMENT									
Employed[7]	1578	1650	61	10.8	7.0	1.76	1.63	12.4	7.9
Unemployed	725	1439	83	11.6	6.5	1.84	1.65	13.7	7.4
INCOME									
$0K-30K	—	1232	58	—	6.4	—	1.62	—	7.2
$30K-50K	—	849	39	—	7.0	—	1.66	—	8.0
$50K-100K	—	409	20	—	7.6	—	1.63	—	8.5
>$100K	—	78	4	—	5.9	—	1.59	—	6.7

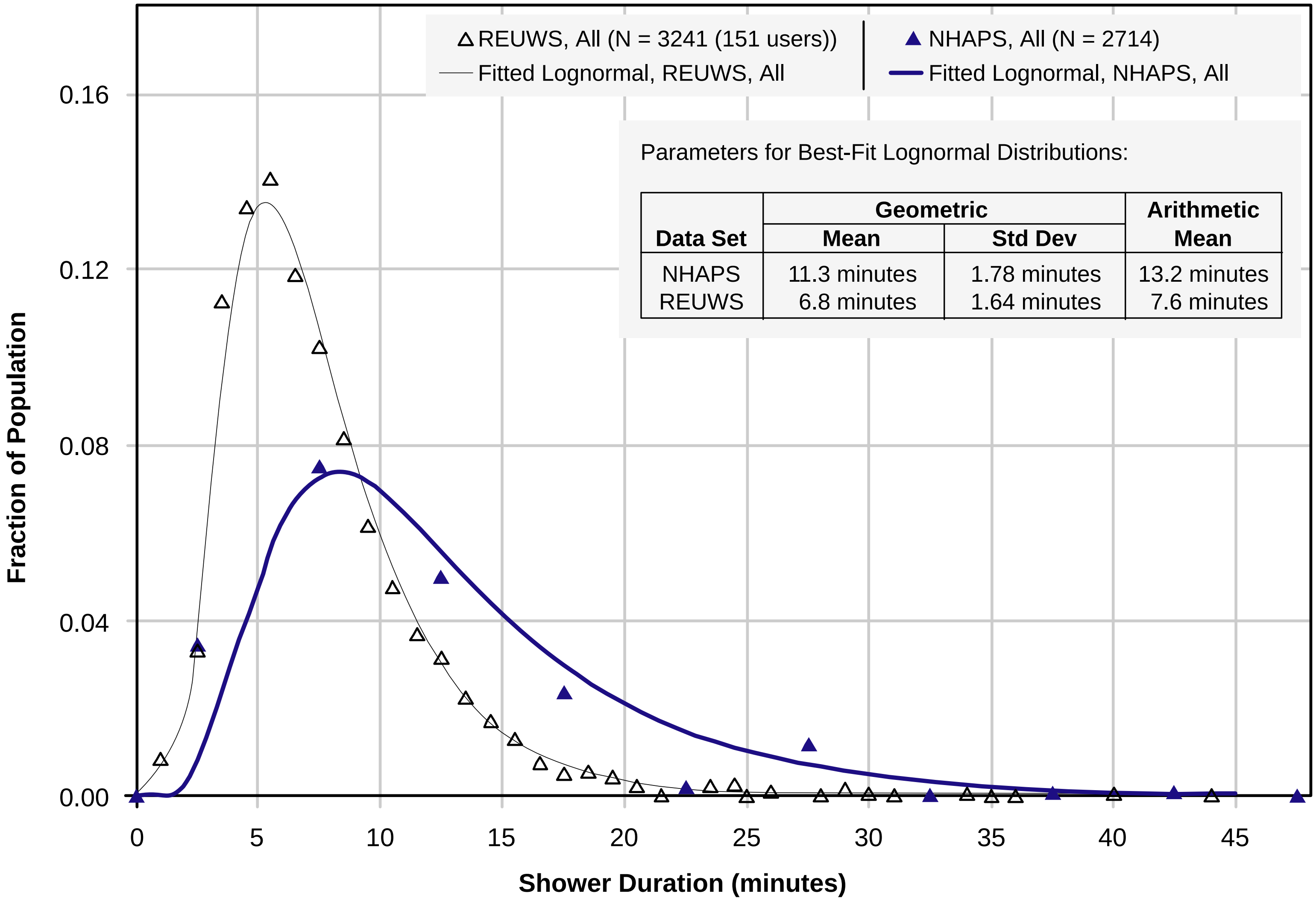
[1] This number includes only those people who took only one shower and also provided an estimate of its duration.

[2] If the space is left blank, the data source did not contain information for these variables.

[3] Assumes data over 60 minutes are 61 minutes.

[6] For REUWS, apartments, duplexes, and triplexes are included in this category.

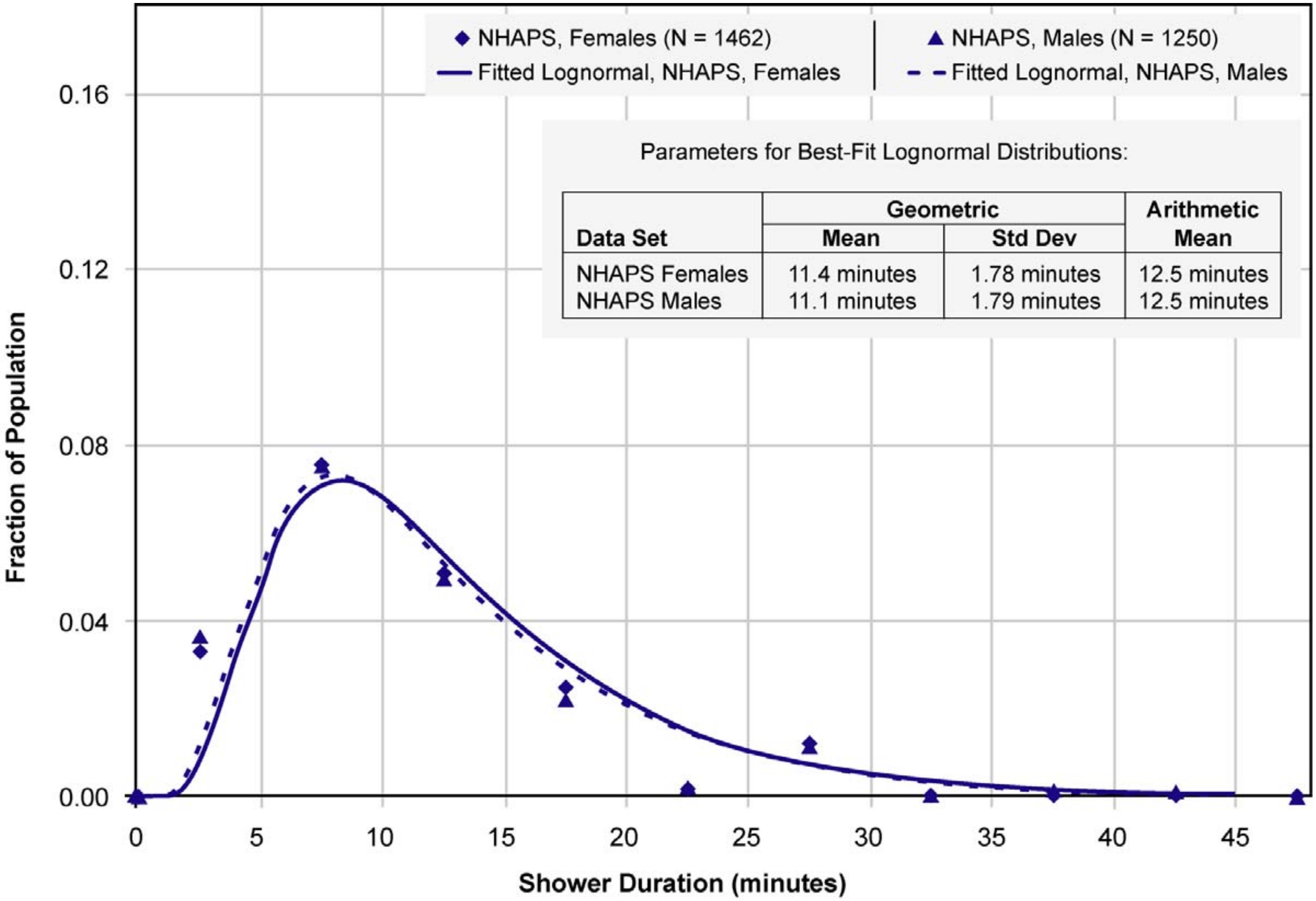
[7] Includes full-time and part-time workers for NHAPS. Includes only individuals employed full-time outside the home for REUWS.



Parameters for Best-Fit Lognormal Distributions:

Data Set	Geometric Mean	Geometric Std Dev	Arithmetic Mean
NHAPS	11.3 minutes	1.78 minutes	13.2 minutes
REUWS	6.8 minutes	1.64 minutes	7.6 minutes

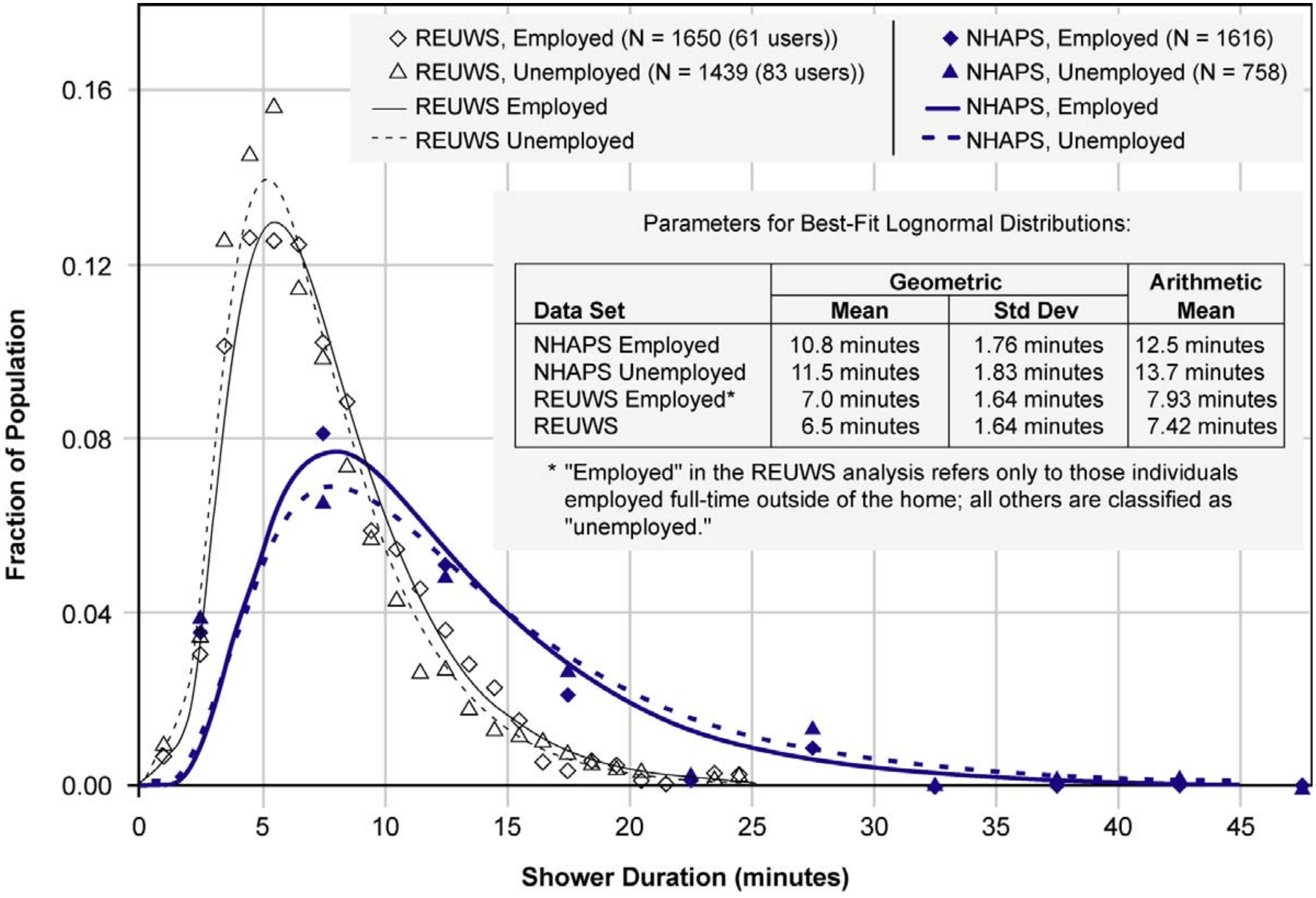
Figure 6-4. Fitted Lognormal for Shower Duration Data for Entire Data Sets, NHAPS and REUWS.



Parameters for Best-Fit Lognormal Distributions:

Data Set	Geometric		Arithmetic
	Mean	Std Dev	Mean
NHAPS Females	11.4 minutes	1.78 minutes	12.5 minutes
NHAPS Males	11.1 minutes	1.79 minutes	12.5 minutes

Figure 6-5. Fitted Lognormal for Shower Duration Data based on Gender, NHAPS.

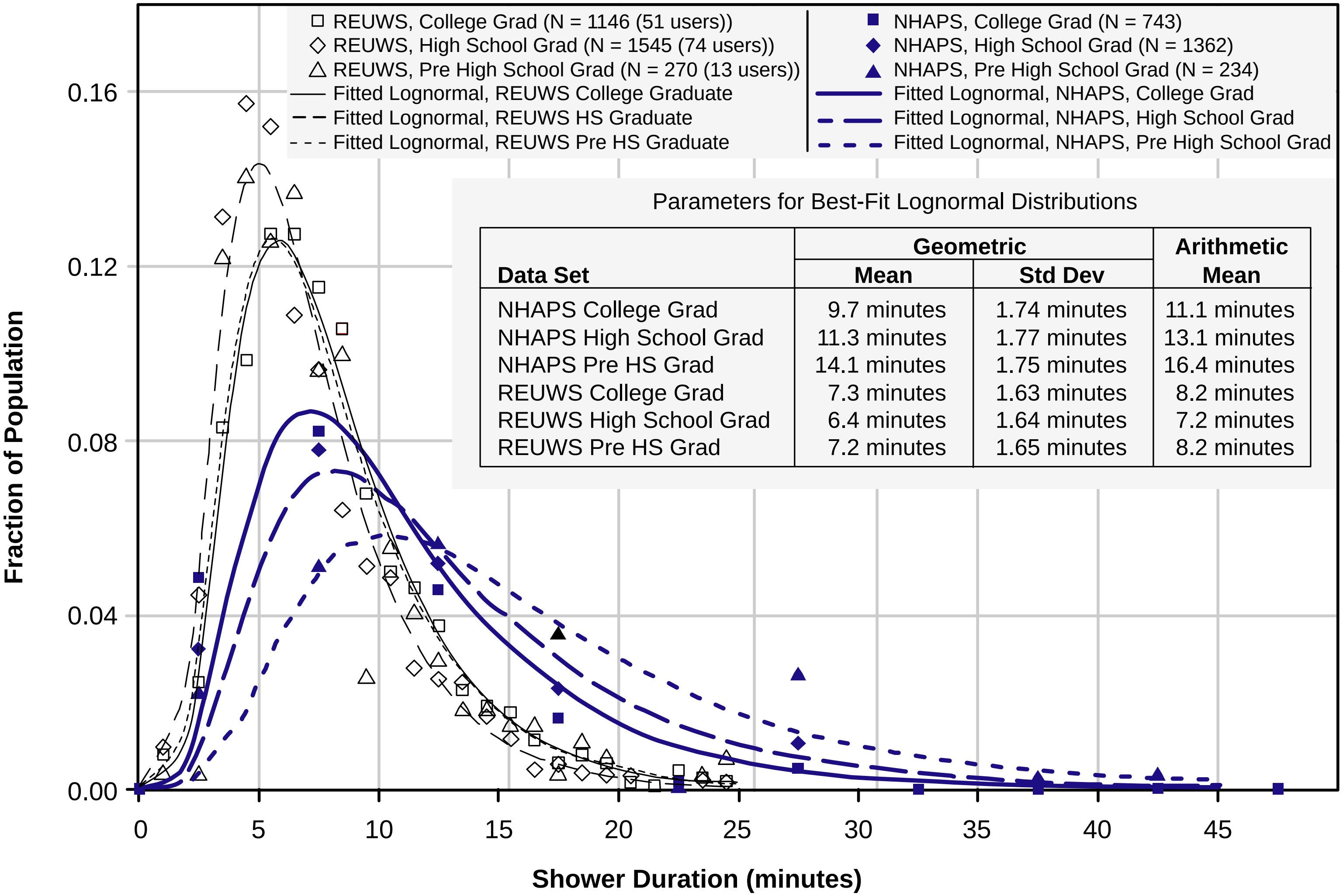


Parameters for Best-Fit Lognormal Distributions:

	Geometric		Arithmetic
Data Set	Mean	Std Dev	Mean
NHAPS Employed	10.8 minutes	1.76 minutes	12.5 minutes
NHAPS Unemployed	11.5 minutes	1.83 minutes	13.7 minutes
REUWS Employed*	7.0 minutes	1.64 minutes	7.93 minutes
REUWS	6.5 minutes	1.64 minutes	7.42 minutes

* "Employed" in the REUWS analysis refers only to those individuals employed full-time outside of the home; all others are classified as "unemployed."

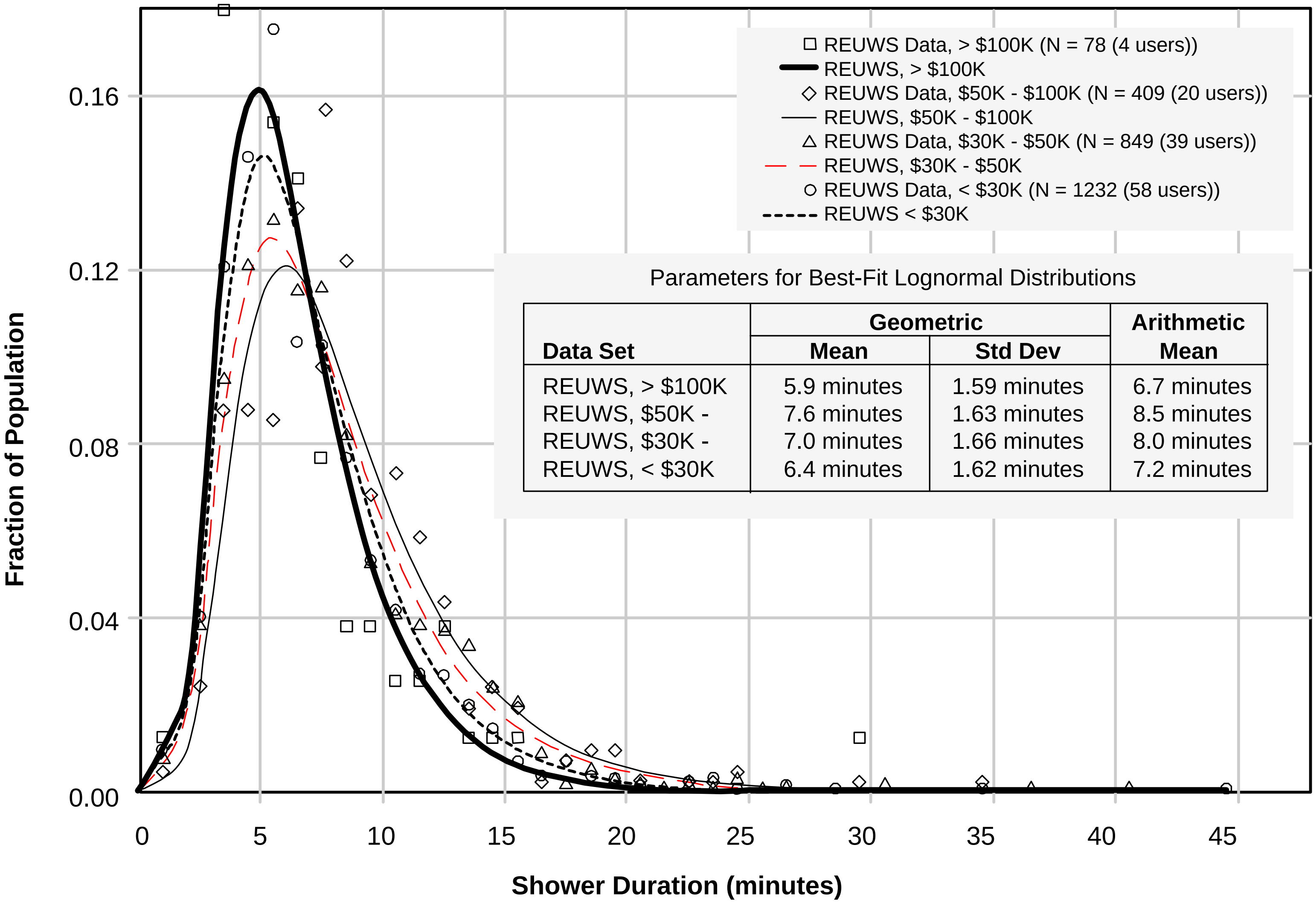
Figure 6-6. Fitted Lognormal for Shower Duration Data based on Employment Status, NHAPS and REUWS.



Parameters for Best-Fit Lognormal Distributions

Data Set	Geometric		Arithmetic
	Mean	Std Dev	Mean
NHAPS College Grad	9.7 minutes	1.74 minutes	11.1 minutes
NHAPS High School Grad	11.3 minutes	1.77 minutes	13.1 minutes
NHAPS Pre HS Grad	14.1 minutes	1.75 minutes	16.4 minutes
REUWS College Grad	7.3 minutes	1.63 minutes	8.2 minutes
REUWS High School Grad	6.4 minutes	1.64 minutes	7.2 minutes
REUWS Pre HS Grad	7.2 minutes	1.65 minutes	8.2 minutes

Figure 6-7. Fitted Lognormal for Shower Duration Data based on Education, NHAPS and REUWS.



Parameters for Best-Fit Lognormal Distributions

Data Set	Geometric Mean	Geometric Std Dev	Arithmetic Mean
REUWS, > $100K	5.9 minutes	1.59 minutes	6.7 minutes
REUWS, $50K -	7.6 minutes	1.63 minutes	8.5 minutes
REUWS, $30K -	7.0 minutes	1.66 minutes	8.0 minutes
REUWS, < $30K	6.4 minutes	1.62 minutes	7.2 minutes

Figure 6-8. Fitted Lognormal for Shower Duration Data based on Income, REUWS.

In addition, there was a problem with how the NHAPS questions regarding baths were phrased: "How many baths did you take or give yesterday?" and "How long did you spend taking or giving the bath(s) in total?" The exposure characteristics for taking a bath are different from those for giving a bath. However, the data do not distinguish between the two. For example, a mother giving her baby a bath in a small portable tub would be recorded as a "bath" in this question, though this scenario, from an exposure perspective, is significantly different from the scenario where the mother takes a bath herself.

6.7.6 NHAPS Bath Duration Analysis and Results

The same general techniques, described in the shower duration section above, were used for the analysis of the bath duration variable. This procedure was conducted for each demographic variable presented in Table 6-3. In each case, the dataset was sorted and condensed, retaining only those persons who took one bath and who gave an estimate of their bath duration. (There were 800 people who took only one bath that day, but 16 of them reported they didn't know its duration). Similar to the shower duration estimations, respondents tended to estimate their bath durations to the closest five-minute interval. The histogram shown in Figure 6-3 displays the clustering of the data around 5, 10, 15, 20 and 30 minutes. Of the 784 people who took only one bath and also provided an estimate of its duration, 95.2% have durations reported at a 5-minute interval. In order to adjust the data for this clustering effect, the data were fit to a continuous lognormal distribution. The maximum likelihood estimator technique for fitting the data to a lognormal distribution was used, as described above in the Analysis Techniques section. The parameters of the fitted lognormal distribution for NHAPS bath durations for each demographic variable have been tabulated in Table 6-10. (Note: this table is labeled as "Preliminary" because it is refined with significance testing and finalized in Table 6-19.)

Table 6-10. Preliminary Summary of Parameters of Fitted Lognormal Distributions as Function of Demographic Group for Bath Durations, NHAPS

Population Group	Number of Persons[1]	Parameters of Fitted LN Distribution: Geometric Mean (minutes)	Parameters of Fitted LN Distribution: Geometric Std. Dev. (minutes)	Arithmetic Mean[2] (minutes)
OVERALL	784	17.6	1.88	20.9
GENDER				
Male	291	17.2	1.95	20.7
Female	493	17.8	1.86	21.0
AGE[3]				
0-5 yrs.	180	19.8	1.88	23.2
5-12 yrs.	116	18.6	1.67	20.8
12-18 yrs.	39	21.6	1.63	24.0
18-33 yrs.	111	17.4	1.82	20.5
33-48 yrs.	116	17.5	2.03	21.7
48-63 yrs.	86	15.3	1.97	18.4
> 63 yrs.	129	15.0	2.59	18.2
RACE				
White	622	17.3	1.92	20.6
Black	106	19.5	1.79	22.7
Other	53	18.4	1.80	21.3

[1] This number includes only people who took only one bath and also provided as estimate of its duration.

[2] Assumes data over 60 minutes are 61 minutes.

[3] The year of birth is recorded in the database, however the actual birth month and day are not given. To calculate the actual age, the birth date is assumed to be July 1 of the year of birth.

Table 6-10. *Continued*

Population Group	Number of Persons[1]	Parameters of Fitted LN Distribution: Geometric Mean (minutes)	Parameters of Fitted LN Distribution: Geometric Std. Dev. (minutes)	Arithmetic Mean[2] (minutes)
EDUCATION				
Pre High School	63	19.6	1.95	23.4
High School Grad	273	15.8	1.93	19.3
College Grad	110	15.5	1.92	18.8
HOUSING				
Single-Family	545	17.1	1.82	20.0
Apartment	144	19.1	1.99	23.2
Townhouse	46	16.2	2.32	20.9
ADULTS				
1 - 2 adults	698	17.4	1.90	20.8
3 - 4 adults	79	19.3	1.73	22.1
> 4 adults	4	20.6	1.68	22.5
EMPLOYMENT[4]				
Employed	234	15.9	1.90	19.0
Unemployed	206	16.6	1.99	20.4

[1] This number includes only people who took only one bath and also provided as estimate of its duration.

[2] Assumes data over 60 minutes are 61 minutes.

[3] The year of birth is recorded in the database, however the actual birth month and day are not given. To calculate the actual age, the birth date is assumed to be July 1 of the year of birth.

[4] Analyzed only respondents >=18 years of age. "Employed" includes full-time and part-time workers.

6.7.7 REUWS Bath Duration

The REUWS database does not contain information on the duration of bathing events. Because the data were compiled from household water-use meters, the durations of the events labeled as baths are the durations that the bath faucet was in use. Thus REUWS contains data on the time it took to fill the tub, but not on how long the person bathed, nor on any time lag between drawing bath water itself and bathing (which would have an impact on the contaminant concentration in the water).

6.7.8 Analysis of Significance

The analysis of shower and bath duration behavior is presented as a function of a variety of demographic variables. In some cases, the behavior appears to vary significantly (e.g., shower durations as a function of age), while in other cases there is little difference in behavior across demographic groups (e.g., shower durations as a function of type of housing). This section presents a statistical analysis of the significance of the differences in showering duration and bathing duration behaviors presented in sections 6.7.1 through 6.7.7.

The Chi-square test (DeGroot, 1987) initially was used to compare the behavior of each sub-population to that of the overall population and to examine the differences between distinct subpopulations. However, in the latter case, the Chi-square test was found to be sensitive to which group was chosen as the base group (i.e., when comparing two groups, the results were not always consistent when the base group was switched). In addition, the Chi-square test proved to be inappropriate for some of the analyses because of the small sample size.

Because the Chi-square test was deemed inappropriate, alternative tests of significance were utilized. First, for each demographic group, an analysis of variance (ANOVA, DeGroot, 1987) was conducted to determine whether the differences across group means were statistically significant. For demographic groups with multiple subgroups (e.g., education has 3 categories, less than high school, high school graduate, and college graduate), if the null hypothesis that the means were the same was rejected, then the Tukey multiple comparison test (NIST/SEMATECH, 2002) was used to determine which inter-group differences were statistically significant. Because the fitted distributions are lognormal, the analyses were conducted by first transforming the data into log space to allow the comparisons to be conducted in normal space.

6.7.8.1 Analysis of Variance (ANOVA)

ANOVA uses the F statistic to determine whether there exists a significant difference across the means of two or more samples. The ANOVA procedure assumes that the observations are independent and normally distributed. Since the data are positively constrained, these assumptions are reasonable for this transformed data set. The results were used to accept or reject the hypothesis that the means of the two distributions are equal.

The ANOVA procedure was performed on the bathing and showering duration results, given in Tables 6-9 and 6-10 in the previous section. A significance level of 0.20 was used (as opposed to a more typical value such as 0.05) because it is preferable to treat population groups separately in cases where they are potentially different. Small differences in showering and bathing durations could have a significant affect on exposure, which argues in favor of a higher significance level. The results of the analyses are given in Tables 6-11, 6-12, and 6-13.

Table 6-11. ANOVA Summary for Analysis of NHAPS Showering Duration

Group	Significance of Difference Between Subgroup Means	Accept or Reject Null Hypothesis*
Gender	0.297	Accept
Age	0.000	Reject
Race	0.000	Reject
Education	0.000	Reject
Housing	0.159	Reject
Number of Adults	0.022	Reject
Employment	0.004	Reject

* Null Hypothesis: Subgroup mean durations are the same as the overall group durations. Chosen Significance level is 0.20. Although this is higher than typically used, it is preferable to treat population groups separately if potential exists that they are different.

Table 6-12. ANOVA Summary for Analysis of REUWS Showering Duration

Group	Significance of Difference Between Subgroup Means	Accept or Reject Null Hypothesis*
Education	0.000	Reject
Income	0.000	Reject
Employment	0.000	Reject

* Null Hypothesis: Subgroup mean durations are the same as the overall group durations. Chosen Significance level is 0.20. Although this is higher than typically used, it is preferable to treat population groups separately if potential exists that they are different.

Table 6-13. ANOVA Summary for Analysis of NHAPS Bathing Duration

Group	Significance of Difference Between Subgroup Means	Accept or Reject Null Hypothesis*
Gender	0.487	Accept
Age	0.001	Reject
Race	0.170	Reject
Education	0.0548	Reject
Housing	0.135	Reject
Number of Adults	0.348	Accept
Employment	0.503	Accept

* Null Hypothesis: Subgroup mean durations are the same as the overall group durations. Chosen Significance level is 0.20. Although this is higher than typically used, it is preferable to treat population groups separately if potential exists that they are different.

The results show that, with the exception of gender for both showering and bathing durations and employment for bathing durations, the demographic subgroup means are significantly different. The rejection of the null hypothesis indicates the need for multiple-comparison tests to determine which specific subgroup means are statistically significant.

6.7.8.2 Tukey Multiple Comparison Tests

The Tukey multiple comparison test is a commonly used multiple comparison procedure, and is also known as the "honestly significant difference test" or HSD test. The Tukey method is exact if sample sizes are the same in all groups and conservative when sample sizes are unequal (Tukey, 1949, NIST/SEMATECH, 2002). The Tukey multiple comparison test examines the significance of the differences in the inter-group means for variables with more than two subgroups (e.g., education has 3 categories, less than high school, high school graduate, and college graduate). The results of the Tukey multiple comparison analyses are given in Tables 6-14 through 6-16. As a basis for accepting or rejecting the null hypothesis, a significance level of 0.20 was used, for reasons discussed above. The comparisons that are rejected are shown with an asterisk (*) in Tables 6-14 through 6-16.

The results of the analysis of NHAPS shower duration behavior (Table 6-14) indicate that, for each subgroup, some refining of the categories can be performed without loss of distinctive characteristics. For example, it is clear that the three youngest age subgroups can be combined into one subgroup. Although the remaining results for the age group are somewhat mixed, a reasonable approach would be to combine the 18-33 and 33-48 age subgroups and to combine the groups older than 48 years into a single subgroup. For the race group, it appears that the white group is significantly different than other subgroups, but that the remaining subgroups can be combined. For the education group, each subgroup is significantly different. For the housing subgroup, people who occupy townhouses and single family homes appear to behave similarly, while those who occupy apartments behave differently. For the number of adults subgroup, two categories are apparent: 1-2 adults, and more than 2 adults.

The results of the analysis of REUWS shower duration behavior (Table 6-15) indicate that income plays a significant role. The results indicate that there are significant differences in behavior between the listed income categories except for the comparison between the lowest income subgroup ($0 - $30K) and the highest income subgroup (> $100K). For practical reasons, it is recommended that all subgroups remain separate. Similarly, in the education group, the results indicate that the lowest education level subgroup (Pre-High School) is similar to the highest education level subgroup (College Graduate), yet the High School Graduates behave significantly different from both other subgroups. Again, for practical reasons, it is recommended that the education subgroups remain separate.

Table 6-14. Summary of Tukey Multiple Comparison Test, Significance Levels for Subgroup Mean Shower Durations (NHAPS)

	Subgroup	5-12 yrs	12-18 yrs	18-33 yrs	33-48 yrs	48-63 yrs	>63 yrs
Age Group	0-5 yrs	0.612	0.958	0.221	**0.040***	**0.003***	**0.009***
	5-12 yrs	--	0.844	0.983	0.398	**0.013***	**0.073***
	12-18 yrs		--	**0.048***	**0.000***	**0.000***	**0.000***
	18-33 yrs			--	0.272	**0.000***	**0.013***
	33-48 yrs				--	**0.160***	0.742
	48-63 yrs					--	0.988

	Subgroup	Black	Other
Race Group	White	**0.010***	**0.002***
	Black	--	0.926

	Subgroup	HS Grad	College Grad
Education Group	Pre-HS	**0.000***	**0.000***
	HS Grad	--	**0.000***

	Subgroup	SF Home	Townhouse
Housing Group	Apartment	**0.191***	0.334
	SF Home	--	0.834

	Subgroup	3-4 Adults	>4 Adults
Num of Adults	1-2 Adults	**0.039***	0.352
	3-4 Adults	--	0.689

Note: The null hypothesis is that two subgroup mean durations are the same. Comparisons for which the null hypothesis was rejected at a significance level of 0.20 are indicated with an asterisk (*).

Table 6-15. Summary of Tukey Multiple Comparison Test, Significance Levels for Subgroup Mean Shower Durations (REUWS)

	Subgroup	$30K-50K	$50K-100K	>$100K
Income Group	$0K-30K	**0.000***	**0.000***	0.579
	$30K-50K	--	**0.039***	**0.022***
	$50K-100K	--	--	**0.000***

	Subgroup	HS Grad	College Grad
Education Group	Pre-HS	**0.001***	0.795
	HS Grad	--	**0.000***

Note: The null hypothesis is that two sub-group mean durations are the same. Comparisons for which the null hypothesis was rejected at a significance level of 0.20 are indicated with an asterisk (*).

Table 6-16. Summary of Tukey Multiple Comparison Test, Significance Levels for Subgroup Mean Bath Durations (NHAPS)

	Subgroup	5-12 yrs	12-18 yrs	18-33 yrs	33-48 yrs	48-63 yrs	>63 yrs
Age Group	0-5 yrs	0.982	0.987	0.616	0.650	**0.027***	**0.002***
	5-12 yrs	--	0.865	0.984	0.989	0.285	0.097*
	12-18 yrs	--	--	0.522	0.547	**0.066***	**0.025***
	18-33 yrs	--	--	--	1.000	0.771	0.512
	33-48 yrs	--	--	--	--	0.725	0.451
	48-63 yrs	--	--	--	--	--	1.000

	Subgroup	Black	Other
Race Group	White	**0.156***	0.825
	Black	--	0.793

Note: The null hypothesis is that two subgroup mean durations are the same. Comparisons for which the null hypothesis was rejected at a significance level of 0.20 are indicated with an asterisk (*).

	Subgroup	HS Grad	College Grad
Education Group	Pre-HS	**0.061***	**0.071***
	HS Grad	--	0.959

	Subgroup	SF Home	Townhouse
Housing Group	Apartment	**0.156***	0.285
	SF Home	--	0.850

	Subgroup	3-4 Adults	>4 Adults
Num of Adults	1-2 Adults	0.358	0.858
	3-4 Adults	--	0.979

The results of the analysis of NHAPS bath duration behavior (Table 6-16) are very similar to those for the NHAPS shower duration behavior. Although the age group results indicate that ages 0-48 could reasonably be combined, it is reasonable to keep the same three subgroups that were identified by the showering analysis (0-18, 18-48, and > 48). Likewise for the race group, the results indicate that a significant difference exists between the behaviors of the white and black subgroups, while the other subgroup could be combined with either. It, therefore, is reasonable to keep the same subgroups as chosen in the shower duration analysis (white and other). As with the shower duration behavior, each education subgroup is significantly different for bath duration behavior. For the housing subgroups, the results are again similar to the shower duration analysis and indicate that the same two subgroups are appropriate (Apartments and Other). The results also indicate that there are no significant differences across subgroups for the number of adults variable; thus this variable can be eliminated for bathing behavior.

The results of the Tukey multiple comparison analysis indicates that a modified set of subgroups are appropriate. The modified list of subgroups is presented in Table 6-17.

Table 6-17. Modified List of Relevant Subgroups Based on ANOVA and Tukey Multiple Comparison Analysis

Main Group	Gender	Age (yrs)	Race	Education	Housing	Adults*	Employment	Income
Sub-groups	None	0–18	White	Pre High School	Apartments	1-2	None	0-30K
		18–48	Other	High School Graduate	Single Family and Townhouses	> 2		30-50K
		> 48		College Graduate				50-100K
								>100K

* The list for number of adults applies to showering duration. This subgroup is eliminated for bath duration.

6.7.9. Summary of Shower and Bathing Duration Parameters for Modified Set of Demographic Groups

The significance analysis presented in section 6.7.8 yielded a modified list of subgroups as presented in Table 6-17. These demographic groups were determined to have mean values significantly different than the overall population and the other subgroups within the same main demographic group. The bath and shower duration analyses presented in Tables 6-9 and 6-10 are repeated for the modified list of subgroups, and the results are presented in Tables 6-18 and 6-19.

6.8 REUWS Shower and Bath Volume and Flow Rate Data

Along with event durations, REUWS also includes the event volumes and flow rates. These values are important for exposure assessment calculations as the emission rate of the contaminant is related to the volume and flow rate of water. The REUWS shower volumes for the entire dataset of single and multiple adult households (no children) are fit to a lognormal distribution using the MLE technique, as shown in Figure 6-9. The REUWS shower flow rates for the same population are fit to a lognormal distribution also using the MLE technique, as shown in Figure 6-10. The REUWS bath volumes were not analyzed because the data may not be accurate as people sometimes add small amounts of water to the tub after the main fill event to adjust the volume or temperature. The REUWS bath faucet flow rates are fit to a lognormal distribution in Figure 6-11.

6.9 Discussion and Conclusions

Analysis of the showering and bathing data of NHAPS and REUWS reveals vast differences between results from the two databases; however, these discrepancies can be explained by examining the strengths and weaknesses of each. For reasons discussed above, the NHAPS frequency data are believed to be more reliable than REUWS frequency data, while REUWS duration data are believed to be more reliable than NHAPS duration data. The reasons for this lie within the manner in which the databases were compiled. NHAPS was compiled from a statistically representative nationwide telephone survey, where respondents were asked to recall their activities during the previous 24 hours. In contrast, REUWS was compiled from direct mechanical measurements of water usage logged at household water meters. The total water flow record was later disaggregated into individual appliance water uses based on a general knowledge of each appliance’s water-use characteristics and the water appliance signatures.

Table 6-18. Final Summary of Parameters of Fitted Lognormal Distributions as Function of Demographic Group for Shower Durations, NHAPS and REUWS

	No. of Persons			Lognormal Distribution Parameters				Arithmetic Mean (minutes)	
		REUWS[2]		Geometric Mean (minutes)		Geometric Std. Dev. (minutes)			
Population Group	**NHAPS[1]**	**Events**	**Users**	**NHAPS**	**REUWS**	**NHAPS**	**REUWS**	**NHAPS[3]**	**REUWS**
OVERALL	2714	3241	151	11.3	6.8	1.78	1.64	13.2	7.7
AGE[4]									
0-18 yrs	358	--	--	13.3	--	1.79	--	15.7	--
18-48 yrs	1411	--	--	11.5	--	1.75	--	13.3	--
>48 yrs	900	--	--	10.3	--	1.82	--	12.1	--
RACE									
White	2295	--	--	11.0	--	1.77	--	12.9	--
Other	388	--	--	12.6	--	1.84	--	15.1	--
EDUCATION[5]									
Pre-High School	234	270	13	14.1	7.2	1.75	1.65	16.4	8.2
High School Grad	1362	1545	74	11.3	6.4	1.77	1.64	13.1	7.2
College Grad	743	1146	51	9.7	7.3	1.74	1.63	11.1	8.2
HOUSING									
Single Fam./Townhouse	1972	2757	134	11.0	6.8	1.79	1.63	12.9	7.7
Apartment[6]	586	270	7	11.6	6.8	1.77	1.73	13.5	7.9
ADULTS									
1-2 adults	2223	--	--	11.1	--	1.79	--	13.0	--
>3 adults	478	--	--	12.0	--	1.80	--	14.1	--
INCOME									
$0K-30K	--	1232	58	--	6.4	--	1.62	--	7.2
$30K-50K	--	849	39	--	7.0	--	1.66	--	8.0
$50K-100K	--	409	20	--	7.6	--	1.63	--	8.5
>$100K	--	78	4	--	5.9	--	1.59	--	6.7

[1] This number includes only those people who took only one shower and also provided an estimate of its duration.

[2] If the space is left blank, the data source did not contain information for these variables.

[3] Assumes data over 60 minutes are 61 minutes.

[4] Year of birth is recorded in the database, however actual birth month and day are not given. To calculate actual age, birth date is assumed to be July 1.

[5] Analyzed only respondents >=18 years of age.

[6] For REUWS, apartments, duplexes and triplexes are included in this category.

Table 6-19. Final Summary of Parameters of Fitted Lognormal Distributions as Function of Demographic Group for Bath Durations, NHAPS

Population Group	Number of Persons[1]	Parameters of Fitted LN Distribution Geometric Mean (minutes)	Geometric Std. Dev. (minutes)	Arithmetic Mean[2] (minutes)
OVERALL	784	17.6	1.88	20.9
AGE[3]				
0-18 yrs	335	19.5	1.79	22.5
18-48 yrs	227	17.5	1.92	21.1
>48 yrs	215	15.0	1.93	18.3
RACE				
White	622	17.3	1.92	20.6
Other	159	19.1	1.75	22.2
EDUCATION				
Pre High School	63	19.6	1.95	23.4
High School Graduate	273	15.8	1.93	19.3
College Graduate	110	15.5	1.92	18.8
HOUSING				
Single-Family/Townhouse	591	17.0	1.86	20.1
Apartment	144	19.1	1.99	23.2

[1] This number includes only people who took only one bath and also provided an estimate of its duration.

[2] Assumes data over 60 minutes are 61 minutes.

[3] The year of birth is recorded in the database, however the actual birth month and day are not given. To calculate the actual age, the birth date is assumed to be July 1 of the year of birth.

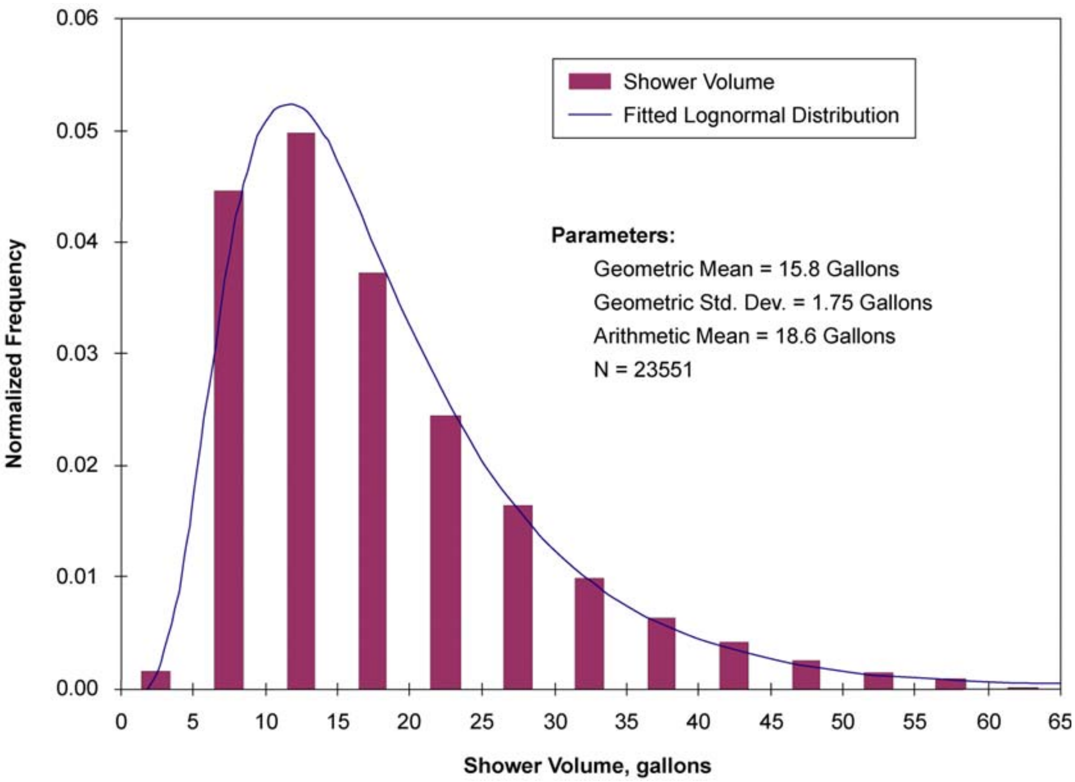


Figure 6-9. Distribution of Water Volumes for Showers, REUWS.

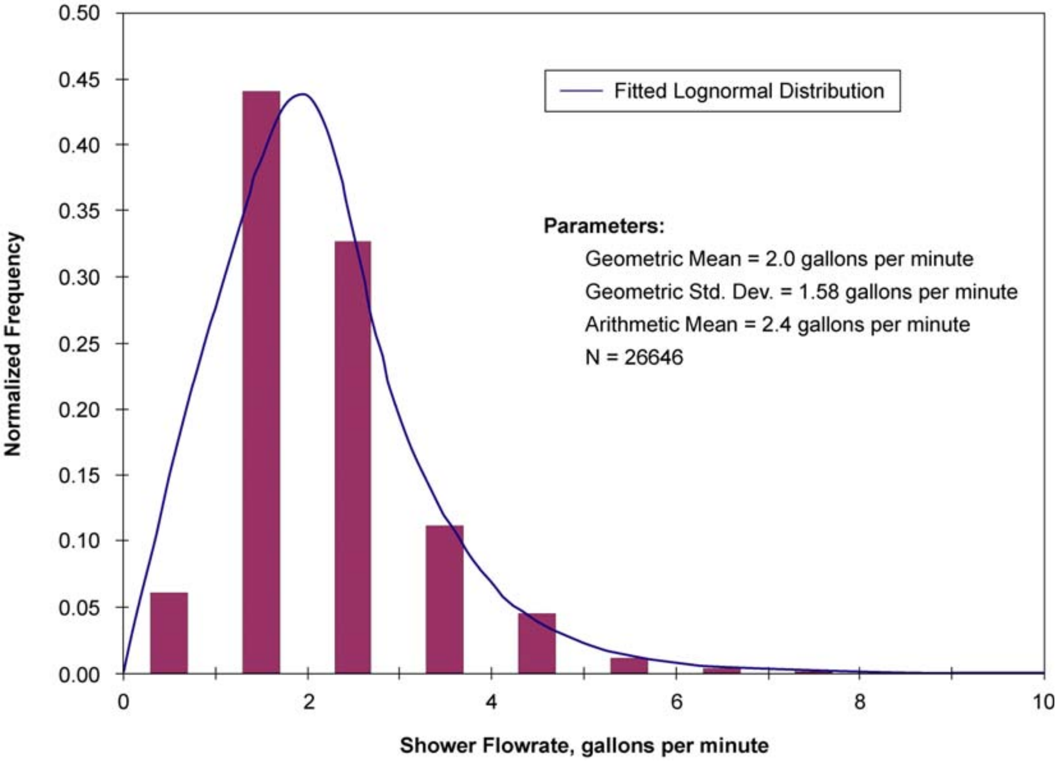


Figure 6-10. Distribution of Water Flow Rates for Showers, REUWS.

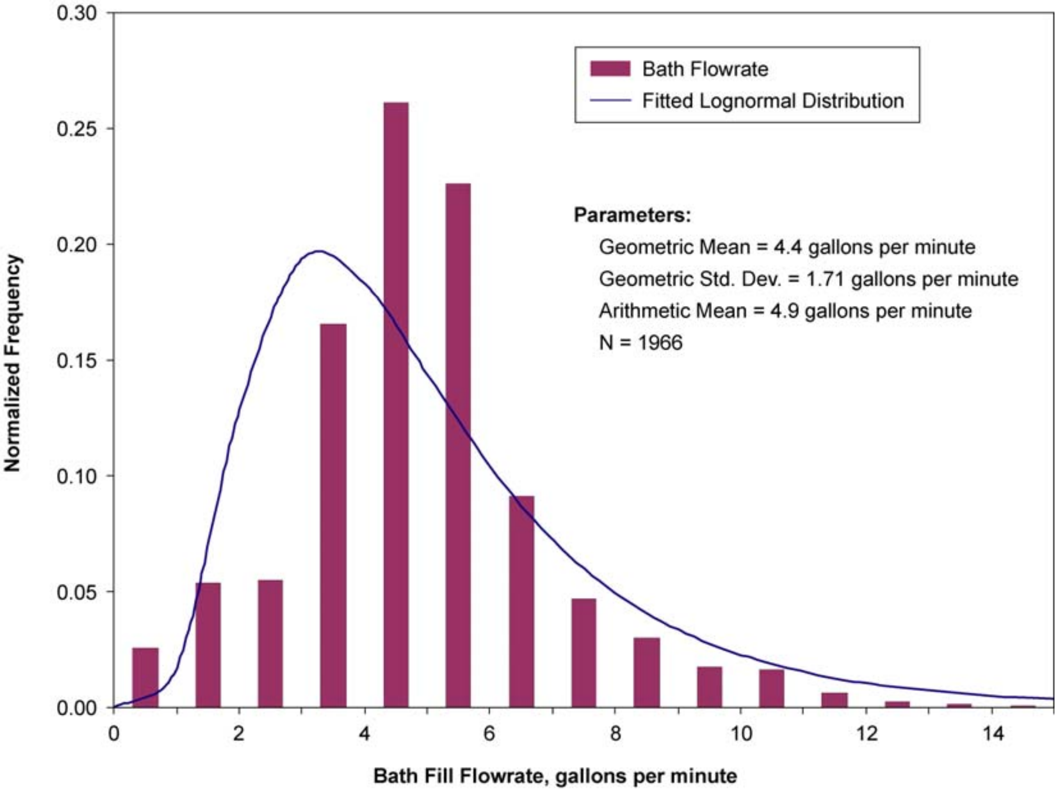


Figure 6-11. Distribution of Water Flow Rates for Baths, REUWS.

In comparing shower frequencies, NHAPS reports that people take 0.98 showers per person-day (spd), while REUWS reports that people take 0.82 spd. NHAPS reports that, overall, 78% of the population took at least one shower in the given day, while REUWS reports that only 56% took at least one shower. The frequencies reported in NHAPS generally agree with previous studies, while the REUWS data is significantly lower. The Brown and Caldwell (1984) study reports 74% of the population take a shower in a given day and the Konen and Anderson (1993) study reports 70%. This supports the conclusion that people are able to accurately recall the number of showers or baths they took during the previous day, because showering and bathing events are relatively infrequent. This in turn, makes NHAPS shower and bath frequency data quite reliable. However, in contrast, REUWS has a few integral limitations that make it less reliable in reference to frequency data. First, with REUWS it is impossible to discern which person is performing which water uses. Therefore, only the data pertaining to single adult households were used in our analysis, allowing us to know, with some degree of certainty, that the same person was using the water in each of the recorded events. However, household visitors would likely influence the shower frequencies, highlighting a major problem with using REUWS for estimating frequencies. Although analyzing only single adult households is a logical way to extract shower frequency data from REUWS, it is unknown whether this value can be compared to the NHAPS data with confidence, as it is unclear whether people living alone have different water-use behaviors than those in multiple-person households (as in NHAPS and other studies). An additional problem with the household-based REUWS database is that it does not capture showers taken at health clubs, gyms, work, and other outside household facilities. This may, in part, account for the number of showers per day being significantly lower than the value seen in NHAPS. Also, the analysis technique used in REUWS has the potential for biasing the frequency results as it may misclassify events (see discussion on REUWS in Section 4 of this report), though this is thought to be rare given our analysis of only single adult households (using single adult households minimizes the occurrence of multiple simultaneous water uses).

Another observation that indicates that the REUWS frequency data may be less reliable than the NHAPS data, is that in REUWS there are a significant number of people who take 3, 4, or 5 showers per day, while in NHAPS the fraction of respondents reporting more than two showers in a day is consistently lower, which seems more reasonable. The larger number of days with greater than two showers reported in REUWS may be due to houseguests or may be due to misclassifying other water events as showers.

In regard to shower durations, the tables turn: REUWS offers accurately measured shower duration data, while NHAPS duration data is biased and appears to be overestimated. The geometric mean of the shower duration in REUWS, for each of the subpopulation groups analyzed, tended to be significantly lower than for NHAPS. The overall-population geometric mean duration for REUWS was 6.8 minutes, while the geometric mean shower duration for NHAPS was 11.3 minutes. The standard deviations were likewise smaller for REUWS than for NHAPS.

The mean shower duration for the overall population analyzed from the REUWS data compares well to previous water-use studies. The HUD report (Brown and Caldwell, 1984), the Tampa study (Konen and Anderson, 1993), and the Oakland study (Aher et al., 1991) reported mean shower durations of 10.4 minutes, 6.3 minutes, and 6.0 minutes, respectively; the REUWS data produces an overall-population shower duration arithmetic mean of 7.65 minutes and a geometric mean of 6.8 minutes. In addition, Burmaster (1997) reports a lognormal distribution with parameters similar to those given in Figure 6-4 for the REUWS dataset. Burmaster presents a lognormal fit to data published by James and Knuiman (1987) measuring domestic water consumption in approximately 3000 Australian homes, and reports a geometric mean of 7.17 minutes as compared to the geometric mean of 6.8 minutes given in Figure 6-4.

Clearly, the fact that NHAPS duration data rely on the respondent's memory and perception introduces a large source of uncertainty and bias. Thus, the greatest unknown from the NHAPS data is the relationship between the reported and actual water-use durations. This is evident in the clustering of reported shower and bath durations around five minute intervals. When asked to estimate their shower duration, 89% of the respondents who reported taking a shower, gave a duration at an exact 5 minute interval, while 95% of those who reported taking a bath, also reported a duration at the 5 minute interval. (It is interesting to note that the durations given in NHAPS were, predominantly, either 5, 10, 15, 20 or 30 minutes, with only very few 25-minute durations reported. Once the perceived duration is over 20 minutes, people may have estimated to the nearest 10 minutes.) These clustering effects, and difficulties in accurately recalling event durations, undoubtedly account for some of the differences between behavior reported in NHAPS and those observed in REUWS and other studies. Also, it is possible that the NHAPS durations were much longer than those in REUWS because the question asked to respondents ("How long did you spend taking the showers in total?") was too vague, and that people included the time it took them to towel dry, etc., not only the time that the shower water was running. Given the observed difference between the REUWS and NHAPS distributions for showering and the fact that NHAPS recall data tended to be overestimated, we expect that the NHAPS bath duration data have a similar bias, and likewise reflect durations longer than actual.

In order to effectively distribute the clustered NHAPS duration data to reflect a more realistic distribution for analysis purposes, the data were fit to lognormal distributions using the MLE method for establishing the statistical parameters for each subpopulation group. The REUWS duration data were also fit to lognormal distributions using this method. The lognormal distributions fit to showering and bathing durations, with parameters reported in Tables 6-9 and 6-10, generally fit the data very well, particularly for shower duration. The fits to bath duration are reasonable, but not as good. Bath durations appear to exhibit a bi-modal tendency, with few reported durations at 20 minutes, but many below 20, and a significant cluster at 30 minutes. It is unclear whether this is a real behavior of the population or an artifact of the reporting and rounding tendencies of the respondents.

The REUWS shower duration analyses exhibit trends related to several demographic variables. The mean duration increases with education, full-time employment outside the home, and income. These trends are graphically displayed in Figure 6-12. It appears that high school graduates take the shortest showers

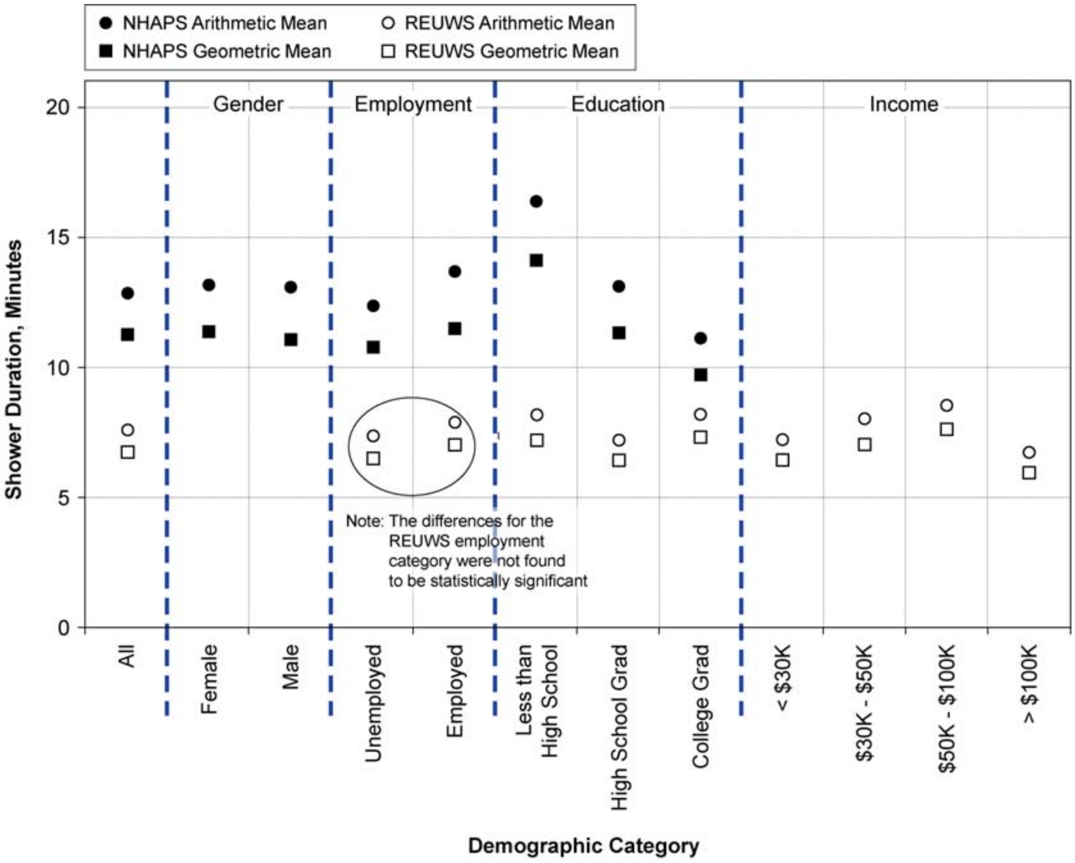


Figure 6-12. Comparative Summary Plot of Shower Duration Parameters for Various Demographic Groups, NHAPS and REUWS.

(6.4 minutes) while non-high school graduates and college graduates take slightly longer showers (7.2 and 7.3 minutes, respectively). And along these same lines, for those whose income is less than $100,000 a year, the people who earn the least amount of money, take the shortest showers. Those with income from $0 to $30K take 6.4-minute showers; those with income between $30 and $50K take 7.0 minute showers, and those with income between $50 and $100K take the longest showers, at 7.6 minutes. However, this tendency falls apart for people with income over $100K, as they are recorded as taking the shortest showers of only 5.9 minutes.

The rounding of reported shower durations to the nearest five-minute increment is likely only partly responsible for the larger reported durations. In addition to the factors discussed above, the relatively large differences, sometimes by a factor of two, may also be related to perceived social factors. For example, the difference may be because people tend to report biased information relating to their hygiene in a manner that will not invite implicit disapproval from the survey questioner.

As with durations, there are also significant differences between the NHAPS and REUWS values for shower frequencies. However, REUWS may not be an accurate indicator of frequencies because of the inability to ascertain the exact user of the showers or baths during a given day, and that REUWS cannot account for showers taken outside the home. Both REUWS and NHAPS display a trend that education and employment increase shower frequency, but NHAPS exhibits a much greater correlation than does REUWS. REUWS shows only a slight difference in shower frequency based on education (Less than High School at 0.81 spd, High School grad at 0.83 spd, and college grad at 0.85) while NHAPS shows that those without a high school degree take 0.92 spd while college graduates take 1.12 spd. In contrast, REUWS shows a much stronger correlation between shower frequency and employment than does NHAPS. Unemployed REUWS individuals report 0.66 spd as compared to 1.03 spd for the employed; while unemployed NHAPS individuals report 0.92 spd and employed report 1.15 spd. The perception and bias issue discussed above (how the questioner may perceive the respondent’s answer or biases related to society’s expectations) may also play a role in how people answered the shower frequency question, however it is impossible to know. Furthermore, because of the way the question was formulated in REUWS, the meaning of the REUWS data is less clear. REUWS only collected information on whether the individual was employed full-time outside the home. In the REUWS database, there are 61 single-occupant households who reported that they were “employed full-time outside the home” as compared to 83 who were not. This data, without further clarification of how many part-time workers or full-time at-home workers, suggests that this is an atypical population, possibly a population with a large percentage of retired elderly people and/or students. Because REUWS does not further clarify employment status, nor does it provide data on the age of the occupants, the representativeness of this population is unclear.

In regard to showering and bathing frequency, several variables emerged as somewhat important predictors of water-use behavior. As shown in Figures 6-1 and 6-2 and Tables 6-6 and 6-8, showering and bathing behavior change with age. Younger ages, particularly under 12 exhibit significantly different behavior than adults. For example, 15% of children under 5 years old showered and 45% of children 5-12 years old showered. This compares with a range of 85% to 93% for persons of ages 12 to 63. In contrast, children under 12 tend to bathe more frequently, with 93% of those under age 5 bathing, and 44% of those between 5 and 12 bathing. This compares with a range of 14% to 18% for persons of ages 12 to 63. In reviewing the bathing frequency data shown in Table 6-8, it is interesting to note that the frequency of multiple baths is greatly increased for the 18 – 48 age range, particularly for frequencies greater than 2 baths per day. There could be several explanations for this observation, but the most plausible is that this age group represents the majority of parents with small children, and as a consequence, these are likely to represent parents giving baths to their children. This conclusion is further supported by a gender analysis of those reporting multiple baths, which revealed that the majority of these multiple baths are reported by females, with 77% of those reporting 1 or more baths on the surveyed day being female.

Education also plays an important role, with less-educated respondents generally reporting less frequent, but longer-duration, showering events, and also reporting a greater frequency of baths. For example, 75%

of respondents with less than a high-school education report taking at least one shower on the survey day, as compared to 89% of college graduates.

Other variables are identified as having little or no correlation with reported water-use behavior in NHAPS. Gender has a minimal impact on the average duration of either showering (males reported 13.1 minute showers; females reported 13.3 minute showers) or bathing (males reported 20.7 minute baths; females reported 21.0 minute baths), but females, on average, tend to take slightly more baths (16.8% males reported baths; 26.6% females reported baths) while males tend to take slightly more showers (80.2% males reported showers; 75.7% females reported showers).

6.10 Recommended Shower- and Bath-Use Parameters

Considering the strengths and weaknesses of the NHAPS and REUWS datasets, as described earlier, recommendations for the use of the data are as follows:

1. Shower and Bath Frequency: The frequency statistics resulting from the NHAPS analysis, presented in Tables 6-6 and 6-8, are believed to most appropriately represent the population frequency of use behavior. Although the impact is believed to be relatively small, potential biases must be recognized including the ability to recall events and biases due to perceived societal expectations.

2. Shower Duration: The duration statistics resulting from the REUWS analysis, presented in Table 6-18, are believed to most appropriately represent the length of showers for the given population. There are, however, factors that may have introduced small uncertainties in the results. The major factors are potential misclassification errors (events classified as showers that were in fact another water-use type); single events reported as multiple events (e.g., a shower that is interrupted and then resumed). We believe that in our analysis we have corrected for the majority of cases reporting single events as multiple events, as described earlier. However, misclassification errors are impossible to correct for with the given dataset. Also, it is important to note that the dataset is not a statistical data sample of the US population, but rather comprised of volunteers in 12 US and Canadian cities.

3. Bath Duration: NHAPS contains the best available dataset for bath durations, since surveys like REUWS contain only the amount of water used to fill the bathtub not the bath duration. Although there are significant biases in the dataset, the duration statistics presented in Table 6-10 are recommended until a more definitive study provides better information. The durations reported in NHAPS are biased by a multitude of factors, mostly resulting from inaccurate memory recall and perception by the survey respondents. Examples of these include the round-off error (94% reported durations at a five-minute interval), estimation errors (based on the comparison between NHAPS, REUWS and other shower duration studies, it appears that people overestimate the duration), and ambiguous questions (from the question, it is unclear whether respondents were asked to give the amount of time in the bathtub, or the time for all bath related activities including filling the tub and drying off).

4. Shower Volume and Flow Rate: The shower volume and flow rate statistics resulting from the analysis of REUWS, presented in Figures 6-9 and 6-10, are believed to most appropriately represent the volumes and flow rates of showers for the given population. However, as with the other REUWS data, this data may be impacted by misclassification and single events reported as multiple events, as described above.

5. Bath Fill Flow Rate: The bath flow rate statistics resulting from the analysis of REUWS, presented in Figure 6-11, are believed to be reasonably representative of this parameter. The bath fill volume is not well enough understood to make a recommendation based on our analysis of the REUWS data. However, the general dimensions of the standard bathtubs are well understood, holding

approximately 50 gallons of water, when filled to the overflow, though this is likely to be reduced by approximately 20-30% due to the bather's body volume.

Even though the data contained in NHAPS and REUWS have some shortcomings, they are the most comprehensive and targeted sets of data for this type of application. As such, these analyses provide the necessary information for representing the showering and bathing behavior for various demographic groups to aid in conducting reasonable assessments of exposure to contaminants in water.

Section 7

Clothes Washers

7.1 Introduction

In this chapter, residential clothes-washer use will be analyzed in an attempt to develop a set of general clothes-washer use characteristics that adequately reflect how often households use the clothes washer, the volume of water used to wash a load of clothes, and the duration of each clothes-washer event. These values are intended for use in modeling human behavior and related exposure in respect to household water use. This chapter will present a review of published literature on clothes-washer use, present a review of manufacturer-supplied information, and present analyses of the clothes-washer use data in the NHAPS, RECS and REUWS databases.

7.2 Review of Published Clothes-Washer Use Studies

To analyze human exposure due to clothes-washer use, we need to understand a variety of parameters including how many households do laundry in their homes, how often, and what are the water-use characteristics of the clothes-washer appliance including volumes and cycle durations. There are only a few studies that address this information, and often indirectly. Current literature on clothes-washer use, manufacturer data, and results from some experimental clothes-washer runs are discussed below. The NHAPS and RECS databases are analyzed in the following subsections for frequency of clothes-washer use and the REUWS database is analyzed for the duration of laundry machine cycles.

Over the last half-century, clothes washing machines have increasingly become a component of nearly every modern home. In the early 1990’s, Chesnutt et. al. (1994) found that approximately 95% of the 2,900 Los Angeles and Santa Monica, California single-family homes they studied for water use (during an ultra-low flow toilet rebate program) had clothes washers, and approximately 75% of the 2,622 apartments had clothes washers. During a 1993-94, Tampa, Florida study (also as part of a toilet rebate program), Ayres and Associates (Anderson, D.L. et al., Nov. 1994) found that approximately 93% of the 613 single-family homes had clothes washers. See Table 7-1 for a tabulation of the percentage of homes owning clothes washers. The Brown and Caldwell (1984) study monitored 181 homes (representing 519 people) for clothes-washer use. They found that based on all the homes monitored in their water-use studies from 1981-1983, (incorporating certain estimates such as faucet use, bath volumes, etc), clothes washers averaged 22% of the per capita interior water use.

An August 1983 Consumer Reports (Brown and Caldwell, 1984) study stated clothes-washer water use ranged from an average of 42 gallons per load for conserving machines, 47.5 gallons per load for average machines, and 55 gallons per load for non-conserving machines. Modern machines in the late 1990’s and 2000 are more in line with the older water-conserving machines. Manufacturer-provided data for current “top-loading” clothes-washer models from General Electric, Maytag and Whirlpool report that today’s extra-large units (approx 2.5 ft^3) use a maximum of between 36 and 40 gallons per load (high-water volume setting) and the super-capacity (approx 3.0 ft^3) units use a maximum of between 44 and 46 gallons per load. A Consumer Reports study reported in July 1998 found that top-loading machines varied from 34 to 44 gallons (See Table 7-2). A Consumer Reports study reported in July 1999 that most top-loading machines have a normal-wash-cycle time of between 37 and 49 minutes and use between 37 and 47 gallons for normal cycle, maximum fill, with maximum load.

Table 7-1. Percentage of Homes Owning Clothes Washers

Housing Type	Avg. Income	Avg. # persons	Percentage of sample with clothes washer	Population, Sample Size	Reference
Single-Family	Approx. $49,300 (Santa Monica) $54,900 (Los Angeles)[1]	2.85	95%	Los Angeles, Calif., (number not given, but combined with Santa Monica = 2,900 homes)	Chesnutt et al. Nov. 1994[2]
Apartments	Not given	2.62	75%	Los Angeles, Calif., (number not given, but combined with Santa Monica = 2,622 apts.)	Chesnutt et al. June 1992[1]
Apartments	Not given	1.63	80%	Santa Monica, Calif., (number not given, but combined with Los Angeles = 2,622 apts.)	Chesnutt et al. June 1992[1]
Apartments	Not given	2.58	74%	Los Angeles, Calif, (number not given, but combined with Santa Monica = 27,000 apts.)	Chesnutt et al. Nov. 1994[2]
Single-family	$38,189	2.49	94%	Tampa, Florida, 394 households	Anderson et al. Nov. 1994[3]
Single-family	$37,018	2.36	93%	Tampa, Florida, 219 households	Anderson et al. Nov. 1994[3]

[1] Chesnutt, June 1992 “Continuous-Time Error Components Models of Residential Water Demand.” Incomes given in this early part of the study, for collective sample size of 1555 single-family homes (sample size for each respective city not given). Based on first year of rebate program, mid-1990-early 1991.

[2] Based on the first four years of same rebate program data as above from 1990 to early 1994.

[3] Based on City of Tampa toilet rebate program May 1993 through March 1994. The 394 households were part of rebate participant group and the 219 households were part of the control group.

The recent introduction of energy- and water-efficient “front-loading” washers in the U.S., however, has the potential to dramatically reduce the water consumption of washing clothes. Though similar residential front-loading machines are common in Europe, they have just recently come onto the American market. General Electric first introduced their residential front-loaded clothes washer in July 1997. In 1997, the Department of Energy conducted a study in the small town of Bern, Kansas (pop. about 200) to analyze the water and energy savings achieved by replacing each of the 103 top-loading washing machines in the town with a new high-efficiency front-loading washer (Consumer Reports, July 1998). During the following month, the town’s water usage had dropped by 50,000 gallons (a drop of 38%); the average wash load consumption dropped from 41.5 to 25.8 gallons per load; and the town used 58% less energy for laundry. Consumer Reports, July 1998, compared the water usage of numerous top-loading and front-loading washers. Assuming that most Americans wash 8 pounds of laundry or less per load, Consumer Reports found that the most efficient machine of the ones they studied in terms of water usage (front-loading Miele W1918A, though this machine is over 50% more expensive and less available than other brands) used about 16 gallons to wash 8 pounds of clothes and the least efficient machine (top-loading Kenmore 1820) used about 35 gallons. Consumer Reports (August 2000) found that a common front-loading washer (Maytag Neptune MAH5500A) used 3.3 gallons of water per pound of laundry while a common top-loading washer (Frigidaire FWS975GH) used 4.6 gallons per pound. Assuming six loads of laundry a week, Consumer Reports found that the Miele would cost about $17 for energy per year, while the most efficient top-loader would use $35 in energy and the least efficient would use $44 per year.

Table 7-2. Clothes-Washer Characteristics from Literature: Top-Loading Machines

Manufacturer	Type	Gallons per Event[1,2]	Total Duration of Event	Reference
General (Machines made prior to 1983)	Top-Loading	42 - 47.5 (varies by model)		Consumer Reports, August 1983 (reported in U.S. HUD, June 1984)
General Machines (around 1999)		37-47 (varies by model)	37-49 minutes	Consumer Reports, July 1999
Kenmore 2891 2693 2683 2670 1820		 40 42 41 41 34		Consumer Reports, July 1998
GE Profile WPSF4170V		 41		
Amana LWA60A		 43		
Whirlpool LSS9244E LSL9345E LSL9244E LSR5233E		 43 42 41 43		
General Electric GE WKSR2100T GE WBXR2060T		 40 39		
Speed Queen LWS55A		 42		
KitchenAid KAWS77E KAWS677E		 43 41		
Maytag LAT9706AA LAT9406AA		 39 39		
Roper RAS8245E		 41		
Hotpoint VWSR4100V		 41		
White-Westinghouse MWS445RE MWX645RE		 44 39		
Frigidaire FWS645GF		 44		
Admiral LATA300AA		 41		
Magic Chef W227L		 42		
Kenmore Elite 2005 2092 2095 2072		 35 30 31 33	 44 minutes 42 minutes 40 minutes 40 minutes	Consumer Reports, August 2000
Maytag MAV700A		 33	 55 minutes	
GE Profile WPSE4270A		 34	 45 minutes	
Hotpoint VWSR311OW		 33	 50 minutes	
Frigidaire Gallery FWS975GH		 37	 51 minutes	

[1] Clothes-washer event includes all water used to wash/rinse a single load of laundry.
[2] Washers were loaded with mixed cotton items to the maximum load size at the maximum water level.

Data from Maytag indicated that the front-loading machines they manufacture use approximately 25 gallons. Data from General Electric indicated that their front-loading machines use approximately 27 gallons per load (except if user selects “knits and delicates,” which would use approximately 22 gallons per load. These General Electric washers use 10 gallons for the wash cycle, 5 gallons for each of the subsequent rinse cycles, and 2 gallons for spray rinses. General Electric data[3] show that their front-loading washers allow the user to select the wash type from “heavy wash”, “regular wash”, “permanent press” or “knits and delicates.” Each of these user-selected wash types utilizes the following sequences: a fill, a main wash, a series of rinses (three rinses for heavy, regular, and permanent press washes, and two rinses for knits and delicates), and one or two spins (one high-speed final spin for heavy and regular options, and two slower spins for the permanent press and delicate options). The main wash portion lasts 18, 14, 13, or 9 minutes, respectively for each of the user-selected wash types: “heavy wash”, etc. Consumer Reports testing found that the front loaders used from 16 gallons to 33 gallons depending on the brand and size.

Table 7-2 presents volume and duration information found in literature for top-loading clothes washer. Table 7-3 presents volume and duration information found in literature for front-loading clothes washers. Washers were loaded with mixed cotton items to the maximum load size at the maximum water level. Most machines achieve a desired water temperature for washing by mixing the incoming cold and hot water, some by either preset proportions and others by adjusting the proportions based on resultant mixed temperatures. Two of the front-loading models studied by Consumer Reports had integral heating elements to raise the water temperature to 160ºF or 170ºF. Table 7-4 presents the clothes-washer information obtained from the manufacturers for both top-loading and front-loading machines.

Table 7-3. Clothes-Washer Characteristics from Literature: Front-Loading Machines

Manufacturer	Type	Gallons per Event[1,2]	Total Duration of Event	Temperature of Water[3]	Reference
Frigidaire Gallery FWT445GE *and* GE WSXH208T	Front-Loading	33			Consumer Reports, July 1998
Miele W1918A		16	105 minutes	Heats water to 170ºF	
Maytag Neptune MAH3000AW		28			
Equator EZ3600C		23	75 minutes		
Asko 11505		24		Heats cold water to 160ºF	
Maytag Neptune MAH5500A		27	72 minutes		Consumer Reports, August 2000
Frigidaire FWT645RH		28	58 minutes		
Kenmore 4004		31	51 minutes		

[1] Clothes-washer event includes all water used to wash/rinse a single load of laundry.

[2] Washers were loaded with mixed cotton items to the maximum load size at the maximum water level.

[3] Most clothes washers mix incoming cold and hot water to obtain desired water temperatures, however, the two washers noted have integral heating elements used to raise washing water temperature.

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[3] Communication with GE via email at GE.Answercenter@appl.ge.com

Table 7-4. Clothes-Washer Characteristics from Manufacturers

Manufacturer	Model	Load Size	Gallons/Fill	Gallons per Event*	Reference
General Electric	Super Capacity	Super	22.2	45.8	GE manufacturer data 8/01. email: GE.Answercenter@appl.ge.com Water consumption data of 1995 models and later.
		Extra Large	19.8	40.9	
		Large	16.5	34.4	
		Medium	13.3	27.8	
		Small and Handwash	10.9	21.9	
	Extra Large Capacity	Extra Large	19.4	40.1	GE manufacturer data 8/01. email: GE.Answercenter@appl.ge.com Water consumption data of 1995 models and later.
		Large	16.6	34.5	
		Medium	14	29.3	
		Small	11.3	23.9	
		Extra Small	9.5	18.9	
	Compact	Large	12.4	34.4	GE website 8/00: www.geappliances.com Water consumption data of 1995 models and later.
		Medium	10.5	29	
		Small	8.2	23	
		Extra Small	6.3	16.4	
	Front Loading	Heavy Wash or Regular Wash or Permanent Press (Regular Cycle)	10 (wash) 5 (per rinse)	27	GE manufacturer data 8/01. email: GE.Answercenter@appl.ge.com
		Knits and Delicates	10 (wash) 5 (per rinse)	22	
Maytag	Front Loading			26 (max)	Maytag manufacturer data 8/01: email: customerservice@maytag.com
	Top Loading			40 (max)	
Whirlpool	Maximum Capacity	Super Capacity (3.0 cubic feet)		44 (max)	Whirlpool manufacturer data 9/00: email: whirlpool@in-response.com
		Extra Large Capacity (2.5 cubic feet)		36 (max)	

* Clothes-washer event includes all water used to wash/rinse a single load of laundry.

In regard to how often people do loads of laundry, we found only one study prior to NHAPS and RECS that discussed frequency. The HUD study (Brown and Caldwell, 1984) monitored 181 households, totaling 519 people, located throughout California, Colorado, District of Columbia, Virginia and Washington. They found that during this study, clothes-washer use averaged six loads per household per week, or 2.1 loads per person per week (0.3 loads per person per day).

7.3 Prevalence and Location of Clothes Washers

The NHAPS survey acquired information on the number of homes with clothes washers, the number of households who did their laundry at home, and the location of the washers in the homes. The analysis of NHAPS (presented in Table 7-5) found that 82% of the respondents interviewed in this 92-94 study did their laundry in the home instead of at a Laundromat or professional service. Home laundry use is generally related to family size, increasing with family size from 68.9% for one-occupant households to 91.8% for households with 5 or more occupants. Similarly, as shown in Table 7-6, a higher percentage of adults with children do their laundry at home. NHAPS respondents were also asked whether their clothes washers were in their basement or in another room in their home, to which 33% responded that their washers were in the basement as shown in Table 7-7. The location of the washer does not appear to be related to household size. Another analysis, not shown, revealed that the location of the washer in the home was similarly not influenced by whether or not the family had children living at home.

Table 7-5. Location Where Household Does Laundry, by Household Size: NHAPS

Where is Laundry Done?	Percentage of Households (Number)					Total
	1 Occupant	2 Occupants	3 Occupants	4 Occupants	5 or more Occupants	
Home	68.9% (661)	84.2% (1,236)	86.0% (620)	87.7% (533)	91.8% (345)	82.1% (3,395)
Laundromat	23.8% (228)	10.8% (159)	10.4% (75)	9.4% (57)	6.4% (24)	13.1% (543)
Other	7.4% (71)	5.0% (73)	3.6% (26)	3.0% (18)	1.9% (7)	4.7% (95)

Table 7-6. Location Where Household Does Laundry, by with and without Children: NHAPS

Where is Laundry Done?	Percentage of Households (Number)		Total
	Households without Children	Households with Children	
Home	79.9% (2,227)	86.8% (1,168)	82.1% (3,395)
Laundromat	15.4% (404)	10.3% (139)	13.1% (543)
Other	5.6% (157)	2.8% (38)	4.7% (195)

Table 7-7. Location of Clothes Washer, by Household Size: NHAPS

Location of Clothes Washer	Percentage of Households (Number)					Total
	1 Occupant	2 Occupants	3 Occupants	4 Occupants	5 or more Occupants	
Basement	31.6% (214)	33.8% (427)	31.2% (196)	36.6% (198)	33.7% (117)	33.3% (1,152)
Other Room	68.4% (463)	66.2% (835)	68.8% (432)	63.4% (343)	66.3% (230)	66.7% (2,303)

7.4 Clothes-Washer Use Frequency

Clothes-washer use frequency information was obtained in both the NHAPS and the RECS surveys. The NHAPS survey asked each respondent one of two questions related to clothes-washer frequency. The Version A question was: “How many separate loads of laundry were done when you were home?” The answers for the Version A question were recorded as actual number of loads under 10, or “over 10”. The Version B question was: “Do you wash clothes in a machine almost everyday, 3-5 times a week, 1-2 times a week, or less often?” The problem with the Version A NHAPS question is that it does not address household clothes-washer use, but instead it was asking the question to obtain information on personal exposure, as it required the individual to be at home during the events. Thus, if for example the respondent was a working male whose wife did the laundry while he was at work, he would have answered the NHAPS question as if no laundry was done. There are three problems with the Version B question in NHAPS with respect to quantifying a reliable estimate of clothes-washer use. The most significant problem is that the question asks how often the respondent himself or herself did the wash, not how often the wash was done in the household. Secondly, the question would most likely be interpreted to mean how many days per week laundry was done (regardless of the number of loads done in one day), when the necessary information for an exposure assessment would be instead, how many individual loads were washed per week. And thirdly, the frequency range in the answer choices is too broad.

In the RECS survey, the question relating to clothes-washer use asked: “In an average week, how many loads of laundry are washed in your clothes washer?” The answer choices were: 1 load or less each week, 2-4 loads, 5-9 loads, 10-15 loads, More than 15 loads, or Don't know. Although the answer choices to this RECS question likewise offered a range, this question is more specific than the frequency questions in NHAPS and clearly addresses household frequencies, regardless of whether the respondent was home or not.

Both the NHAPS and the RECS databases are analyzed for frequency of clothes-washer use in the following sections. The frequency behaviors from REUWS were not analyzed because each time the laundry machine was filled with water (fill cycle, rinse cycle, spritzes, etc) it was registered as an individual clothes-washer event, such that it was difficult to accurately determine which events comprised a single load of laundry, and therefore making the frequency calculation very uncertain. Furthermore, as discussed below in the section on REUWS duration analysis, many of the records in REUWS had to be excluded because in many cases the start of a clothes-washer event was not labeled correctly or the data were unrealistic, preventing its use for estimating clothes-washer use frequency. In conclusion, the RECS data was determined to be the most valuable reference for clothes-washer use frequency.

7.4.1 RECS Clothes-Washer Frequency Analysis and Results

RECS was analyzed for clothes-washer frequency behavior, based on household size, as shown in Table 7-8. Laundry-use frequency logically increases as the number of occupants increases, from an estimated 3.18 loads per week for a household of one occupant to 9.21 loads per week for a household of five or more occupants. The number of laundry loads per capita decreases as the household size increases, from an estimated 3.18 loads a week for a person that lives alone, to an estimated 1.84 loads per week for a person that lives with at least four other individuals. This may be the result of larger families tending to wash larger loads, as they combine all the family used towels, or all the sheets, or all the clothes together, thereby almost always washing a full load, while a person that lives alone may wash his/her towels once per week regardless of whether the load is full or not.

Table 7-8. Frequency of Clothes-Washer Use, by Household Size: RECS

	Percentage of Households					
Frequency of Clothes-Washer Use	**1 Occupant**	**2 Occupants**	**3 Occupants**	**4 Occupants**	**5 or more Occupants**	**Total**
15+ loads per week	0.2	1.1	3.4	8.8	15.0	4.2
10-15 loads per week	1.4	5.9	14.8	27.6	29.4	12.9
5-9 loads per week	14.2	40.3	50.2	45.9	41.6	38.2
2-4 loads per week	62.3	48.2	28.8	16.0	12.3	38.0
1 or less loads per week	21.9	4.4	2.9	1.7	1.7	6.7
Estimated household mean frequency* (loads per week)	3.18	5.19	6.75	8.47	9.21	6.09
Estimated per capita frequency (loads per person per week)	3.18	2.60	2.25	2.12	1.84	2.29

* Estimated mean frequency was calculated assuming the midpoint value for each frequency range and a frequency of 16 loads/week for the “15+ loads/week” range.

7.4.2 NHAPS Clothes-Washer Frequency Analysis and Results

In the NHAPS survey, as mentioned previously, Version B of the questionnaire asked respondents “Do you wash clothes in a machine almost everyday, 3-5 times a week, 1-2 times a week, or less often?” The data from 4,211 respondents were analyzed (not including cases answered by or in proxy for children) to determine if there were differences in clothes washing behavior based on household size and whether they had children. The frequency of clothes washing is tabulated in Table 7-9 with respect to the number of occupants that live in the house (household size). As expected, larger households responded with a higher frequency of clothes washing: 37.9% of households with five or more members did laundry daily, while only 5.6% of households with only one person did laundry daily. Most of the households (48.9%, out of all respondents with clothes washers) responded that they did their laundry one to two times per week, 15.3% did it daily, 28.7% did it three to five times per week, and 7.1% did it less than once per week. As shown in Table 7-10, households with children were more likely to do the laundry everyday or 3 to 5 times per week, while adult-only households are more likely to do laundry only 1 to 2 times per week or less.

Table 7-9. Frequency of Clothes-Washer Use, by Household Size, NHAPS

Frequency of Clothes-Washer Use	Percentage of Households (Number)					Total
	1 Occupant	2 Occupants	3 Occupants	4 Occupants	5 or more Occupants	
Daily	5.6% (51)	11.6% (159)	21.4% (115)	28.9% (114)	37.9% (89)	15.3% (528)
3-5 days per week	16.6% (152)	32.0% (439)	36.1% (194)	30.7% (121)	36.2% (85)	28.7% (991)
1-2 days per week	64.1% (585)	51.3% (705)	37.9% (204)	36.0% (142)	23.0% (54)	48.9% (1,690)
Less than 1 day per week	13.7% (125)	5.2% (71)	4.6% (25)	4.3% (17)	3.0% (7)	7.1% (245)
Total	100% (913)	100% (1374)	100% (538)	100% (394)	100% (235)	100% (3454)
Estimated mean frequency* (days per week)	2.02	2.86	3.51	3.79	4.45	2.95
Estimated per capita frequency* (days per person per week)	2.02	1.43	1.17	0.95	0.89	1.27

* Estimated mean frequency was calculated assuming the midpoint value for each frequency range: e.g., daily, 4 times per week, 1.5 times per week. Zero times per week was assumed for the “less than 1 times per week” category.

Table 7-10. Frequency of Clothes-Washer Use, by Households with and without Children, NHAPS

Frequency of Clothes-Washer Use	Percentage of Households (Number)		Total
	Households without Children	Households with Children	
Daily	11.1% (294)	29.2% (234)	15.3% (528)
3-5 days per week	26.5% (703)	35.9% (288)	28.7% (991)
1-2 days per week	54.4% (1,443)	30.8% (247)	48.9% (1,690)
Less often than 1-2 times per week	8.0% (212)	4.1% (33)	7.1% (245)

7.4.3 Clothes-Washer Frequency

The RECS data for clothes-washer frequency was judged to be the most reliable, as it reflects total household clothes-washer use, not only the clothes-washer use of the respondent as does NHAPS. However, both surveys allowed for large ranges in the answers (e.g., 2 to 4 loads per week, or 3 to 5 loads, etc.). It seems that NHAPS underestimates the number of clothes-washer loads done in the household, as it reflects the loads done only by the respondent, not by the household. The vast majority of respondents in RECS answered that they did 2-4 loads (38% of population) or 5-9 loads (38.2% of population) per week, whereby NHAPS results indicate that most people (48.9% of population) did wash only 1-2 times per week, though it is unclear whether this reflects the actual number of loads of laundry or only the days laundry was done.

7.5 Clothes-Washer Cycle Durations and Volumes

The REUWS database was the only database found with clothes-washer duration and volume information. Three of the leading clothes-washer manufacturers (Whirlpool, GE and Maytag) also provided some duration and volume data, presented earlier in this section. Furthermore, two clothes-washer machines were evaluated for duration using various settings for load size and temperature. Both the manufacturer supplied data and the experimental data were used to set reasonable duration and volume boundaries for the REUWS analysis.

7.5.1 REUWS Clothes-Washer Duration, Flow Rate and Volume Analysis and Results

The REUWS database was analyzed to provide an understanding of clothes-washer cycle durations, flow rates and volumes. It is the best dataset available for this purpose as it holds measured real-time water-flow data obtained from the water meter-logging device, Meter-Master[4], connected to the water meter for each household in the study. REUWS used the software program, Trace Wizard[5], to disaggregate the raw total household waterflow into its individual water uses (See the Database descriptions in Section 4.0 for further discussion on REUWS and Trace Wizard). Each water use in the dataset was analyzed by Trace Wizard, recording its estimated volume of water used, peak flow rate, mode flow rate, start date, start time, end time, and from these data determining the type of water-use appliance (e.g., toilet, clothes washer, shower, etc.).

Trace Wizard was used in REUWS to attribute specific water uses to a specific appliance. The algorithms implemented in Trace Wizard used characteristics such as peak flow, volume and duration to make this assignment. There appears to be significant problems with properly assigning water uses to specific appliances during multiple water uses and during water uses with multiple water draws (e.g., clothes washer), as discussed later in this section. Therefore, the REUWS data were carefully screened in order to minimize the presence of erroneous events that were mistakenly labeled “clotheswasher” use by Trace Wizard. To this end, a set of criteria was developed to eliminate any clothes-washer events that were unreasonable.

The REUWS database contains 120,756 records identified as clothes-washer uses, each representing a single water draw. One load of laundry may use from 2 to 6 or more water draws during its wash and rinse cycles. Each of these draws is recorded separately in the REUWS database.

The following definitions are used in the discussion to describe the clothes-washer water uses:

- A water use occurs each time the water draw starts and stops;
- A clothes-washer event is defined as one load of laundry;
- A fill is a large continuous water draw, usually used to describe when the laundry machine is filling to the water level selected by the user (such as x-large, large, medium, small) for the wash cycle or rinse cycle;
- A cycle is from the beginning of a fill, through the agitation and spin, until the next fill begins or the event ends;
- A spritz is a small water draw sometimes used during the spin to aid in removing the soap.

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[4] Meter-Master 100EL, manufactured by F.S. Brainard and Company, P.O. Box 366, Burlington, NH 08016

[5] Trace Wizard, developed by Aquacraft Engineering, Inc., 2709 Pine Street, Boulder, CO 80304

A typical clothes-washer event for the common brands of clothes washers consists of 1 large fill for the wash cycle and 1 or 2 large fills for the rinse cycles with spritzes intermixed within the rinse cycles. The Trace Wizard software (used to disaggregate and label the various water uses from the water meter data) attempted to identify the first fill of each load of laundry, and label it CLOTHESWASHER1, and all subsequent fills were labeled as “CLOTHESWASHER.” For purposes of identifying and analyzing durations of clothes-washer use per laundry load, all water draws pertaining to a single load were combined into one event by combining each CLOTHESWASHER1 occurrence with all following “CLOTHESWASHER” occurrences prior to the next CLOTHESWASHER1.

The analysis proceeded with the goal of eliminating questionable clothes-washer events and compiling a subset of clothes-washer events correctly identified with a high degree of certainty. Preliminary examinations found a number of problems with the dataset. The most apparent problems were events with a large number of water draws. There were 81 clothes washer events having 15 or more water draws and 171 events having more than 12 water draws.

A subset of the clothes-washer events was created containing 26,982 events having 12 or less water draws. During a preliminary analysis of this dataset, it became evident that some of the resultant event records were clearly not a typical clothes-washer use, possibly due to Trace Wizard mislabeling some of the individual water draws. For example, a number of the events took over 8 hours or used over 100 gallons of water. See Table 7-11 for a short list of anomalous records. Possibly, in these cases, either Trace Wizard had difficulty distinguishing between “CLOTHESWASHER1” and “CLOTHESWASHER” or misidentified another appliance’s water use as a clothes-washer use. Therefore, in order to eliminate these erroneous events from the dataset, criteria were developed to define reasonable or acceptable events.

Table 7-11. Unrealistic Clothes-Washing Events in Consolidated REUWS Dataset

Criteria	Number of Cases
Total Number of Fills per Event*	
> 12	171
> 15	81
Total Time per Event (not including final drain and spin)	
> 4 hours	289
> 12 hours	163
Volume of Fill	
> 30 gallons	858
> 40 gallons	245
Total Volume of Event	
> 100 gallons	82
> 125 gallons	11

* Each “event” in the dataset (N=26,982) is a collection of a water draw labeled “CLOTHESWASHER1” (supposed first fill of laundry load) plus all “Clotheswasher” water draws until but not including the next “CLOTHESWASHER1” water draw. If the total number of water draws exceeds 12, the “event” is truncated at the 12th “Clotheswasher” water draw. Each “fill” is a large water draw labeled either “CLOTHESWASHER1” or “Clotheswasher.”

To identify “reasonable” criteria for clothes-washer operations and water usage, limited literature and manufacturer data (presented earlier in Tables 7-2, 7-3 and 7-4) were obtained and analyzed, and a series of field tests was run on two different clothes washers (one Kenmore Series 70 –1992 and one Kenmore Series 90 - 1999), measuring frequencies and durations of fill, agitation, soak, and rinse portions for various load sizes, water temperatures, wash durations, and number of rinse cycles. See Table 7-12 for the results of these field tests. It was noted that in addition to the water draws for the wash and rinse cycles, there are also small water draws used during the spinning after the rinse, possibly to assist in removing soap. We refer to these as “spritzes.”

From these experimental trials, we discovered that the filling time for both hot and cold water (approximately 7.1-7.5 minutes) took nearly twice as long as the filling time for warm water (approximately 3.5-3.8 minutes). This is probably due to the fact that with warm inflow, both the cold and hot water pipes are being used, thereby increasing the flow.

Using insight from the analysis of manufacturer data and field test results, a set of criteria was developed to screen out the suspected non-clothes-washer event records. When the record for an event violated the criteria, the event was removed. Because there are numerous manufacturers of washing machines and various user-selected options on each machine (e.g., water temperature, water volume, wash cycle length, and number of rinse cycles), an effort was made to maintain a very broad range of “acceptable” possibilities. The goal was to eliminate cases that were clearly not clothes-washer events (the mislabeled events).

Table 7-13 presents the criteria that were used to eliminate the obviously mislabeled records, and presents the impact of the criteria by presenting the number of records remaining in the dataset after each subsequent elimination criterion was implemented. The number of events remaining in our final dataset for analysis was 51.6 percent of the original clothes-washer events identified by Trace Wizard. The purpose of the selection criteria was to make a reasonable effort to reduce the data set to “likely” clothes-washers events without biasing the dataset by eliminating a type of clothes washer (e.g., large capacity machines). It is believed that most of the cases dropped were either misclassified by Trace Wizard and were really some other type of water use (e.g., faucet, shower), or the CLOTHESWASHER1 (first water draw of each load) was not correctly distinguished from the other clothes-washer water draws.

After the elimination of the records not consistent with these criteria, there remained 13,925 “acceptable” clothes-washer events in the dataset on which the analysis was conducted.

To further ensure that this resultant dataset represented actual clothes-washer events, all single-person households were extracted from the original 26,982 events and the same elimination criteria were applied. The small-scale evaluation study of the Meter-Master and Trace Wizard techniques used in REUWS (presented in Appendix A) found that Trace Wizard was significantly more accurate in characterizing water uses when the water uses occurred alone, (non-overlapping), while Trace Wizard exhibited numerous disaggregation and identification errors when water uses overlapped. It was hypothesized that single-person households were less likely to have simultaneous water uses and therefore, Trace Wizard would more likely correctly identify the type of water usage.

Interestingly, after the elimination process on the single-occupant household data, 51.4% of the events remained in the dataset, compared to the 51.6% of the remaining dataset for the entire population. In order to further test the validity of the final dataset, some of the following analyses performed on the entire dataset, are also performed on the single-occupant household data and compared. The similarity in results from the two datasets provide evidence that after the elimination process, the water draws in the final dataset are largely clothes-washer draws (not other types of water uses mislabeled by Trace Wizard).

Table 7-12. Clothes-Washer Experimental Trials

Machine Type	Clothes-Washer Scenario	Wash Cycle Fill (min)	Agitation (min)*	Drain/Spin (min)	1st Rinse Fill (min)	Agitation (min)	Drain/ Spin (min)	2nd Rinse Fill (min)	Agitation (min)	Drain/ Spin (min)	Total Duration (min)
Kenmore Heavy Duty 70 Series, 1992	High water level 1 warm wash, 1 cold rinse Regular cycle 10 minute wash	3.8	9.9	4.1	7.3	4.1	8.0	N/A	N/A	N/A	37.2
	High water level 1 warm wash, 1 cold rinse Heavy Duty cycle 14 minute wash	3.8	14.0	4.0	7.8	3.9	8.0	N/A	N/A	N/A	41.3
	Low water level 1 warm wash, 1 warm rinse Regular cycle 2 minute wash	2.2	2.0	4.0	2.2	3.9	8.1	N/A	N/A	N/A	22.3
	High water level 1 cold wash, 2 cold rinses Permanent Press cycle 10 minute wash	7.5	10.0	1.0 partial drain 1.3 pause	4.0	2.0	4.0	7.4	4.0	8.0	49.2
Kenmore Super Capacity 90 Series, 1999	High water level 1 warm wash, 2 warm rinses Heavy Duty cycle 14 minute wash	3.5	13.9	4.1	4.9	4.0	8.0	4.7	4.0	6.0	53.0
	High water level 1 hot wash, 1 cold rinse Heavy Duty cycle 14 minute wash	7.1	14.0	4.0	5.6	4.0	8.0	N/A	N/A	N/A	42.6
	High water level 1 hot wash, 2 cold rinses Regular cycle 14 minute wash	7.1	14.0	4.0	5.6	4.0	8.0	5.6	4.0	6.1	58.3
	Low water level 1 warm wash, 1 warm rinse Regular cycle 6 minute wash	1.9	6.5	4.1	1.8	4.0	3.0				21.3

* “min.” means minutes. These trials were performed to obtain approximate “reasonable” durations for various portions of the clothes-washer event.

Table 7-13. Elimination Criteria for Clothes-Washer Events, REUWS

Elimination Criteria	Description	Number of Records Remaining
Original number of clothes-washer events in dataset		26,982
Each event must have 2, 3 or 4 fills between 6 and 23 gallons	Typical clothes washers have one large fill for the wash cycle followed by one, two or possibly three rinse fills. According to manufacturer literature (General Electric, Maytag, Whirlpool), the smallest load setting available used 6.3 gallons per fill in the GE Compact washer on the "extra small" load setting. The largest capacity residential laundry machine (GE Super Capacity) used 22.2 gallons per fill on the "super" large load setting.	23,396
The 1st fill must be between 6 and 23 gallons	The first fill, determined to be the fill for the wash cycle in most cases, must be one of the large fills.	22,334
Total running time must be between 14 and 70 minutes	Field test data (See Table 7-12) was used to define acceptable durations for doing a load of laundry. Because REUWS records reflect water draws through the house water meter, it does not include the time for the final drain and spin, when no water is being drawn. Therefore, the running time starts at the beginning of the first fill until the end of the last water draw, either the rinse fill or a spritz. The lowest water setting and the shortest wash cycle time led to a duration of around 14 minutes (not including the drain and spin). The largest load size, longest wash cycle and two rinses on our test machines led to a maximum duration of around 53 minutes. However, it is recognized that some machines may have an option for three rinse cycles, a longer wash cycle, or an option to soak the clothes, thereby increasing the running time. Therefore, the upper bound was liberally increased to account for these uncertainties. Table 7-11 shows that out of the 26,982 records analyzed, 289 were eliminated because they had a total duration of over 4 hours, 163 lasted over 12 hours.	20,477
Event must not have more than 6 total cycles (incl. small draws)	A total of 6 water draws accounts for one wash fill, up to three rinse fills, and two spritzes.	17,502
Event must not have any cycles greater than 23 gallons	Although a previous criterion required from 2 to 4 "large" fills between 6 and 23 gallons each, it did not eliminate cases with additional fills larger than 23 gallons. Table 7-11 shows that out of the total 26,982 records analyzed, 858 were eliminated because they had a fill over 30 gallons.	17,114
Time between 1st and 2nd fills must be ≥ 4 minutes and < 26 minutes, time between 2nd and 3rd fills and 3rd and 4th fills must be ≥ 2 minutes and < 16 minutes	Four minutes (though unlikely) was selected as the minimum time between the 1st and 2nd fills accounting for two minutes of wash time and two minutes to drain and spin. The maximum time between the 1st and 2nd fills seen in the field tests was 18 minutes, therefore, in order to account for other possible user-selected options (including soaks), a maximum time of 26 minutes was selected as the criteria. For the time between the remaining fills, two minutes was selected as the minimum and 16 minutes as the maximum. As confirmed in the field studies, rinse cycles are usually shorter than wash cycles.	14,037
Ratios between the mode flow rates of the 2nd, 3rd and 4th fills and the 1st fill must be between 0.25 and 4	It was determined that the mode flow for subsequent large fills should be within a certain range of the first large fill. Differences in the mode flow can be explained, however, by the user selected water temperature for the wash being different from the temperature for the rinse, or because another household appliance was drawing water at the same time as the clothes washer.	13,925

7.5.2 Results of REUWS Analysis for Clothes-Washer Volume and Duration

The summary statistics for three clothes-washer parameters: volume, time between fills, and mode flow are shown in Table 7-14. Time between fills is from the end of one fill until the start of the next fill. These statistics are shown for all cases and for single-person households. The table shows that the average volume for the first fill, presumably the wash fill, is the highest (16.6 gallons) and subsequent rinse fills have a slightly smaller volume. The data also show that the time between fills is longest, on average, between the first and second fills (about 15 minutes). This is thought to be because the wash cycle is longer than the subsequent rinse cycles and the mode flow is slightly higher for the first fill than the other fills. It is thought that the user-selected water temperature has great influence over the mode flow rate as does the use of other appliances during clothes-washer use.

In general, people choose the highest water setting (largest load), the longest wash time and one rinse cycle. There are significantly fewer events with three or four fills (2,606) than there are with two large fills (11,319), therefore, most loads of laundry comprise two big fills. However, the time between the first and second fills is significantly longer than the time between the subsequent fills, because this is the wash cycle, which requires adequate time and agitation to remove the dirt from the clothes. The remaining fills are part of rinse cycles. During the rinse cycles, any remaining soap is removed from the clothes. Each rinse cycle takes approximately the same amount of time. As before, the data for all cases and single-person households are very similar and reinforce the notion that clothes-washer events have indeed been selected correctly out of the original 26,982 records.

Table 7-15 shows the percentiles for the same parameters mentioned above (volume, time between fills and mode flow). The 10th through 90th percentiles are shown for every 10th percentile and so are the 95th, 99th, and 100th percentiles. The similarity of the single-occupant household values and those of the entire dataset once again supports the elimination criteria.

The volume and time between fills were selection criteria with a minimum and maximum. Therefore, the higher percentiles reflect the selection criteria limits. The mode flow, however, was required only to be within a 4/1 ratio between fills of the same event. Therefore, the similar volume statistics for the various flows as well as between single-occupant households and the entire dataset is compelling evidence that the elimination criteria accomplished their goal of removing most of the misclassified water uses.

Figures 7-1 to 7-14 show the clothes-washer data from the analyses of REUWS in a graphical format to supplement the tabular format shown above for the data after the elimination criteria are applied. (All events that do not satisfy the following criteria are eliminated: includes only events with a total time 14-70 minutes; 1st fill 6-23 gal; 2 to 4 fills 6-23 gal; 6 or fewer total fills; no fills > 23 gal; time between fills ranging 2-25 min; ratio of mode flows between 0.25 and 4). Plots of volume, mode flow rate, time between fills, and the ratio of mode flow rates to each other are shown. All the plots include the number of cases represented as well as the mean and standard deviation. Only data for the full final dataset (13,925) are shown because, as mentioned earlier, it was determined that the data for the single-person households are nearly identical to the full dataset and do not need to be shown separately.

Figures 7-1 to 7-5 show volume distributions. Figure 7-1 is the volume of the 1st fill and Figure 7-2 is the volume of fills 2-4. Figures 7-3 and 7-4 show the total volume for the load of laundry. Figure 7-3 is the total volume for all fills and Figure 7-4 includes only the total for the big fills. The small fills are thought to be spritzes that take place during the rinse cycle. Figure 7-5 shows a distribution of the excluded small fills (spritzes). The average volume for a spritz is 1.85 gallons. Most of the individual spritz volumes are between 0.75 gallons and 1.5 gallons. The mean volume of water used for all spritzes occurring during one load of laundry is 2.8 gallons.

Table 7-14. Summary Statistics of Final Dataset for Fill Volume, Peak Flow and Time Between Fills: REUWS

	Volume (gallons)									
	All Valid Events (number) (percentage)					Single Households (number) (percentage)				
Statistic	**Fill 1 (13,925) (100%)**	**Fill 2 (13,925) (100%)**	**Fill 3 (2,606) (18.7%)**	**Fill 4 (113) (0.81%)**	**Total Event[1]**	**Fill 1 (862) (100%)**	**Fill 2 (862) (100%)**	**Fill 3 (116) (13.5%)**	**Fill 4 (3) (0.35%)**	**Total Event[1]**
Mean	16.6	15.2	16.2	14.9	34.9	16.3	15.2	15.9	18.2	33.7
Minimum	6.0	6.0	6.0	6.0	12.3	6.0	6.1	6.1	17.3	15.8
Maximum	23.0	23.0	23.0	22.8	79.8	22.9	22.9	22.7	19.8	66.1
Standard Deviation	3.9	4.2	3.7	4.4	9.0	4.0	4.0	3.9	1.4	8.6

	Time Between Fills[2] (minutes)					
Statistic	**Fill 1 & 2 (13,925)**	**Fill 2 & 3 (2,606)**	**Fill 3 & 4 (113)**	**Fill 1 & 2 (862)**	**Fill 2 & 3 (116)**	**Fill 3 & 4 (3)**
Mean	14.7	6.7	8.3	14.7	7.3	8.8
Minimum	4.0	2.0	2.3	4.0	2.0	2.7
Maximum	26.0	16.0	16.0	25.8	15.8	13.8
Standard Deviation	4.0	3.5	3.9	4.0	3.5	5.7

	Mode Flow (gallons per minute)							
Statistic	**Fill 1 (13,925)**	**Fill 2 (13,925)**	**Fill 3 (2,606)**	**Fill 4 (113)**	**Fill 1 (862)**	**Fill 2 (862)**	**Fill 3 (116)**	**Fill 4 (3)**
Mean	5.0	4.4	4.5	4.3	5.0	4.3	4.7	4.9
Minimum	0.2	0.2	1.0	1.3	1.0	1.3	1.6	2.7
Maximum	14.4	14.2	12.0	7.7	13.2	13.1	9.5	7.1
Standard Deviation	1.7	1.3	1.5	1.6	1.9	1.3	1.7	2.2

[1] Total clothes-washer event includes all sequential fills used to wash/rinse a single load of laundry. This total event volume does not include small sprays during rinses as sprays were indistinguishable from other small water uses such as faucets.

[2] Time between fills is from the start of one fill until the start of the next fill.

Table 7-15. Final Dataset Percentiles for Volume, Time Between Fills and Mode Flows: REUWS

Percentile	Volume (gallons)									
	All Valid Events (number)					Single Households (number)				
	Fill 1	Fill 2	Fill 3	Fill 4	Total Event[1]	Fill 1	Fill 2	Fill 3	Fill 4	Total Event[1]
10th	10.9	9.0	10.8	8.2	23.2	11.0	9.4	10.4	17.4	22.2
20th	12.9	11.0	13.1	10.3	27.3	12.3	11.1	11.8	17.4	25.9
30th	14.7	12.8	14.7	13.4	30.5	14.1	12.8	13.8	17.4	29.4
40th	16.1	14.5	15.6	15.1	32.9	15.9	14.5	15.7	17.4	31.8
50th	17.1	15.8	16.4	15.8	35.0	16.8	15.8	16.4	17.4	33.8
60th	18.0	16.9	17.4	16.5	37.2	17.7	16.9	17.3	17.9	35.9
70th	19.2	17.9	18.5	17.4	39.4	18.7	17.8	18.2	18.3	38.2
80th	20.4	19.1	19.7	18.4	41.8	20.1	18.9	19.4	18.8	40.9
90th	21.6	20.5	20.8	20.2	44.7	21.5	20.4	21.0	19.3	43.3
95th	22.1	21.3	21.5	20.7	50.9	22.0	21.1	22.1	19.6	47.0
99th	22.8	22.4	22.4	22.0	59.3	22.7	22.2	22.6	19.8	59.8
100th	23.0	23.0	23.0	22.8	79.8	22.9	22.9	22.7	19.8	66.1

Percentile	Time Between Fills [2] (minutes)					
	Fill 1 & 2	Fill 2 & 3	Fill 3 & 4	Fill 1 & 2 (862)	Fill 2 & 3 (116)	Fill 3 & 4 (3)
10th	9.7	2.8	2.7	9.8	3.9	4.1
20th	11.7	3.2	4.6	11.7	4.3	5.5
30th	12.0	4.3	5.9	11.8	5.7	7.0
40th	13.8	5.7	7.7	13.7	5.8	8.4
50th	14.7	5.8	7.8	14.1	5.8	9.8
60th	15.8	6.0	8.1	15.7	6.5	10.6
70th	16.8	7.7	9.8	16.8	7.7	11.4
80th	17.8	9.8	11.8	17.8	10.7	12.2
90th	20.0	12.0	13.8	19.8	12.8	13.0
95th	21.8	13.8	15.4	21.8	14.9	13.4
99th	24.3	15.7	16.0	23.6	15.8	13.7
100th	26.0	16.0	16.0	25.8	15.8	13.8

Percentile	Mode Flow (gallons per minute)							
	Fill 1	Fill 2	Fill 3	Fill 4	Fill 1 (862)	Fill 2 (862)	Fill 3 (116)	Fill 4 (3)
10th	3.0	2.9	2.9	1.9	3.0	2.9	2.9	3.1
20th	3.6	3.4	3.4	2.7	3.6	3.4	3.6	3.5
30th	4.1	3.7	3.8	3.3	3.9	3.7	3.8	3.9
40th	4.4	4.0	4.1	3.8	4.3	3.9	4.0	4.4
50th	4.8	4.3	4.4	4.3	4.6	4.2	4.4	4.8
60th	5.3	4.6	4.8	4.9	5.0	4.5	4.8	5.2
70th	5.8	4.9	5.1	5.1	5.7	4.8	5.0	5.7
80th	6.3	5.3	5.6	5.7	6.4	5.1	5.5	6.2
90th	7.2	5.9	6.1	6.6	7.5	5.8	7.2	6.6
95th	8.0	6.5	7.1	7.0	8.1	6.7	8.5	6.9
99th	9.5	8.4	9.1	7.3	10.8	9.1	9.1	7.1
100th	14.4	14.2	12.0	7.7	13.2	13.1	9.5	7.1

[1] Clothes-washer event includes all sequential fills used to wash/rinse a load of laundry. Volume does not include small sprays during rinses as sprays were indistinguishable from other small water uses such as faucets.

[2] Time between fills is from the start of one fill until the start of the next fill.

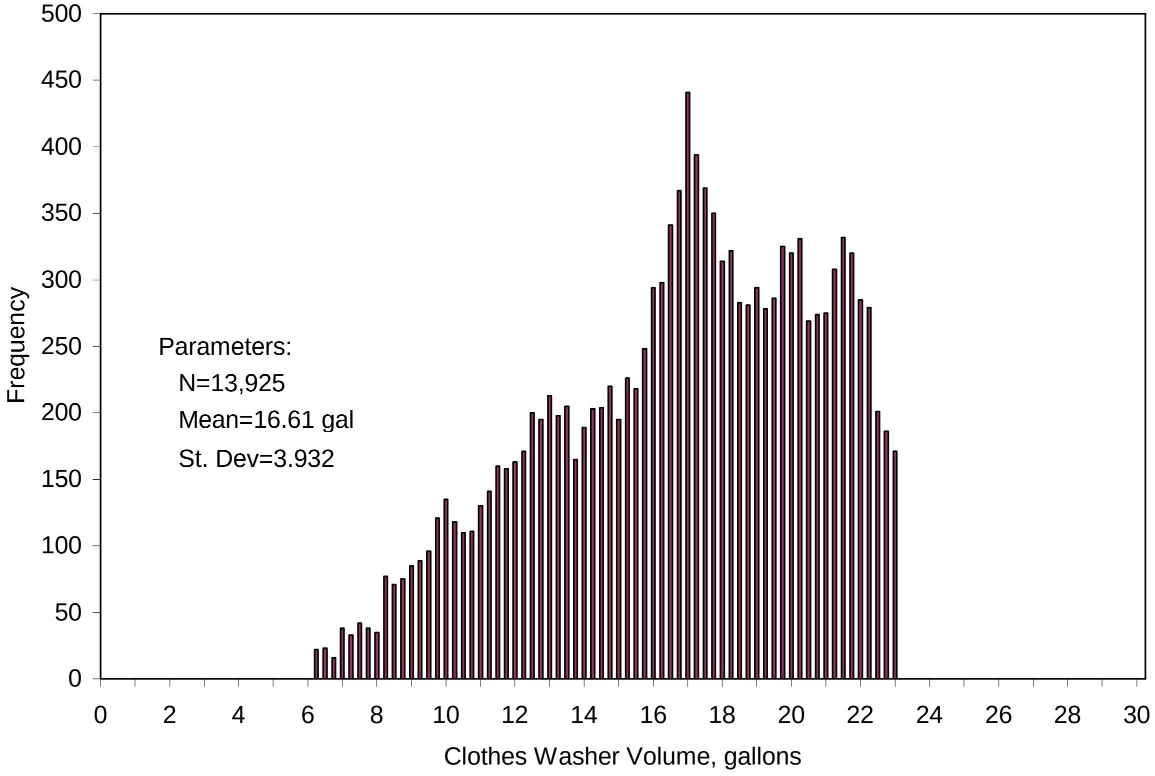


Figure 7-1. Distribution of Clothes-Washer 1st Fill Volumes, REUWS.

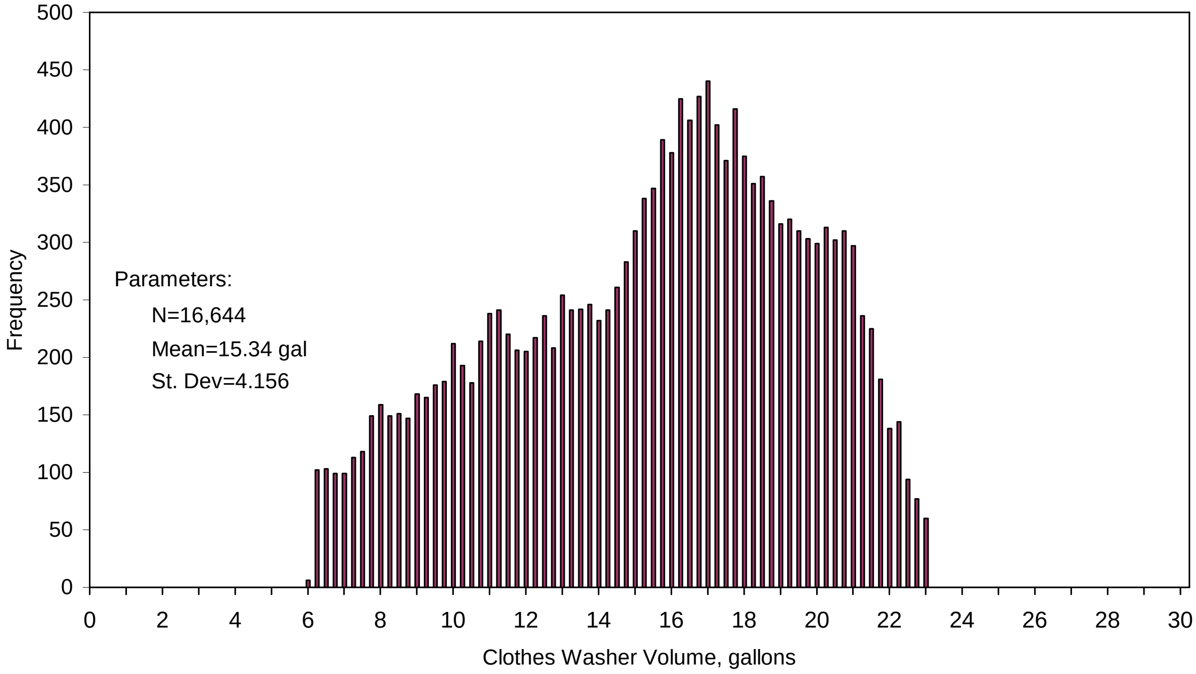


Figure 7-2. Distribution of Clothes-Washer Volumes for all Fills except 1st Fills, REUWS.

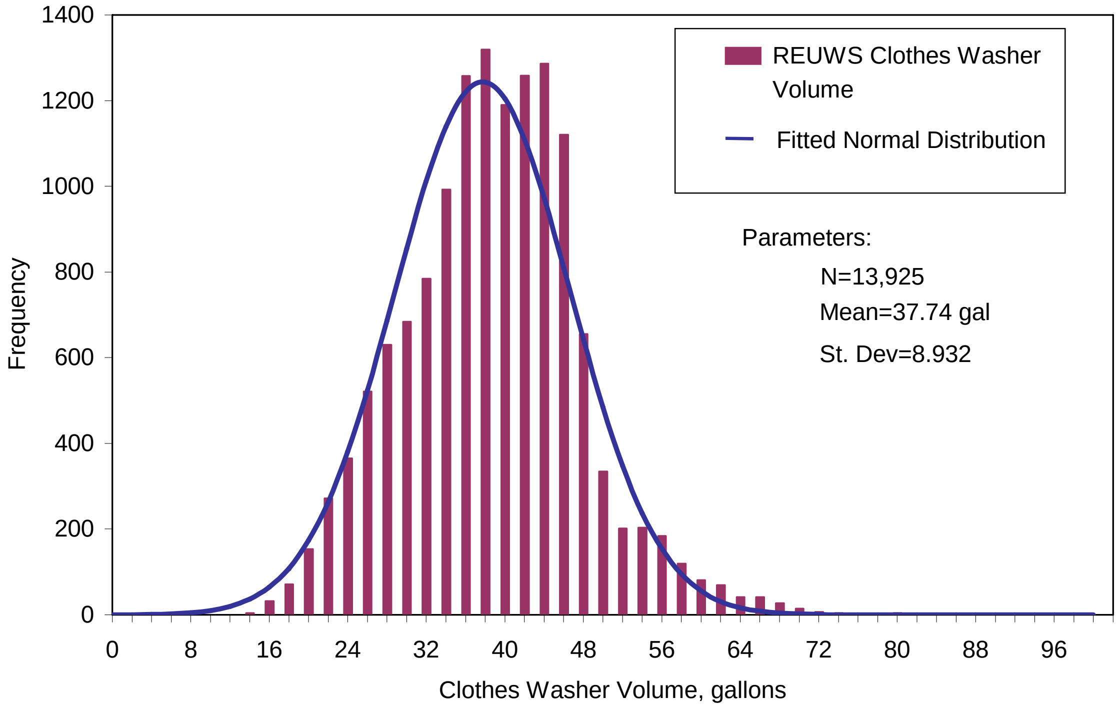


Figure 7-3. Distribution of Total Volume for Clothes-Washer Events for All Fills, REUWS.

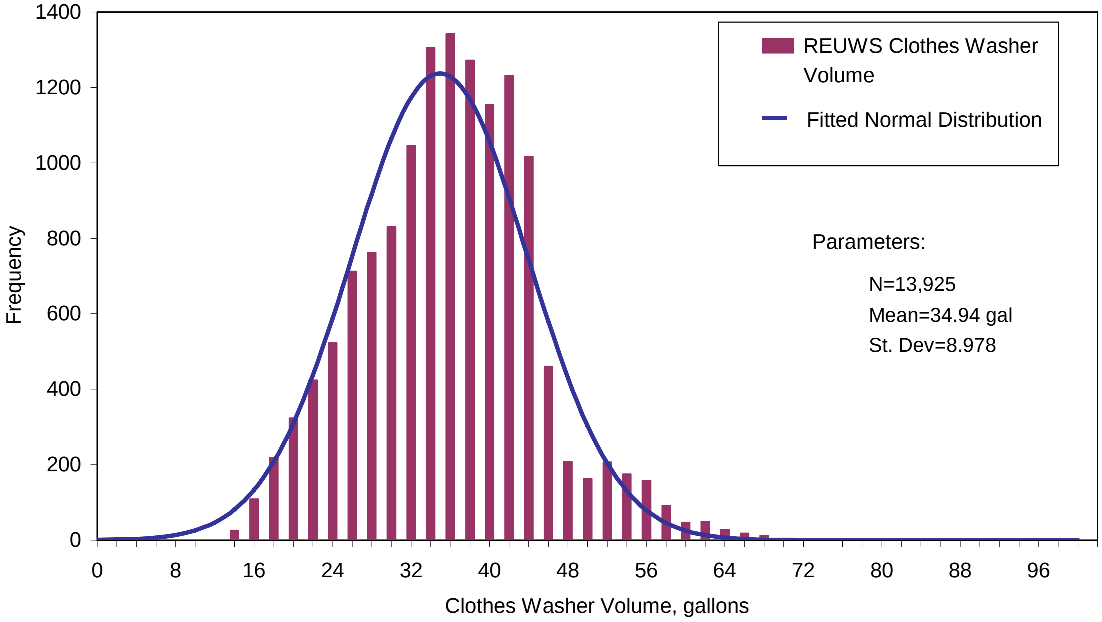


Figure 7-4. Distribution of Total Volume for Clothes-Washer Fills Greater Than Six Gallons, REUWS.

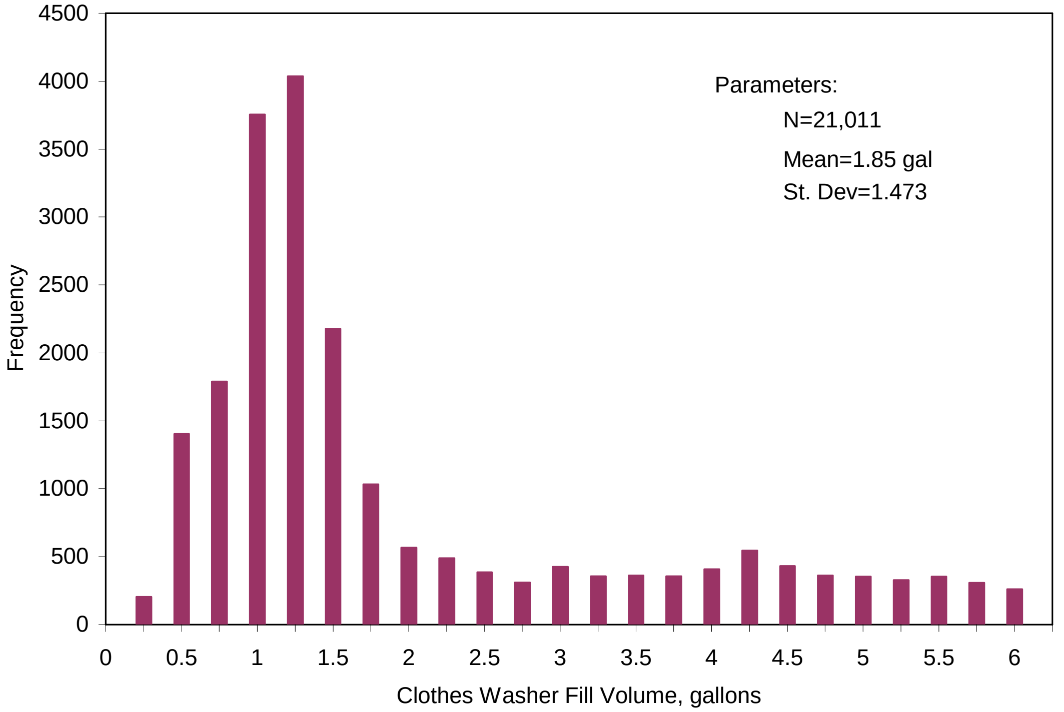


Figure 7-5. Distribution of Volumes for Clothes-Washer Water Draws Less Than Six Gallons, REUWS.

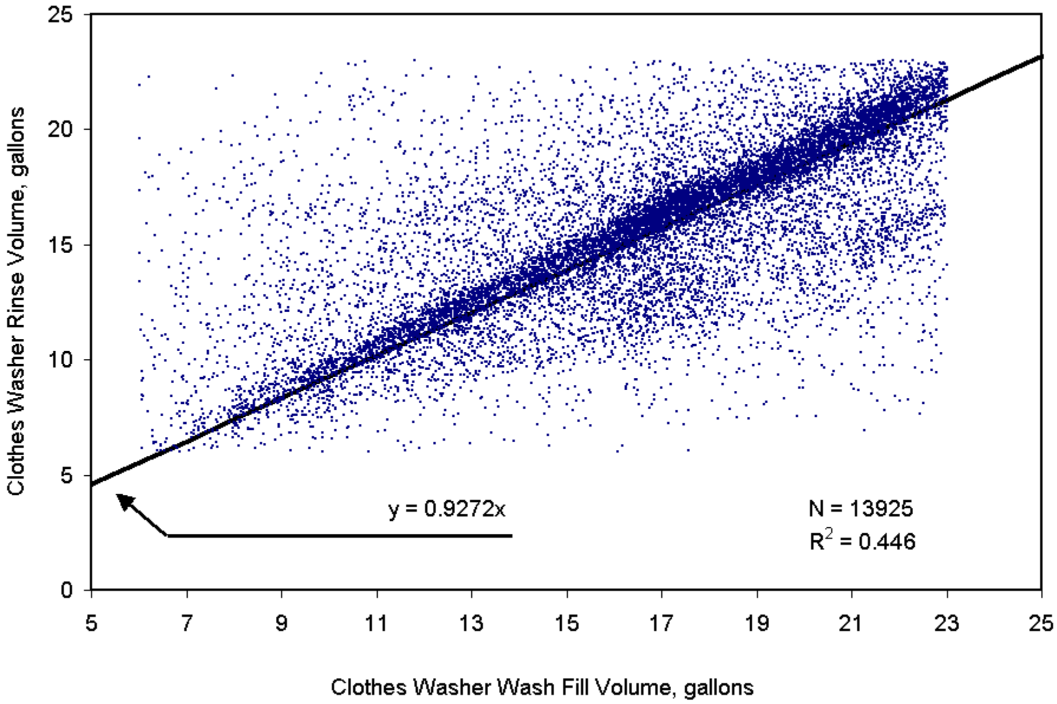
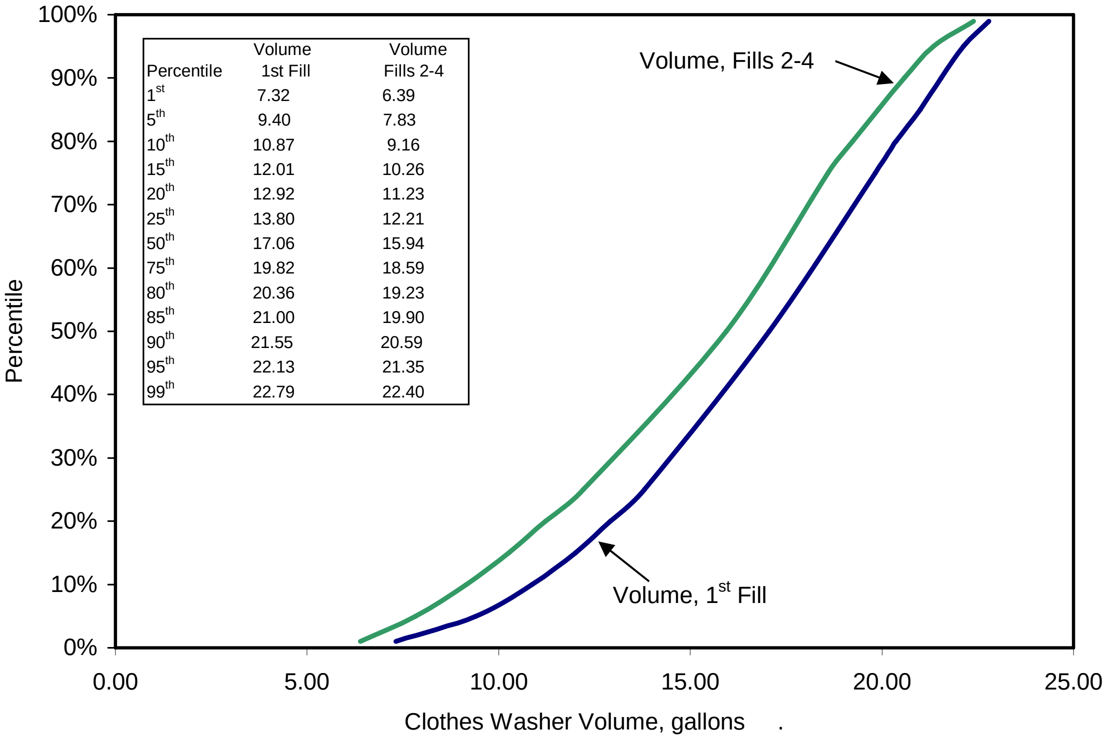


Figure 7-6. Relationship Between Wash-Fill Volume and Average Rinse-Fill Volume, REUWS.



Percentile	Volume 1st Fill	Volume Fills 2-4
1st	7.32	6.39
5th	9.40	7.83
10th	10.87	9.16
15th	12.01	10.26
20th	12.92	11.23
25th	13.80	12.21
50th	17.06	15.94
75th	19.82	18.59
80th	20.36	19.23
85th	21.00	19.90
90th	21.55	20.59
95th	22.13	21.35
99th	22.79	22.40

Figure 7-7. Clothes-Washer Fill Volume for Selected Percentiles, REUWS.

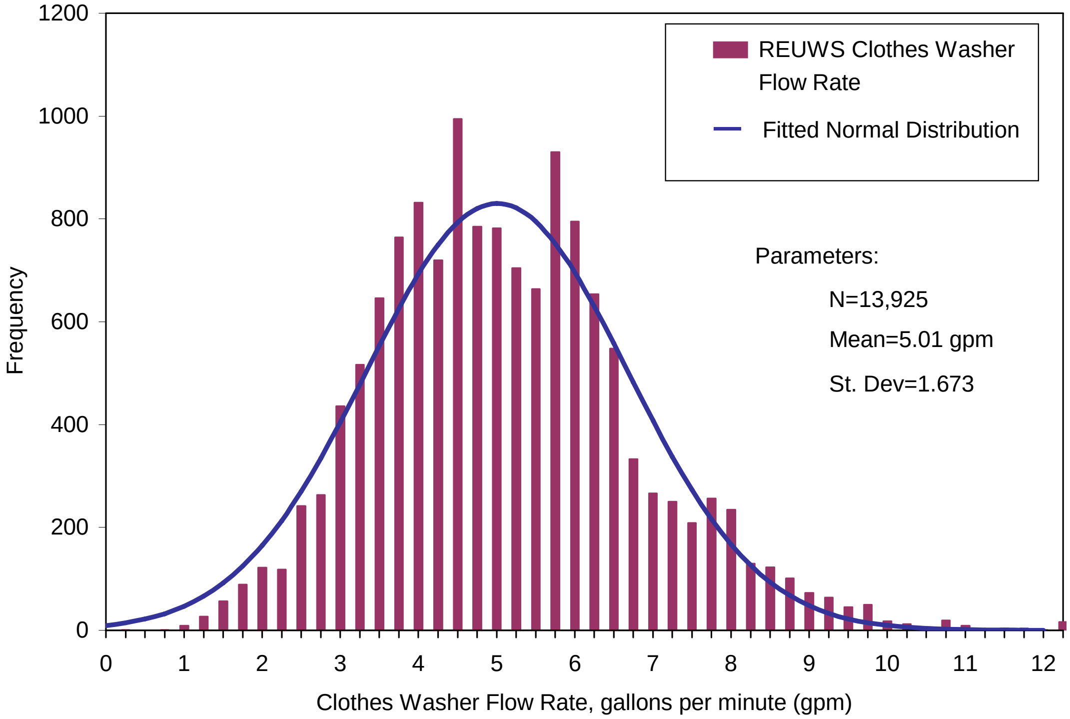


Figure 7-8. Distribution of Mode Flow Rates for the Clothes-Washer 1st Fill, REUWS.

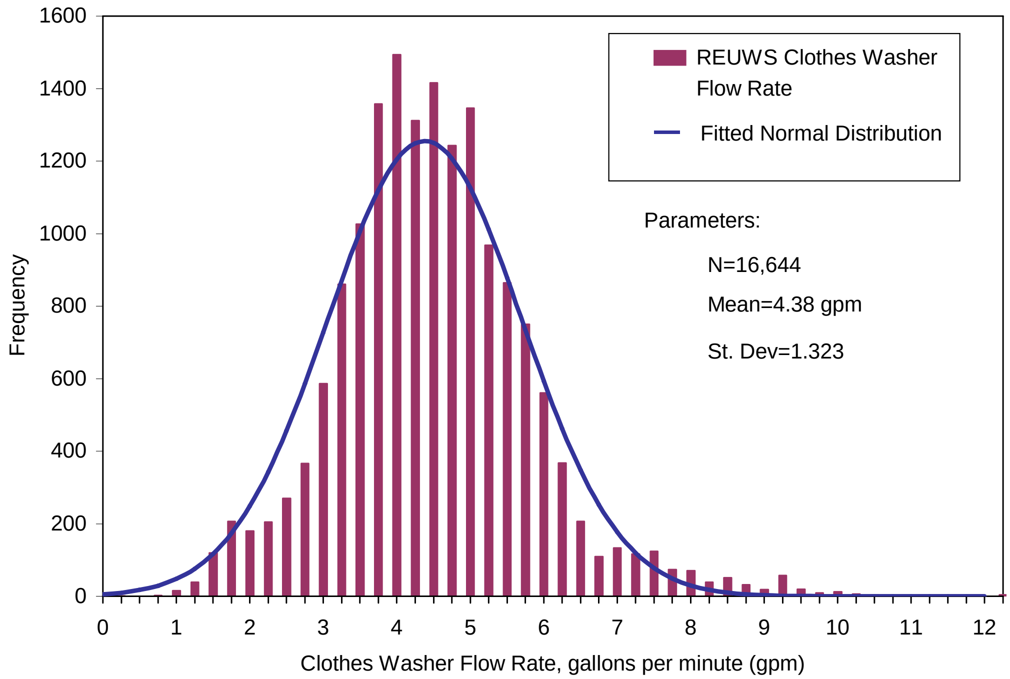


Figure 7-9. Distribution of Mode Flow Rates for Clothes-Washer 2nd to 4th Fills, REUWS.

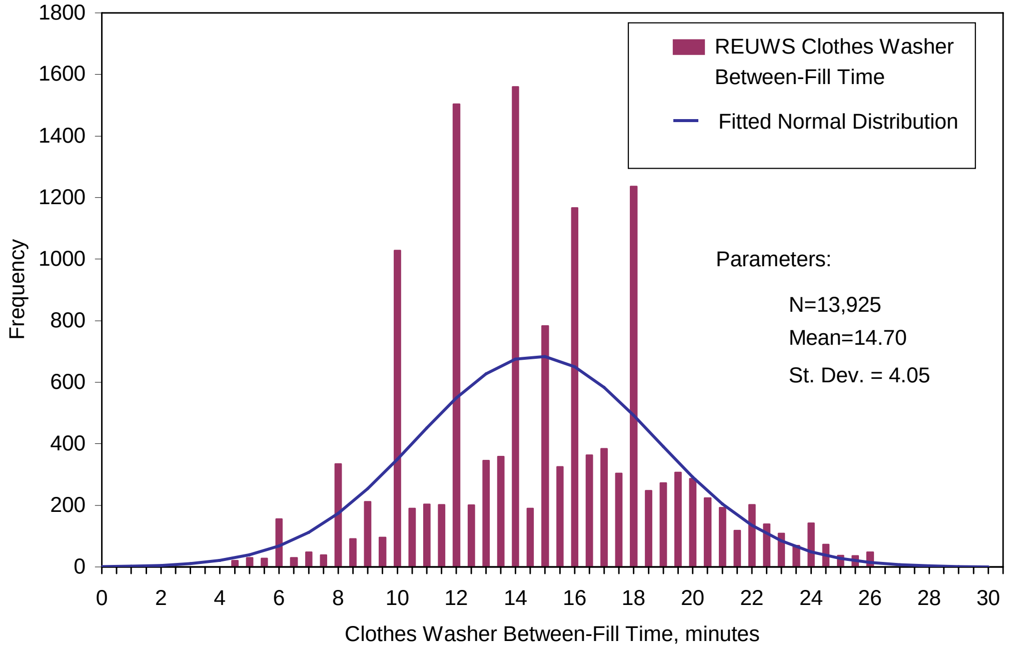


Figure 7-10. Distribution of Time Between the Clothes-Washer 1st and 2nd Fills, REUWS.

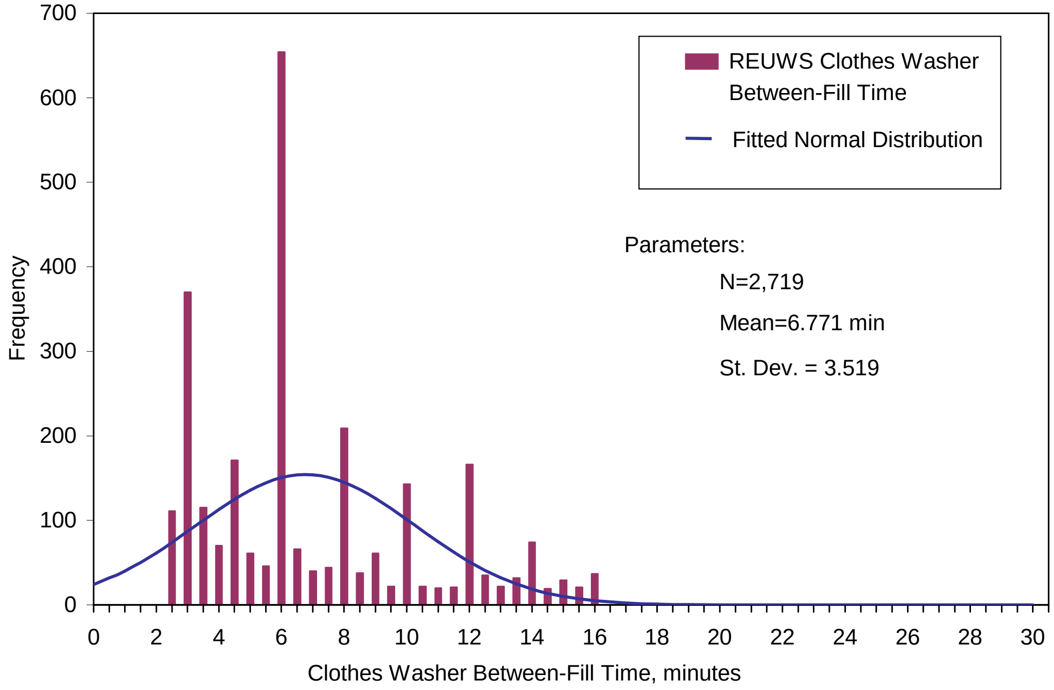


Figure 7-11. **Distribution of Time Between Clothes-Washer 2nd & 3rd Fills and 3rd & 4th Fills, REUWS.**

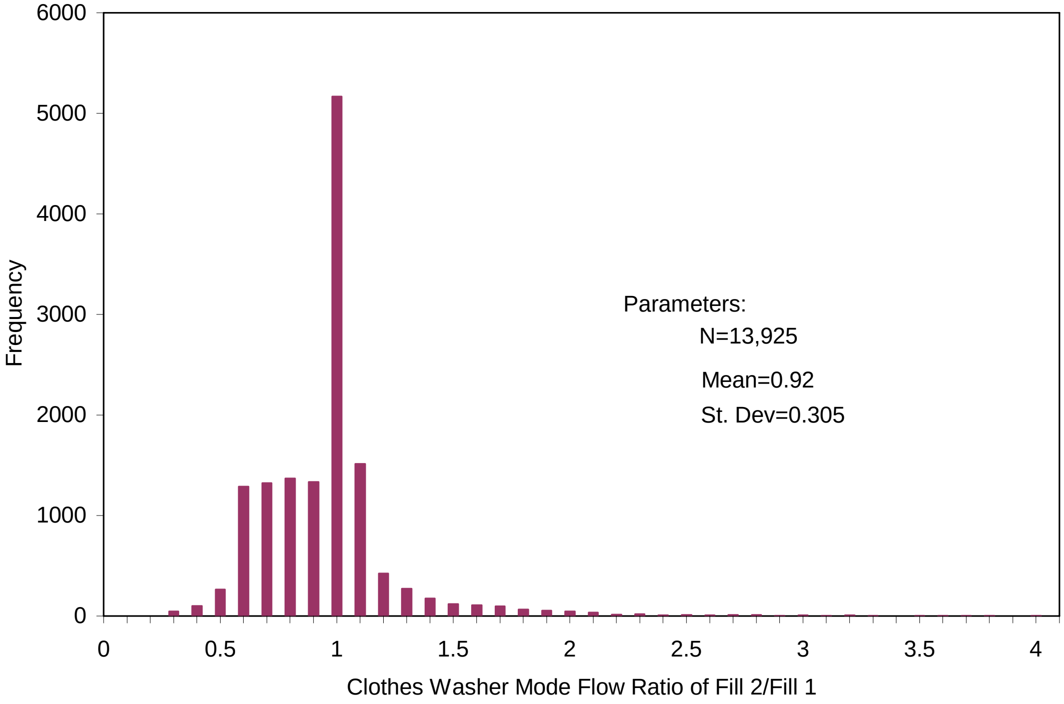


Figure 7-12. **Distribution of Ratio of Mode Flows for Clothes-Washer Fill 2/Fill 1, REUWS.**

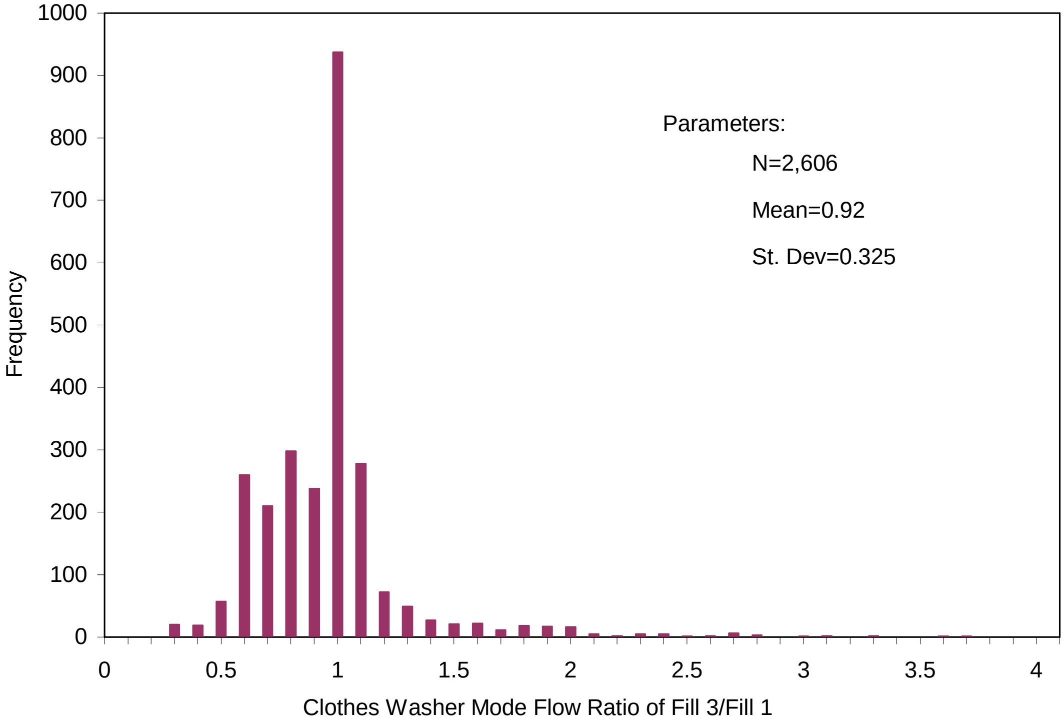


Figure 7-13. Distribution of Ratio of Mode Flows for Clothes-Washer Fill 3/Fill 1, REUWS.

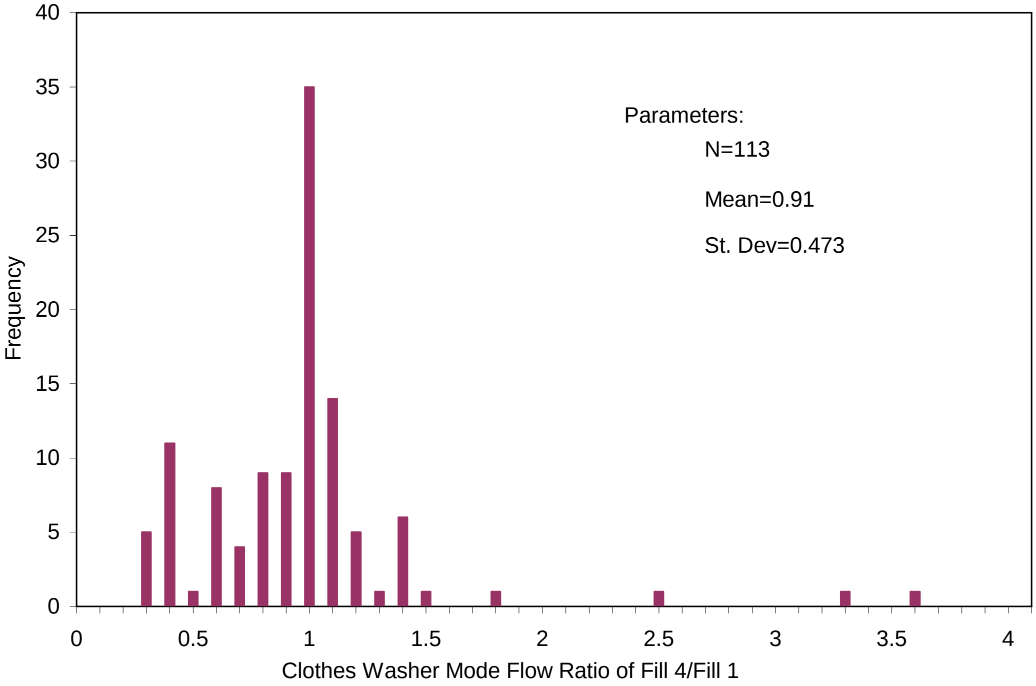


Figure 7-14. Distribution of Ratio of Mode Flows for Clothes-Washer Fill 4/Fill 1, REUWS.

Figure 7-6 shows a scatter plot of the relationship between the volume of water used for the wash fills and the average of the rinse fills. Regression analysis was conducted with the wash fill as the independent variable and the mean of the rinse fills as the dependent variable. Although the data points, representing a wash-fill volume with a corresponding rinse-fill volume, are widely scattered around the line, there is clearly a dense cluster surrounding the regression line. This cluster of points around the line shows that the volume of the rinse cycle is related to the volume of the wash cycle in most cases. The figure indicates that rinse cycles, on average, use 7% less water volume than the associated wash cycle. The scatter of the points provides evidence of the performance of the water-use assignment algorithms used by Trace Wizard. The data points that fall a large distance from the correlation line likely represent misclassified water draws. These cases can be explained by either or both the wash or the rinse water draws being misclassified or a problem with disaggregating clothes washer water draws from other water uses.

Figure 7-7 shows the clothes-washer volume for the first fill and for the second fill through the fourth fill for selected percentiles. The figure illustrates that the volume for the first fill is slightly higher than the volume for subsequent fills and that all fills during the same load are a similar volume.

Figure 7-8 shows the mode flow rate for the 1st fill and Figure 7-9 shows the mode flow rate for fills 2 through 4. In addition, the flow rates for the 1st fill are high with a high standard deviation as compared to the flow rates for the other fills. This is consistent with the ability of the user to select hot, cold, or warm for the first fill which results in a higher flow when warm is selected and a higher standard deviation because of the larger number of selection options.

Figures 7-10 and 7-11 show the distribution of the time between fills. The noteworthy feature of these three plots is the frequency spikes on the whole minute and in most cases on the even minute. In Figure 7-10, the spikes are at 6, 8, 10, 12, 14, 15, 16 and 18 minutes. It looks like a pattern whereby the wash cycles for most machines are similar and the user can select a wash time between about 4 and 20 minutes (allowing for filling time). This pattern is also evident in Figure 7-11 showing the time between what is presumably two rinse cycles.

Figures 7-12 to 7-14 show the ratio of the mode flow rate between the 2nd fill and 1st fill, 3rd fill and 1st fill, and 4th fill and 1st fill, respectively. In all three plots the spike in frequency is seen at 1, meaning the mode flow rate for the subsequent fills is the same as the mode flow rate during the 1st fill. The mean for all three cases is the same at 0.9. This means that on average, the mode flow rate is higher for the 1st fill than the other fills (the 1st fill is the denominator in the ratio). This was also seen in earlier plots (Figures 7-8 and 7-9) where the mean of the mode flow rate was higher during the 1st fill. As mentioned in the previous section, the ratio was used as a selection criterion and cases with a ratio below 0.25 or above 4 were excluded from the analysis. Overall, most of the ratios are between 0.5 and 1.5.

7.6 Conclusions

The RECS database proved to be the most reliable resource for clothes-washer use frequency, as its data directly reflects household clothes-washer use. The survey specifically asked how many loads of wash were done in the household that week. The only drawback with RECS is that the range of answers is too broad and it isn’t possible to determine if the usage was spread-out throughout the week or if it was concentrated on 1 or 2 days. In contrast, the NHAPS database seems to underestimate the amount of clothes-washer loads for the household, as its questionnaire asked the respondent how often he/she personally used the clothes washer, not how many loads of wash were done in the household. The NHAPS question not only does not accurately reflect household use, but it is unclear whether the answer reflects the number of actual loads done, or the number of days on which laundry was done, irrespective of how many sequential loads were done on one day. RECS indicated that the most common clothes-washer use frequency was 2-4 loads per week (38%) or 5-9 loads per week (38.2%), whereby NHAPS indicated that most people do wash only 1-2 times per week (unknown number of loads). It was not possible to use the REUWS database for frequency analysis because many of the records had to be eliminated because they exceeded the reasonable boundary conditions.

The REUWS database was used for volume and duration analysis as its data are based on actual water flow measurements. During analysis, it was found that many of the REUWS records were unrealistic in comparison to manufacturer data, and were therefore eliminated from the final dataset. The removal criteria represented reasonable, but not restrictive boundaries on number of fills, volume of water, duration of the event, and flow rates. The inherent uncertainty in the removal criteria is recognized, but it is correcting for flaws in the Trace Wizard methods. Although it is likely that the dataset still contains misclassified events, it is believed that the number of misclassified events is small and they have a minimal impact on the results.

Three types of information sources were identified and considered for determining volume and duration characteristics of clothes-washer usage: the REUWS database, manufacturer-supplied data, and studies conducted and published by Consumer Reports Magazine. In general, the three data sources were consistent with one another. Analysis of the REUWS database, which included monitored water use data from approximately 1200 single-family homes in major U.S. and Canadian cities, resulted in a mean volume per clothes-washer event of 34.9 gallons with a standard deviation of 9.0 gallons, indicating that approximately 68% of the events fall within the range of 25.9 gallons to 43.9 gallons (one standard deviation from the mean, see Table 7-14). These values, however, do not include the small sprays that may have occurred during the rinses. The information supplied by the manufacturers indicated that top-loading machines with large size loads used about 34.4-36 gallons and extra-large to super-large loads used about 40-45.8 gallons. The information published in the various Consumer Reports magazines (July 1998, July 1999, and August 2000) states top-loading clothes washers manufactured around 1998 used between 34 and 44 gallons per event and washers manufactured around 2000 used between 30 and 37 gallons per event. The results of the REUWS analysis are consistent with the published data and therefore serve as confirmation of the analysis procedures used in regard to water volume. The information provided by the manufacturers and Consumer Reports offers possible ranges of water use when the machines are filled to the maximum levels, however, the REUWS analysis provides more realistic values of how the clothes washers are actually used in real homes. The REUWS analysis also provides information on the water usage of each of the various wash/rinse cycles, in addition to the total volume for the event.

7.7 Recommended Clothes-Washer Use Parameters

This section recommends parameters for representing clothes-washer use in exposure assessment studies. The recommendations are taken from the analysis presented in this section and use the most appropriate data source for each parameter.

Table 7-16 presents the recommended frequency of clothes-washer use for households from one to five or more occupants. These frequency data are derived from our analysis of RECS.

Table 7-16. Recommended Frequency Data of Clothes-Washer Use as a Function of Household Size

	Frequency of Clothes-Washer Use*					
	1 Occupant	**2 Occupants**	**3 Occupants**	**4 Occupants**	**5 or more Occupants**	**Total**
Estimated household mean frequency (loads per week)	3.2	5.2	6.8	8.5	9.2	6.1
Estimated per capita frequency (loads per week)	3.2	2.6	2.3	2.1	1.8	2.3

* Based on RECS.

In regard to duration, analysis of REUWS provides data on the durations of the individual cycles (wash and rinses). However, REUWS does not provide data on the duration of the entire event, but only on the time it takes from the start of the first fill until the end of the last fill, as it is based on water draws only. For individual cycle duration information (wash fill, rinse fill), the REUWS data is used. For information on the final spin durations, the experimental and published machine characteristic information is used. Table 7-17 presents a summary of the recommended typical volume and duration characteristics of the separate clothes-washer wash and rinse cycles. The volumes for fill and rinse cycles are based on REUWS data. The duration values for time to fill, time to agitate, and time to drain/spin are based on the experimental trials (see Table 7-12). According to the REUWS data, the fill (1st cycle) and first rinse (2nd cycle) are 100% likely to occur. The second (3rd cycle) and third rinses (4th cycle) are 18.7% and 0.8% likely to occur. Weighting the duration values for these additional rinses, the total duration of the washing event in this configuration would be 43.1 minutes. Table 7-18 presents average values for representing total event duration and volumes based on the various Consumer Reports' data (July 1998, July 1999, August 2000). If the particular manufacturer model number of the clothes washer is known and presented within Tables 7-2, 7-3 or 7-4, the values given in those tables may be used for total event volume and duration.

Table 7-17. Recommended Typical Top-Loaded Clothes-Washer Cycle Volume and Duration Data

Parameter	**Typical Top-Loaded Clothes Washer**	**Comments**
Cycle 1	**Wash**	
Volume	16.6 gallons	Mean volume for first fills (REUWS)
Time to Fill	3.8 minutes	Based on experimental data on time to fill for a typical wash cycle*
Time to Agitate	12.0 minutes	Based on experimental data on time to agitate for a typical wash cycle*
Time to Drain/Spin	4.0 minutes	Based on experimental data on time to drain and spin for a typical wash cycle*
Cycles 2, 3 and 4	**Rinse**	
Volume	15.3 gallons	Mean volume for second fills (REUWS)
Time to Fill	7.5 minutes	Based on experimental data on time to fill for a typical rinse cycle*
Time to Agitate	4.0 minutes	Based on experimental data on time to agitate for a typical rinse cycle*
Time to Drain/Spin/Spray	8.0 minutes	Based on experimental data on time to drain, spin and spray for a typical rinse cycle*
Cycle 2 is 100% likely to occur Cycle 3 is 18.7% likely to occur Cycle 4 is 0.8% likely to occur		Based on REUWS data
Average Total Time for Washing Event (for this configuration)	43.1 minutes	Time for 1st cycle (19.8 minutes) plus (1.0 + 0.187 + 0.008) multiplied by time for rinse cycle (19.5 minutes)

* Average calculated using only settings to high-water level.

Table 7-18. Recommended Total Event Clothes-Washer Volume and Duration Data

Machine Type	Approximate Gallons per Load	Approximate Total Duration of Event	Comments
Top-Loading (manufactured 1998 or earlier)	41	43 minutes	Gallons per load based on mean and median value for all top-loading washers reviewed in Consumer Reports (July 1998). Duration of event based on range of durations given in Consumer Reports (July 1999).
Top-Loading (manufactured around 2000)	33	45 minutes	Gallons per load and durations based on mean value for all top-loading clothes washers reviewed in Consumer Reports (August 2000).
Front-Loading (manufactured around 2000)	27	64 minutes	Gallons per load and duration based on mean value for all front-loading clothes washers reviewed in Consumer Reports (July 1998, August 2000). (Not including the Miele)

Section 8

Dishwashers

8.1 Introduction

In this chapter, residential dishwasher use will be analyzed in an attempt to develop a set of general dishwasher-use characteristics that adequately reflect how often households use the dishwasher, the volume of water used to wash a load of dishes, and the duration of each dishwasher event. These values are intended for use in modeling human behavior and related exposure in respect to household water use. This chapter will present a review of published literature and manufacturer-supplied information on dishwasher use, and present analyses on the dishwasher-use data in the NHAPS, RECS and REUWS databases.

8.2 Review of Published Dishwasher-Use Studies

There were very few studies found on water-use characteristics of dishwashers. The summary of dishwasher characteristics found in literature is presented in Table 8-1. The studies showed that the amount of water used per load for a dishwasher has decreased in modern machines as compared to those manufactured in 1970s and early 1980s. Consumer Reports (August 1983) stated that machines made prior to the early 1980's use approximately 14 gallons per load, machines manufactured in the early 1980's use approximately 10 gallons per load, and modern machines use about 7.7 gallons per event (Consumer Reports, March 1998). Brown and Caldwell found that, in general, households in the early 1980’s ran the dishwasher 3.7 times per week. Consumer Reports, March 1998, reported that contemporary dishwashers operate on average for approximately 104 minutes.

Table 8-1. Summary of Reported Dishwasher-Use Characteristics

Machine Type	Frequency	Gallons per Event*	Total Duration*	Reference
General: Avg. Machine	3.7 loads/house/ week or 1.2 loads/ pers/week or 0.17 loads/pers/day			Brown and Caldwell, June 1994: 151 households, 450 persons, in CA, CO, D.C., VA, WA
Machines Manufactured prior to 1983		14		Consumer Reports, August, 1983
Machines Manufactured around 1983		8.5 – 12		Consumer Reports, August 1983
Kenmore Dirt Sensor 1583, 1595		7 – 9.5	116 minutes	Consumer Reports, March 1998
Kenmore QuietGuard 1568, 1579		7	100 minutes	
Frigidaire Gallery FDB949GF		7.5	116 minutes	

* Volume and duration based on “Normal Wash” option.

Table 8-1. *Continued*

Machine Type	Frequency	Gallons per Event*	Total Duration*	Reference
Maytag Quiet Plus II MDB6000A		5 – 10	104 minutes	Consumer Reports, March 1998
Maytag Quiet Pack MDB4000A		7	102 minutes	
GE Profile Performance GSD4920Z		7.5 – 10.5	96 minutes	
GE Profile Quiet Power GSD4320Z		9	92 minutes	

* Volume and duration based on "Normal Wash" option.

8.3 Manufacturer Data

Water-use characteristic information for various dishwashers on the current market was obtained from manufacturers of three widely used brands: Maytag, General Electric (GE) and Whirlpool. Each manufacturer has provided specifications on the water volume and number of fills used during the various options (eg. normal, pots & pans, sani-scrub, etc.) available on some of their current models (Whirlpool models GU980SCG, DU920PFG, DU850DWG; GE Potscrubber; and Maytag in general). Maytag also provided the total duration of the various options. Tables 8-2, 8-3, and 8-4 present a summary of the manufacturer supplied machine characteristics for the Whirlpool, Maytag and GE machines, respectively.

The data supplied by the manufacturers indicate that most of the current models operate similarly. The Whirlpool machine with many cycle selections, Model GU980SCG, uses between 2.2 gallons ("Rinse Only – Light Soil") and 10.8 gallons ("Normal – Heavy Soil", "Heavy – Medium or Heavy Soil"), depending on the option chosen. The "Normal – Medium Soil" setting uses 8.6 gallons per load. The other models listed (DU920PFG and DU850DWG) similarly use 2.2 and 2.9 gallons, respectively, for the "Rinse Only" option; 6.9 and 7.2 gallons, respectively for the "Normal" setting; and 8.6 gallons of water for the "Heavy" and "Pots'N'Pans" options. The Maytag dishwashers (across most models) range from a minimum of 2 gallons for the "Rinse & Hold" option; 6.3 gallons per load with the "Normal" setting; and a maximum of 11 gallons for the "Sani-Scrub" option. The General Electric dishwasher models (GSD3735FWW, GSD5930FWW, GSD2000FWH) use 2.8, 1.6, and 3.9 gallons, respectively for the "Rinse Only" options; 8.7, 9.9, and 8.0 gallons of water, respectively, for the "Normal" settings; and 10.2 11.5, and 9.5, respectively, for the "Pots and Pans" options.

The amount of water used per fill depends on the cycle selected. The heavy-soil cycles in the Whirlpool machines use from 1.7 to 3.6 gallons of water per fill for normal wash cycles depending on light or heavy soil. The more basic Whirlpool model and the GE Potscrubber uses approximately 1.4 gallons per fill for a normal wash. The number of fills reported by the manufacturers was a minimum of two fills and a maximum of seven fills. The total duration of a Maytag dishwasher load took 96 minutes for a normal wash, 10 minutes for a rinse only load, and 104 minutes for the sani-scrub wash option.

Table 8-2. Whirlpool Dishwasher Information Summary

User Selected Option	Total Volume (gallons)[1]	Number of Fills[1]	Average Volume per Fill (gallons)[2]
Dishwasher Model: Whirlpool GU980SCG			
Rinse Only – Heavy Soil	4.3	2	2.2
Rinse Only – Light Soil	2.2	2	1.1
Quick Wash – Heavy Soil	6.9	2	3.5
Quick Wash – Light Soil	4.8	2	2.4
China – Heavy Soil	8.6	3	2.9
China – Light Soil	6.5	3	2.2
Low Energy – Heavy Soil	8.6	3	2.9
Low Energy – Light Soil	6.5	3	2.2
Normal – Heavy Soil	10.8	3-4[3]	3.1
Normal – Medium Soil	8.6	3-4[3]	2.5
Normal – Light Soil	6.9	3-4[3]	2.0
Heavy – Heavy Soil	10.8	5	2.2
Heavy – Medium Soil	10.8	5	2.2
Heavy – Light Soil	8.6	5	1.7
Dishwasher Model: Whirlpool DU920PFG			
Rinse Only	2.2	2	1.1
Low Energy/China	6.5	3	2.2
Normal	6.9	3	2.3
Heavy	8.6	5	1.7
Pots-N-Pans	8.6	5	1.7
Dishwasher Model: Whirlpool DU850DWG			
Rinse Only	2.9	2	1.5
Light Wash	5.8	4	1.5
Normal	7.2	5	1.4
Pots-N-Pans	8.6	6	1.4

[1] Data from whirlpool@in-response.com dated 9/2000.

[2] Calculated information: Total Volume/Number of Fills.

[3] Range of 3-4 fills was supplied by manufacturer. A value of 3.5 was used to calculate average volume per fill.

Table 8-3. Maytag Dishwasher Information Summary (Across most models)

User Selected Option	Cycle Sequence*	Total Duration* (minutes)	Total Volume* (gallons)
Rinse & Hold	Rinse	10	2.0
Quick Wash	Wash, Rinse, Dry	18	3.9
Light/China	Main Wash, Hi-Temp Rinse, Dry	86	4.2
Light	Pre-Wash (w/sensor), Main Wash, Hi-Temp Rinse, Dry	94	6.5
Normal	Pre-Wash, Main Wash, Hi-Temp Rinse, Dry	96	6.3
Pots & Pans	Pre-Wash (w/sensor), Pre-Rinse (w/sensor), Main Wash, Hi-Temp Rinse, Dry	102	8.5
Power Scrub	Pre-Wash, Pre-Rinse, Main Wash, Hi-Temp Rinse, Dry	104	8.5
Sani Scrub	Pre-Wash, 2 Pre-Rinses, Main Wash, 2 Rinses, Dry	104	11

* Data acquired from Maytag 9/1999, publication entitled “Maytag Dishwasher Cycle Sequences.”

Table 8-4. GE Dishwasher Information Summary

User Selected Option	Total Volume (gallons)	Duration[1] (minutes)	Number of Fills	Average Volume per Fill[6] (gallons)
Dishwasher Model: GE GSD3735FWW[2]				
Pots & Pans, Heavy Wash	10.2	68	7	1.5
Normal Wash	8.7	68	6	1.5
Light Wash	7.3	68	5	1.5
China/Crystal	5.8	68	5	1.2
Rinse Only	2.8	9	2	1.4
Dishwasher Model: GE Profile GSD5930FWW[3]				
Sani-Wash	8.5	56-101	5	1.7
Pots & Pans, Heavy	11.5	70-85	7	1.6
Pots & Pans, Medium	9.9	65	6	1.7
Pots & Pans, Light	8.2	61	5	1.6
Normal, Heavy	11.5	64	7	1.6
Normal, Medium	9.9	59	7	1.4
Normal, Light	8.2	55	5	1.6
China/Crystal	6.6	34	4	1.7
Speed Wash	8.3	39	5	1.7
Rinse Only	1.6	5	1	1.6
Dishwasher Model: GE GSD2000FWH[4]				
Pots & Pans	9.5	62	7	1.4
Heavy Wash	9.5	62	7	1.4
Normal Wash	8.0	62	6	1.3
Short Wash	6.6	52	5	1.3
Rinse Only	3.9	12	3	1.3
Dishwasher Model: GE Potscrubber[5]				
Rinse and Hold	3.0		2	1.5
Short Wash	7.0		5	1.4
Water Saver	6.1		4	1.5
China/Crystal	7.3		5	1.5
Light Wash	7.0		5	1.4
Normal Wash	8.5		6	1.4
Potscrubber	10.1		7	1.4

[1] Duration does not include drying time. Drying time is approximately 30 minutes.
[2] Data from GE GSD3735FWW Dishwashers Owner's Manual.
[3] Data from Triton™, Profile™ Dishwashers GE Appliances Owner's Manual.
[4] Data from GE GSD2000FWH Dishwashers Owner's Manual.
[5] Data from ANSWERCTR@exchange.appl.ge.com.
[6] Calculated information: Total Volume/Number of Fills.

8.4 Prevalence of Dishwashers

The 1992-1994 NHAPS survey acquired information on the number of homes with dishwashers. During this time period, in the 48 contiguous United States, approximately 56% of the survey respondents had dishwashers in their homes. See Tables 8-5 and 8-6 for a breakdown of the percentage of homes that have dishwashers based on the number of household occupants, and whether the family had children living at home or not. The likelihood that a household had a dishwasher increased with the increasing number of occupants. Forty-three percent of the homes with one occupant had a dishwasher, while 62% of the homes with 4 persons had a dishwasher. Homes with children were only slightly more likely to have a dishwasher than homes without, 58.9% versus 54.7% respectively.

Table 8-5. Percent of Homes with Dishwashers, by Household Size, NHAPS

Is there a dishwasher in the home?	Percentage of Households (Number)					Total
	1 Occupant	2 Occupants	3 Occupants	4 Occupants	5 or more Occupants	
No	56.9 (547)	41.4 (608)	39.4 (285)	37.7 (229)	39.4 (148)	43.9 (1,817)
Yes	43.1 (414)	58.6 (860)	60.6 (439)	62.3 (379)	60.6 (228)	56.1 (2,320)
Total	23.2 (961)	35.5 (1,468)	17.5 (724)	14.7 (608)	9.1 (376)	100.0 (4,137)

Table 8-6. Percent of Homes with Dishwashers, by Households with and without Children, NHAPS

Is there a dishwasher in the home?	Percentage of Households (Number)		Total
	Households without Children	Households with Children	
No	45.3 (1,264)	41.1 (553)	43.9 (1,817)
Yes	54.7 (1,526)	58.9 (794)	56.1 (2,320)
Total	67.4 (2,790)	32.6 (1,347)	100.0 (4,137)

8.5 Dishwasher-Use Frequency

Dishwasher-use frequency information was obtained in both the NHAPS and the RECS surveys. The NHAPS survey asked half of the respondents (Version A), “Was a dishwasher used yesterday when you were home?” and asked the other half of the respondents (Version B) “Do you use the dishwasher almost every day, 3-5 times a week, 1-2 times a week, or less often?” The problem with the Version A question was that it gathered data only on dishwasher use when the respondent was home. This question is in line with the underlying purpose of the NHAPS survey, which was to examine exposure scenarios; however, it is not ideal for the purposes of determining household dishwasher-use frequency. The problem with the Version B question was that it gathered data on whether the respondent him/herself used the dishwasher, not whether the dishwasher was used by the family. This clearly does not provide a good representation of dishwasher-use frequency for the household. If, for example, the respondent was not the person who usually did the dishes in the family, he or she therefore would have answered “Less often.” However, his family may indeed use the dishwasher every day. Furthermore, another problem is the answer choices provided a range of loads per week, not a specific number of loads.

In the RECS survey, the question relating to dishwasher use was, “Which category best describes how often your household actually uses the automatic dishwasher in an average week? Less than 4 times a week, 4 to 6 times a week, or at least once each day.” This question is directly related to household dishwasher use, and is therefore more reliable than the question asked in NHAPS. However, the problem with this question, similar to NHAPS, is that the answers allow for a broad range for dishwasher-use frequency, which adds uncertainty to the estimate of actual use frequency.

8.5.1 NHAPS Dishwasher-Use Frequency Analysis and Results

The responses to the NHAPS Version B dishwasher-use question were analyzed and the results are presented below in Table 8-7. The results show that dishwasher-use frequency is directly related to household size. Larger households are more likely to use the dishwasher daily, while single-person households are more likely to use the dishwasher only once or twice a week. The data in Table 8-7 suggest there are a significant number of households that rarely use the dishwasher (less than once per week), even though they have one. This tendency not to use the dishwasher appears to increase as family size increases. However, this tendency may not be a true representation of household frequency, but instead may be a reflection of larger households being more likely to have the phone (and survey) answered by family members who do not do the dishes.

The frequency data from NHAPS are also summarized below in Table 8-8 based on whether the household had children or not. The table shows that families with children are more likely to use the dishwasher daily and families with no children are more likely to use the dishwasher three to five times a week. However, the frequency data from NHAPS presented in both Tables 8-7 and 8-8 may not be meaningful due to the ambiguity of the question. Since the question only pertained to how often the respondent him/herself used the dishwasher, it is not certain whether the results of this analysis reflect actual household use.

Table 8-7. Frequency of Dishwasher Use by Household Size, NHAPS

Frequency of Dishwasher Use	Percentage of Households (Number)					Total
	1 Occupant	2 Occupants	3 Occupants	4 Occupants	5 or more Occupants	
Daily	9.0 (37)	21.2 (180)	24.8 (107)	29.2 (107)	35.6 (79)	22.4 (510)
3-5 times per week	23.4 (96)	34.0 (289)	29.2 (126)	22.8 (84)	14.0 (31)	27.4 (626)
1-2 times per week	39.3 (161)	24.5 (208)	14.4 (62)	9.3 (34)	8.1 (18)	21.2 (483)
Less often	28.3 (116)	20.3 (172)	31.6 (136)	38.7 (142)	42.3 (94)	29.0 (660)
Total	100.0 (410)	100.0 (849)	100.0 (431)	100.0 (367)	100.0 (222)	100.0 (2,279)
Estimated mean frequency per week*	2.2	3.2	3.1	3.1	3.2	3.0
Estimated mean per capita frequency per week*	2.2	1.6	1.0	0.8	0.6	1.1

* Estimated mean frequency was calculated assuming the midpoint value for each frequency range: e.g., daily, 4 times per week, 1.5 times per week. Zero times per week was assumed for the “less than 1 times per week” category.

Table 8-8. Frequency of Dishwasher Use, by Households with and without Children, NHAPS

Frequency of Dishwasher Use	Percentage of Households (Number)		Total
	Households without Children	Households with Children	
Daily	20.0 (302)	27.1 (208)	22.4 (510)
3-5 times per week	31.2 (471)	20.2 (155)	27.5 (626)
1-2 times per week	27.3 (413)	9.1 (70)	21.2 (483)
Less often than 1 time per week	21.5 (325)	43.6 (335)	29.0 (660)
Total	66.3 (1,511)	33.7 (768)	100.0 (2,279)

8.5.2 RECS Dishwasher Frequency Analysis and Results

The responses to the RECS dishwasher-use question were analyzed and are presented below in Table 8-9. Similar to the NHAPS data, the dishwasher-use frequency is directly related to household size.

Of the three databases analyzed, the RECS data are the most reliable due to the directness of the question, clearly relating to household dishwasher use. The majority of single-person households and households with two or three persons use the dishwasher less than four times per week, while the majority of households with five or more persons use the dishwasher daily. Households with four persons appear to be just as likely to use the dishwasher in any of the three ranges given. Fifty-six percent of the households use the dishwasher less than four times per week. The major problem with the RECS data, however, is that the respondent choices are too limited. More than half of the respondents (56.3%) said their household used the dishwasher less than 4 times per week, yet it is unknown how many of those households used the dishwasher 0, 1, 2, or 3 times per week.

Table 8-9. Frequency of Dishwasher Use by Household Size, RECS

Frequency of Dishwasher Use	Percentage of Households (Number) 1 Occupant	2 Occupants	3 Occupants	4 Occupants	5 or more Occupants	Total
Daily	5.0	11.5	18.5	32.1	44.4	18.4
4-6 loads per week	9.7	26.4	29.6	33.6	27.9	25.3
Less than 4 loads per week	85.3	62.1	51.9	34.3	27.7	56.3
Total	100.0	100.0	100.0	100.0	100.0	100.0
Estimated mean frequency per week*	2.5	3.4	3.8	4.6	5.1	3.7
Estimated mean per capita frequency per week*	2.5	1.7	1.3	1.2	1.0	1.4

* Estimated mean frequency was calculated assuming the midpoint value for each frequency range: e.g., daily, 5 loads per week (for 4-6 loads per week category), and 2 loads per week (for less than 4 loads per week category).

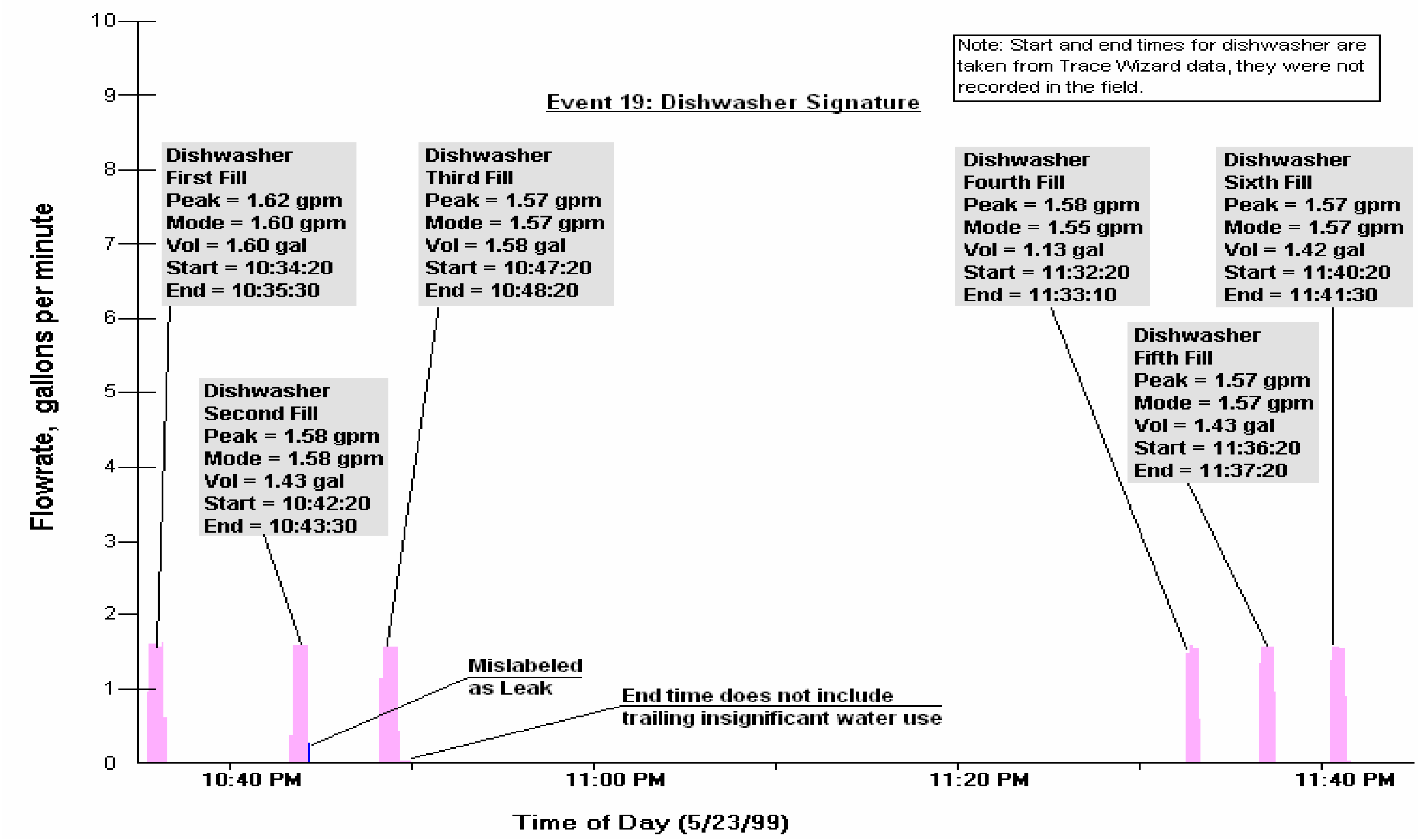
8.6 Dishwasher-Cycle Durations

8.6.1 REUWS Dishwasher Duration Analysis and Results

An analysis of dishwasher use was performed on the REUWS data in a similar manner to that used for clothes washers. In the REUWS database, the Meter-Master recorded the various characteristics of each water draw during the monitoring period, including peak flow, mode flow, volume, start/end time, etc. The Trace Wizard software attempted to identify the type of appliance in use during each water draw. Since a typical dishwasher load is comprised of at least 2 or 3 separate water draws, it was necessary to combine the associated water draws into their respective dishwasher event. Trace Wizard attempted to identify the first water draw of a dishwasher event, labeling it as DISHWASHER1, and labeling the subsequent dishwasher water draws as DISHWASHER.

In our analysis, each DISHWASHER1 water draw was combined with subsequent DISHWASHER water draws (prior to the next DISHWASHER1) into a single dishwasher event, This analysis revealed many inconsistencies in the data. Many of the resultant dishwasher events appeared unrealistic (e.g. excessive durations or volumes, too many water draws, etc.) when compared to the manufacturer-supplied information shown in Tables 8-2, 8-3 and 8-4.

In an attempt to salvage the useful data, several boundary criteria were applied to the REUWS data, including boundaries on the volume of water per fill, the duration of each cycle, and the total event duration. The information identified by the prior literature review (Table 8-1) and supplied by the manufacturers (Tables 8-2, 8-3, and 8-4) helped to establish reasonable guidelines for dishwasher water consumption for the purpose of this analysis. Additional information was derived from the Meter-Master evaluation study presented in Appendix A. The results from the study are presented in Figure 8-1, showing the water-use signature for a monitored dishwasher using the Meter-Master and Trace Wizard. In this small evaluation field study, the total duration between the start of the first fill and the end of the final fill was 67 minutes, 10 seconds. The entire wash cycle used 6 fills, with individual fills ranging from 1.13 to 1.6 gallons per fill. The entire dishwasher event used 8.59 gallons of water.



Event 19: Dishwasher Signature

Note: Start and end times for dishwasher are taken from Trace Wizard data, they were not recorded in the field.

Dishwasher
First Fill
Peak = 1.62 gpm
Mode = 1.60 gpm
Vol = 1.60 gal
Start = 10:34:20
End = 10:35:30

Dishwasher
Second Fill
Peak = 1.58 gpm
Mode = 1.58 gpm
Vol = 1.43 gal
Start = 10:42:20
End = 10:43:30

Dishwasher
Third Fill
Peak = 1.57 gpm
Mode = 1.57 gpm
Vol = 1.58 gal
Start = 10:47:20
End = 10:48:20

Dishwasher
Fourth Fill
Peak = 1.58 gpm
Mode = 1.55 gpm
Vol = 1.13 gal
Start = 11:32:20
End = 11:33:10

Dishwasher
Fifth Fill
Peak = 1.57 gpm
Mode = 1.57 gpm
Vol = 1.43 gal
Start = 11:36:20
End = 11:37:20

Dishwasher
Sixth Fill
Peak = 1.57 gpm
Mode = 1.57 gpm
Vol = 1.42 gal
Start = 11:40:20
End = 11:41:30

Mislabeled as Leak

End time does not include trailing insignificant water use

Figure 8-1. Water-Use Signature for a GE Powerscrubber 1235 Dishwasher with “Normal Wash” Selected, Trace Wizard.

The REUWS data were evaluated using constraints developed from analysis of the manufacturer data, literature, and field data, as follows:

1. Volume analysis: The analysis of manufacturer data and published literature lead to the criteria that for modern day dishwashers not allowing the “rinse only” option, the total volume of a dishwasher event should fall between 3.7 and 14 gallons. Of the approximately 6809 dishwasher-use events in the REUWS, 670 (9.8%) used greater than 14 gallons of water, and another 50 (0.7%) dishwasher uses were less than 3.7 gallons. If we assume primarily modern dishwashers with no “rinse only” events, approximately 10.5% of the events fall outside of the expected range for volume of water.

2. Analysis of the number of fills within single events: The analysis of the manufacturer-supplied data indicates a minimum of two fills and a maximum of 7 fills for modern dishwasher events. Of an initial 6809 dishwasher events reported in REUWS, 199 (2.9%) events have more than 7 fills and 5 (< 1%) have less than 2 fills.

3. Duration Analysis: The data provided by Maytag, shown in Tables 8-2 and 8-3, show a wide variety of combinations of possible event durations. The maximum duration between the start of the first fill and the end of the last fill, as shown in Table 8-2, is approximately 64 minutes. Neglecting the “Rinse Only” option, the shortest duration is approximately 10 minutes. Based on the above discussion, reasonable boundary conditions for event durations of between 10 and 70 minutes were selected. A relatively small fraction of the REUWS data falls outside of the expected range for dishwasher duration. Of 6809 dishwasher events recorded in REUWS, 117 (1.7%) are shorter than 10 minutes, and 410 (6.0%) are longer than 70 minutes.

In summary, the events failing to meet all of the boundary criteria for volume (>=3.7 gallons and <= 14 gallons) and for duration (>= 10 minutes and <= 70 minutes) were a relatively small fraction of both the total number of events as well as the total number of households. Of the 6809 dishwasher events (1188 total households) in REUWS 122 (80 households) were outside of both the volume and duration boundary conditions. In addition 1076 dishwasher events (473 households) were outside of at least one boundary condition.

A review of the remaining dataset revealed many suspect records, leading to uncertainty about the ultimate quality of the analysis. It is likely that Trace Wizard was inaccurate in assigning or not assigning water uses to the Dishwasher because the water signature of a typical dishwasher fill (approximately 1-2 gallons) looks similar to many common household water uses, such as faucets. For these reasons, and because the amount of water used by dishwashers does not constitute necessary conditions for a large exposure, the duration analysis was discarded.

8.7 Recommended Dishwasher-Use Parameters

As compared to other water sources in a household, dishwasher uses represent a relatively small source because of the infrequent usage, small water volume, and the relatively sealed washing compartments. As such, the exposure resulting from dishwasher use can be expected to be a very small portion of an occupant’s overall exposure to water-borne contaminants. For these reasons, general manufacturer data is sufficient to represent volume and duration characteristics of dishwashers. Based on the information available for dishwasher frequency and water-use characteristics, the typical dishwasher event is defined as follows in Table 8-10.

Table 8-10. Recommended Dishwasher Volume and Duration Data

Characteristic	Recommended Value*	Comments
Duration	100 minutes	Average of information found in Tables 8-1, 8-3 and 8-4.
Total Volume of Water	8 gallons	Average of information found in Tables 8-1, 8-2, 8-3 and 8-4.
Number of Fills	5 fills	Average of information found in Tables 8-2, 8-3 and 8-4.

* Based on approximate characteristics of Normal wash option across brands, from manufacturer data and data documented in Consumer Reports.

To represent the frequency of dishwasher use, the most reliable data was judged to be from the RECS analysis. RECS was chosen as more reliable over NHAPS because the RECS survey question reflected household use, while the NHAPS survey question reflected dishwasher use of the respondent. However, as discussed above, the RECS data did not capture the lower frequencies of use, as the data lumped all frequencies of “less than 4 loads per week” into one category. Considering that 56.3% of the respondents answered “less than 4 loads per week”, this data is clearly lacking definition. The recommended frequency values are presented in the following Table 8-11.

Table 8-11. Recommended Frequency Data of Dishwasher Use

Frequency of Dishwasher Use	Percentage of Households (Number)					Total
	1 Occupant	2 Occupants	3 Occupants	4 Occupants	5 or more Occupants	
Estimated mean frequency per week*	2.5	3.4	3.8	4.6	5.1	3.7
Estimated mean per capita frequency per week*	2.5	1.7	1.3	1.2	1.0	1.4

* Based on RECS. Estimated mean frequency calculated assuming the median value for each frequency range.

Section 9

Toilets

9.1 Introduction

In this chapter, residential toilet use will be analyzed in an attempt to develop a set of general toilet-use characteristics that adequately reflect how often people use the toilet, and the volume, flow rate and fill duration of each toilet flush. These values may be used for the purpose of modeling human behavior in respect to household water use. This chapter will present a review of published literature on toilet use, and present findings from analyses of the REUWS database. There were no questions asked about toilet use in either the NHAPS or RECS databases.

9.2 Review of Published Toilet-Use Studies

Several published studies focused on the performance of ultra-low flow toilets (ULF, rated 1.6 gallons per flush, gpf), contrasting their performance after retrofit with the performance of the low-flow industry standard (rated 3.5 gpf) and the older non-conserving toilets (approx. 5 to 7 gpf) they replaced.

The studies presented in Table 9-1 demonstrate the effect of retrofitting homes with ultra-low flow toilets. The Tampa Florida study (Konen and Anderson, March 1993) retrofitted the showers and toilets in 25 single-family homes with ultra-low flow devices and monitored their water usage for 30 days before and 30 days after retrofit. The Oakland, California study (Aher et al., Oct. 1991) retrofitted 25 single-family homes with ultra-low flow toilets and monitored their water usage for 21 days before and 21 days after retrofit. Although the local use patterns are different in Tampa, Florida as compared to Oakland, California, the retrofit produced similar relative results. In both cases the frequency of toilet use increased, approximately 18% in Tampa and 16% in Oakland. However, the volume of toilet water use decreased, by 6.1 gallons per person per day in the Tampa study and 5.3 gallons per person per day in the Oakland study. Possibly the increased flushing frequency resulted from the need to double flush (when a second flush is needed to clear the toilet bowl) with the ultra-low flow toilets. However, Konen and Anderson reported that, in the Tampa study, the rise in overall flushing frequency resulted from significant increases in flushing at several homes and not a general increase in all homes. Furthermore, responses to a follow-up questionnaire (30-60 days after installation) indicated that, “in general, the homeowners felt the flushing performance of the ULV fixtures was equal to their previous conventional toilets.”

Another ultra-low flush toilet rebate program occurred in Tucson, Arizona in 1991-92 (Henderson and Woodard, 2000). Tucson’s toilet-study program involved collecting data from 170 single-family households whose toilets were previously retrofitted, and resulted in an average savings of 33 gallons of water per dwelling per day, or 26 gallons per toilet per day. Follow-up studies were conducted to assess the satisfaction of the participants with their ultra-low flow toilets.

The follow-up study in Tucson was conducted specifically to assess the functioning of the toilets after 7 years of use (Henderson and Woodard, 2000). Electronic data loggers (Meter-Master 100EL) were placed on the household main water line meters of 200 of the original 477 households that participated in the rebate program. From these, usable waterflow data were collected from 170 of these homes for a duration of four days. Using the Trace Wizard software developed by Aquacraft Engineering, Inc., the toilet flushes were isolated from the whole house waterflow data, and the peak flows, durations, and volumes of flushes were identified (De Oreo, 1996). A survey was later conducted by phone to confirm the number and type of toilets in the house (Henderson and Woodard, 2000). The study revealed that 57.1% of the homes had no detectable problems with their ultra-low flow toilets during the seven years since their installation. However, the remaining 42.9% had problems with higher flush volumes, increased double flushing and recurring flapper leaks. Data logging revealed that in 26.5% of the homes there was at least one ULF toilet with a flush volume greater than 2.2 gpf, instead of the 1.6 gpf they were designed to use. The average flush volume of the ULF toilets in the study was found to be 1.98 gallons per flush (gpf), which is 24% higher than the standard 1.6 gpf. Double flushing occurred at least once a day in 10.9% of the ULF rebated toilets, compared to 6.6% of the non-low-consumption non-rebate toilets. There were recurring flapper leaks in the ULF toilets in at least 12.1% of the households. A study done by the Metropolitan Water District of Southern California in 1994 (and discussed in Henderson and Woodard, 2000) found that halogenating bowl cleaning solutions, (cleaners placed in the tank to continuously clean over a long period of time) could deteriorate the flappers. A follow up 1998 study found that newer flappers made of other materials were more resistant to the halogenating compounds.

Table 9-1. Summary of Published Studies of Toilet-Use Characteristics

Toilet Type	Reported Frequency (fpcd)[1]	Volume (gal/flush)	Population/ Sample Size	Reference	Special Study Conditions
Low-Flow (Avg. 3.6 gpf)	Mean = 3.8 Min = 1.8 Max = 8.4	Mean = 3.6 Min = 1.7 Max = 5.6	Tampa, Florida, 25 single family homes	Konen and Anderson, March 1993	Comparison of low flow to ultra-low flow retrofit (average 2.9 persons/home)
Ultra-low Flow (rated 1.6 gpf)	Mean = 4.5 Min = 1.7 Max = 12.8	Mean = 1.6 Min = 1.1 Max = 3.0	Tampa, Florida 25 single family homes	Konen and Anderson, March 1993	
Low-Flow (avg. 4.0 gpf)	Mean = 3.2 or 12.8 fphd[2]	Mean = 4.0	Oakland, California, 25 single family homes	Aher et al., Oct. 1991	Comparison of low flow to ultra-low flow retrofit (average 4.4 persons/home)
Ultra-low Flow (rated 1.6 gpf)	Mean = 3.7 or 15.9 fphd	Mean = 1.8 Min = 1.34 Max = 2.44	Oakland, California, 25 single family homes	Aher et al., Oct. 1991	
Ultra-low Flow (rated 1.6 gpf) 7 years after installation		Mean = 1.98	Tucson, Arizona 170 single family homes	Henderson and Woodard, Oct. 2000	Assess performance of ULF toilets 7 years after installation
Variety of toilets (33% low volume models or devices)	Mean = 4.0		CA, CO, D.C., VA, WA, 196 households, 545 persons, 356 toilets	Brown and Caldwell, June 1984	Subjects recorded toilet-flush frequencies

[1] fpcd: Flushes per capita day
[2] fphd: Flushes per home per day

9.3 Toilet-Use Frequency

Neither the NHAPS nor the RECS surveys asked questions related to toilet use. The REUWS database, however, contains records of household toilet use obtained during four weeks of household water-use monitoring via the Meter-Master device placed on each home's water meter.

9.3.1 REUWS Toilet-Flush Frequency Analysis and Results

The monitored data in REUWS were collected from 1,188 volunteer households during four weeks at each house (two weeks in warm months and two weeks in cooler months). The average household size was 2.8 occupants. For the purpose of determining daily frequency of toilet use, the data was first pared to full 24-hour days that included only days in which the occupants were assumed to be at home. Each full-use day was analyzed as an independent data point. Full days began at 12:00 midnight and extended until the following midnight. Any partial days in the beginning or end of the record were discarded. It was assumed that during normal occupation, residents would use the water at least three times a day. Therefore, any full days with less than three water uses were assumed to be unoccupied days and were discarded. It is conceivable that while the home was unoccupied, there could still be one or two water uses, such as the ice-maker, lawn sprinkler, etc.

In the REUWS database, the Trace Wizard software disaggregated the household water-use flows and labeled and characterized each distinctive water appliance use. Trace Wizard delineated each individual water-use event by its start and end times, volume and flow rate. According to a recent small-scale evaluation study of the Trace Wizard software (see Appendix A), Trace Wizard did a fairly accurate job overall discerning which water uses were toilets, as toilet flushes have distinct water flow signatures. Toilets have certain distinct peaks in flow rate and consistent durations with each flush. Because of this accuracy, especially with single (non-overlapping) water uses, it was not necessary to develop a protocol for eliminating unrealistic, and probably mislabeled, water-use events, as it was when analyzing other water uses like clothes washers or dishwashers. However, because no toilet uses were eliminated, a few erroneous entries may have been included in the dataset. Trace Wizard identified two types of toilet uses, TOILET, which represented standard flushes, and TOILET@, which represented anomalous flushes that were either too long/short or used too much/little water. These anomalous flushes are discussed further in the following section on duration, volume, and flow rate. All toilet records were included in the frequency analyses (TOILET and TOILET@), however, only the standard toilet records were included in the duration, volume and flow rate analyses.

Table 9-2 presents the number of toilet flushes per person per day based on the number of occupants in the household. Table 9-2 suggests that as family size increases, per capita flushes decrease. Figure 9-1 shows the distribution of the number of flushes per person per day from the analysis of REUWS. The average number of flushes per person per day was found to be between 5 and 6 flushes (mean = 5.51 flushes, S.D.=3.23). However, on 45% of the days, occupants flushed between 3 and 5 times per day. Figure 9-2 presents the distribution of flushes per person per day as a function of number of occupants in the household. The figure shows that as household size increases, the per capita frequency of flushing decreases.

Table 9-3 presents the number of flushes per household per day as a function of the number of occupants in the household. As expected, the analysis presented in Table 9-3 suggests that toilet use increases with family size. Figure 9-3 presents the distribution of flushes per household per day from the analysis of REUWS. All households are included in the analysis regardless of the number of occupants in the household. On average, each household flushed about 13 times (mean = 12.87 flushes, S.D.=7.16).

9.4 Toilet-Fill Characteristics

9.4.1 REUWS Toilet-Tank Fill Duration, Volume and Flow Rate Analysis and Results

The REUWS database provides data on the durations, volumes, and flow rates of the water draws used to fill up the toilet tanks after each flush, as recorded by the household water meter and analyzed by Trace Wizard. Trace Wizard differentiated standard toilet-tank fills from abnormal toilet-tank fills when the duration was abnormally longer than a standard fill. Standard toilet fills were labeled TOILET and abnormal toilet fills were labeled TOILET@ in the REUWS database. The frequency analyses (see above section) were based on all toilet flushes including both standard as well as abnormal water draws, however, the duration, volume and flow rate analyses focused on only the standard toilet water draws.

Table 9-2. Per Capita Frequency of Toilet Use as a Function of Family Size, REUWS

Number of Flushes per Person per Day	Cumulative Percent of Days (Number of Days)*						
	1 Occupant	2 Occupants	3 Occupants	4 Occupants	5 Occupants	6 or more Occupants	Total
1	4.3 (131)	3.5 (310)	4.1 (172)	6.2 (248)	4.2 (73)	8.0 (66)	4.4 (1000)
2	11.7 (359)	11.7 (1026)	13.4 (563)	20.1 (810)	18.2 (313)	30.5 (252)	14.7 (3323)
3	21.1 (647)	22.3 (1955)	28.7 (1204)	40.6 (1635)	43.2 (743)	58.0 (479)	29.5 (6663)
4	30.8 (941)	35.3 (3089)	46.6 (1956)	61.3 (2473)	70.3 (1208)	80.6 (666)	45.8 (10333)
5	40.2 (1229)	48.2 (4220)	63.0 (2643)	77.6 (3127)	86.1 (1480)	92.7 (766)	59.6 (13465)
6	47.7 (1461)	60.4 (5285)	75.8 (3183)	87.9 (3543)	93.5 (1608)	97.2 (803)	70.3 (15883)
7	55.7 (1705)	70.0 (6125)	85.5 (3588)	93.8 (3783)	97.6 (1678)	99.0 (818)	78.4 (17697)
8	61.8 (1890)	78.6 (6875)	91.3 (3832)	97.1 (3915)	99.2 (1706)	99.8 (824)	84.3 (19042)
9	68.5 (2097)	85.1 (7445)	94.9 (3984)	98.6 (3977)	99.8 (1715)	99.8 (824)	88.8 (20042)
10	73.4 (2247)	90.0 (7873)	97.1 (4077)	99.3 (4002)	99.9 (1717)	99.9 (825)	91.8 (20741)
11	78.4 (2400)	93.0 (8134)	98.3 (4126)	99.6 (4015)	99.9 (1717)	99.9 (825)	94.0 (21217)
12	82.5 (2523)	95.2 (8330)	99.0 (4155)	99.9 (4026)	99.9 (1717)	99.9 (825)	95.5 (21576)
13	85.7 (2621)	96.7 (8458)	99.4 (4173)	99.9 (4027)	99.9 (1718)	99.9 (825)	96.6 (21822)
14	88.4 (2705)	97.8 (8558)	99.6 (4181)	99.9 (4029)	99.9 (1718)	99.9 (825)	97.5 (22016)
15	90.2 (2760)	98.5 (8618)	99.7 (4185)	100.0 (4031)	99.9 (1718)	99.9 (825)	98.0 (22137)
> 15	100.0 (3060)	100.0 (8748)	100.0 (4197)	100.0 (4032)	100.0 (1719)	100.0 (826)	100.0 (22582)
Average # flushes per person per day for each household size	7.6	6.1	5.0	4.2	3.9	3.4	5.5

* Dataset includes only full 24-hour days with at least three water uses during that day.

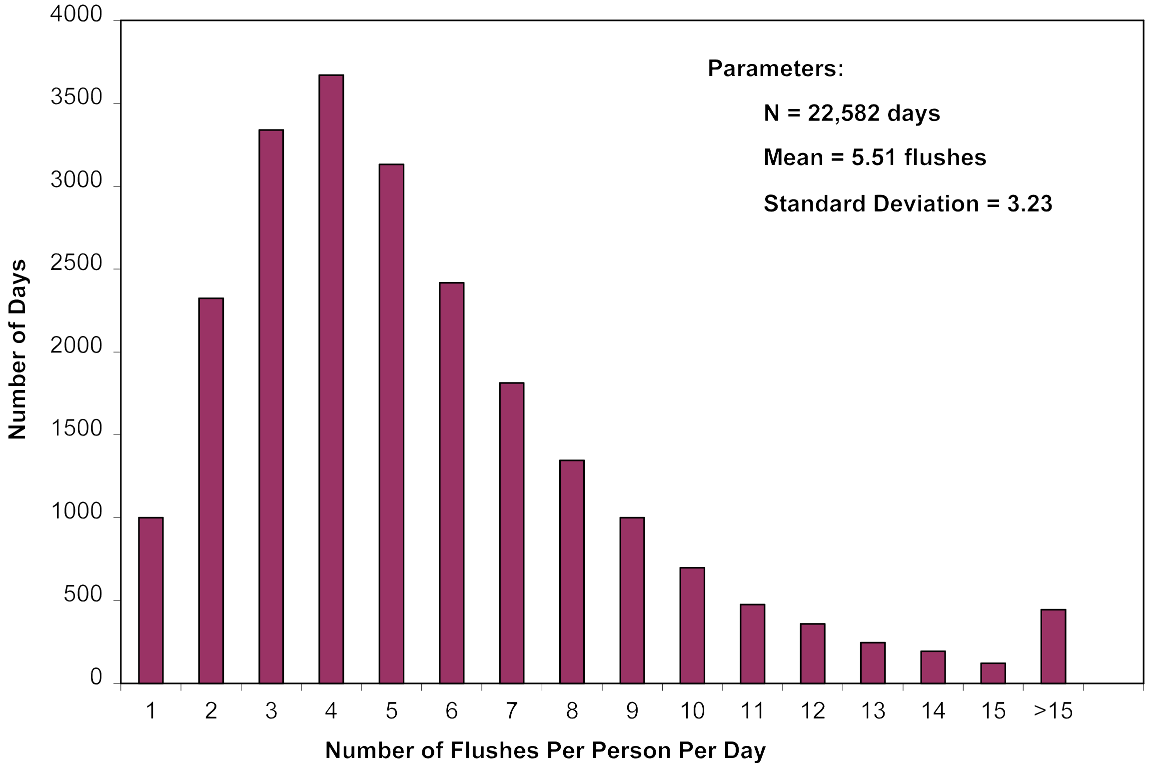


Figure 9-1. Distribution of Number of Flushes Per Person Per Day, REUWS.

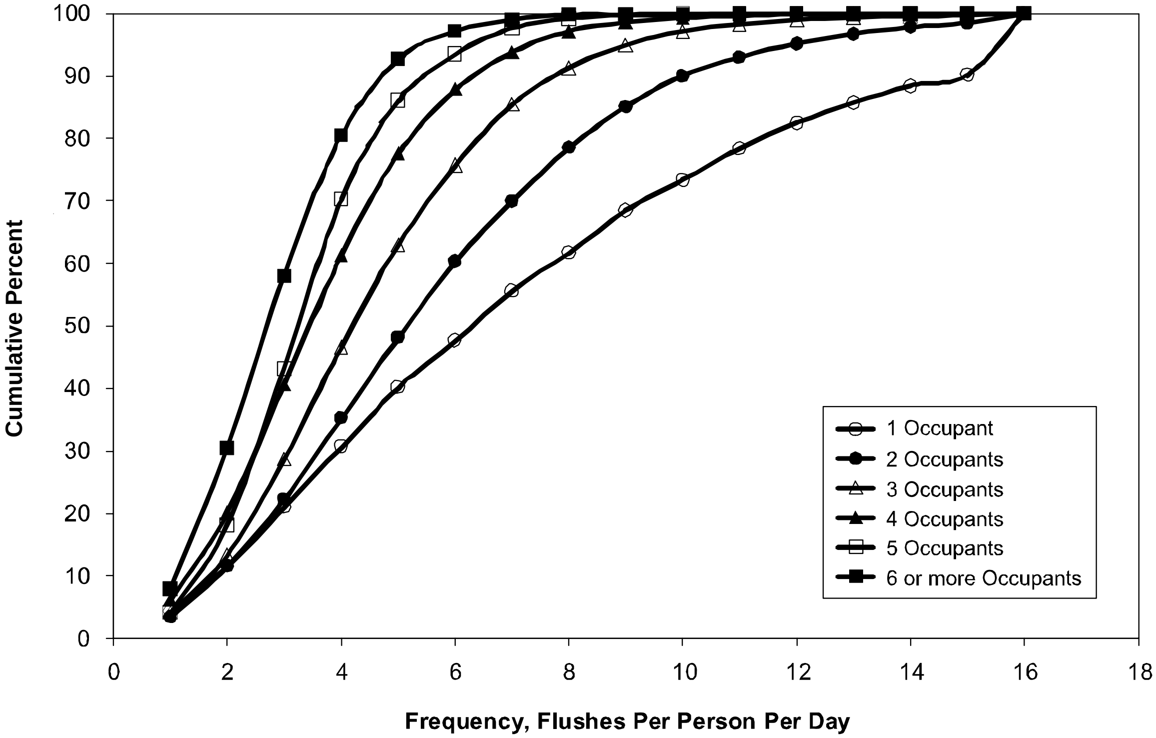


Figure 9-2. Per Capita Frequency of Toilet Flushes as a Function of Household Size, REUWS.

Table 9-3. Household Frequency of Toilet Use as a Function of Family Size, REUWS

Number of Flushes per Household per Day	Percent of Days (Number of Days)*						
	1 Occupant	2 Occupants	3 Occupants	4 Occupants	5 Occupants	6 or more Occupants	Total
1	4.3 (131)	1.5 (129)	0.8 (35)	0.9 (35)	0.6 (10)	1.1 (9)	1.5 (349)
2	7.5 (228)	2.1 (181)	1.3 (54)	1.2 (48)	0.5 (9)	0.4 (3)	2.3 (523)
3	9.4 (288)	3.5 (307)	2.0 (83)	2.0 (79)	1.0 (17)	0.6 (5)	3.4 (779)
4	9.6 (294)	4.7 (409)	2.2 (92)	2.1 (86)	1.0 (17)	0.8 (7)	4.0 (905)
5	9.4 (288)	5.0 (440)	3.4 (144)	2.6 (103)	1.2 (20)	0.8 (7)	4.4 (1002)
6	7.6 (232)	5.6 (489)	3.7 (155)	3.3 (133)	1.8 (31)	2.1 (17)	4.7 (1057)
7	8.0 (244)	5.8 (507)	3.9 (163)	3.5 (142)	1.9 (32)	2.3 (19)	4.9 (1107)
8	6.0 (185)	7.2 (627)	5.0 (208)	4.6 (184)	2.9 (50)	2.7 (22)	5.7 (1276)
9	6.8 (207)	6.5 (571)	6.4 (270)	4.6 (187)	3.4 (59)	3.6 (30)	5.9 (1324)
10	4.9 (150)	6.4 (560)	5.4 (228)	5.4 (217)	4.0 (68)	3.0 (25)	5.5 (1248)
11	5.0 (153)	6.4 (561)	6.3 (266)	5.4 (219)	4.9 (84)	4.5 (37)	5.8 (1320)
12	4.0 (123)	5.8 (504)	6.1 (258)	5.0 (202)	4.9 (84)	4.8 (40)	5.4 (1211)
13	3.2 (98)	5.2 (452)	5.3 (222)	5.8 (232)	4.7 (81)	4.7 (39)	5.0 (1124)
14	2.7 (84)	4.4 (388)	5.5 (229)	4.9 (199)	5.3 (91)	4.5 (37)	4.6 (1028)
15	1.8 (55)	4.3 (375)	5.6 (236)	5.5 (221)	5.2 (90)	4.1 (34)	4.5 (1011)
16	1.9 (57)	4.3 (375)	5.4 (228)	4.6 (186)	5.3 (91)	5.0 (41)	4.3 (978)
17	1.5 (45)	3.7 (323)	3.8 (159)	5.0 (201)	6.7 (115)	4.8 (40)	3.9 (883)
18	1.3 (39)	2.8 (247)	3.6 (153)	4.0 (160)	6.1 (104)	4.6 (38)	3.3 (741)
19	0.7 (20)	2.5 (221)	3.6 (152)	4.3 (172)	5.0 (86)	3.1 (26)	3.0 (677)
20	0.6 (17)	2.4 (207)	3.2 (135)	3.0 (121)	4.0 (69)	3.3 (27)	2.6 (576)
21	0.7 (20)	1.6 (142)	2.8 (118)	3.3 (134)	3.6 (62)	3.8 (31)	2.2 (507)
22	0.4 (11)	1.4 (119)	2.3 (96)	2.5 (100)	3.6 (62)	4.1 (34)	1.9 (422)
23	0.4 (11)	1.4 (119)	1.8 (77)	2.5 (100)	2.5 (43)	4.1 (34)	1.7 (384)
24	0.3 (9)	0.9 (77)	1.7 (71)	2.0 (82)	3.3 (57)	3.3 (27)	1.4 (323)
25	0.2 (6)	0.7 (63)	1.3 (56)	2.1 (84)	2.8 (48)	3.4 (28)	1.3 (285)
26	0.3 (10)	0.7 (65)	1.3 (54)	1.3 (54)	2.0 (34)	1.9 (16)	1.0 (233)
27	0.2 (5)	0.7 (58)	1.0 (42)	1.6 (64)	1.6 (27)	2.5 (21)	1.0 (217)
28	0.2 (5)	0.5 (42)	0.8 (35)	0.9 (38)	1.2 (20)	1.6 (13)	0.7 (153)
29	0.3 (10)	0.3 (30)	0.9 (36)	0.9 (37)	1.6 (27)	2.1 (17)	0.7 (157)
30 or more	1.1 (35)	1.8 (160)	3.4 (142)	5.3 (212)	7.6 (131)	12.3 (102)	3.5 (782)
Total	100.0 (3060)	100.0 (8748)	100.0 (4197)	100.0 (4032)	100.0 (1719)	100.0 (826)	100.0 (22582)

* Dataset includes only full 24-hour days with at least three water uses during that day.

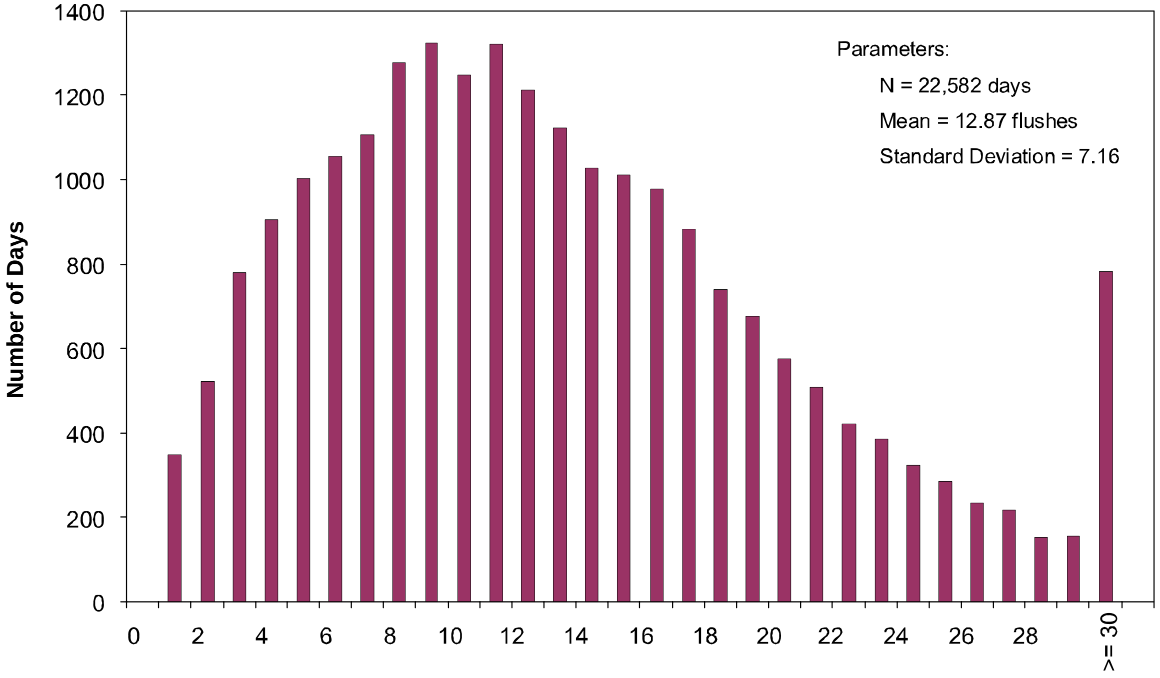


Figure 9-3. Household Frequency of Toilet Flushes, REUWS.

Two of the most probable scenarios for an abnormal toilet-tank fill are 1) when the user flushed the toilet for a second time (double flushes) while the tank was still being filled from the first flush, possibly because the first flush did not successfully remove all of the waste; or 2) when the flapper did not seal completely, thereby causing a leak in the tank and causing the tank to fill for a longer duration and greater volume than normal. Overall, there were 50,329 abnormal flushes (17%) out of the 295,660 flushes in the REUWS database. Because Trace Wizard identified the abnormal flushes as anomalies, they were discarded in the volume and duration calculations.

The 245,328 standard toilet flushes in REUWS were analyzed and the results are presented in Table 9-4. The table presents the summary statistics and selected percentiles for toilet duration, volume, and flow rate. The majority of the toilet events appear to be of reasonable duration, supporting the credibility of the Trace Wizard assignment algorithm. The maximum duration is 2,720 seconds (approximately 45 minutes). This duration is clearly outside the boundaries of how a toilet would operate, as is the minimum of 10 seconds. However, the breakdown of the percentiles show that most of the cases fall well within the range of what would be considered reasonable; 99 percent of the cases are 170 seconds (2.8 minutes) or less indicating that there are only a few unreasonable cases. Similarly the values for volume and flow rate are also within reasonable ranges. Although there are some outliers that could have been dropped from the analysis, most data fall within a reasonable range. The mean duration of the single flushes dataset was 71.4 seconds (1.2 minutes), the mean volume was 3.5 gallons and the mean flow rate was 3.9 gallons per minute.

Similarly, the volume values are also reasonable, as 99% of the volumes were measured as 6.49 gallons per flush or less, and only 1% was 1.3 gallons or less. The mean volume was 3.5 gallons per flush, which is consistent with the Konen and Anderson, 1993, and the Aher et al., 1991 studies, which documented conventional toilets having means of 3.6 and 4.0 gallons per flush (gpf). According to an investigation by Aquacraft Engineering, Inc., small water-volume usages of approximately 0.1 gallons (typically faucet usage for hand washing, which occurs while the toilet tank is filling) may be hidden in the volume recorded for the toilet flush, and this usage immediately following toilet use may cause the recorded toilet-flush volume to be slightly higher than actual (Henderson and Woodard, 2000).

Table 9-4. Summary Statistics and Percentiles for the Duration, Volume and Flow Rate of Toilet Water Draws, REUWS

Statistic[1]	Duration (seconds)	Volume (gallons)	Flow Rate (gallons per minute)
Minimum	10.0	0.3	0.0
Maximum	2,720.0	9.8	14.1
Mean	71.4	3.5	3.9
Standard Deviation	29.8	1.2	1.3
1st percentile	30.0	1.3	0.5
5th percentile	30.0	1.6	1.7
10th percentile	40.0	1.8	2.3
25th percentile	50.0	2.6	3.1
50th percentile	70.0	3.5	3.9
75th percentile	80.0	4.3	4.7
90th percentile	110.0	5.0	5.5
95th percentile	120.0	5.4	6.0
99th percentile	170.0	6.5	7.0
Number of Records	245,328	245,328	245,328

[1] This analysis is based on standard toilet water draws only (TOILET not including TOILET@)
No TOILET records were eliminated from the analysis, therefore some faulty records were included

Figures 9-4 to 9-6 show histograms of the duration, volume and mode flow for the standard toilet-tank fill. Also shown on each plot are the statistics that were presented in Table 9-4 including the number of cases.

Figure 9-4 shows that most toilets take between 40 and 110 seconds (10th and 90th percentiles, respectively) to refill the tank. There were only 1,260 cases (0.5%) of 200 seconds or more and 1,101 cases (0.45%) of 30 seconds or less.

Figure 9-5 shows the distribution of toilet volume in bins of 0.25 gallons. The mean volume per flush is 3.48 gallons. It is interesting to note that there is an apparent bi-modal shape to the flush volume distribution, with the first mode between approximately 1.5 – 2.5 gallons (containing 47,246 of the records, 19.3%) and a second, broader mode between approximately 3 and 5 gallons (containing, 141,988 of the records, 57.9%). Perhaps this reflects the prevalence of both the 3.5 gallon per flush “low flow” toilets that were conventional throughout the1970s and 1980s and the 1.6 gallon per flush “ultra-low flow” toilets introduced in the late 1980s and mandated in 1992 by congress for use in new construction.

The mode flow rates of toilet flushes (flow rate that occurred most often during the flush) are shown in Figure 9-6 in bins of 0.5 gallons per minute. Most of the flush mode flow rates are between 3 and 5 gallons per minute. The highest-frequency bins represent 58 percent of the cases (143,735 flushes). The mean flow rate is 3.9 gallons per minute.

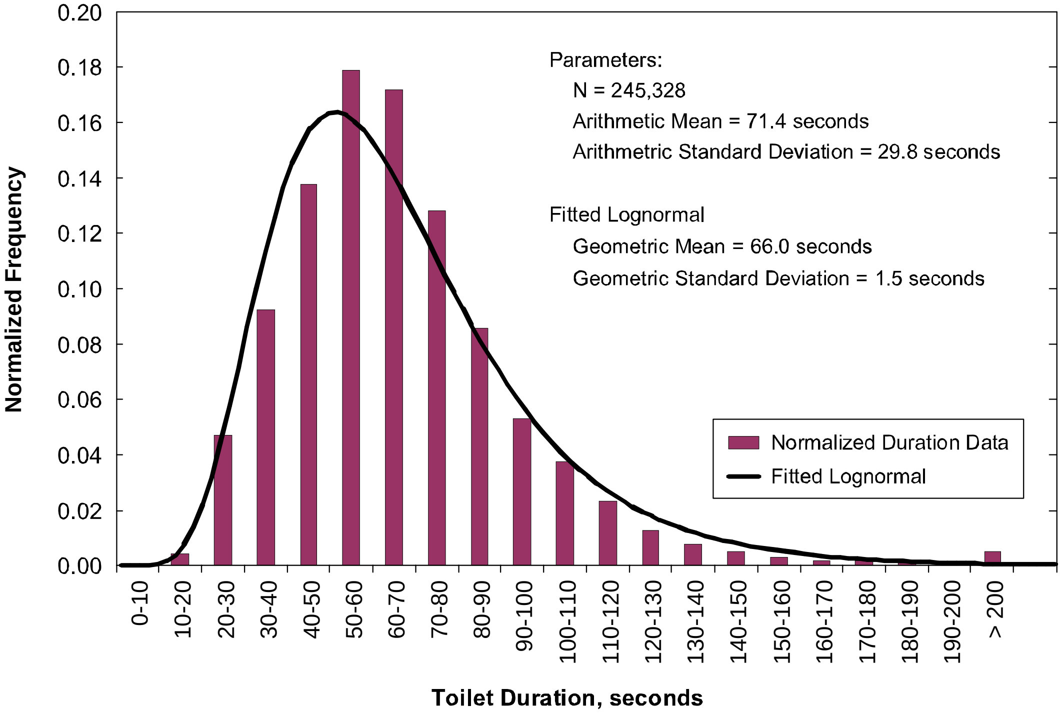


Figure 9-4. Distribution of Toilet Water-Draw Duration, REUWS.

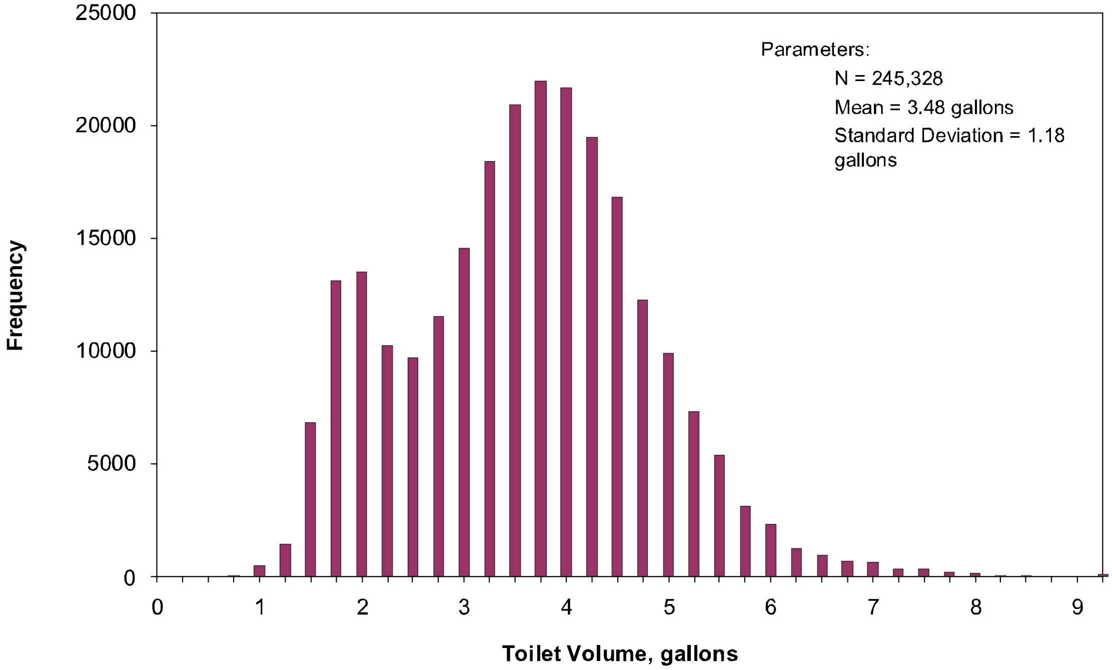


Figure 9-5. Distribution of Toilet-Tank Fill Volume, REUWS.

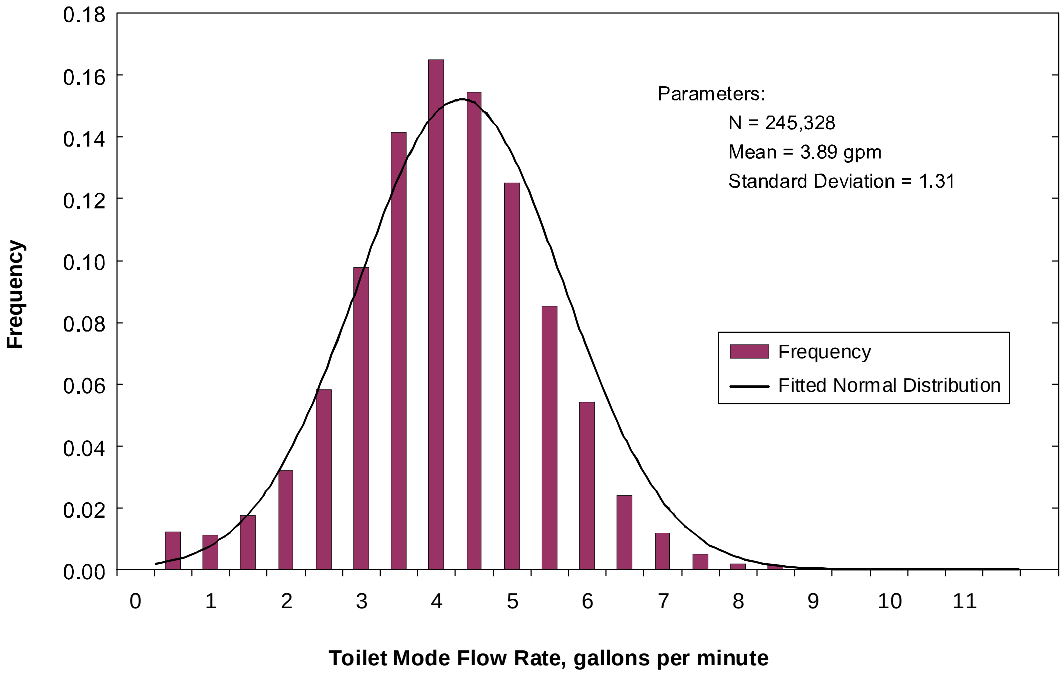


Figure 9-6. Distribution of Toilet-Flush Flow Rates, REUWS.

9.5 Recommended Toilet-Use Parameters

The REUWS appears to provide reliable information on toilet-use behavior of the studied households. Based on the analysis of the REUWS data, the following parameters (presented in Table 9-5) are recommended for use in representing household toilet use:

1. The frequency of residential toilet use for the general population can be reasonably represented as a mean frequency of 5.2 flushes per person per day.
2. The volume per flush was best represented as a normal distribution with a mean of 3.48 gallons and a standard deviation of 1.2 gallons.
3. The time to refill the tank following a flush was found to have a mean of 71.4 seconds with a standard deviation of 29.8 seconds. As shown in Figure 9-4, this data can also be represented as a lognormal distribution with a geometric mean of 65.9 seconds and a geometric standard deviation of 1.49.

Table 9-5. Statistics for Toilet Flushes from REUWS

	All Flushes			Single Flushes Only		
	Frequency (flushes per person per day)	**Family Size**	**Sampling Days**	**Duration of Tank Fill (seconds)**	**Volume (gallons)**	**Mode Flow (gallons per minute)**
Minimum	0.03	0.00	1.00	10.00	0.29	0.00
Maximum	42.73	9.00	16.00	2,720.00	9.77	14.10
Mean	5.23	2.76	10.65	71.43	3.48	3.89
Standard Deviation	3.15	1.37	1.63	29.77	1.18	1.31
Number of Records or Households[1]	2,145[2]	2,158	2,158	245,328	245,328	245,328

[1] Number of households reflects the combined total of homes participating in the first sampling period (1,173) and second sampling period (985).

[2] 13 surveys indicated "0" for Question 31 or Question 30 regarding the number of people in selected age groups (households aggregated from 295,660 records).

Section 10

Faucets

10.1 Introduction

In this chapter, residential faucet use from the REUWS database will be analyzed in an attempt to develop a set of general faucet-use characteristics that adequately reflect how often people use the various faucets in their house, and the volume, duration and flow rate of each use. There were no published studies found on human activity patterns related to faucet use, and the NHAPS database provided very limited information on frequencies of some types of faucet use (e.g., washing hands).

Faucet use is extremely difficult to characterize for many reasons. People draw water from faucets quite frequently and sporadically during the day, at various locations throughout the home, and most likely at different flow rates, temperatures, and durations each time. People use faucets to get water for numerous reasons, such as: for cooking, house-cleaning, personal hygiene, drinking, etc. Because of this high frequency rate, it is often difficult for people to recall the exact number of faucet uses in a day. Therefore, surveys like NHAPS that are based on recall are often inaccurate. Furthermore, because faucet uses have user-variable flow rates and durations, their water draw signatures are difficult to identify. Therefore, the REUWS study, which attempts to characterize each household water use by identifying its signature, may at times be inaccurate. According to our small-scale evaluation field study of Trace Wizard presented in Appendix A, Trace Wizard had some difficulty isolating the faucet uses when they occurred simultaneously during another water use such as a toilet, and occasionally small portions of faucet uses were misclassified as leaks. However, REUWS contains, by far, the best available data on faucet use, as it records the faucet uses (including flow rates, durations, and volumes) directly by monitoring and analyzing the household water meter.

10.2 Types of Faucets in Home

The REUWS survey included several questions related to faucets. The questions were as follows: "Indicate how many of the following types of water-using appliances or fixtures you have around your home: toilets, bathtub with shower, bathtub only, shower only, whirlpool bathtub with jets, bathroom sink, kitchen faucet, indoor utility/garage sink. Answer choices: 0, 1, 2, 3, 4, 5, 6, 7, or more." Table 10-1 shows summary statistics for the number of different types of faucets that participants reported were in their home. On average, there were approximately 4 faucets in each home, including bathroom, kitchen, and utility (laundry) faucets.

Outdoor water uses (lawn hoses) are not shown in this section because Trace Wizard attempted to classify them as "irrigation." Bathtub faucets likewise are not included as Trace Wizard attempted to classify them as bathtub uses.

Table 10-1. Selected Types of Faucets in Homes, REUWS*

Statistic	Number of Bathroom Sinks	Number of Kitchen Faucets	Number of Utility/Garage Sinks	Total Number of Faucets
Mean	2.66	1.10	0.45	4.21
Mode	2.00	1.00	0.00	3.00
Minimum	0.00	0.00	0.00	0.00
Maximum	7.00	4.00	3.00	12.00
Standard Deviation	1.33	0.36	0.55	1.65
Number of Cases	958	958	958	958

* Non-responses in any of the three types of sinks resulted in the entire case (house) being dropped from the analysis.

10.3 Faucet-Use Frequency

In the NHAPS survey, there were no questions directly related to how often people used the faucets, however, there were questions related to how often hands were washed, dishes washed, and tap-water drinks consumed. These relevant questions were as follows: “How many times did you wash your hands yesterday?” (The possible choices were: none, 1-2 times, 3-5 times, 6-9 times, 10-19 times, 20-29 times, 30+ times, or don’t know): “How often do you wash dishes by hand?” (Almost every day, 3-5 times a week, 1-2 times a week, less often). “How many eight ounce glasses of tap water did you drink yesterday? How many 8 ounce glasses of orange juice, lemonade, Kool-Aid® or other drinks made of tap water did you drink yesterday? (0, 1-2, 3-5, 6-9, 10-19, 20+,DK). These few questions do not deal with all the possible faucet uses during a day, so therefore, the data were not used for the purpose of determining overall faucet-use frequency. Also, as mentioned before, one flaw with recall type surveys is that people have difficulty remembering the exact number of occurrences of high frequency events. REUWS, on the other hand, offers a valuable data resource for characterizing household daily faucet use provided that faucet events are identified in the database with a reasonable degree of accuracy.

10.3.1 REUWS Faucet-Use Frequency Analysis and Results

For the purpose of determining daily frequency of faucet use, the REUWS data were first pared to full 24-hour days that included only days in which the occupants were assumed to be at home. Each full-use day was analyzed as an independent data point. Full days began at 12:00 midnight and extended until the following midnight. Any partial days in the beginning or end of the record were discarded. It was assumed that during normal occupation, residents would use the water at least three times a day. Therefore, any full days with less than three water uses were assumed to be unoccupied days and were discarded. It is conceivable that while the home was unoccupied, there could still be one or two small water uses, such as the icemaker, lawn sprinkler, etc. After reducing the data set to full occupied days, there remained 973,717 faucet uses for analysis.

In the REUWS database, the Trace Wizard software disaggregated the household water-use flows and labeled and characterized each distinctive water appliance use. Trace Wizard delineated each individual water-use event by its start and end times, volume and flow rate. Because faucet uses are so variable in their durations, flow rates, and volumes, it was impossible to develop criteria for eliminating unrealistic or possibly mislabeled faucet uses. Therefore, all water uses labeled “faucets” were included in the analysis. However, through examination of the summary statistics there is evidence that some water draws have been mislabeled as faucets. To illustrate the point that some records are problematic, Table 10-2 shows six different homes broken down by the number of faucet uses per sampling day. These homes were selected because the number of faucet uses per person per day or the volume of water per person per day was unusually high. Although there are no means for verifying the accuracy of these records, this seems unreasonable, even in a large household.

Table 10-2. Number of Faucet Uses per Sampling Day for Selected Houses from REUWS

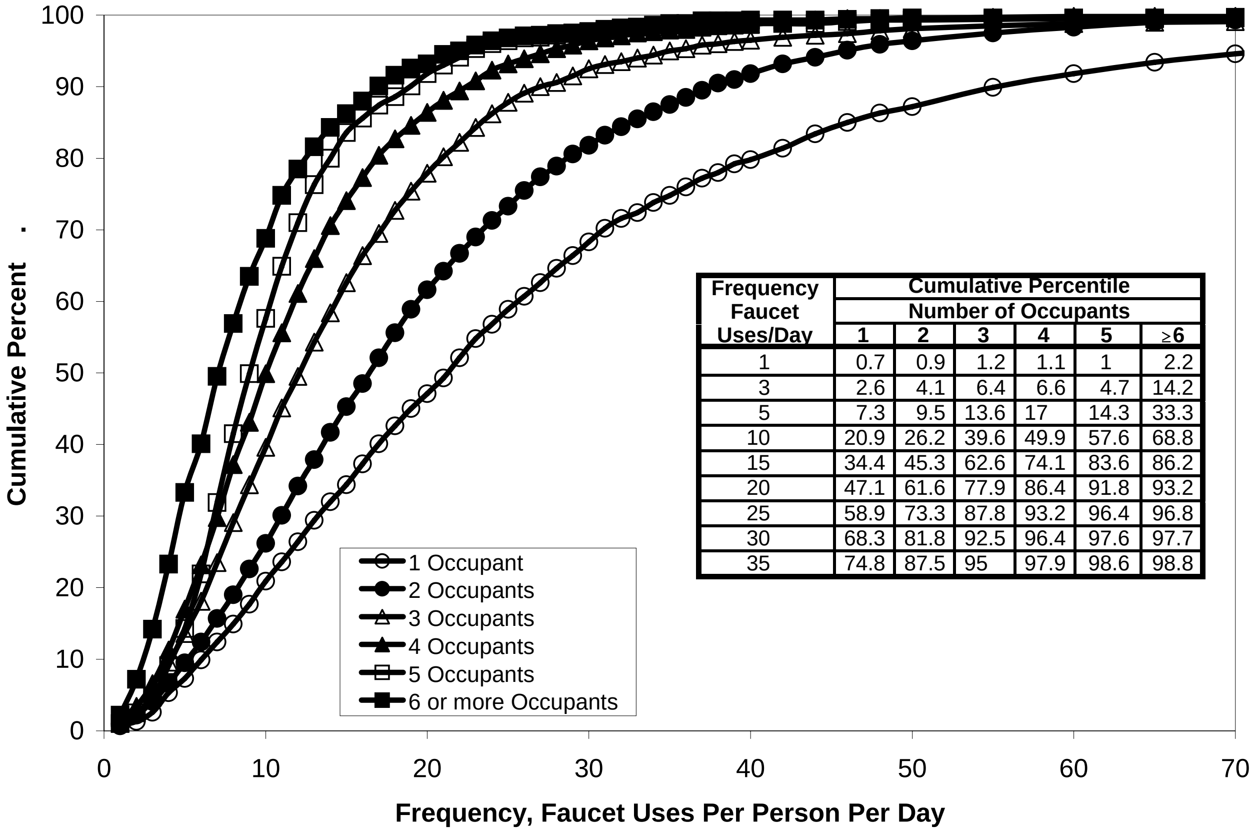
Day	Number of Faucet Uses per Person per Day					
	REUWS House #12131	REUWS House #18448	REUWS House #18227	REUWS House #19246	REUWS House #17260	REUWS House #15176
1	377	302	108	337	104	160
2	31	533	119	278	93	126
3	323	252	81	129	108	157
4	229	159	69	102	146	136
5	67	355	83	81	95	187
6	33	445	74	75	117	115
7	64	212	76	84	118	97
8	203	368	85	85	105	144
9	189	456	86	73	104	98
10	198	272	81	60	102	195
11	127	302	N/A	108	134	160
12	N/A	N/A	N/A	55	90	N/A
Total	**1841**	**3656**	**862**	**1467**	**1316**	**1575**

A number of potential explanations exist for these small but frequent uses. It is possible that a significant number of these uses classified as “faucet” are actually other uses similar in appearance, such as water purifiers, humidifiers, water softeners, icemakers, toilet leaks or faucet leaks. Without more information, it is impossible to eliminate cases that may not be faucets and therefore, the following analysis includes all records labeled as faucets. It is likely that although there are some non-faucet water uses embedded within this analysis, the impact is small and a high percentage of the nearly 1 million uses are very likely to be faucets.

Table 10-3 shows the average number of faucet uses per person per day based on the number of occupants in the household. Figure 10-1 presents the cumulative distribution of faucet uses per person per day as a function of the number of occupants in the household. The data seem to indicate the trend that as the size of the family increases, the number of faucet uses per person decreases. Whereas the occupant in a one-person household uses the faucet an average of 27.4 times per day, an occupant in a household with 5 or more people uses the faucet an average of 10.2 times a day. This trend may result from the numerous faucet uses that are household-based not individual-based, such as cleaning, preparing meals, etc. In addition, to the extent other water uses are misclassified as faucet uses, the impact would likely be less for larger households since many of these misassigned uses would be distributed across the number of occupants. Occupants of larger families are attributed only a fraction of the household faucet uses, whereas occupants of single-person households are attributed all of these faucet uses. Table 10-4 shows that there was no significant difference between the mean frequency of faucet use in the warmer months (17.6) versus the cooler months (17.1).

Table 10-3. Frequency of Faucet Use, by Number of Occupants in the Household, REUWS

Number of Occupants	Mean Faucet Uses (per person per day)	Standard Deviation	Number of Cases
1	27.4	17.4	134
2	19.5	10.3	367
3	14.8	9.0	185
4	12.4	6.6	172
5 or more	10.2	5.5	107
Total	**17.4**	**11.6**	**965**



Frequency Faucet Uses/Day	Cumulative Percentile					
	Number of Occupants					
	1	2	3	4	5	≥6
1	0.7	0.9	1.2	1.1	1	2.2
3	2.6	4.1	6.4	6.6	4.7	14.2
5	7.3	9.5	13.6	17	14.3	33.3
10	20.9	26.2	39.6	49.9	57.6	68.8
15	34.4	45.3	62.6	74.1	83.6	86.2
20	47.1	61.6	77.9	86.4	91.8	93.2
25	58.9	73.3	87.8	93.2	96.4	96.8
30	68.3	81.8	92.5	96.4	97.6	97.7
35	74.8	87.5	95	97.9	98.6	98.8

Figure 10-1. Cumulative Distribution of Per Capita Faucet-Use Frequency as a Function of Household Size.

Table 10-4. Frequency of Faucet Use by Sampling Period, REUWS

Statistic	Number of Uses per Person per Day		
	Sampling Period 1 (Warmer Months)[1]	Sampling Period 2 (Colder Months)[1]	Total Dataset[2]
Mean	17.6	17.1	17.4
Minimum	0.1	0.5	2.3
Maximum	167.4	122.3	143.0
Standard Deviation	13.5	12.1	11.6
Number of Cases	965	965	965

[1] These columns contain data from only those houses that are found in both sampling periods and reported the number of occupants.

[2] The total dataset includes all households.

10.4 Faucet-Use Volume, Duration, and Flow Rate

The REUWS database provides data on the volumes, durations, and flow rates of the water draws identified as faucet uses by Trace Wizard. Faucet uses differ from other types of water uses in several ways. Faucets are used in a variety of tasks, which result in large variations in the faucet-use duration. In addition, the user tends to use greater discretion in setting the flow rate, resulting in large variations in flow rate. These factors lead to greater uncertainty in Trace Wizard's ability to correctly identify faucet uses. In general, Trace Wizard assigns uses to faucets that have a flow rate in the range expected for faucets and do not conform to the expected signature for other appliances. Exceptions to this are the small flows (~ 0.1 gallons or less) which are often identified as "leaks."

10.4.1 REUWS Faucet-Use Volume, Duration and Flow Rate Analysis and Results

The entire dataset of faucet uses from the REUWS database based on number of occupants in the household and by sampling period is analyzed and presented in Table 10-5. The mean volume per person per day decreases as the number of occupants in the household increases. The overall mean volume of water used per day for all cases was 11.2 gallons per person. As with frequency, there was little significant difference between the volume of water used in the warmer months compared to the cooler months. The people used on average 11.4 gallons per person per day in the warm months and 10.8 gallons per person per day in the cooler months. Table 10-6 shows mean volume, duration and flow rate of water used per event. The faucet uses had a mean volume of 0.7 gallons per use and a mean duration of 33.9 seconds. Figure 10-2 shows the histogram of the volumes used during each faucet use in the REUWS database, as well as the representative lognormal distribution with a geometric mean of 0.36 gallons and a geometric standard deviation of 2.97 gallons. The volume per use, generally on the order of 1 gallon or less, is highly correlated with the faucet durations, which are generally less than a minute in length. Figure 10-3 shows the histogram of the durations used during each faucet use in the REUWS database, as well as the representative lognormal distribution with a geometric mean of 20.26 seconds and a geometric standard deviation of 2.76 seconds. The plot shows that most of the faucet uses are relatively short in duration. The average duration of a faucet use was 33.9 seconds. Approximately 36% of the faucet uses were 10 seconds or less, and 61% were 20 seconds or less. Approximately 93% of all faucet uses in the database were less than 1.5 minutes in duration. The mode flow rate of the faucets in the REUWS database are presented in the histogram of Figure 10-4. In contrast to the flow rate for mechanical uses, which were generally well represented as normal distributions, the flow rates are well represented as a lognormal distribution, also shown in Figure 10-4, with a geometric mean of 1.04 gpm and a geometric standard deviation of 1.70 gpm. The lognormal characteristic is due to the impact of the user choosing the flow rate.

10.5 Recommended Faucet-Use Parameters

Faucet usage is probably the most difficult household water use to characterize in general terms because each water use may differ greatly from the next in its duration, volume, flow rate and temperature. The wide variance in faucet usage results from its varying purposes ranging from a quick hand wash to a longer duration as someone fills a pot to boil pasta. The REUWS database is the best available source of frequency, volume, duration, and flow rate information regarding faucet use. It is shown that frequency of faucet use is dependent on the number of occupants in the household, as the mean faucet uses per person per day decreases as the household size increases. This results from the many faucet uses that are house-related not individual-related, such as for cooking or cleaning. Table 10-3 presents the faucet use per person per day based on the number of occupants in the household. The mean faucet use overall is 17.4 uses per person per day (standard deviation 11.6). Table 10-6 presents summary statistics for the faucet volume, duration, and mode flow rate derived from an analysis of the REUWS database. The results indicate a mean volume of 0.7 gallons per event, a mean duration of 33.9 seconds and a mean mode flow rate of 1.2 gallons per minute.

Table 10-5. Mean Volume per Faucet Use by Number of Occupants in the Household and by Sampling Period

Number of Occupants	Sampling Period 1 (Warm Months)[1]			Sampling Period 2 (Cooler Months)[1]			Total for Dataset		
	Mean (gallons) (ppd)[2]	Standard Deviation (ppd)	Number of Cases	Mean (gallons) (ppd)	Standard Deviation (ppd)	Number of Cases	Mean (gallons) (ppd)	Standard Deviation (ppd)	Number of Cases
1	16.9	11.1	139	15.7	10.1	137	16.3	9.6	134
2	12.7	7.3	370	12.3	7.5	380	12.6	6.7	367
3	10.0	6.5	176	9.5	5.7	177	9.8	5.5	185
4	8.3	5.7	172	7.4	3.8	170	8.1	4.4	173
5 or more	6.9	4.1	108	7.0	4.1	101	7.4	4.0	106
Total	**11.4**	**7.9**	**965**	**10.8**	**7.4**	**965**	**11.2**	**7.0**	**965**

[1] These sampling period columns contain data from only those houses that are found in both sampling periods and reported the number of occupants.

[2] Per person per day.

Table 10-6. Faucet Volume, Duration and Flow Rate Characteristics for all Faucet Uses Combined, REUWS

Statistic*	Volume per event (gallons)	Duration per event (seconds)	Mode Flow Rate (gallons per minute)
Mean	0.7	33.9	1.20
Minimum	0	10.0	0
Maximum	37.6	5400.0	10.7
Standard Deviation	1.0	45.6	0.68
Number of Cases	973717	973717	973717

* No records were dropped from this analysis

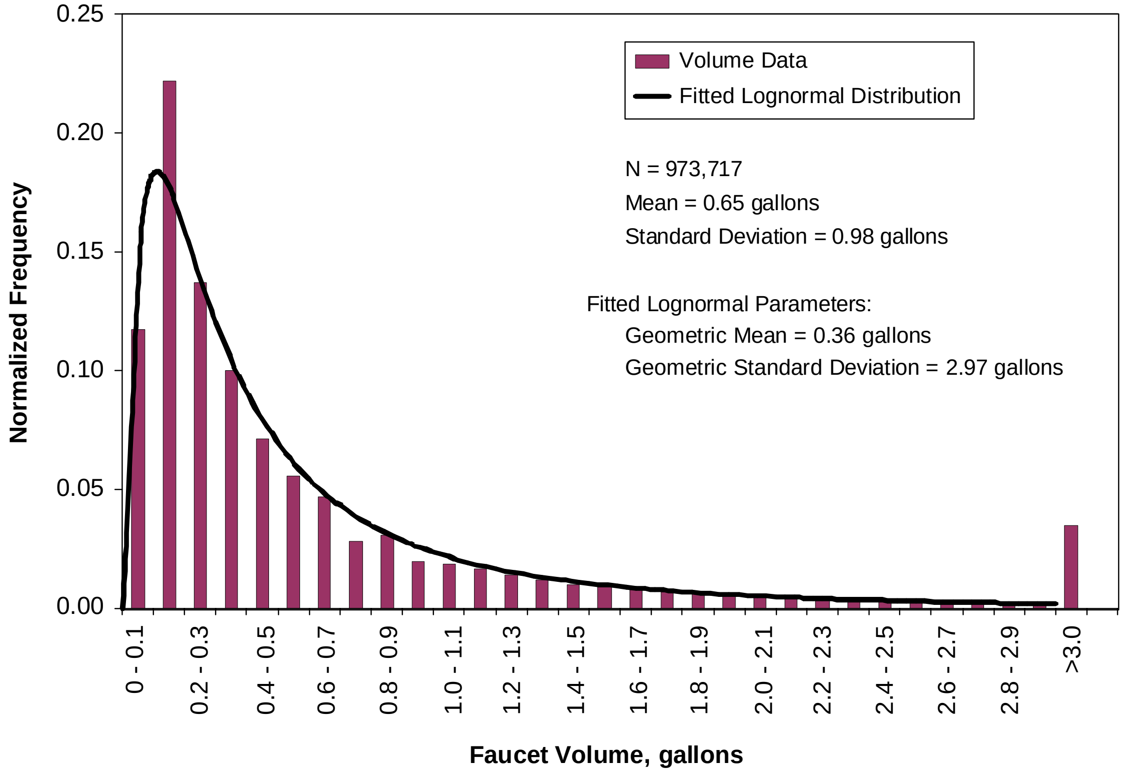


Figure 10-2. Distribution of Faucet Volume, REUWS.

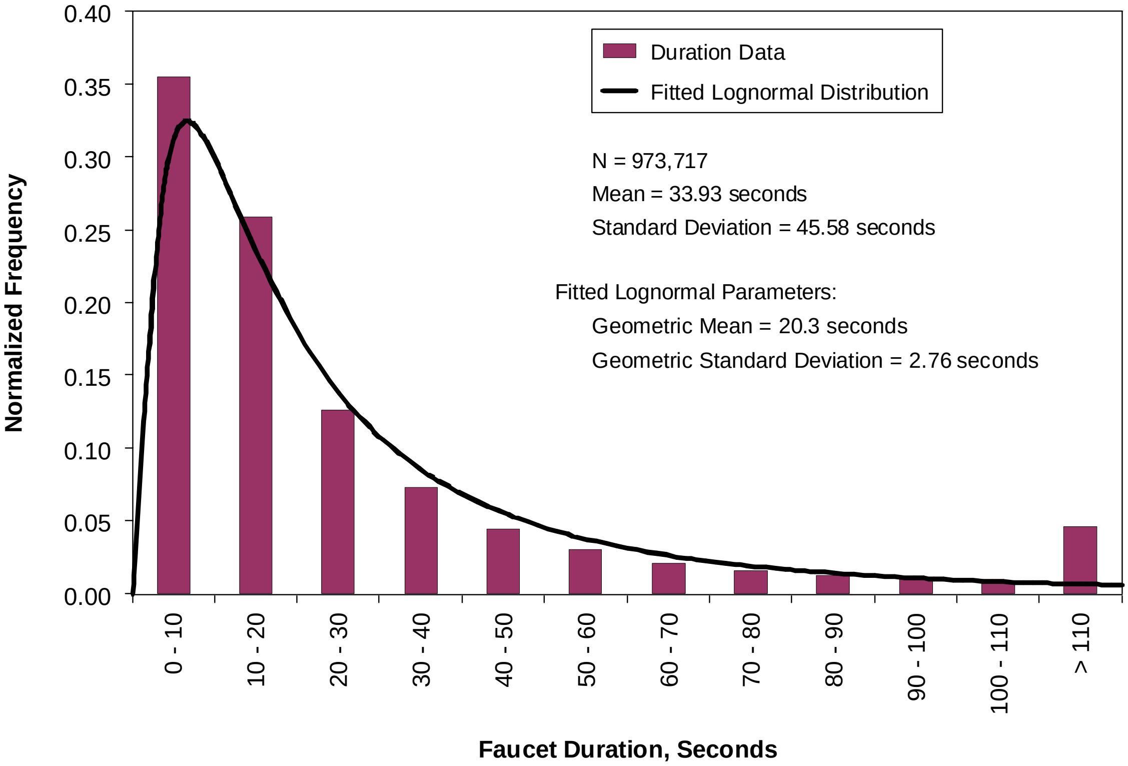


Figure 10-3. Distribution of Faucet Duration, REUWS.

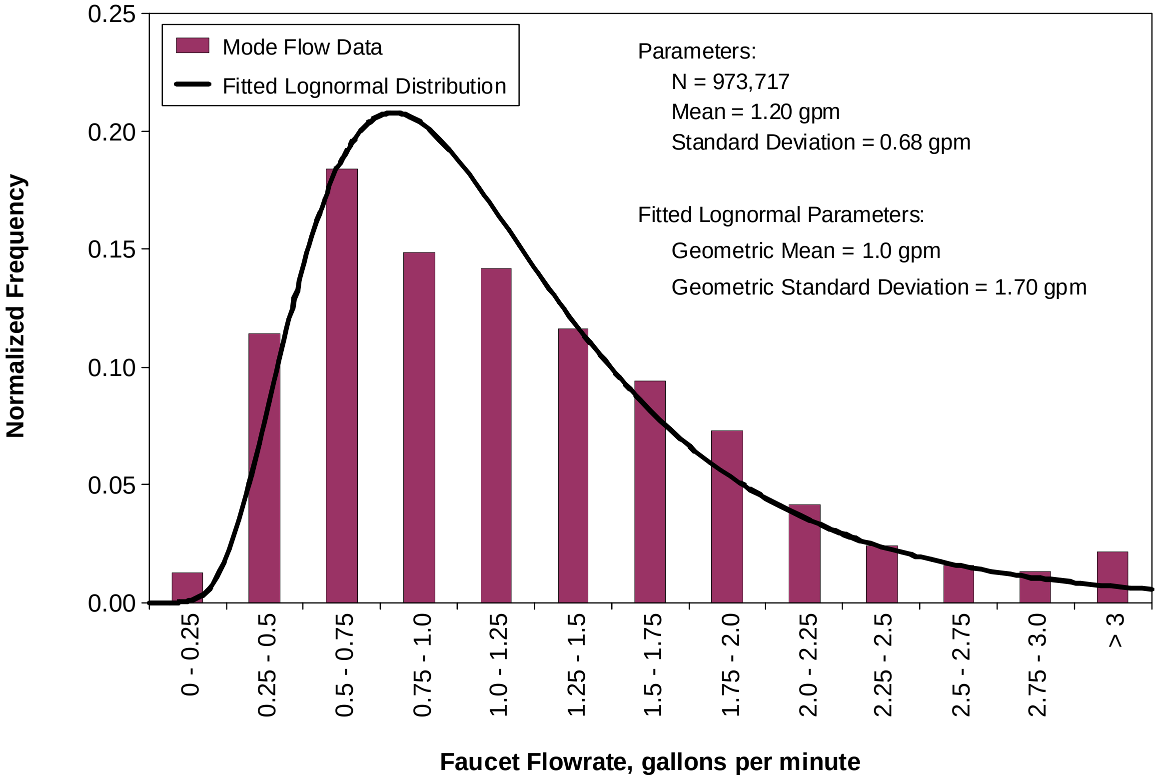


Figure 10-4. Distribution of Faucet Mode Flow Rate, REUWS.

Section 11

Drinking-Water Consumption

11.1 Introduction

The most obvious route of human exposure to water-borne contaminants is via ingestion. Daily, nearly every person drinks water directly and consumes water indirectly in juices, sodas, soups, and foods. In order to assess someone's ingestion exposure to chemicals found in the water system, it is important to appropriately estimate the amount of water that person consumes (both directly and indirectly), and to the extent possible, behavioral factors that affect the water concentration (e.g., boiling the water and other processing behavior). An understanding of consumption behavior is needed for estimating population-based exposure to disinfection by-products (DBPs), microbials, radon, and other water contaminants, as well as for helping to identify sub-populations with increased health risks from exposure to contaminants in drinking water. This report examines available data sources from which we can estimate human water consumption, and it presents summary information useful for modeling human exposure to water-borne contaminants.

11.2 Background

Prior to the 1997 publication of the Exposure Factors Handbook, the U.S. EPA typically assumed that adults consumed a quantity of 2 liters of tap water per day and infants (body mass of 10 kg. or less) consumed 1 liter per day (U.S. EPA, 1997). Currently, a value of 1.41 liters per day is used as the recommended average tap-water intake rate, and 2.35 liters per day is the upper limit (associated with the 90th-percentile values from the various studies examined in the Exposure Factors Handbook) (U.S. EPA, 1997). These rates include the tap water consumed directly and the tap water consumed in other drinks like juices, coffee, etc. Because ingestion exposure in the context of this report is concerned with contaminants in the public water supply, we focus on the tap-water intake, not the total fluid intake, which also includes other liquids like milk, soft drinks, and water intrinsic in foods. In conducting this analysis, we recognize that exposure to highly volatile compounds will be influenced by the manner in which the water is handled. For example, water that is used for cooking or otherwise prepared will have lower concentrations as a result of volatilization. In addition, water contained in beverages such as milk and produce does not necessarily contain the same waterborne contaminants, such as disinfection by-products. However, Wallace (1997) showed that ingested liquids may contain these same contaminants. Therefore, it is important to distinguish between direct and indirect consumption, and to the extent possible, understand the origin and processing of the water.

Prior to 1995, the primary survey used to estimate tap-water intake in the U.S. was the USDA's 1977-1978 National Food Consumption Survey. However, this survey is over 20 years old. Consumption habits in the U.S. may have changed over recent years, as people now drink more bottled or filtered water than ever before in history, and people are drinking more soda and other canned drinks. Furthermore, water intake is assumed to vary with levels of physical activity and outdoor temperatures (EPA, 1997). Therefore, to most accurately estimate the amount of tap-water ingestion, we look to the most recent survey results.

Two more recent major surveys are examined for insight into the amount of water people ingest per day. One is the Combined 1994-1996 Continuing Survey of Food Intake by Individuals (CSFII) conducted by the U.S. Department of Agriculture (USDA), and the other is the National Human Activity Patterns Survey (NHAPS) conducted in 1996 by the U.S. Environmental Protection Agency (EPA). Analysis of the data within the CSFII and NHAPS have resulted in useful and more current information on U.S. residents' consumption of water.

11.3 Literature Review of Water Consumption Data and Characteristics

The Exposure Factors Handbook (EFH) Volume I, Chapter 3 (EPA, 1997) discusses the key and relevant drinking-water intake studies prior to 1995. For these studies in the EFH, 'tap water' and 'total tap water' were defined as water directly consumed from tap or used to prepare other drinks or foods. 'Total water' was defined as tap water plus "water intrinsic to foods and beverages", at the time of purchase. These studies are presented below, listing the survey descriptions and general results. The CSFII and NHAPS data are described and analyzed in more detail in the following sections.

1977-1978 USDA Nationwide Food Consumption Survey (NFCS). *Total Water and Tapwater Intake in the United States: Population-Based Estimates of Quantities and Source*, by Ershow and Cantor, 1989 (see EPA, 1997), presents analyses of water intake rates based on data from the 1977-1978 USDA Nationwide Food Consumption Survey (NFCS). The data included consumption of tap water and total water. The population study of over 26,000 people statistically matched the U.S. population of 1977. The data generally followed a lognormal distribution. For adults (ages 20 to 65+), the mean tap-water intake was approximately 1.4 liters per day and the 90th percentile intake was approximately 2.3 liters per day. This study was very comprehensive, however it is over 20 years old and consumption habits possibly have changed.

Ershow and Cantor, 1989 (see EPA, 1997), analyzed the data for subpopulation groups, including various age groups of males, females and children. The data listed in the EFH, related to adults, lists intake for males and females combined (not separately), segregated by age groups. Adults between 15 and 19 years (sample size = 2998) were found to have a mean tap-water intake of 999 ml/day (SD=593 ml/day), and adults between 20 and 44 years (sample size = 7171) had a mean tap-water intake of 1255 ml/day (SD=709 ml/day). Children between the ages of 1-10 had a mean tap-water intake of 736 ml/day (SD = 410 ml/day). Consumption per unit body weight was also examined. Generally, adults over 45 had a mean tap-water intake of about 22 ml/kg/day. Adults younger than 45 and older teenagers had a unit consumption rate lower than 20 ml/day. For young teenagers and pre-teen children, unit consumption rates generally decreased with age, from a mean of about 52 ml/kg/day for infants to a mean at approximately 20 ml/kg/day for young teens.

Intake of Tap Water and Total Water by Pregnant and Lactating Women, by Ershow et al., 1991 (see EPA, 1997), presents the specific water consumption data (from the 1977-78 USDA study) for pregnant and lactating women (ages 15-49). The study included 188 pregnant, 77 lactating, and 6,201 non-pregnant, non-lactating women. The women were interviewed on their behavior for the prior 24 hours and then asked to record a diary for the following two days. Pregnant women were found to consume a mean total tap water intake of 1189 ml/day (SD=699 ml/day) (or mean 18.3 ml/kg/day, SD=10.4 ml/kg/day). Lactating women consumed a mean total tap water intake of 1310 ml/day (SD=591 ml/day) (or mean 21.4 ml/kg/day, SD= 9.8 ml/kg/day). The control group of non-pregnant, non-lactating women between 15 and 49 consumed a mean total tap water intake of 1157 ml/day (SD=635 ml/day) (or mean 19.1 ml/kg/day, SD 10.8 ml/kg/day).

Lognormal Distributions for Water Intake, by Roseberry and Burmaster, 1992 (see EPA, 1997), presents fitted lognormal distributions to this USDA data reported by Ershow and Cantor, 1989 (See EPA, 1997). The published parameters of the best-fit lognormal distributions for total tap-water intake based on age groups are as follows: For ages 1 to 10, mean=6.429, S.D.=0.498; for ages 11 to 19, mean=6.667, S.D.=0.535; for ages 20 to 64, mean=7.023, S.D.=0.489; for over age 65, mean=7.088, S.D.=0.476.

1978 Drinking-Water Consumption in Great Britain, by Hopkins and Ellis, 1980 (see EPA, 1997), presents data from interviews of 3,564 persons randomly selected throughout Great Britain to estimate drinking-water consumption rates. The respondents completed a questionnaire and diary indicating the amount and type of beverages they consumed over a week. They defined total tap-water intake as tap water drunk directly or used to make beverages such as tea or coffee. They also analyzed total liquid intake that included purchased drinks. A breakdown of the various types of drinks is published. Females between 18 and 30 consumed a mean tap-water intake of 0.991 L/day and females between 31 and 54 consumed 1.091 L/day. Males between 18 and 30 years consumed a mean tap-water intake of 1.006 L/day and males between 31 and 54 consumed a mean tap-water intake of 1.201. Female children between 5 and 11 consumed 0.533 L/day and male children between 5 and 11 consumed 0.550 L/day.

Canada Department of Health and Welfare (1981) – Tap-Water Consumption in Canada, by The Canadian Department of Health (see EPA, 1997), presents survey data from 970 individuals from 295 households in 1977 and 1978 to determine per capita total tap-water intake rates for various age/sex groups, during winter and summer, and according to level of physical activity. Each participant monitored intake for two days (1 weekday and 1 weekend day) in both the summer (1977) and the winter (1978). The survey assumed that a small glass of water holds 4 ounces of water, and a large glass holds 9 ounces. The survey did not distinguish between tap water consumed at home and tap water consumed away from home. The concluding results showed that the average daily total tap-water intake rates for all ages and seasons was 1.34 L/day, and the 90th percentile rate was 2.36 L/day. Children 3 to 5 years old consumed an average daily tap-water intake of 48 ml/kg, and children 6 to 17 years old consumed 26 ml/kg. Females between 18 and 34 years consumed 23 ml/kg and females between 35 and 54 consumed 25 ml/kg. Males between 18 and 54 consumed 19 ml/kg. According to a Canadian health study, the average female weighs 55.6 kg and the average male weighs 65.1 kg. There was nearly no difference between consumption in summer versus winter. There was also little significant difference due to levels of physical activity. This may be due to the cooler climate of Canada.

Bladder Cancer, Drinking-Water Source, and Tap-Water Consumption Study. The results from this 1987 National Cancer Institute (NCI) study are reported in Cantor et al., 1987 (see EPA, 1997), and summarized in EFH. This was a population-based, case-control study to investigate the possible relationship between bladder cancer and drinking water. Approximately 8,000 white adults residing throughout the United States (10 states) between 21 and 84 years of age were asked to recall tap-water intake over the prior week. The data for the 5258 control cases were analyzed and presented in the Exposure Factors Handbook. Females claimed to have consumed an average of 1.35 L/day. Males claimed to have consumed an average of 1.4 L/day. Females and males (combined) between the ages of 21 and 44 claimed to have consumed 1.3 L/day.

Table 11-1 summarizes the major tap-water consumption data from these studies.

Table 11-1. Tap-Water Consumption Characteristics Found in Literature

Population		Average Consumption (units)	
1977 – 78 USDA Nationwide Food Consumption Survey (NFCS)[1]: N = 26,000			
Children, <1 Year[2]	(N=403)	302 ml/day	43.5 ml/kg/day[6]
Children, 1-3 Years[2]	(N=1498)	646 ml/day	46.8 ml/kg/day
Children, 4-6 Years[2]	(N=1702)	742 ml/day	37.9 ml/kg/day
Children, 7-10 Years[2]	(N=2405)	787 ml/day	26.9 ml/kg/day
Teens, 11-19 Years[2]	(N=5801)	965 ml/day	18.2 ml/kg/day
Adults, 20-44 Years[2]	(N=7171)	1255 ml/day	18.6 ml/kg/day
Adults, 45-64 Years[2]	(N=4560)	1546 ml/day	22.0 ml/kg/day
Adults, 65+ Years[2]	(N=2541)	1459 ml/day	21.8 ml/kg/day
Pregnant Women[3]	(N=188)	1189 ml/day	18.3 ml/kg/day
Lactating Women[3]	(N=77)	1310 ml/day	21.4 ml/kg/day
Non-Pregnant, Non-Lactating Women, 15-49 Years[3]	(N=6201)	1157 ml/day	19.1 ml/kg/day
Adults, 20 to 64 Years 90th Percentile	(N=11731)	1366 ml/day 2268 ml/day	19.9 ml/kg/day 33.7 ml/kg/day

1978 Drinking-Water Consumption in Great Britain[4]: N = 3564 People					
	Female	**Male**	**Females**	**Males**	**All**
Children, 1-4 Years	(N=75)	(N=88)	464 ml/day	477 ml/day	---
Children, 5-11 Years	(N=201)	(N=249)	533 ml/day	550 ml/day	---
Teens, 12-17 Years	(N=169)	(N=180)	725 ml/day	805 ml/day	---
Adults, 18-30 Years	(N=350)	(N=333)	991 ml/day	1006 ml/day	---
Adults, 31-54 Years	(N=551)	(N=512)	1091 ml/day	1201 ml/day	---
Adults, 55+ Years	(N=454)	(N=396)	1027 ml/day	1133 ml/day	---
All individuals 90th Percentile	(N=3564)				955 ml/day 1570 ml/day

1977-78 Canadian Department of Health[5]: 970 individuals, 295 households				
		Females	**Males**	**All**
Children, < 3 Years	(N=47)	53 ml/kg/day	35 ml/kg/day	45 ml/kg/day
Children, 3-5 Years	(N=250)	49 ml/kg/day	48 ml/kg/day	48 ml/kg/day
Children, 6-17 Years	(N=232)	24 ml/kg/day	27 ml/kg/day	26 ml/kg/day
18-34 Years	(N=254)	23 ml/kg/day	19 ml/kg/day	21 ml/kg/day
35-54 years	(N=153)	25 ml/kg/day	19 ml/kg/day	22 ml/kg/day
55+ Years	(N=34)	24 ml/kg/day	21 ml/kg/day	22 ml/kg/day
Average Daily Consumption 90th Percentile	(All) (N=970)	24 ml/kg/day	21 ml/kg/day	22 ml/kg/day 2360 ml/day

1987 National Cancer Institute Study[7]: N = 5258 White Adults				
		Females	**Males**	**All**
21-44 Years	(N=291)	---	---	1300 ml/day
45-64 Years	(N=1991)	---	---	1480 ml/day
65-84 Years	(N=2976)	---	---	1330 ml/day
All participants (21-84 Years)	(N=5258)	1350 ml/day	1400 ml/day	1390 ml/day

[1] Ershow and Cantor, 1989
[2] Ershow and Cantor, 1989
[3] Ershow and Cantor, 1991
[4] Hopkins and Ellis, 1980
[5] Canadian Ministry of National Health and Welfare, 1981
[6] ml/kg of body weight/day
[7] Cantor et al., 1987

11.4 1992-1994 National Human Activities Pattern Survey (NHAPS)

In the 1992-94 U.S. EPA National Human Activities Pattern Survey (NHAPS), over 4,000 U.S. residents provided questionnaire responses regarding the amount of water consumed during the previous 24 hours. NHAPS was extensively analyzed by Klepeis et al. (1996) and drinking-water intake results were presented in the Exposure Factors Handbook, Vol. 1; however, for this report, we did our own analysis (see below).

The two NHAPS questions pertaining to water ingestion were: 1) How many 8-ounce glasses of tap water did you drink yesterday? (recorded as code GLASS#), and 2) How many 8-ounce glasses of orange juice, lemonade, Kool-Aid, or other drinks made with tap water did you drink yesterday? (recorded as code JUICE#). The answers were recorded as either zero, 1-2 glasses, 3-5 glasses, 6-9 glasses, 10-19 glasses, or 20 or more glasses. The wide range in the higher answer categories lead to significant uncertainty in the specific amount of ingested water. However, although NHAPS does not provide precise data for specific tap-water exposure/dose modeling studies, the data are useful for providing a general understanding of consumption and for contrasting consumption behavior as a function of demographic characteristics. Therefore, the NHAPS data are analyzed for this report and presented below in Table 11-2 differentiated by age and gender. For the analysis, the number of glasses of liquid consumed is assumed to be the median of the category (e.g., an answer of 3-5 glasses is assumed to be 4 glasses). The total tap water ingested is the number of glasses of water (GLASS#) plus number of glasses of drinks mixed with tap water (JUICE#). All glasses are assumed have a volume of liquid of 8 ounces. The final amount of estimated liquid ingested is converted to units of ml/day in order to offer a comparison with the other studies.

Table 11-2. Average Ingestion of Tap Water (ml/day) by Age and Gender, NHAPS

	Average Amount of Tap Water Ingested Per Day*		
Age	**Females (ml/day)**	**Males (ml/day)**	**All (ml/day)**
Children, < 1 Year	1158	982	1090
Children, 1-<5 Years	671	778	727
Children, 5-<12 Years	908	1003	957
Teens, 12-<18 Years	1052	1185	1112
Adults, 18-<33 Years	1054	1232	1143
Adults, 33-<48 Years	1030	1335	1172
Adults, 48-<63 Years	1260	1258	1259
Adults, 63+ Years	1370	1453	1400
Total	**1120**	**1237**	**1174**

* Version B of the questionnaire only. Values are derived from NHAPS data as follows: number of glasses of liquid are assumed to be the median of the category (e.g., an answer of 3-5 glasses is assumed to be 4 glasses); > 20 glasses per day was assumed to equal 20 glasses; total tap water ingested is number of glasses of water (GLASS#) plus number of glasses of drinks mixed with tap water (JUICE#); All glasses are assumed to be 8 ounces; 0.034 ounces equals 1 ml.

Klepeis et al. (1996) analyzed NHAPS for consumption as a function of a variety of demographic variables, including age, gender, employment status, education, etc. A summary of their analysis is presented in Chapter 3 of the Exposure Factors Handbook, Volume 1 (USEPA, August 1997).

11.5 USDA's Combined 1994-1996 Continuing Survey of Food Intake by Individuals (CSFII)

In their recent report entitled, "Estimated Per Capita Water Ingestion in the United States, Based on Data Collected by the United States Department of Agriculture's 1994-96 Continuing Survey of Food Intakes by Individuals," United States Environmental Protection Agency, EPA-822-R-00-008, April 2000 (Jacobs et al., 2000), authors Jacobs, Du, Kahn, and Stralka discuss the CSFII survey and present a statistical analysis of the data set. The CSFII survey was conducted over the three-year period between January 1994 and January 1997. The data set is a "nationally representative sample of non-institutionalized persons residing in United States households." The households are sampled from the 50 states and Washington DC. A total of 15,303 individuals were interviewed on 2 non-consecutive days with questions about what drinks and foods they consumed in the previous 24 hours. The dietary recall information was collected by an in-home interviewer who provided the participants with instructions and standard measuring cups and spoons to assist in calculating the food and drink consumption amounts. Proxy interviews were conducted for children under 6.

The survey and analysis were conducted using the following definitions:

- Water, Direct: plain water consumed directly as a beverage.
- Water, Indirect: water used to prepare foods and beverages at home or in a restaurant. Examples of indirect tap water include the water added to tea, coffee, baby formula, dried foods, concentrated juices, canned soup, and homemade foods.
- Water, Intrinsic: water contained in foods and beverages at the time of market purchase before home or restaurant preparation. Intrinsic water includes both the 'biological water' of raw foods and any 'commercial water' added during manufacturing or processing. Intrinsic water is not included in the following analyses.
- Community Water: includes direct and indirect water but not intrinsic water.
- Consumers Only: includes only those respondents in the population (or subpopulation) of interest who reported ingestion of the water from the source under consideration during the two survey days and excludes those who stated they had "zero" intake.

Relevant Questions:

The following list contains the questions used to gather information on direct and indirect water consumption in the CSFII survey:

- What is the main source of water used for cooking? (Community water, private well, spring, bottled, other?)
- What is the main source of water used for preparing beverages?
- What is the main source of plain drinking water?
- How many fluid ounces of plain drinking water did you drink yesterday?
- How much of this plain drinking water came from your home? (All, most, some, none)
- What was the main source of plain drinking water that did not come from your home? (Tap or drinking fountain, bottled, other, don't know)
- Respondents were asked to recall everything they ate over the past 24 hours. (Categorized according to the 7,300 USDA food codes, which provide standard recipes for each, including quantity of water.)

Jacobs et al. analysis of CSFII provides estimated mean and estimated percentiles for various subpopulations based on age, gender, and some other demographic variables. The estimated mean two-day average per person was 927 ml of ingested direct and indirect community water for all surveyed individuals, per person per day. The estimated 90th percentile of the empirical distribution of the two-day average for this same group of all surveyed individuals was reported by Jacobs et al. as 2.016 liters/person/day of community water. The authors, Jacob et al. (2000), point out in their Executive Summary that this data indicates that "90 percent of the United States population ingests an amount of community water which is approximately less than or equal to the two liters/person/day estimate used as a standard ingestion value by many federal agencies." Also, "the standard one liter ingestion rate used in risk assessments for a 10-kilogram child is approximately less than or equal to the 90th percentile of the empirical distribution of community water ingestion for babies less than one year old when considering 'consumers only.'" Furthermore, Jacobs et al. state, "the one liter standard ingestion rate used in risk assessments for a 10-kilogram child is approximately less than or equal to the 90th percentile of the empirical distribution of community water ingestion for children one to ten years old when considering 'consumers only.'"

According to the CSFII report, bottled water accounts for approximately 13% of total (direct and indirect) water intake. This is considered a substantial proportion of U.S. residents' water intake.

11.6 Application of the CSFII Data to Exposure Assessment

The data from the CSFII report (Jacobs et al., 2000) have been fitted to distributions to allow sampling of the distributions as input for exposure assessments. Table 11-3 presents data summarizing the amount of drinking water consumed directly and indirectly by "consumers only", who are those individuals of the surveyed population who reported that they consumed tap water during the studied time period. The percentages of each subpopulation that were consumers of tap water, and therefore part of the analysis, are also included in Table 11-3. The table presents the parameters (geometric mean and geometric standard deviation) of the fitted distributions for each subpopulation based on age, gender and whether the woman is pregnant or lactating. These parameters are estimated by the Log-Probit technique described in Section 5, which performs a least squares fit between the population cumulative consumption and the value predicted by a representative lognormal distribution. Table 11-3 also presents the arithmetic means for the given subpopulations as presented in the CSFII report, Part III Tables A1-A3, and Part IV Tables A1-A3.

Figures 11-1 and 11-2 present the fitted lognormal distribution for direct water consumption based on age groups in ml/person/day and in a per unit of weight basis (ml/kg of body weight/day), respectively. Figures 11-3 and 11-4 present the fitted lognormal distribution for indirect water consumption based on age groups in ml/person/day and in ml/kg/day, respectively. Figures 11-5 and 11-6 present the fitted lognormal distribution for direct and indirect water consumption by gender in ml/person/day and in ml/kg/day, respectively. Figures 11-7 and 11-8 present the fitted lognormal distribution for direct and indirect water consumption for pregnant, lactating, and other women of childbearing ages from 15-44 years, in ml/person/day and in ml/kg/day, respectively.

Table 11-3. Direct and Indirect Water Consumption for Selected Populations

Population (Consumers Only)[1]	Percent of Consumer Population[2]	Arithmetic Mean[3], ml/day	Arith. Mean[3] ml/kg of body weight/day	Parameters to Fitted Distribution			
				Total Consumption ml/day		Unit Consumption ml/kg/day	
				Geom. Mean	Geom. Std. Deviation	Geom. Mean	Geom. Std. Deviation
Water Consumption: Direct for Fine Age Categories							
< 0.5 years	24.5	102	16	61.73	2.41	8.83	2.54
0.5-0.9 years	47.6	202	24	112.24	2.65	13.72	2.75
1-3 years	62.5	295	21	191.33	2.36	14.48	2.33
4-6 years	72.5	378	19	228.01	2.55	12.17	2.54
7-10 years	78.9	402	13	243.98	2.55	8.54	2.37
11-14 years	77.4	535	11	315.39	2.69	6.77	2.50
15-19 years	75.1	706	11	410.06	2.67	6.69	2.49
20-24 years	71.9	875	12	472.91	2.93	6.77	2.91
25-54 years	71.3	787	10	467.41	2.66	6.70	2.49
55-64 years	72.4	776	10	492.55	2.34	6.47	2.40
>= 65 years	75.1	789	11	509.89	2.29	7.61	2.18
All Ages	72.1	702	12	404.52	2.74	7.12	2.58
Water Consumption: Indirect for Fine Age Categories							
< 0.5 years	49.3	518	86	264.57	3.08	33.53	3.31
0.5-0.9 years	78.3	403	44	177.74	3.77	16.37	3.45
1-3 years	84.0	154	12	81.72	3.32	6.17	2.95
4-6 years	84.3	172	8	82.91	3.53	4.56	2.80
7-10 years	77.6	175	6	80.63	3.77	3.98	2.37
11-14 years	78.8	228	5	100.99	4.04	2.53	2.77
15-19 years	80.0	286	4	126.31	3.90	2.54	2.88
20-24 years	86.6	398	6	181.89	3.86	3.74	2.51
25-54 years	89.0	608	8	314.57	3.27	4.92	2.68
55-64 years	89.2	651	9	387.77	2.76	5.17	2.56
>= 65 years	88.1	606	9	398.14	2.44	5.77	2.29
All Ages	86.0	489	8	223.03	3.78	4.52	2.90
Water Consumption: Direct and Indirect for Women, Men and Both Sexes							
Women, Direct	71.3	677	12	393.15	2.70	7.85	2.44
Women, Indirect	86.7	459	9	174.76	3.92	4.53	2.91
Men, Direct	72.9	728	11	407.32	2.79	7.01	2.56
Men, Indirect	85.3	521	8	195.25	3.98	4.42	2.87
All, Direct	72.1	702	12	404.52	2.74	7.12	2.58
All, Indirect	86.0	489	8	181.07	4.02	4.52	2.90
Water Consumption: Direct and Indirect for Pregnant Women, Lactating Women, and Women 15-44 Years							
Pregnant, Direct	63.1	800	13	379.67	3.28	6.36	3.16
Pregnant, Indirect	88.7	353	5	155.52	3.96	2.72	3.39
Lactating, Direct	61.1	1484	22	795.36	2.77	13.23	2.73
Lactating, Indirect	79.3	596	10	365.26	2.60	5.32	3.04
Women 15-44 yrs, Direct	69.0	750	11	440.06	2.69	6.89	2.77
Women 15-44 yrs, Indirect	87.8	460	7	174.69	3.97	4.29	2.89

[1] The data in this table reflects “consumers only”: those individuals who reported drinking tap water directly or indirectly.

[2] Percentage of survey population that were consumers of tap water and therefore were included in this analysis. Population of Consumers only for ml/person/day varied slightly from ml/kg of body weight/day. These values pertain to ml/person/day.

[3] Arithmetic means taken from CSFII report (EPA, April 2000). ml/person/day from Part III, Tables A1, A2, A3. ml/kg of body weight/day from Part IV, Tables A1, A2, A3. See report for discussion of sample population and technique.

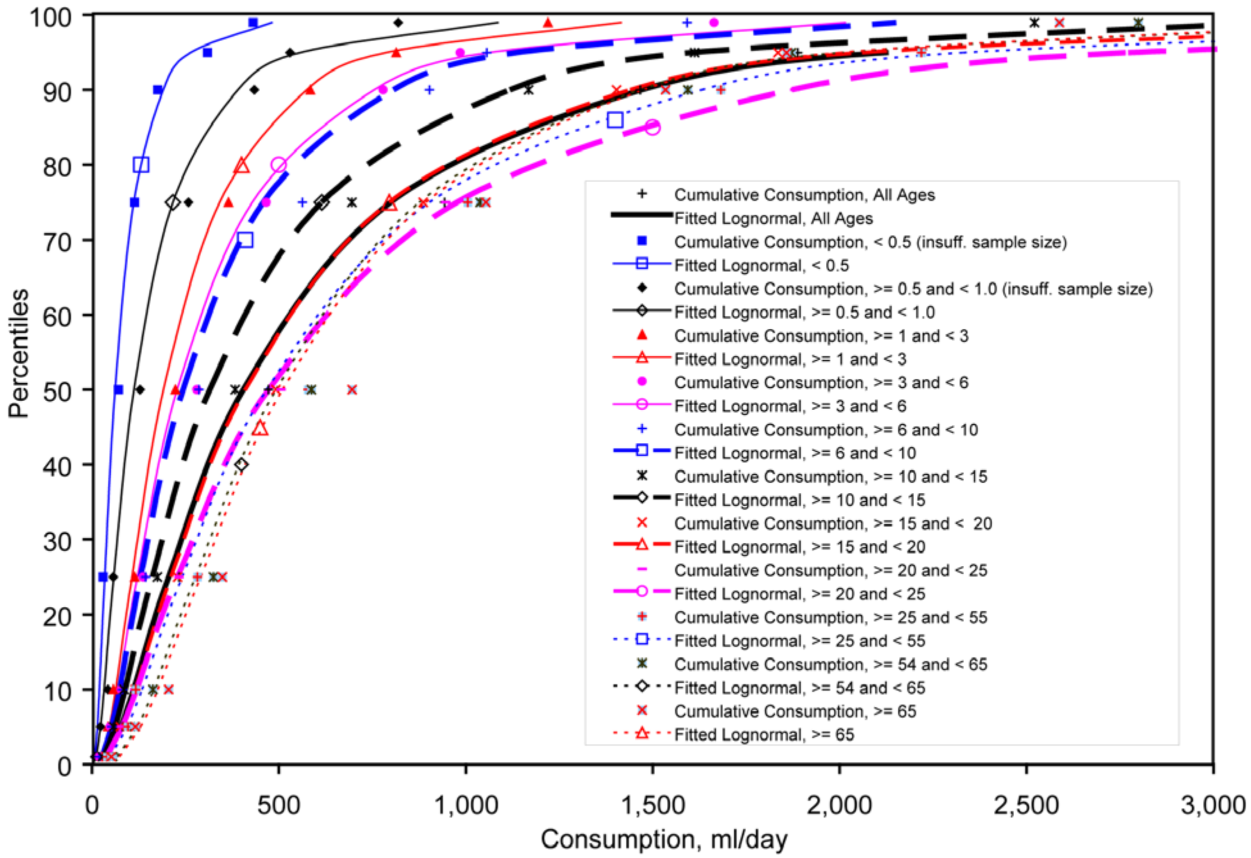


Figure 11-1. Direct Water Consumption by Age Categories in ml/person/day.

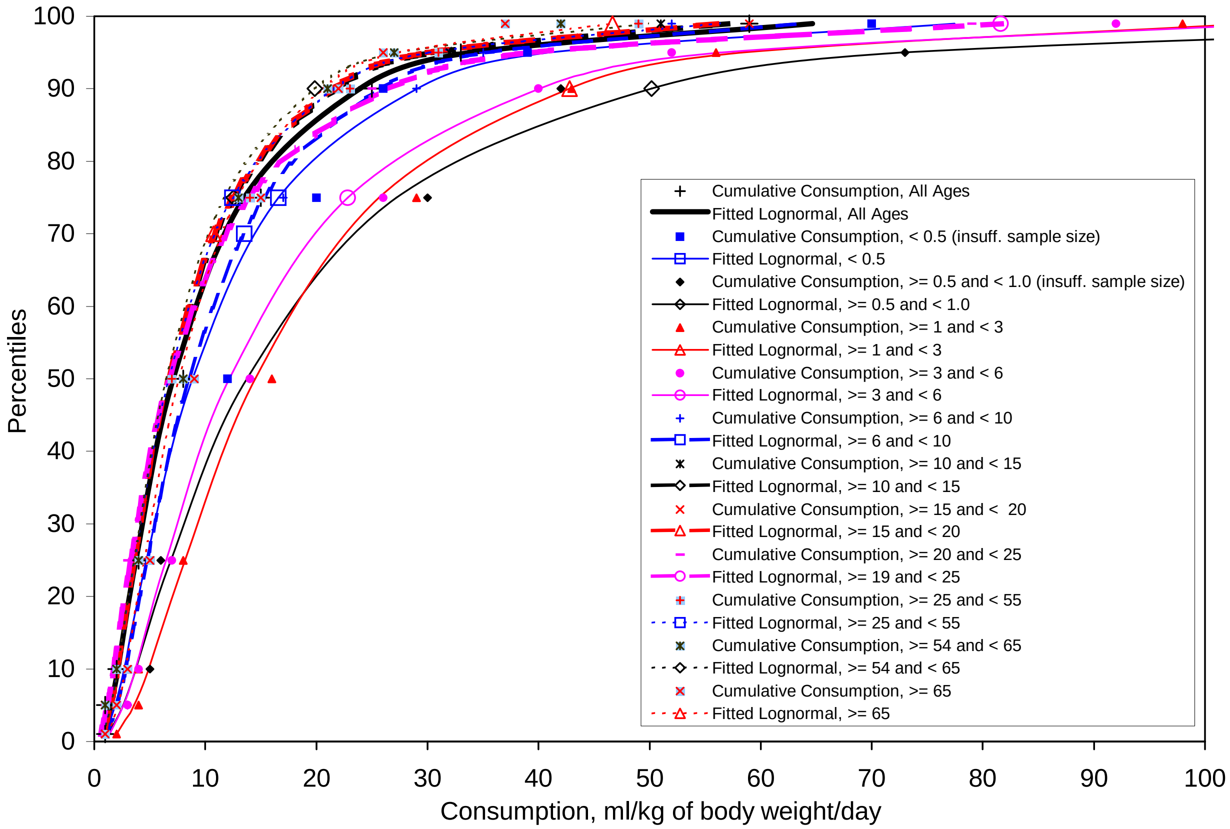


Figure 11-2. Direct Water Consumption by Age Categories in ml/kg of body weight/day.

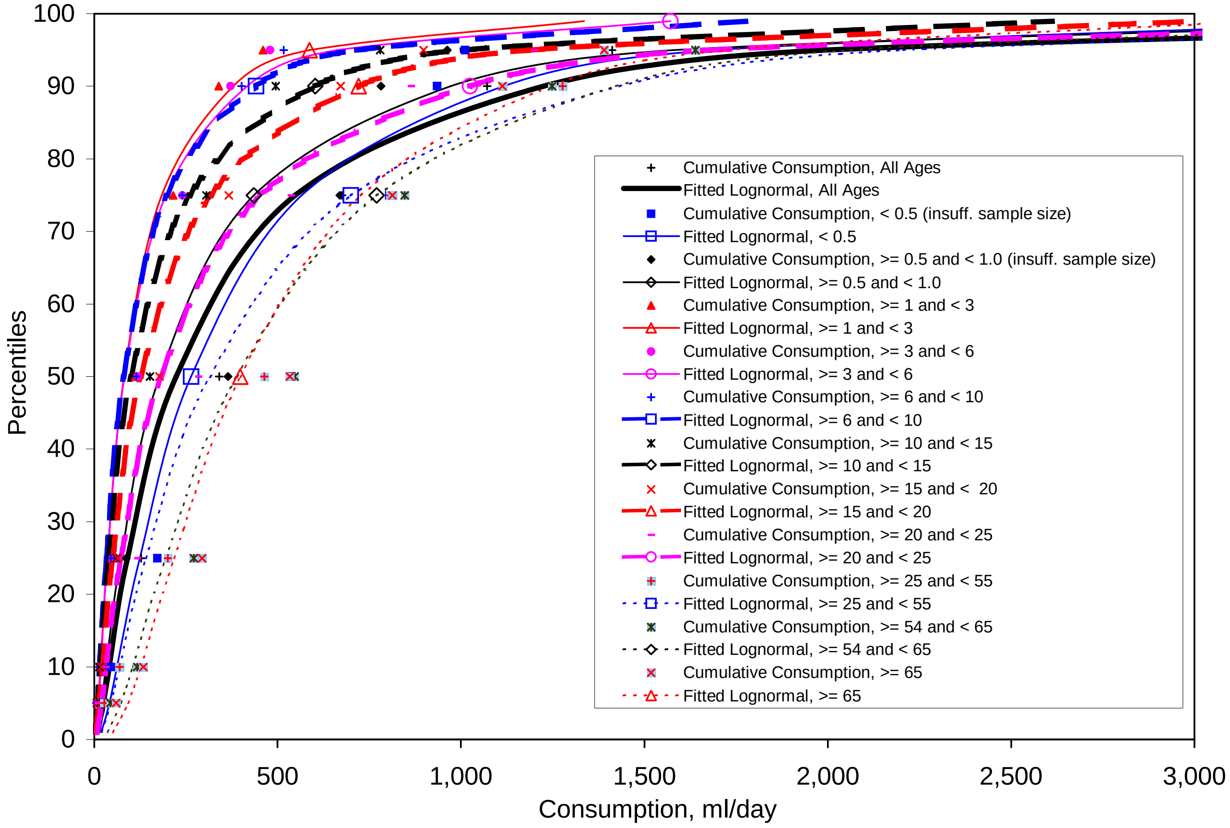


Figure 11-3. Indirect Water Consumption by Age Categories in ml/person/day.

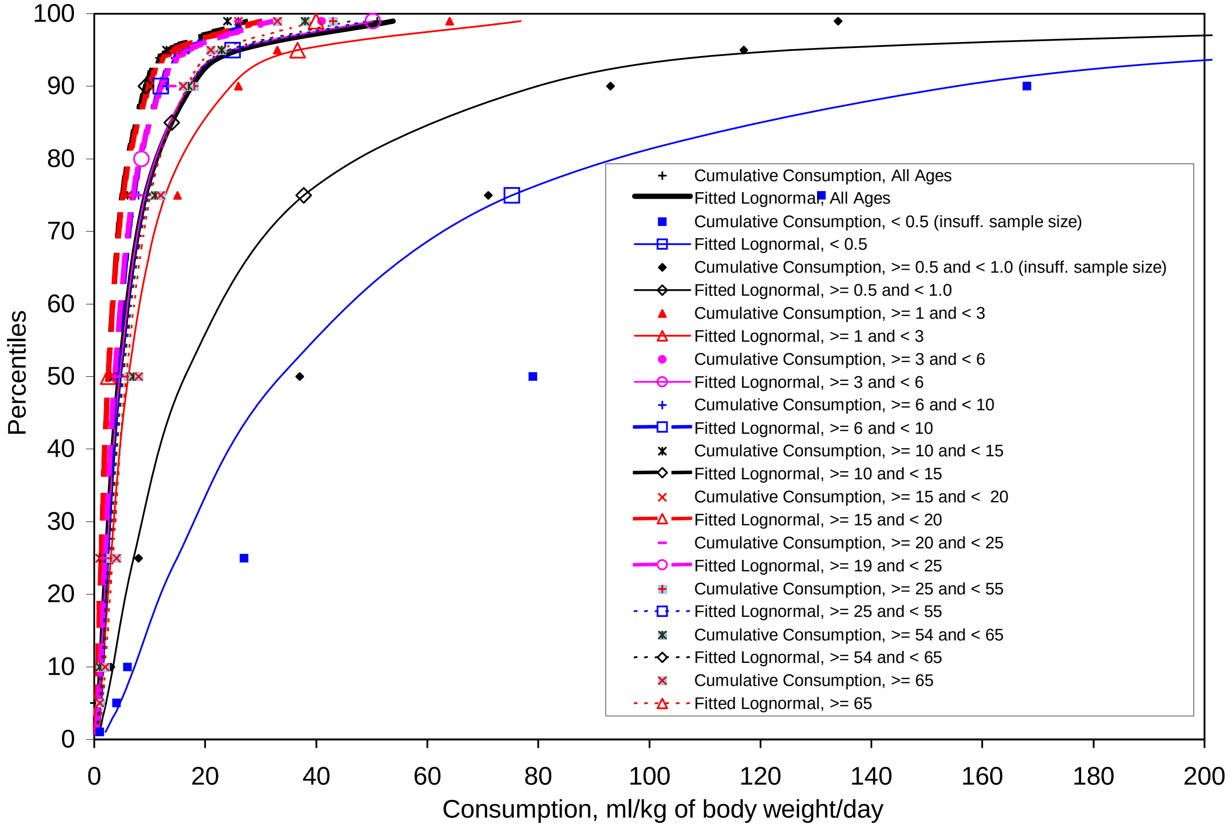


Figure 11-4. Indirect Water Consumption by Age Categories in ml/kg of body weight/day.

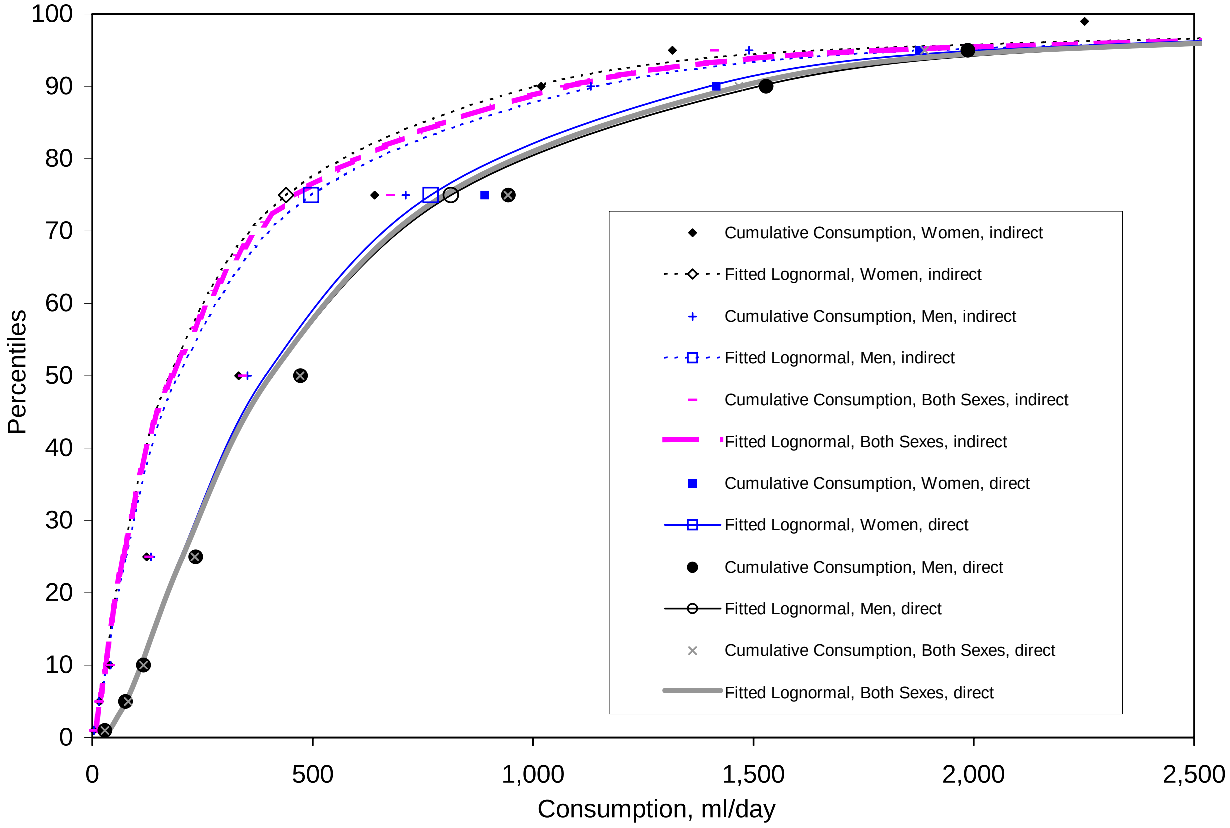


Figure 11-5. Direct and Indirect Water Consumption by Gender in ml/person/day.

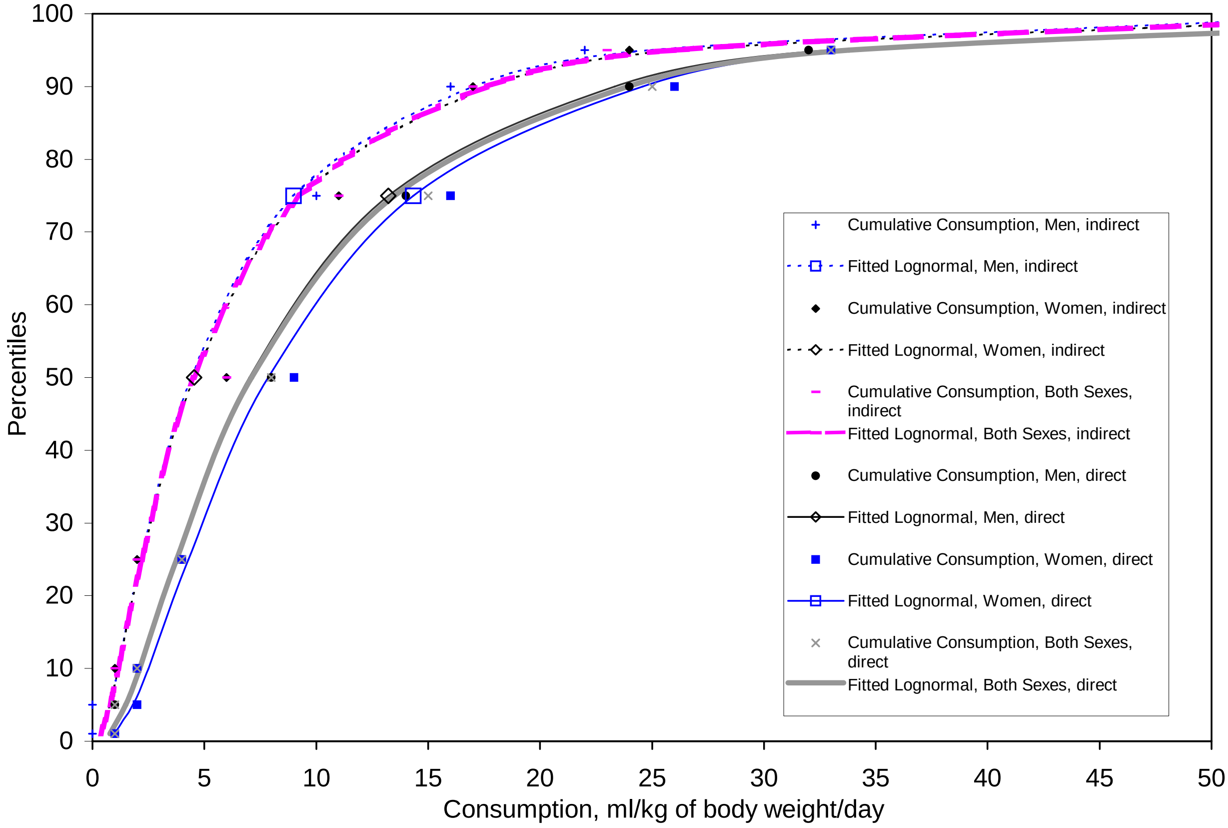


Figure 11-6. Direct and Indirect Water Consumption by Gender in ml/kg of body weight/day.

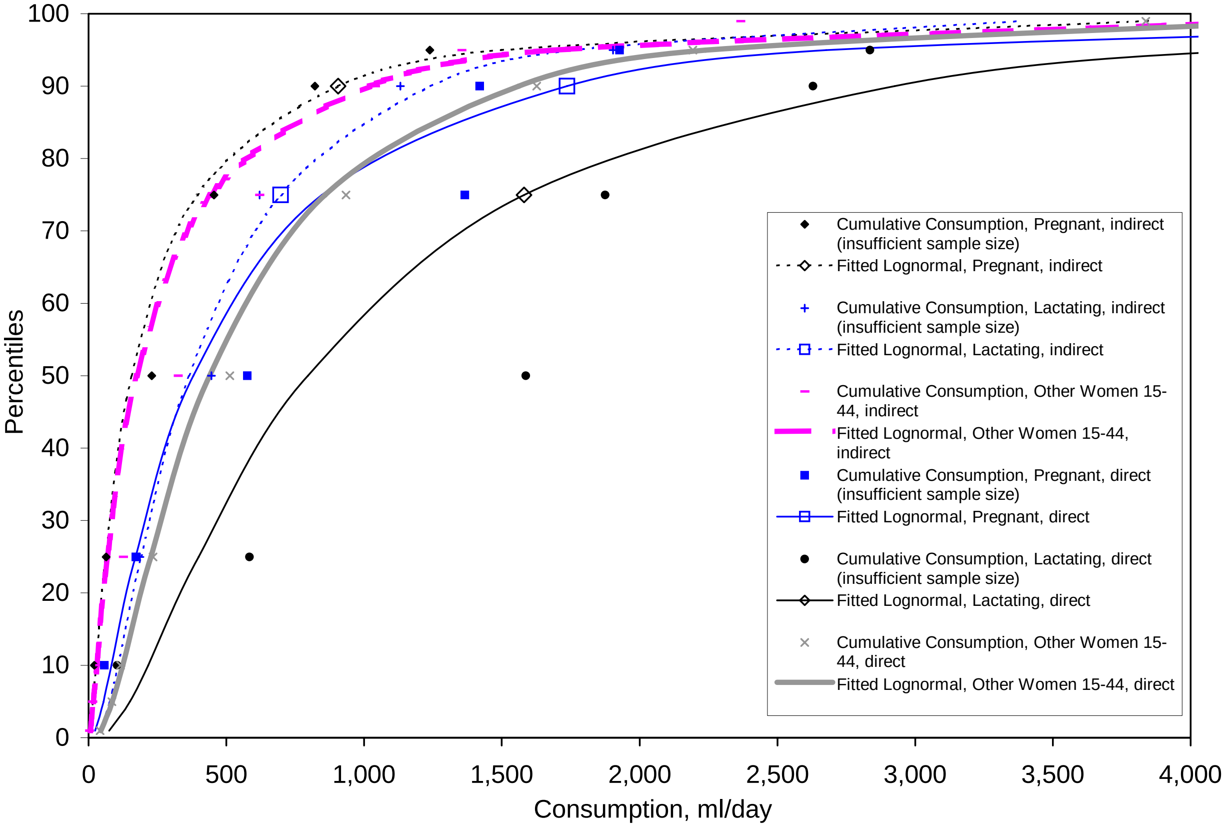


Figure 11-7. Direct and Indirect Water Consumption for Pregnant Women, Lactating Women, and Other Women 15-44 Years in ml/person/day.

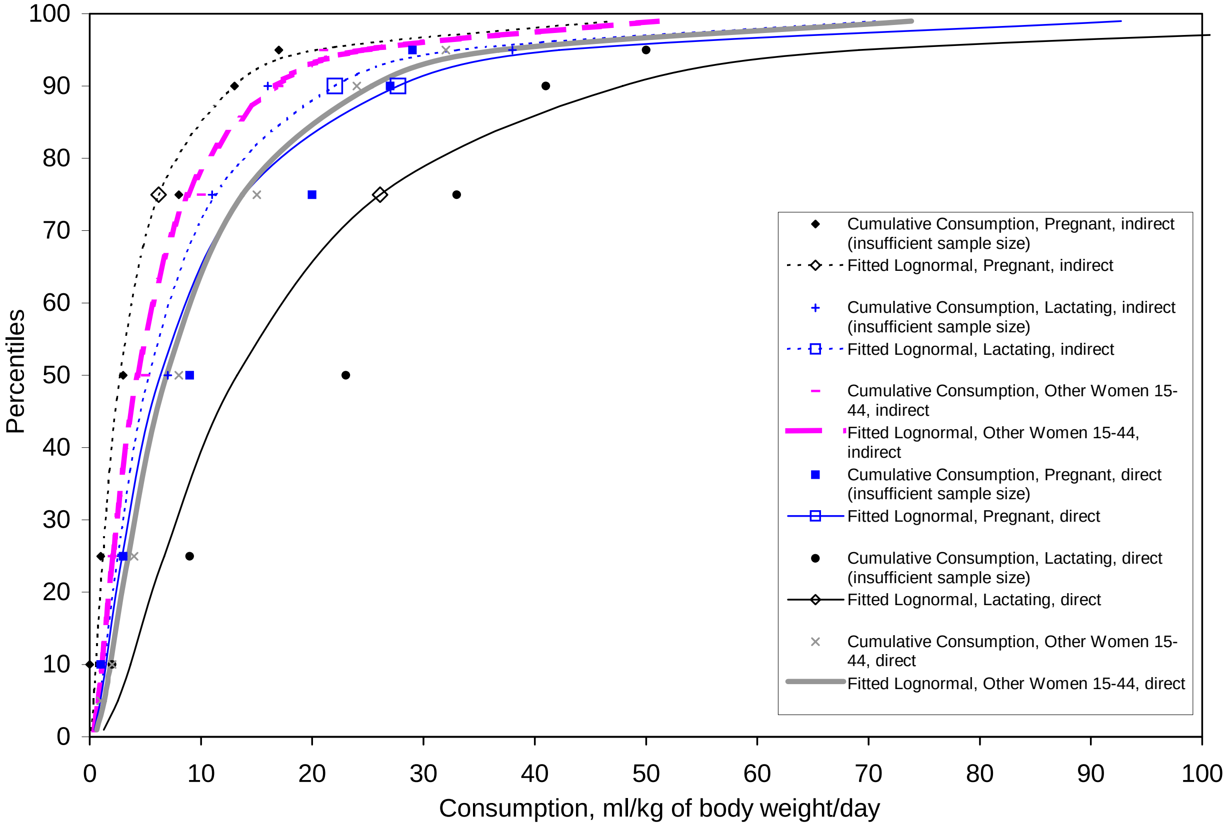


Figure 11-8. Water Consumption: Direct and Indirect for Pregnant Women, Lactating Women, and Other Women 15-44 Years in ml/kg of body weight/day.

Section 12

References

Anderson, D.L., W. Nero, N. Mingledorff, D. Mulville-Friel, and P. Fourie. November 1994. Single Family Residential Toilet Rebate Program Evaluation. Ayres Associates. Report Ayres JN: 30-0108.00.

Aher, A., A. Chouthai, L. Chandrasekar, W. Corpening, L. Russ, and B. Vijapur. October 1991. East Bay Municipal Utility District Water Conservation Study. Stevens Institute of Technology. Report No. R219.

Bellar, T., J. Lichtenberg, and R. Kroner. 1974. "The Occurrence of Organohalides in Chlorinated Drinking Water." *Journal of the American Water Works Association.* 66: 703-706.

Brown, and Caldwell. June 1984. Residential Water Conservation Projects, Summary Report. U.S. Department of Housing and Urban Development. Office of Policy Development and Research. Building Technology Division. HUD-0003623.

Burmaster, D.E. 1998. "A Lognormal Distribution for Time Spent Showering." *Risk Analysis*. 18(1):33-35.

California Air Resources Board. May 1991. Activity Patterns of California Residents. Research Division. California Air Resources Board. Final Report. Contract No. A6-177-33.

Consumer Reports. August 2000. “Clean machines. Top-Loader or Front-Loader?” Consumers Union of U.S., Inc, publisher. Yonkers, NY. Vol. 65, No. 8. pp. 32-35.

Consumer Reports. July 1999. “Spin City. Ratings of Washing Machines and Clothes Dryers.” Consumers Union of U.S., Inc, publisher. Yonkers, NY. Vol. 64, No. 7. pp. 30-33.

Consumer Reports. March 1998. “Dishing Out Dollars. Many Pricey Dishwashers Offer Surprisingly Few Pluses.” Consumers Union of U.S., Inc, publisher. Yonkers, NY. Vol. 63, No. 3. pp. 37-40.

Consumer Reports. July 1998. “A New Spin on Clothes Washers. Is It Time to Switch to a Front-Loader?” Consumers Union of U.S., Inc, publisher. Yonkers, NY. Vol. 63, No. 7. pp. 50-54.

Consumer Reports. August 1983. “Dishwashers.” Consumers Union of U.S., Inc., publisher. Yonkers, NY. Vol. 48, No. 8. pp. 406-411.

Crow, E.L., and K. Shimizu, (Eds.). 1988. LogNormal Distributions, Theory and Applications. Marcel Dekker, New York, NY.

DeGroot, M.H. 1987. Probability and Statistics. Second Edition. Addison-Wesley Publishing Company, Reading, MA.

DeOreo, W.B., J.P. Heaney, and P.W. Mayer. 1996. “Flow Trace Analysis to Assess Water Use.” *Journal of the American Water Works Association*. Vol. 88, No. 1, Jan.

Giardino, N.J., and J.P. Hageman. 1996. “Pilot Study of Radon Volatilization from Showers with Implications for Dose.” *Environmental Science & Technology*. Vol. 30, No. 4, pp. 1242-44.

Giardino N.J., and C.R. Wilkes. August 8 - 13, 1999. “A Community Comparison of Exposures and Risks from TCE in a Contaminated Groundwater Supply vs. DBPs in a Municipal Water Supply; Part II: Risk Assessment.” Proceedings: The Eighth International Conference on Indoor Air Quality and Climate. Edinburgh, Scotland. Vol. 2. pp. 818-823.

Henderson, J., and G. Woodard. October 2000. Functioning of Aging Low-Consumption Toilets in Tucson. Issue Paper #22. Water Resources Research Center. University of Arizona.

Hoke, J.R. (Ed.). 1994. Architectural Graphic Standards. 9th edition, John Wiley and Sons, New York, NY.

Hoke, J.R. (Ed.). 1988. Architectural Graphic Standards. 8th edition, John Wiley and Sons, New York, NY.

Ireland, J., L. Moore, H. Pourmoghaddas, and A. Stevens. 1988. "Gas Chromatography/Mass Spectrometry Study of Mixed Haloacetic Acids Found in Chlorinated Drinking Water," *Biomedical and Environmental Mass Spectrometry*, 17: 483-486.

Jacobs, H.L., J.T. Du, H.D. Kahn, and K.A. Stralka. April 2000. Estimated Per Capita Water Ingestion in the United States, Based on Data Collected by the USDA 1994-96 Continuing Survey of Food Intakes by Individuals. EPA/822/00/008. U.S. EPA, Office of Water.

James, I.R., and M.W. Knuiman. 1987. “An Application of Bayes Methodology to the Analysis of Diary Records from a Water Use Study.” *J. Am. Stat. Assoc.* 832(399). 705-711.

Klepeis, N.E., A.M. Tsang, and J.V. Behar. July 1996. Analysis of the National Human Activity Pattern Survey (NHAPS) Respondents from a Standpoint of Exposure Assessment. EPA/600/R-96/074. U.S. EPA, National Exposure Research Laboratory, Office of Research and Development.

Konen, T.P., and D.L. Anderson. March 1993. The Impact of Water Conserving Plumbing Fixtures on Residential Water Use Characteristics: A Case Study in Tampa, FL. Stevens Institute of Technology and Ayres Associates.

Koontz, M.D., and H.E. Rector. 1995. Estimation of Distributions for Residential Air Exchange Rates, Report No. IE-2603, GEOMET Technologies, Germantown, MD.

Krasner, S.W., M.J. McGuire, J.G. Jacangelo, N.L. Patania, K.M. Reagan, and E.M. Aieta. Aug 1989. “The Occurrence of Disinfection By-products in US Drinking Water.” *Journal of the American Water Works Association.* pg 41.

Lewis, W., and W. Whitman. 1924. "Principles of Gas Absorption." *Industrial and Engineering Chemistry*. **16**(12): 1215.

Lyman, W.J., W.F. Reehl, and D.H. Rosenblatt. 1990. Handbook of Chemical Property Estimation Methods. American Chemical Society. Washington, DC.

Lynberg, M., J.R. Nuckols, P. Langlois, D. Ashley, P. Singer, P. Mendola, C. Wilkes, H. Krapfl, E. Miles, V. Speight, B. Lin, L. Small, A. Miles, M. Bonin, P. Zeitz, A. Tadkod, J. Henry, and M.B.

Forrester. In press. “Assessing Exposure to Disinfection Byproducts in Women of Reproductive Age Living in Corpus Christi, Texas, and Cobb County, Georgia: Descriptive Results and Methods.” Accepted for publication in *Environmental Health Perspectives*.

Matsuda, H., T. Sato, H. Nagase, Y. Ose, H. Kito, and K. Sumida. 1992. "Aldehydes as Mutagens Formed by Ozonation of Humic Substances," *Sci Total Environ*, 114(0): 205-213.

Mayer, P.W., W.B. DeOreo, E.M. Opitz, J.C. Kiefer, W.Y. Davis, B. Dziegielewski, and J.O. Nelson. 1998. Residential End Uses of Water. American Water Works Association Research Foundation.

Miles, A.M., P.C. Singer, D.L. Ashley, M.C. Lynberg, P.A. Mendola, J.R. Nuckols, and P. Langlois. “Comparison of Trihalomethanes Measured in Tap Water with Levels Measured in Blood Samples.” (Submitted for publication).

Miller, R.E., S.J. Randike, L.R. Hathaway, and J.E. Denne. March 1990. “Organic Carbon and THM Formation Potential in Kansas Groundwaters,” *Journal of the American Water Works Association.* 82(3): 49-64.

Miltner, R.J., E.W. Rice, and A.A. Stevens. 1990. “Pilot-Scale Investigation of the Formation and Control of Disinfection Byproducts.” In: 1990 Annual Conference Proceedings. AWWA Annual Conference, Cincinnati, OH. 2:1787-1802.

Miltner, R.J., E.W. Rice, and B.L. Smith. 1992. “Ozone's Effect on Assimilable Organic Carbon, Disinfection Byproducts and Disinfection Byproduct Precursors.” Proceedings, WQTC, AWWA, Orlando, FL.

Miltner, R., H. Shukairy, and R. Summers. 1992."Disinfection By-product Formation and Control by Ozonation and Biotreatment." *Journal of the American Water Works Association.* 84(11): 53-62.

NIST/SEMATECH. November 2002. e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/.

Olin, S.S. (Ed.). 1999. Exposure to Contaminants in Drinking Water: Estimating Uptake Through the Skin and by Inhalation. International Life Sciences Institute (ILSI). CRC Press.

Persily, A.K. 1998. A Modeling Study of Ventilation, IAQ and Energy Impacts of Residential Mechanical Ventilation. Report No. NISTIR 6162, National Institute of Standards and Technology, Gaithersburg, MD.

Peters, C., R. Young, and R. Perry. 1980. "Factors Influencing the Formation of Haloforms in the Chlorination of Humic Materials." *Environmental Science and Technology*, 14: 1391.

Rector, H.E., C.R. Wilkes, and A.D. Mason. 2001. Techniques for Modeling Building Systems in TEM. Draft report prepared for Office of Research and Development, U.S. EPA.

Rector, H.E., C.R. Wilkes, and N. J. Giardino. 1996: “Effects Of Human Behavior On Inhalation Exposure To Radon Volatilized From Domestic Water Uses.” Proceedings of the 1996 International Radon Symposium, pp I-8.1 – I-8.8, American Association of Radon Scientists and Technologists, McClean, VA.

Richardson, S.D. 1998. “Identification of Drinking Water Disinfection By-Products,” In: Encyclopedia of Environmental Analysis and Remediation, R.A. Meyers, ed. 3:1398-1421, Wiley and Sons.

Rook, J. 1974. "Formation of Haloforms During Chlorination of Natural Water." *Water Treatment and Examination.* 23: 234-243.

Shukairy, H.M., R.J. Miltner, and S.R. Summers. June 1994. "Bromide's Effect on DBP Formation, Speciation and Control: Part I, Ozonation." *Journal of the American Water Works Association*. 86(6):72-87.

Small, M.J. 1990. "Probability distributions and statistical estimation." Chapter in Uncertainty. Morgan, M.G., and M. Henrion. Cambridge University Press. NY, NY.

Travis, C.C., and M.L. Land. 1990. "Estimating the Mean of Data Sets with Nondetectable Values." *Environmental Science and Technology*. 24(7) pp. 961-962.

Tsang, A.M., and N.E. Klepeis. 1996. Descriptive Statistics Tables from a Detailed Analysis of the National Human Activity Pattern Survey. EPA/600/R-96/074. U.S. Environmental Protection Agency, Washington, DC.

Tukey, J.W. 1949. "Comparing Individual Means in the Analysis of Variance." *Biometrics* Vol. 5. pp. 99-114.

Urano, K., H. Wada, and T. Takemasa. 1983. "Empirical Rate Equation for Trihalomethane Formation with Chlorination of Humic Substances in Water." *Water Research*. 17:17.

USDOE. 1995. Residential Energy Consumption Survey (RECS): Housing Characteristics. 1993. Report No. DOE/EIA-0314(93), U.S. Department of Energy, Energy Information Administration, Washington, DC.

USDOE. 1999. Housing Characteristics 1997. Report No. DOE/EIA-0632 (97). U.S. Department of Energy, Energy Information Administration. Washington, DC.

USEPA. August 1997. Exposure Factors Handbook, Volume III, Activity Factors. EPA/600/P-95/002Fc. U.S. EPA, Office of Research and Development, National Center for Environmental Assessment.

USEPA. August 1997. Exposure Factors Handbook, Volume I, General Factors. EPA/600/P-95/002Fa. U.S. EPA, Office of Research and Development, National Center for Environmental Assessment.

USEPA. 1998. Residential Building Characteristics. pp 17-1 - 17-32. In: Exposure Factors Handbook, Report No. EPA-600/P-95/002BA, U.S. Environmental Protection Agency. National Center for Environmental Assessment. Washington, DC.

Wallace, L.A. 1997. "Human Exposure and Body Burden for Chloroform and Other Trihalomethanes (Review)." *Critical Reviews in Environmental Science and Technology*, 27(2): 113-194.

Westrick, J.J., J.W. Mello, and R.F. Thomas. March 1984. "The Groundwater Supply Survey." *Journal of the American Water Works Association*. p52-59.

Wilkes, C.R., M.J. Small, J.B. Andelman, N.J. Giardino, and J. Marshall. August 1992. "Inhalation Exposure Model for Volatile Chemicals from Indoor Uses of Water." *Atmospheric Environment*, 26A(12):2227-2236.

Wilkes, C.R. April, 1994. Modeling Human Inhalation Exposure to VOCs Due to Volatilization from a Contaminated Water Supply. Ph.D. Dissertation. Department of Civil Engineering, Carnegie Mellon University. Pittsburgh, PA.

Wilkes, C.R., M.J. Small, C.I. Davidson, and J.B. Andelman. 1996. "Modeling the Effects of Water Usage and Co-Behavior on Inhalation Exposures to Contaminants Volatilized from Household Water." *Journal of Exposure Analysis and Environmental Epidemiology*. 6(4):393-412.

Wilkes, C.R., and N.J. Giardino. August 8 - 13, 1999. "A Community Comparison of Exposures and Risks from TCE in a Contaminated Groundwater Supply vs. DBPs in a Municipal Water Supply; Part I: Risk Assessment." Proceedings: The Eighth International Conference on Indoor Air Quality and Climate. Edinburgh, Scotland. Vol. 2. p800-817.

Wilkes, C.R. 1999. Chapter Seven "Case Study" and portions of Chapter Four "Developing Exposure Estimates." Exposure to Contaminants in Drinking Water: Estimating Uptake Through the Skin and by Inhalation, edited by S.S. Olin. International Life Sciences Institute (ILSI). CRC Press. p. 184-224.

Appendix A

Evaluation of the Meter-Master Data Logger and the Trace Wizard Analysis Software

Appendix A

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Water Meter Data Logger Evaluation Study

A-1 Introduction

The Meter-Master 100EL records a signal from a magnetic sensor attached to the house's water meter, which is subsequently converted to a water-flow time series representing the water flow through the meter. The Trace Wizard software applies algorithms to disaggregate the total water flow into individual appliance and fixture water uses. The REUWS database contains nearly two million water use records resulting from data recorded by the Meter-Master 100EL and disaggregated into individual uses by the Trace Wizard software.

This study was conducted with the objectives of evaluating the accuracy and precision of the water meter data logging equipment (Meter-Master 100EL[1]); evaluating the ability of the data analysis software (Trace Wizard, Version 2.1[2], DeOreo, 1996) to disaggregate individual appliance water flows from the total water flows; and evaluating the ability of Trace Wizard to assign individual water uses to specific household appliances. This evaluation is conducted for two primary reasons: (1) to provide insight into the Residential End Use Water Survey (REUWS) database and (2) to examine the utility of this technique for use in future water-use exposure studies. The results of this evaluation study will assist in both better interpretations of the data in REUWS, and in understanding the potential for misclassification of water uses. In addition, if this technology proves reliable for quantifying water use of individual appliances, it would be a valuable addition to water-use exposure studies.

This study was necessitated by the recognition that the REUWS data was extremely valuable for use in assessing exposure to waterborne contaminants and by the discovery that no validation studies have been conducted on the methodology upon which REUWS is based. This study was conducted with a limited budget which therefore resulted in a modest set of objectives. The results of this study indicate a more comprehensive validation study is warranted.

The main report to which this Appendix is attached analyzes the REUWS database and other resources for water use behavior related to exposure to waterborne contaminants. Important water-use behaviors impacting exposure include the type of appliance, the volume, flow rate, temperature, and frequency of water use, and the location of these water uses in the home. With the exception of water temperature, the REUWS purports to provide insight into these characteristics over an approximately four-week study period (two weeks in the fall and two weeks in the spring) for 1188 homes in 12 different North American cities. The data stored in REUWS was collected and disaggregated using the Meter-Master 100EL data logger and the Trace Wizard, Version 2.1 software.

A review of the literature prior to undertaking this study revealed no significant studies that quantified the ability of the Meter-Master and Trace Wizard combination to properly assign water uses to the actual appliances of use. As a prerequisite to utilizing the REUWS data for representing exposure-related water-use behavior, it is very desirable to understand the relationship between the actual water-use behavior and the records in the database. Because no study that quantitatively compares the "actual"

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[1] F.S. Brainard and Company, P.O. Box 366, Burlington, NH 08016

[2] Aquacraft Engineering, Inc., 2709 Pine Street, Boulder, CO 80304

water-use characteristics with the Meter-Master/Trace Wizard analysis has been conducted, this evaluation study is designed to provide an initial assessment.

This study is meant as a preliminary study toward better understanding the capabilities of the Trace Wizard analysis algorithms relative to the stated objectives. It is designed to implement a series of realistic water-use activities to evaluate the ability of Trace Wizard to correctly identify the appliance, the appliance type, and volume of water used. The study implements a number of pre-planned water-uses designed to fall into three categories:

1. Single water uses with no overlap.
2. Double water uses, such that smaller individual water uses occur simultaneously with a large continuous water use (e.g., shower). At most, two appliances are drawing water simultaneously, and the start of the large water use occurs without another use.
3. Triple water uses with as many as three water uses occurring simultaneously.

The planned water uses are not intended to be representative of a typical day of water uses, but rather to cover the spectrum of possible water-use behavior that could be found in multi-resident households. As such, this study was designed to challenge the Trace Wizard software with increasingly difficult water-use scenarios, from very simple single water uses with no overlap to fairly complex scenarios with as many as three simultaneous water uses. The percentage of water uses in actual households that fall into each of the above categories is not known, but is expected to be heavily weighted toward single water uses.

A-2 Overview

This study was conducted in a single-family residence over the course of five days. The data logger was installed on the house's water meter to record all water-use activities. The logger was calibrated by drawing a known amount of water, and each water-use appliance was turned on individually to establish its flow signature. During subsequent days, the field personnel implemented a pre-designed scenario of water-use activities for each appliance and recorded the location, durations, and where possible, the volumes of approximately 50 water-using events. The characteristics of the water-use events were recorded to use in an evaluation of the Trace Wizard's ability to identify individual appliances and fixtures from the composite water-use signatures. These water-use tests were conducted so that some water uses occurred individually, while others overlapped. At various times, two or three water uses occurred simultaneously in order to simulate possible real-life scenarios. At the end of the field study, additional calibration draws were taken.

Following the fieldwork, the calibration data, appliance signature data, and the data logger itself were sent to Aquacraft for their analysis using the flow analysis software, Trace Wizard. The actual appliance/fixture use data were not forwarded to Aquacraft, but were retained for comparison after the Trace Wizard analysis was completed. Aquacraft used their flow analysis software, Trace Wizard, to create a final database intended to fully define the water-use activities during the logger's operation. The database included water-use dates, appliance identifications, start and end times, durations, volumes, peak flows, and mode flow (most frequent flow rate).

This report compares the Trace Wizard analysis to the data recorded by the field personnel at the test household.

A-3 Equipment

The study involved the use of the following:

Equipment:

Data Logger: Meter-Master 100EL, Manufactured by Brainard Co., Burlington, NJ (See Figure A-1).

PC-Based Flow Analysis Software: Trace Wizard, Aquacraft, Inc., Boulder, CO.

Acculab bench scale, model SV-30.

Calibration Weights: 10 Kg (±1 mg) Troemner Cast Iron Weight and a 20 Kg (±2 mg) Troemner Cast Iron Weight

Timex Digital Watch

Graduated Cylinders: 2L and 100 ml

Plastic 16 gallon Tub and Other Containers

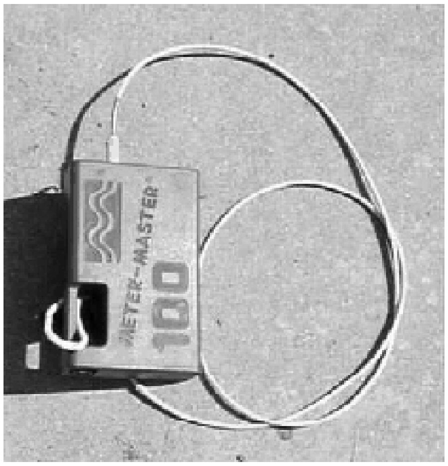

Figure A-1. Meter-Master 100EL, Data Logger.

A-4 Procedures

A-4.1 Site Selection

The site selected is a two-story single-family house. It has a magnetic-type water meter, which is required for this study because the Meter-Master data logger is designed to operate on these units. (98% of all meters in common use are magnetic-type meters[3]). The water meter is a Badger Recordall PD, Model 15, manufactured by Badger Meter, Inc[4]. The site also has a wide variety of common appliances, such as a dishwasher, clothes washer, four showers, numerous faucets, etc.

A-4.2 Installation of Meter-Master

The Meter-Master data logger was programmed by entering the date, time, meter brand and model number, and other site-specific information. Then the sensor was attached to the water meter (located in the meter pit in the driveway) using a heavy Velcro strap. The logger was activated on May 21, 1999 at approximately 4 pm EDT, and it responded by emitting a two-second red flash. Next, a small amount of water was run through the outside hose, causing the logger sensor to emit red flashes indicating that the magnetic pulses were being picked up and recorded.

A-4.3 Calibration of the Meter-Master

The field technicians measured and recorded the exact volume, start time, and end time of two water draws from the hose in the back of the house (with all other water appliances/faucets off). This information was used to calibrate the flow signal during the analysis.

The procedure involved the following:

- Using the bench scale, measure and record the weight of the empty 16 gallon tub.

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[3] F.S. Brainard & Company, Burlington, N.J.

[4] Badger Meter, Inc., Milwaukee, WI (www. badgermeter.com)

- Fill tub to an arbitrarily marked level, recording the precise start and end times of water draw.
- Weigh the filled tub.
- Subtract tare weight of container.
- Convert weight of water to volume of water using known density of water.
- During the calibration draws, the logger was active, recording the volume of water used every 5 seconds.
- The calibration data was provided to Aquacraft (presented in Table A-1).

Table A-1. Logger Installation and Calibration Draws **DATE: 5-21-99**

Appliance Number/Description	Start Time	End Time	Volume of Water Used (gallons)	Meter Reading (gallons)
Logger Installation/initiation	4:01:00 pm	NA		1,237,436.7
Hose 2: Calibration Draw #1	4:04:00 pm	4:09:15 pm	24.26 L (6.41 gallons)	1,237,442.8 (after draw)
Hose 2: Calibration Draw #2	4:17:00 pm	4:19:25 pm	27.105 L (7.16 gallons)	1,237,449.7 (after draw)

A-4.4 Water Appliance Signatures

The flow analysis software, Trace Wizard, identifies particular appliances being used by looking for patterns of water flow. To help Trace Wizard identify individual appliances and fixtures, signatures of each water-use device were provided to Aquacraft. To provide these signatures, the field personnel operated each water-using appliance for a minimum duration of 30 seconds, or one entire event in the case of the clothes washer and dishwasher (with no other water uses occurring), recorded its identification number and type (e.g., faucet 1, shower 2), and recorded the start and end times of the water-use event. Signatures were provided for each of the 21 separate appliances and fixtures in the house. The appliance descriptions along with the field signature data are presented in Tables A-2 and A-3 respectively.

Table A-2. Available Water Appliances at Test Home

Appliance Number	Appliance Description	Floor	Appliance Location
1	Shower 1	2nd	Master Bathroom
2	Toilet 1	2nd	Master Bathroom
3	Faucet 1	2nd	Master Bathroom Sink, nearest to the door
4	Faucet 2	2nd	Master Bathroom Sink, farthest from the door
5	Bathtub 1	2nd	Upstairs Hall Bathroom
6	Shower 2	2nd	Upstairs Hall Bathroom
7	Toilet 2	2nd	Upstairs Hall Bathroom
8	Faucet 3	2nd	Upstairs Hall Bathroom Sink
9	Clothes Washer	2nd	Laundry Room
10	Faucet 4	2nd	Laundry Room Sink
11	Faucet 5	1st	Kitchen Sink
12	Dishwasher	1st	Kitchen
13	Bathtub 2	1st	Downstairs Hall Bathroom
14	Shower 3	1st	Downstairs Hall Bathroom
15	Toilet 3	1st	Downstairs Hall Bathroom

Table A-2. *(Continued)*

Appliance Number	Appliance Description	Floor	Appliance Location
16	Faucet 6	1st	Downstairs Hall Bathroom Sink
17	Shower 4	1st	Guest Room Bathroom
18	Toilet 4	1st	Guest Room Bathroom
19	Faucet 7	1st	Guest Room Bathroom
20	Hose 1	NA	Outside, Carport
21	Hose 2	NA	Outside, Side of House

Table A-3. Water Appliance Signatures **DATE: 5-23-99**

Appliance Description	Start Time	End Time	Volume of Water Used (gallons)
Shower 1	10:54:00 am	10:57:30 am	
Toilet 1	10:59:00 am	10:59:49 am	
Faucet 1	11:00:41 am	11:01:44 am	
Faucet 2	11:03:12 am	11:03:59 am	
Bathtub 1	11:08:50 am	11:09:55 am	
Shower 2	11:11:00 am	11:14:45 am	
Toilet 2	11:06:35 am	11:07:27 am	
Faucet 3	11:04:47 am	11:05:51 am	
Clothes Washer	09:41:30 pm	See below	
Faucet 4	11:16:15 am	11:17:22 am	
Faucet 5	11:18:30 am	11:19:35 am	
Dishwasher	10:33:00 pm	Unknown	
Bathtub 2	11:20:45 am	11:21:59 am	Transition from bath to shower
Shower 3	11:21:59 am	11:25:11 am	
Toilet 3	11:26:30 am	11:28:36 am	
Faucet 6	11:30:00 am	11:31:11 am	
Shower 4	11:32:15 am	11:35:38 am	
Toilet 4	11:36:30 am	11:37:37 am	
Faucet 7	11:38:15 am	11:39:15 am	
Hose 1 (5-24-99)	06:34:00 am	6:37:00 am	
Hose 2 (5-24-99)	06:50:00 am	6:53:00 am	

Note: All times in Eastern Daylight Savings Time (EDT)

Faucets: All single pole faucets – center (warm), full flow position.
All double pole faucets – opened both faucets to full flow position.

Showers: Adjusted to full flow, warm (approximate showering temperature)

Clothes Washer: Water level at smallest load setting, water temperature at cold/cold
3 water draws (wash fill): start @ 9:41:30 pm; end @ 9:44:05 pm
rinse and spin: start @ 9:57:03 pm; end @ 9:58:04 pm
rinse and fill: start @ 9:59:09 pm; end @ 10:01:34 pm

A-4.5 Water-Use Field Study

The water-use part of the study was intended to test both the ability of the flow analysis software to disaggregate individual water uses as well as to estimate the accuracy and precision of the logger. Over 50 water-using events were planned and performed, starting with straightforward water-uses and gradually moving toward more challenging combinations of water uses. First, events referred to as “Single Water Uses” were conducted by operating individual appliances with all other water sources off to represent the most straightforward water-use behavior. Then, “Double Water Uses” were conducted by operating appliances in a manner such that two events overlapped each other in order to simulate real-life scenarios. Finally, “Triple Water Uses” were conducted by operating a series of three appliances simultaneously such that the uses overlapped. During the faucet and shower uses, the water flows were placed in the fully opened position, with a medium water temperature. For each event, the start and end times were recorded. Furthermore, for over half of the events, the field personnel measured the water volume by drawing the water into a container, and then weighing the water and converting it to volume. Only the field data from the signatures were provided to Aquacraft. The field data from the single, double, and triple water uses were used as a means of evaluating the Trace Wizard's ability to identify the devices and disaggregate the total flows into individual water uses.

A-4.6 Logger Retrieval and Submittal

Following the field study, two final calibration draws were taken, one at hose 1 and one at hose 2. Then the final meter reading was recorded, and the logger was disconnected from the meter on May 26, 1999 and shipped to Aquacraft for analysis. This logger retrieval data is presented in Table A-4. On May 26th, 1999, the Meter-Master data logger was submitted for analysis along with the following data tables:

- Table A-1: Logger Installation Calibration Draws
- Table A-2: Available Water Appliances at Test Home
- Table A-3: Water Appliance Signatures
- Table A-4: Logger Retrieval

Table A-4. Logger Retrieval

Appliance Number/Description	Start Time	End Time	Volume of Water Used (gallons)	Meter Reading
Hose 1: Calibration Draw #3	12:34:30 pm	12:36:15 pm	24.49 L (6.47 gal)	1,238,498.3 (prior to hose 1)
Hose 2: Calibration Draw #4	12:43:00 pm (approx. 10 sec)	12:44:15 pm	26.81 L (7.08 gal)	1,238,504.5 (prior to hose 2)
Logger Removal		12:49:30 pm		1,238,511.35

A-5 Results

As water uses occurred in the household, the data logger recorded the number of revolutions of the household water meter impeller every 10 seconds, which are then used to estimate the volume of water. The volumes of water associated with each record are converted to an average flow rate over the 10-second interval, as shown in Figures A-2 through A-7. Imbedded in the raw data shown in these figures are the water-use signatures, the planned field study water uses, and the general household water uses that are not a part of the study.

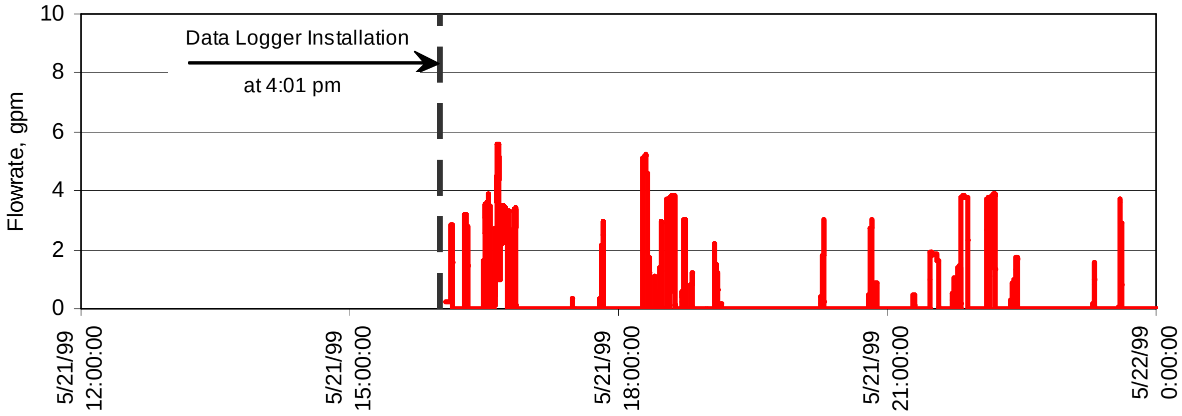


Figure A-2. Water Use Record for Day 1 (May 21, 1999).

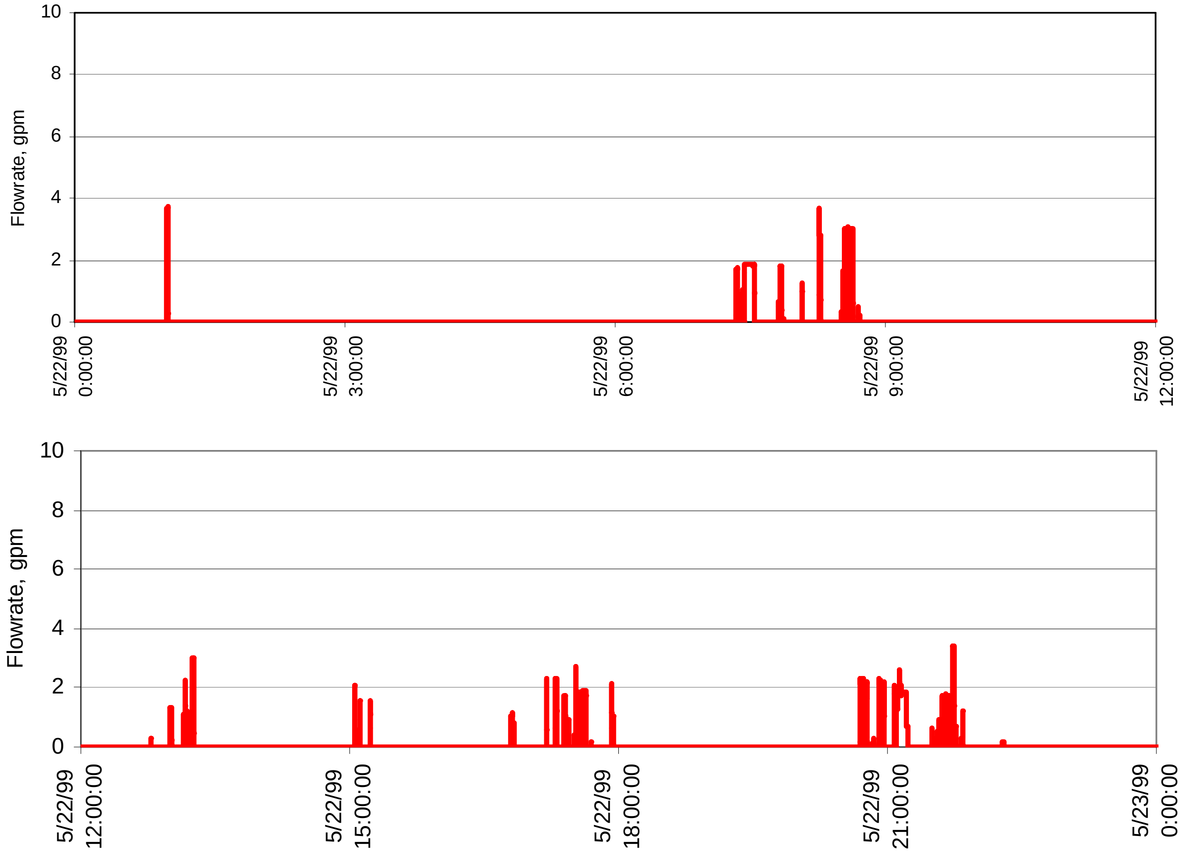


Figure A-3. Water Use Record for Day 2 (May 22, 1999).

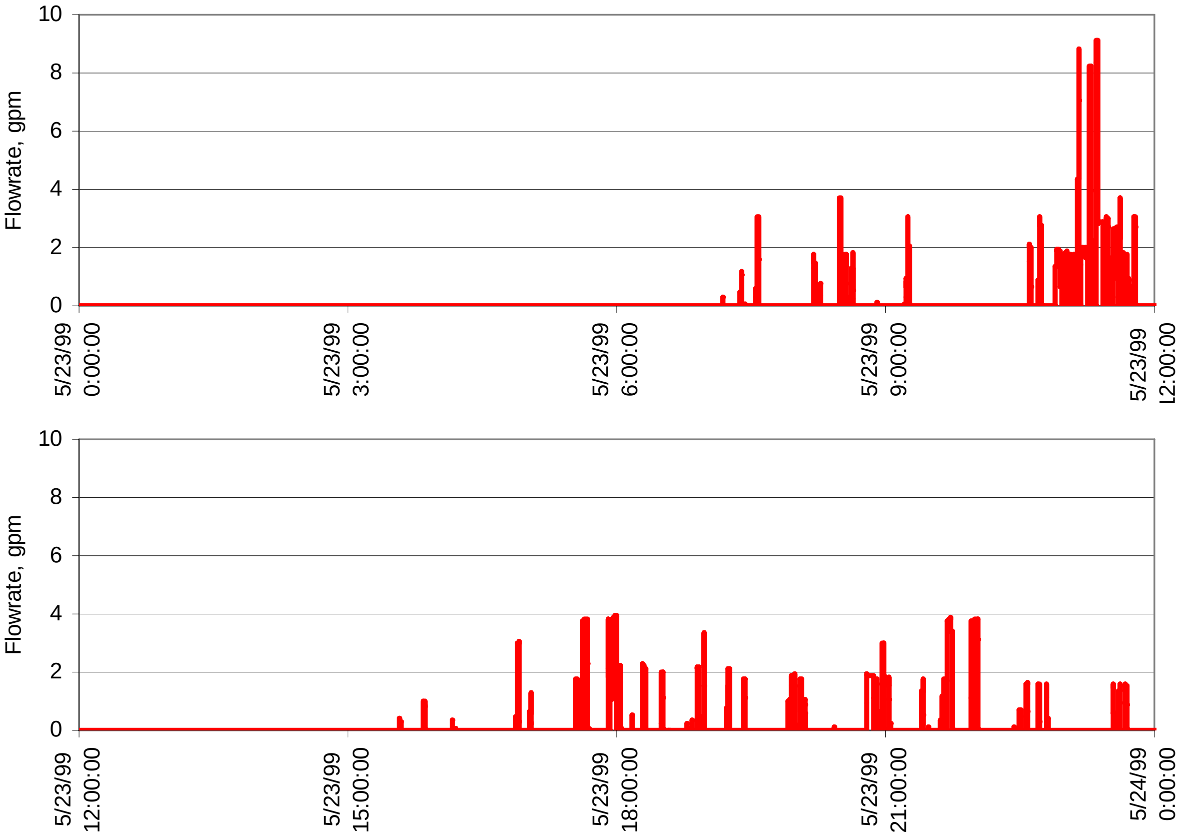


Figure A-4. Water Use Record for Day 3 (May 23, 1999).

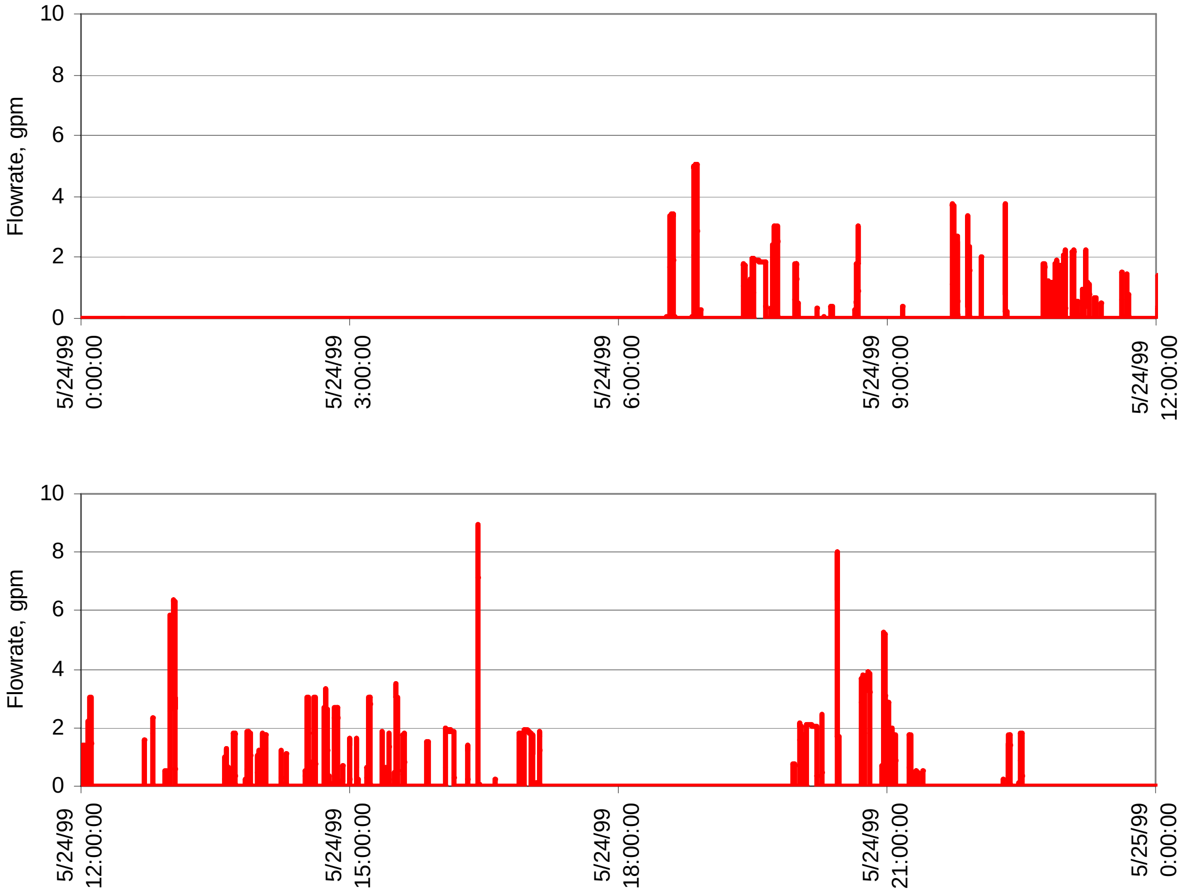


Figure A-5. Water Use Record for Day 4 (May 24, 1999).

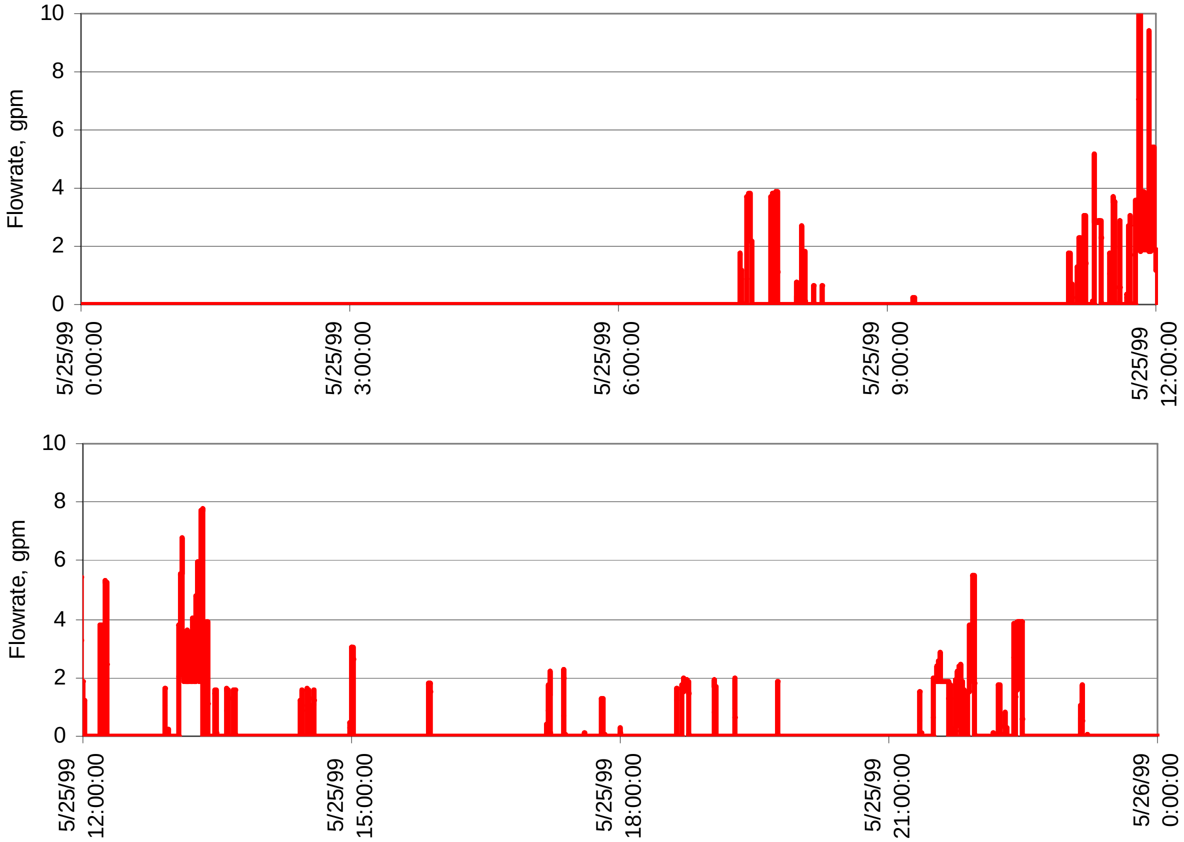


Figure A-6. Water Use Record for Day 5 (May 25, 1999).

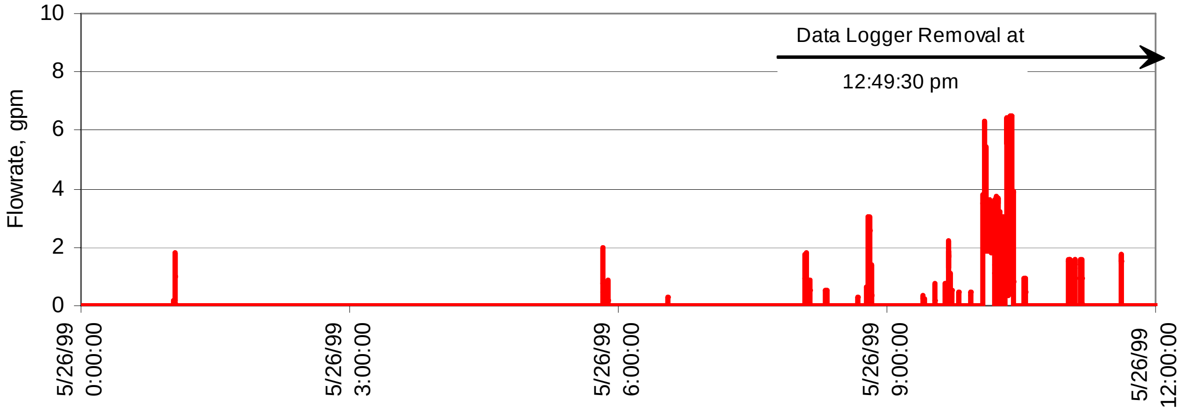


Figure A-7. Water Use Record for Day 6 (May 26, 1999).

A-5.1 Calibration Draws

The calibration draws are identified in the raw data by using the times recorded in the field study. The water volumes measured in the field are used to calibrate the meter to the volume of water use per impeller rotation. The calibration draws are shown in Figure A-8, with the field data shown in Tables A-1 and A-4.

A-5.2 Signature Results

During the initial phase of the field study, water-use signatures were acquired for each appliance by operating the appliance for a minimum of 30 seconds, or one full event (in the case of the clothes washer and dishwasher), in order to record individual water-use signatures on the Meter-Master. As described above in Section 4.4, these signatures were intended to be used by the Trace Wizard software to identify (via comparison) the various appliances in use throughout the rest of the study. The water-use appliance signatures recorded in the field are presented in Table A-3 and the signatures seen by the data logger are graphically displayed in Figures A-9 through A-14.

A-5.3 Field Results

During the study, the water-using appliances were turned on and off in a fashion such that each appliance was operated alone and in combination with other water sources. As discussed in the above Section 4.5, when appliances were operated alone, they were called “Single” water uses; when two appliances were operated simultaneously or their uses overlapped, they were called “Double” water uses; and when three appliance water uses overlapped, they were called “Triple” water uses. During this part of the study, the field personnel recorded the start and end times and frequently (where possible) the volume of water used during the event. These data are presented in Table A-5, under the columns labeled “Type of Use”, “Actual Device”, “Actual Start Time”, “Actual End Time”, and “Actual Volume.”

A-5.4 Field versus Trace Wizard Data

Aquacraft retrieved the field study data recorded by the Meter-Master data logger during the 5 days of the field study. They used the Trace Wizard software to analyze the data by disaggregating the individual appliance water uses from the total water-flow record. The software identifies individual appliance water-use signatures, and uses this information to determine when and which appliance is in use. The Trace Wizard software created a database of water uses for the study period. The resultant database contained records for each of the Trace Wizard assigned individual water uses, each with an identification of the appliance in use, start and end times, duration, volume, peak flow, and mode. Aquacraft provided the resultant database and presented most of the results in table and graph format. These tables and graphs contained in Aquacraft’s final report are presented in Section A-9.

The results from the Trace Wizard analysis were compared to the data recorded by the field personnel during the days of the study. Table A-5 lists the data from the field study (as discussed above) as well as the respective results from the Trace Wizard analysis, and compares field measured values to Trace Wizard assigned values for appliance identification, start and end times, and water volume.

Note that Figures A-2 through A-7 represent 10-second average water flow rates for the approximately 5-day period. The water uses appear as spikes because of the compressed time scale. Figures A-8 through A-22 present the water flow rates for specific events at a much larger time resolution, and give examples of the shapes of a variety of the water-uses.

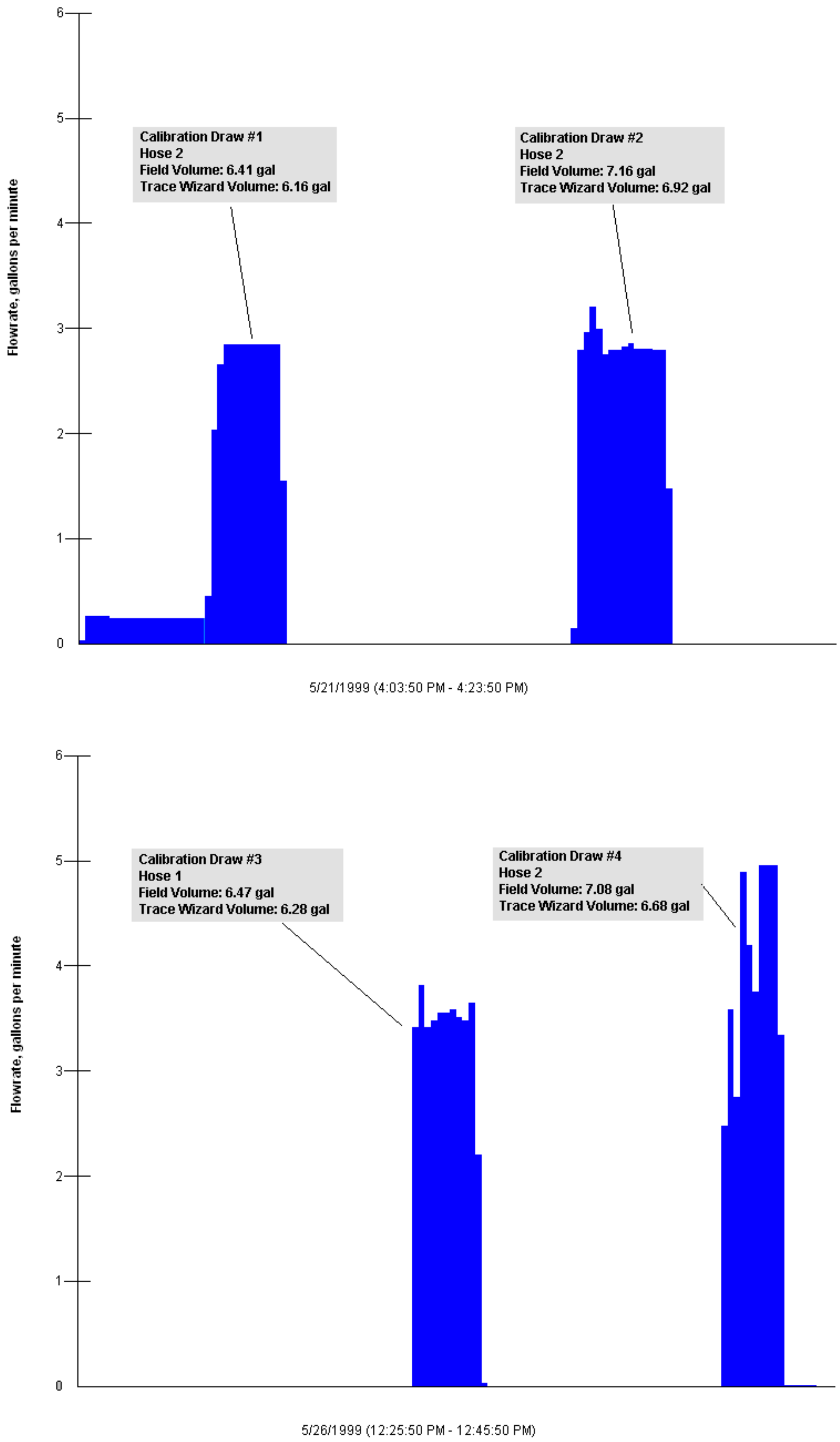


Figure A-8. Comparison of Field Data versus Data Logger Data for the Calibration Water Draws.

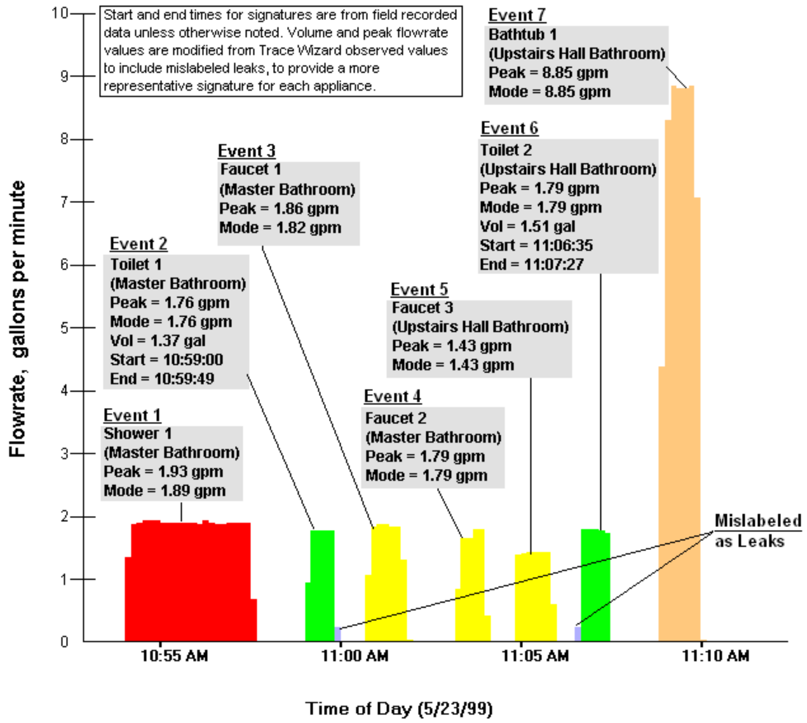


Figure A-9. Data Logger Water-Use Signatures: Shower 1, Toilet 1, Toilet 2, Faucet 1, Faucet 2, Faucet 3, and Bathtub 1.

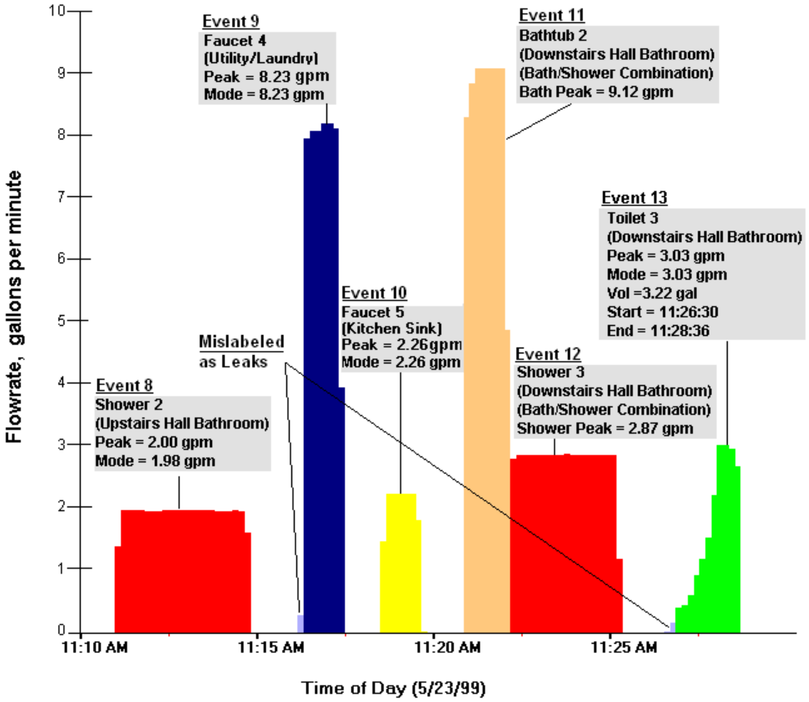


Figure A-10. Data Logger Water-Use Signatures: Shower 2, Shower 3, Toilet 3, Faucet 4, Faucet 5, and Bathtub 2.

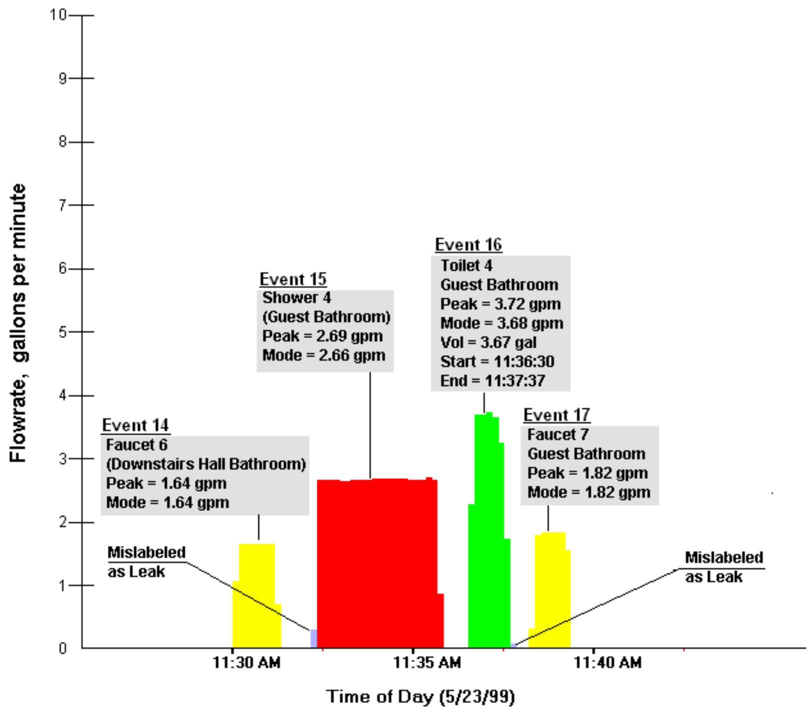


Figure A-11. Data Logger Water-Use Signatures: Shower 4, Toilet 4, Faucet 6, and Faucet 7.

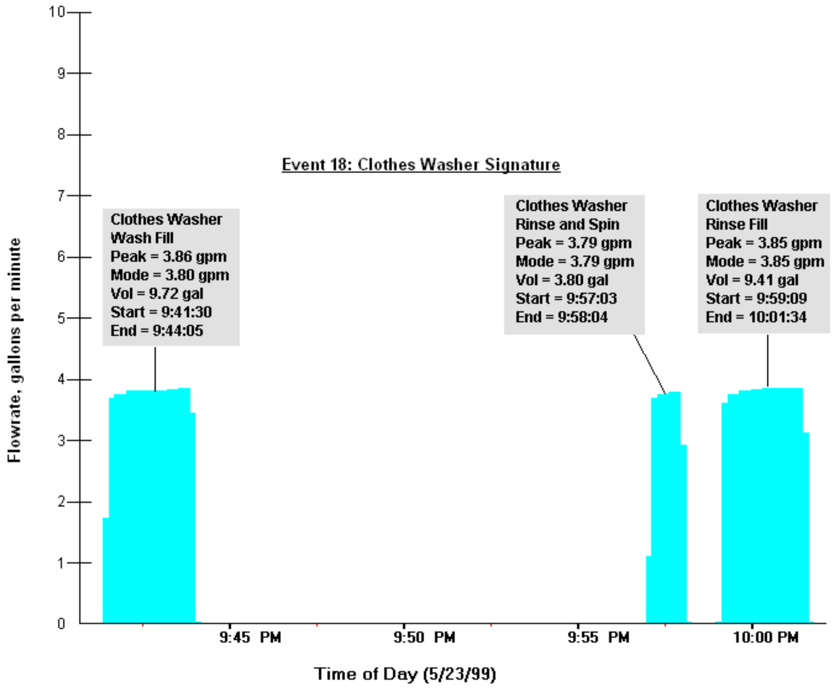


Figure A-12. Data Logger Water-Use Signatures: Clothes Washer.

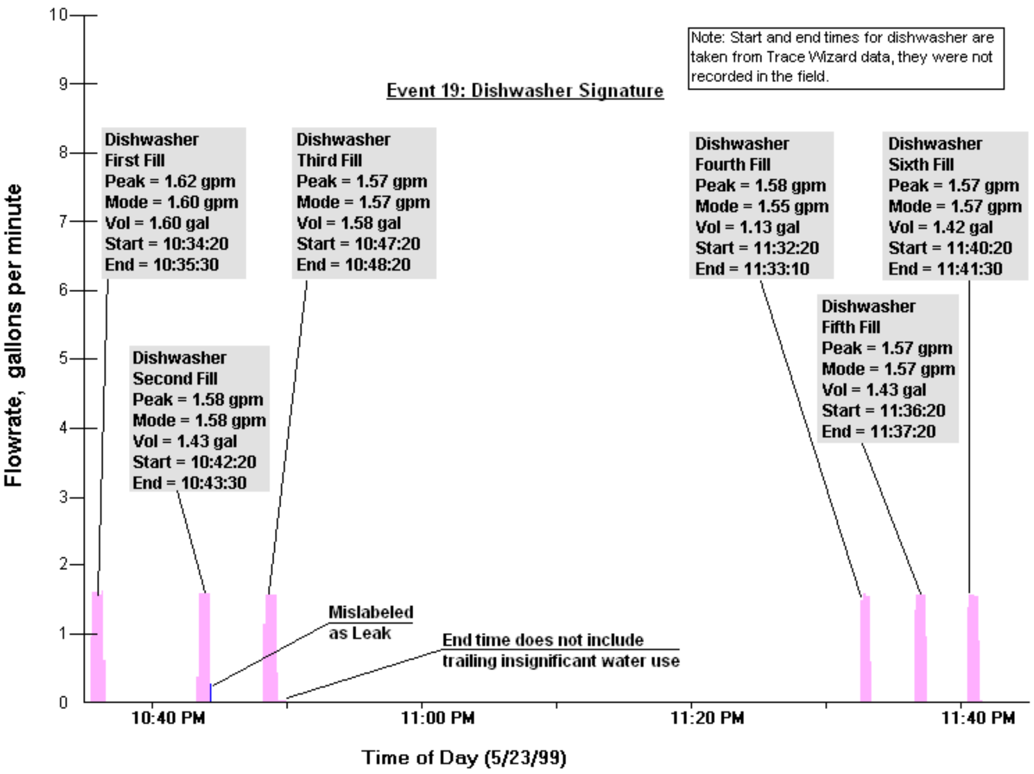


Figure A-13. Data Logger Water-Use Signatures: Dishwasher.

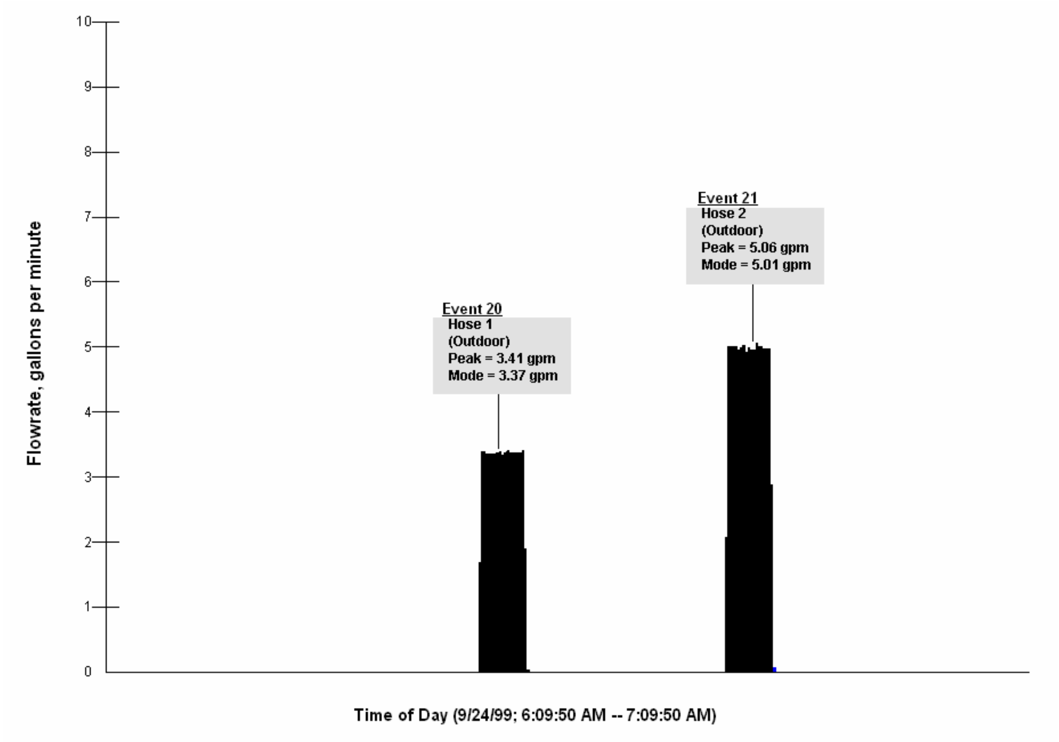


Figure A-14. Data Logger Water-Use Signatures: Outdoor Hoses.

Table A-5. Comparison of Actual Water Uses to Water Uses Identified by Trace Wizard

Event No.	Type of Use	Date	Type of Match	Actual Device	Actual Start Time	Actual End Time	Actual Volume (gallons)	Trace[A] Wizard Assignment	Trace Wizard Observed Start Time	Trace Wizard Observed End Time	Trace Wizard Observed Volume (gallons)	Trace Wizard Observed Peak Flow (gpm)	Trace Wizard Observed Mode (gpm)
1	Signature	5/23/99	NA	Shower 1	10:54:00	10:57:30	Unknown	Shower 1	10:54:00	10:57:40	6.64	1.93	1.89
2	Signature	5/23/99	NA	Toilet 1	10:59:00	10:59:49	Unknown	Toilet 1	10:59:00	10:59:50	1.33	1.76	1.76
3	Signature	5/23/99	NA	Faucet 1	11:00:41	11:01:44	Unknown	Faucet 1	11:00:40	11:02:00	1.93	1.86	1.82
4	Signature	5/23/99	NA	Faucet 2	11:03:12	11:03:59	Unknown	Faucet 1	11:03:10	11:04:10	1.35	1.79	1.79
5	Signature	5/23/99	NA	Faucet 3	11:04:47	11:05:51	Unknown	Faucet 1	11:04:50	11:06:00	1.52	1.43	1.43
6	Signature	5/23/99	NA	Toilet 2	11:06:35	11:07:27	Unknown	Toilet 1	11:06:40	11:07:30	1.47	1.79	1.79
7	Signature	5/23/99	NA	Bathtub 1	11:08:50	11:09:55	Unknown	Bathtub 1	11:08:50	11:10:10	9.18	8.85	8.85
8	Signature	5/23/99	NA	Shower 2	11:11:00	11:14:45	Unknown	Shower 1	11:11:00	11:14:50	7.43	2	1.98
9	Signature	5/23/99	NA	Faucet 4	11:16:15	11:17:22	Unknown	Faucet 4	11:16:20	11:17:30	8.80	8.23	8.23
10	Signature	5/23/99	NA	Faucet 5	11:18:30	11:19:35	Unknown	Faucet 1	11:18:30	11:19:50	2.43	2.26	2.26
11	Signature	5/23/99	NA	Bathtub 2	11:20:45	11:21:59	Unknown	Shower 1	11:20:50	11:25:20	20.09	9.12	2.87
12	Signature	5/23/99	NA	Shower 3	11:21:59	11:25:11	Unknown					(2.87)[B]	
13	Signature	5/23/99	NA	Toilet 3	11:26:30	11:28:36	Unknown	Toilet 3	11:26:50	11:28:40	3.19	3.03	3.03
14	Signature	5/23/99	NA	Faucet 6	11:30:00	11:31:11	Unknown	Faucet 1	11:30:00	11:31:20	1.93	1.64	1.64
15	Signature	5/23/99	NA	Shower 4	11:32:15	11:35:38	Unknown	Shower 1	11:32:20	11:35:50	9.02	2.69	2.66
16	Signature	5/23/99	NA	Toilet 4	11:36:30	11:37:37	Unknown	Toilet 4	11:36:30	11:37:40	3.66	3.72	3.68
17	Signature	5/23/99	NA	Faucet 7	11:38:15	11:39:15	Unknown	Faucet 1	11:38:10	11:39:20	1.82	1.82	1.82
18	Signature	5/23/99	NA	Clothes Washer									
				1st fill	21:41:30	21:44:05	Unknown	Clothes Washer 1	21:41:30	21:44:20	9.72	3.86	3.8
				2nd fill	21:57:03	21:58:04	Unknown	Clothes Washer 2	21:57:00	21:58:20	3.80	3.79	3.79
				3rd fill	21:59:09	22:01:34	Unknown	Clothes Washer 1	21:59:00	22:01:50	9.41	3.85	3.85
19	Signature	5/23/99	NA	Dishwasher[D]									
				1st fill	22:33:00	Unknown	Unknown	Dishwasher 1	22:34:20	22:35:30	1.60	1.62	1.60
				2nd fill	Unknown	Unknown	Unknown	Dishwasher 1[C]	22:42:20	22:43:20	1.38	1.58	1.58
				3rd fill	Unknown	Unknown	Unknown	Dishwasher 1[C]	22:47:20	22:49:20	1.58	1.57	1.57
				4th fill	Unknown	Unknown	Unknown	Dishwasher 1[C]	23:32:20	23:33:10	1.13	1.58	1.55
				5th fill	Unknown	Unknown	Unknown	Dishwasher 1[C]	23:36:20	23:37:20	1.43	1.57	1.57
				6th fill	Unknown	Unknown	Unknown	Dishwasher 1[C]	23:40:20	23:41:30	1.42	1.57	1.57

Table A-5. *(Continued)*

Event No.	Type of Use	Date	Type of Match	Actual Device	Actual Start Time	Actual End Time	Actual Volume (gallons)	Trace[A] Wizard Assignment	Trace Wizard Observed Start Time	Trace Wizard Observed End Time	Trace Wizard Observed Volume (gallons)	Trace Wizard Observed Peak Flow (gpm)	Trace Wizard Observed Mode (gpm)
20	Signature	5/24/99	NA	Hose 1	6:34:00	6:37:00	Unknown	Outdoor Hose	6:34:00	6:37:20	10.16	3.41	3.37
21	Signature	5/24/99	NA	Hose 2	6:50:00	6:53:00	Unknown	Outdoor Hose	6:50:00	6:53:10	14.96	5.06	5.01
22	Single	5/24/99	No	Shower 4	14:49:15	14:51:33	6.25	Unknown	14:49:20	14:51:40	6.11	2.67	2.67
23	Single	5/24/99	Category	Faucet 6	15:04:30	15:04:55	0.69	Faucet 1	15:04:30	15:05:00	0.65	1.65	1.65
24	Single	5/24/99	Exact	Toilet 3	15:11:20	15:13:23	Unknown	Toilet 3	15:11:30	15:13:40	3.27	3.06	3.06
25	Single	5/24/99	Exact	Faucet 1	15:21:20	15:21:55	1.09	Faucet 1	15:21:20	15:22:00	1.04	1.86	1.86
26	Single	5/24/99	Category	Toilet 2	15:25:40	15:26:31	Unknown	Toilet 1	15:25:40	15:26:50	1.50	1.79	1.79
27	Single	5/24/99	Exact	Toilet 1	15:35:40	15:36:28	Unknown	Toilet 1	15:35:40	15:37:00	1.38	1.79	1.76
28	Single	5/24/99	Exact	Shower 1	16:04:00	16:10:15	11.89	Shower 1	16:04:00	16:10:20	11.80	1.96	1.88
29	Single	5/24/99	Category	Faucet 3	16:18:45	16:19:15	0.72	Faucet 1	16:18:50	16:19:20	0.68	1.41	1.41
30	Single	5/24/99	No	Bathtub 1	16:25:30	16:26:22	7.96	Faucet 4	16:25:30	16:26:40	7.55	8.92	8.85
31	Single	5/24/99	Category	Shower 2	20:06:30	Unknown	13.98	Shower 1	20:06:30	20:13:50	13.97	2.13	2.06
32	Single	5/24/99	No	Faucet 4	20:26:45	20:27:05	2.79	Clothes Washer 1	20:26:50	20:27:20	2.67	7.99	7.99
33	Single	5/25/99	Category	Clothes Washer									
				1st fill	7:26:10	7:28:49	10.23	Clothes Washer 1	7:26:10	7:29:50	9.98	3.82	3.8
				2nd fill	7:41:24	Unknown	4.03	Clothes Washer 2	7:42:30	7:43:40	3.87	3.82	3.79
				3rd fill	7:44:27	7:47:04	9.87	Clothes Washer 1[C]	7:44:30	7:47:10	9.55	3.86	3.86
34	Single	5/25/99	Category	Faucet 5	11:07:45	11:09:03	2.92	Faucet 1	11:07:50	11:09:20	2.87	2.27	2.24
35	Single	5/25/99	Category[E]	Bathtub 2	11:18:11	11:18:27	2.47	Shower 1	11:18:20	11:23:30	14.89	5.2	2.83
36	Single	5/25/99		Shower 3	11:18:27	11:23:09	13.75						
37	Single	5/25/99	Category	Faucet 7	11:29:15	11:29:41	0.77	Faucet 1	11:29:20	11:30:00	0.75	1.76	1.76
38	Single	5/25/99	Exact	Toilet 4	11:31:00	11:32:07	Unknown	Toilet 4	11:31:10	11:32:30	3.60	3.72	3.72
39	Double	5/25/99	Partial	Shower 1	11:46:02	12:00:28	26.71	Shower 1	11:46:10	12:00:40	29.61	3.56	1.86
40	Double	5/25/99	No	Toilet 1	11:46:20	11:47:10	Unknown	---	---	---	---	---	---
41	Double	5/25/99	Exact	Faucet 1	11:47:54	11:48:20	0.80	Faucet 1	11:48:00	11:48:30	0.73	1.68	1.68
42	Double	5/25/99	No	Bathtub 1	11:48:45	11:49:04	2.81	Faucet 4	11:48:50	11:49:20	2.59	8.23	8.23
43	Double	5/25/99	No	Shower 2	11:49:35	11:52:10	5.52	Faucet 1	11:49:40	11:52:20	5.24	2.06	2.03
44	Double	5/25/99	No	Toilet 2	11:52:45	11:53:37	Unknown	---	---	---	---	---	---
45	Double	5/25/99	Exact	Faucet 4	11:55:15	11:55:35	2.72	Faucet 4	11:55:20	11:55:50	2.49	7.54	7.54

Table A-5. *(Continued)*

Event No.	Type of Use	Date	Type of Match	Actual Device	Actual Start Time	Actual End Time	Actual Volume (gallons)	Trace[A] Wizard Assignment	Trace Wizard Observed Start Time	Trace Wizard Observed End Time	Trace Wizard Observed Volume (gallons)	Trace Wizard Observed Peak Flow (gpm)	Trace Wizard Observed Mode (gpm)
46	Double	5/25/99	Partial	Clothes Washer									
				1st fill	11:56:15	Unknown	10.08	Clothes Washer 1	11:56:20	11:59:10	9.53	3.60	3.60
				2nd fill	12:11:38	Unknown	Unknown	Clothes Washer 2	12:11:40	12:12:50	3.91	3.82	3.82
				3rd fill	Unknown	12:16:10	9.82	Clothes Washer 1[C]	12:13:40	12:16:20	10.68	5.3	5.27
47	Double	5/25/99	No	Toilet 1	12:14:45	12:15:38	Unknown						
48	Triple	5/25/99	No	Clothes Washer									
				1st fill	13:04:16	13:06:51	9.99	---	---	---	---	---	---
				2nd fill	13:19:28	13:20:33	3.65	---	---	---	---	---	---
				3rd fill	13:21:28	13:23:58	9.78	Unknown	13:21:30	13:24:10	9.44	3.92	3.90
49	Triple	5/25/99	Partial	Shower 1	13:05:00	13:19:55	27.61	Shower 1	13:04:20	13:20:40	37.06	4.13	1.86
50	Triple	5/25/99	Partial	Toilet 1	13:06:10	13:07:04	Unknown	Toilet 3	13:05:10	13:07:00	3.39	2.67	1.41
51	Double	5/25/99	Category	Toilet 2	13:07:41	13:08:33	Unknown	Toilet 1	13:07:50	13:08:40	1.39	1.69	1.66
52	Double	5/25/99	No	Faucet 1	13:09:36	13:10:02	0.80	---	---	---	---	---	---
53	Double	5/25/99	Category	Faucet 3	13:11:23	13:11:51	0.65	Faucet 1	13:11:30	13:12:00	0.61	1.34	1.34
54	Double	5/25/99	Category	Faucet 5	13:13:02	13:13:50	1.88	Faucet 1	13:13:10	13:14:00	1.76	2.20	2.17
55	Triple	5/25/99	No	Shower 3	13:15:07	13:17:19	Unknown	Unknown	13:15:10	13:17:30	6.73	4.13	2.67
56	Triple	5/25/99	No	Faucet 6	13:16:10	13:16:43	0.89						
57	Triple	5/25/99	No	Hose 1	13:18:27	13:20:00	5.19	Unknown[F]	13:18:30	13:20:30	7.17	5.9	3.21
58	Triple	5/26/99	No	Clothes Washer									
				1st fill	10:03:30	10:06:12	Unknown	Shower 1	10:03:40	10:11:50	23.98	5.03	5.03
				2nd fill	Unknown	10:21:11	Unknown	Bathtub 1	10:18:50	10:25:00	19.41	6.40	NA
				3rd fill	10:22:11	10:24:42	Unknown						
59	Triple	5/26/99	No	Dishwasher									
				1st fill	10:04:17[C]	Unknown	Unknown	Shower 1	---	---	---	---	---
				2nd fill	Unknown	Unknown	Unknown	[G]	---	---	---	---	---
				3rd fill	Unknown	Unknown	Unknown	[H]	---	---	---	---	---

Table A-5. *(Continued)*

Event No.	Type of Use	Date	Type of Match	Actual Device	Actual Start Time	Actual End Time	Actual Volume (gallons)	Trace[A] Wizard Assignment	Trace Wizard Observed Start Time	Trace Wizard Observed End Time	Trace Wizard Observed Volume (gallons)	Trace Wizard Observed Peak Flow (gpm)	Trace Wizard Observed Mode (gpm)
60	Triple	5/26/99	Partial	Shower 1	10:05:10	10:11:35	Unknown	See Footnote[I]					
61	Double	5/26/99	No	Toilet 1	10:06:46	10:07:35	Unknown						
62	Double	5/26/99	No	Faucet 1	10:08:03	10:08:34	Unknown						
63	Double	5/26/99	No	Faucet 3	10:09:02	10:09:41	Unknown						
64	Double	5/26/99	No	Toilet 2	10:10:15	10:11:17	Unknown						
65	Double	5/26/99	No	Faucet 5	10:12:30	10:13:06	Unknown	Toilet	10:12:30	10:13:30	2.75	3.75	3.75
66	Single	5/26/99	Exact	Toilet 4	10:14:00	10:15:09	Unknown	Toilet 4	10:14:10	10:15:20	3.84	3.7	3.7
67	Single	5/26/99	Category	Faucet 7	10:16:11	10:16:33	Unknown	Faucet 1	10:16:20	10:17:00	0.66	1.76	1.76
68	Double	5/26/99	No	Faucet 6	10:17:27	10:17:39	Unknown	Dishwasher[H]	---	---	---	---	---
69	Double	5/26/99	No	Toilet 3	10:18:25	10:20:30	Unknown	Bathtub[J]					
70	Double	5/26/99	No	Toilet 3	10:21:15	10:23:02	Unknown	Bathtub[J]					

A. Trace Wizard did not label the appliances with the same numbering system as was done in the field. Therefore, for consistency purposes, the Trace Wizard labels were adjusted to match the Field Study labels. Using the unique appliance signatures, appliance identifications were matched up and the following changes were made: Trace Wizard "Utility Faucet 1" was relabeled as Faucet 4, Trace Wizard "Toilet 2" was relabeled as Toilet 3; Trace Wizard "Toilet 3" was relabeled as Toilet 4. These changes were maintained throughout our analysis.

B. Trace Wizard failed to separate the bath and shower events. The volume 9.12 gal. is the peak flow of the bath, and 2.87 gal. is the peak flow of the shower identified manually from the data.

C. Although this part of the event is labeled as the correct appliance, it is really a misclassification as it is classified as a new separate event not part of a series of water draws. This misclassification will affect the apparent frequency of clothes washer or dishwasher events reported by Trace Wizard.

D. Actual Start Time indicates the time the appliance was started, not the start time of the water fill.

E. Although events #35 and #36 are distinct events, they make up a bathtub/shower combination event where the bathtub portion simulates the user adjusting flow and temperature to the desired level followed by the showering event. Trace Wizard classified the entire event as a shower, which is consistent with the intended use and therefore was classified as a category match.

F. Trace Wizard assigned parts of actual hose and clothes washer water uses into "Unknown" and part into concurrent shower use.

G. Trace Wizard combined the second dishwasher water draw of event #59 and Faucet 5 (Actual start 10:12:30) and designated them as a toilet use.

H. Trace Wizard combined the third dishwasher water draw of event #59 and Faucet 6 (Actual start 10:17:27) and designated them as dishwasher use. If Trace Wizard failed to correctly assign each of the water draws of the dishwasher event, the entire event is labeled as a "No Match."

I. Trace Wizard assigned the time period covering these events to the shower use (TW start time 10:03:40) and incorrect faucet, toilet, and dishwasher uses.

J. Trace Wizard combined these actual toilet uses with actual clothes washer fills and labeled them a bathtub use.

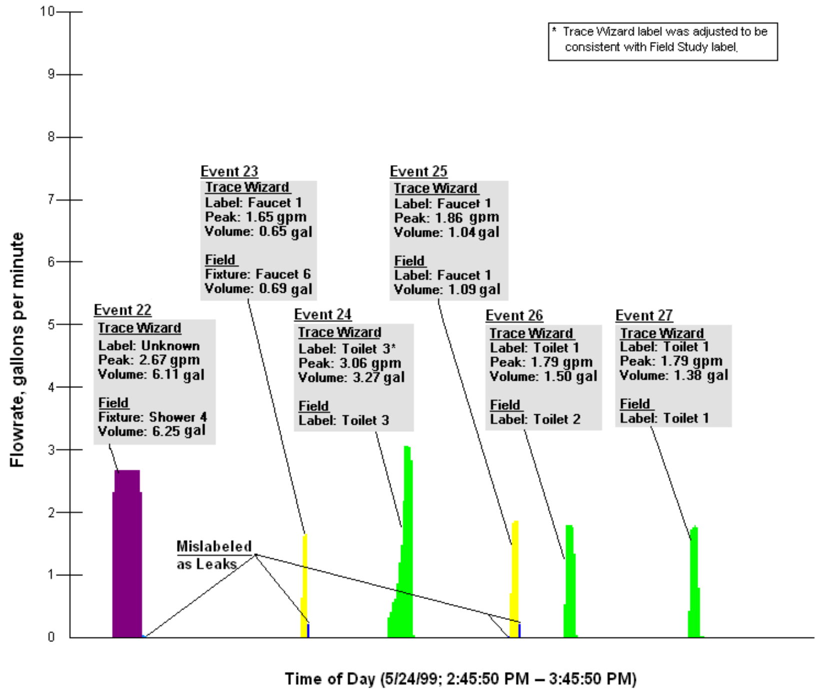


Figure A-15. Comparison of Field Data and Data Logger Record for Single Water-Use Events: May 24, 2:46 PM – 3:46 PM.

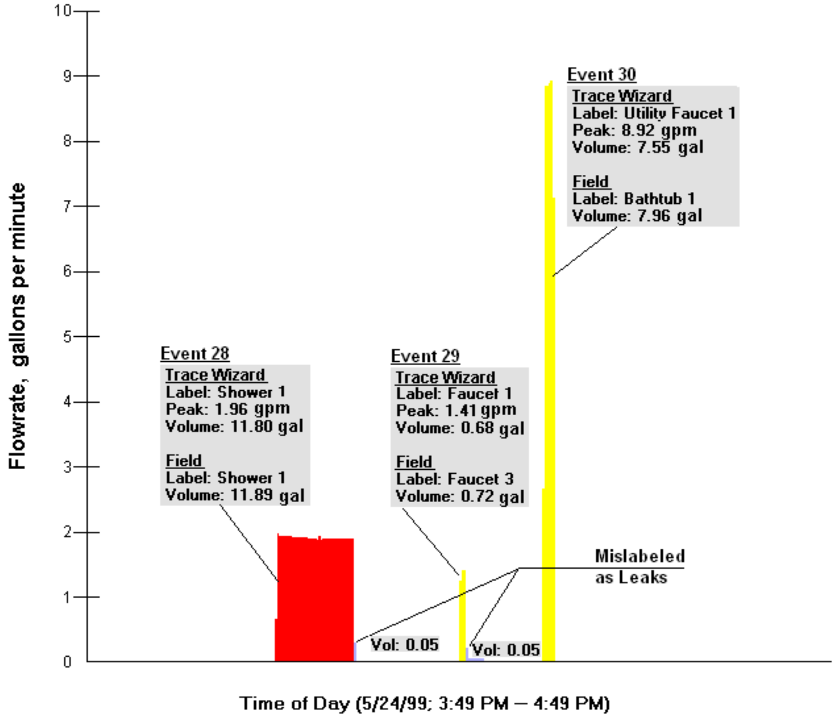


Figure A-16. Comparison of Field Data and Data Logger Record for Single Water-Use Events: May 24, 3:39 PM – 4:49 PM.

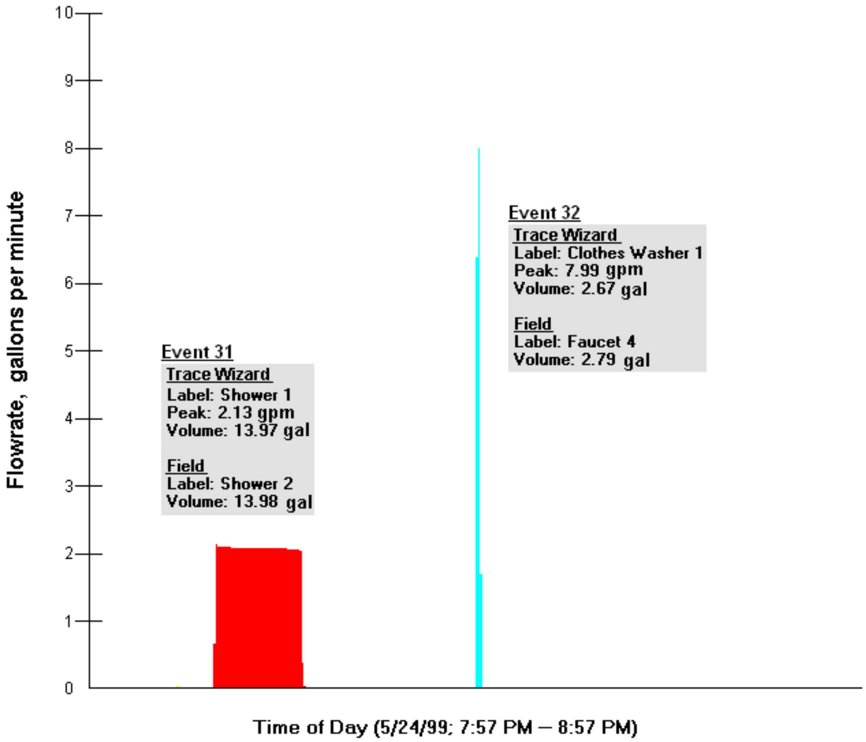


Figure A-17. Comparison of Field Data and Data Logger Record for Single Water-Use Events: May 24, 7:57 PM – 8:57 PM.

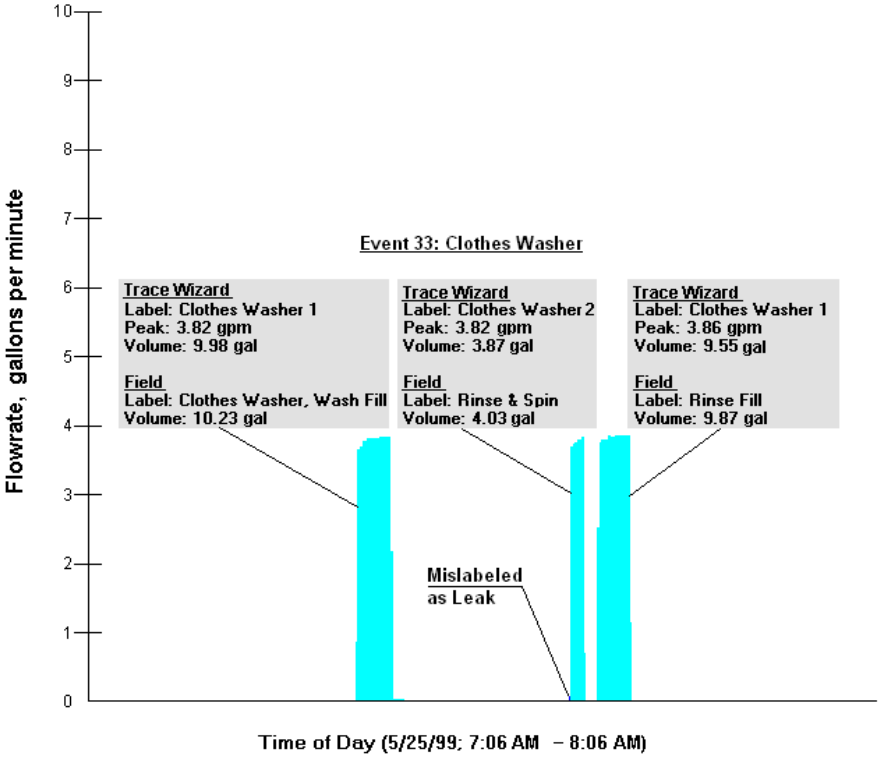


Figure A-18. Comparison of Field Data and Data Logger Record for Single Water-Use Events: May 25, 7:06 AM – 8:06 AM.

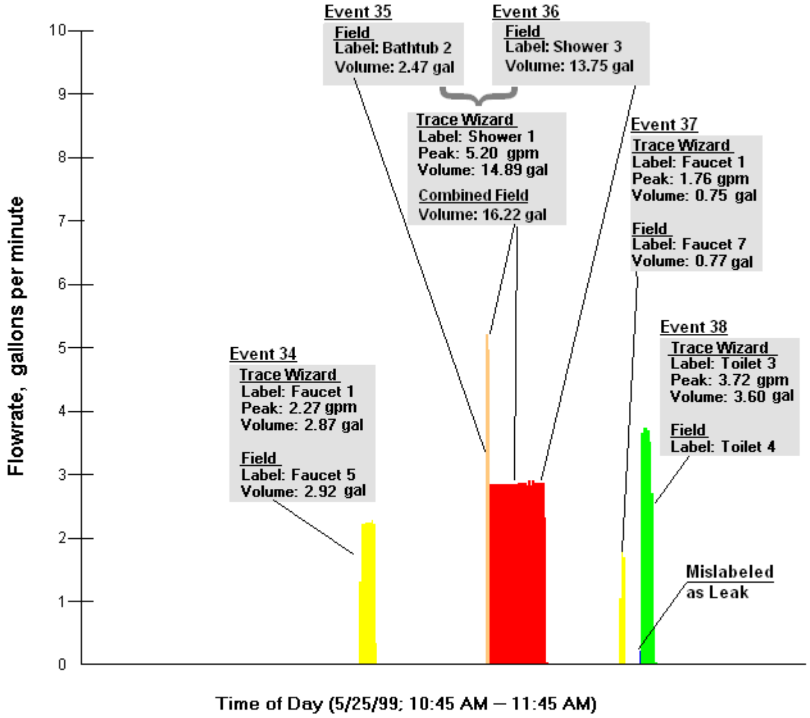
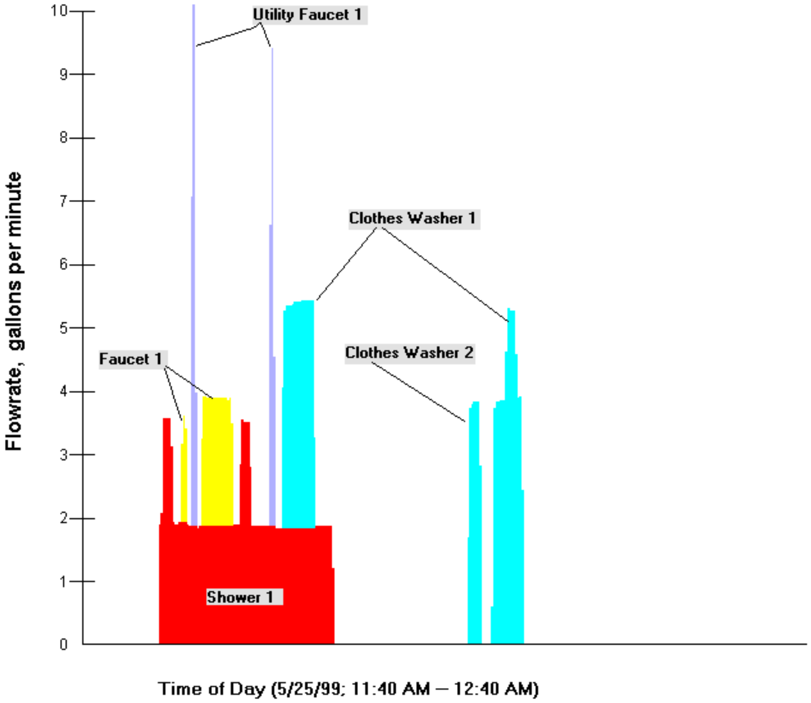
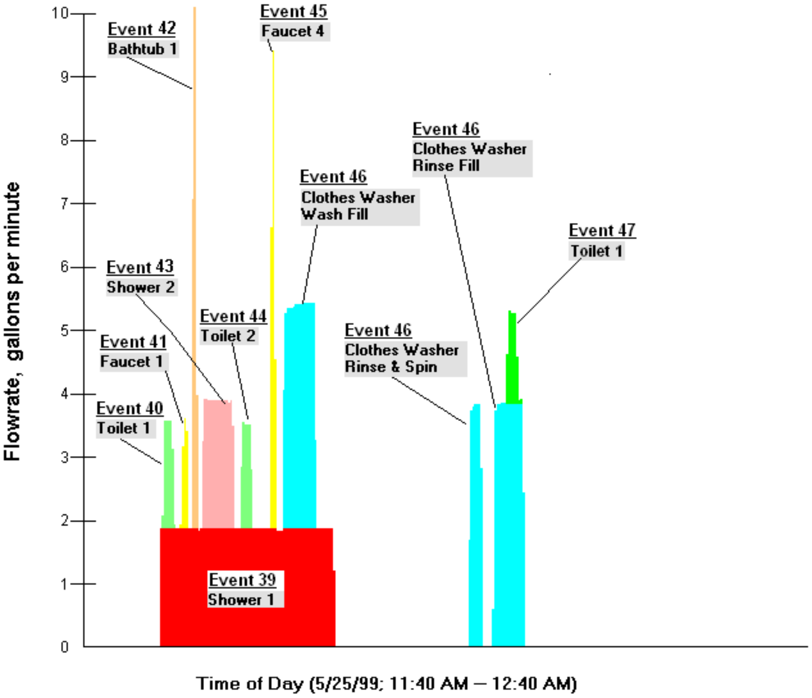


Figure A-19. Comparison of Field Data and Data Logger Record for Single Water-Use Events: May 25, 10:45 AM – 11:45 AM.

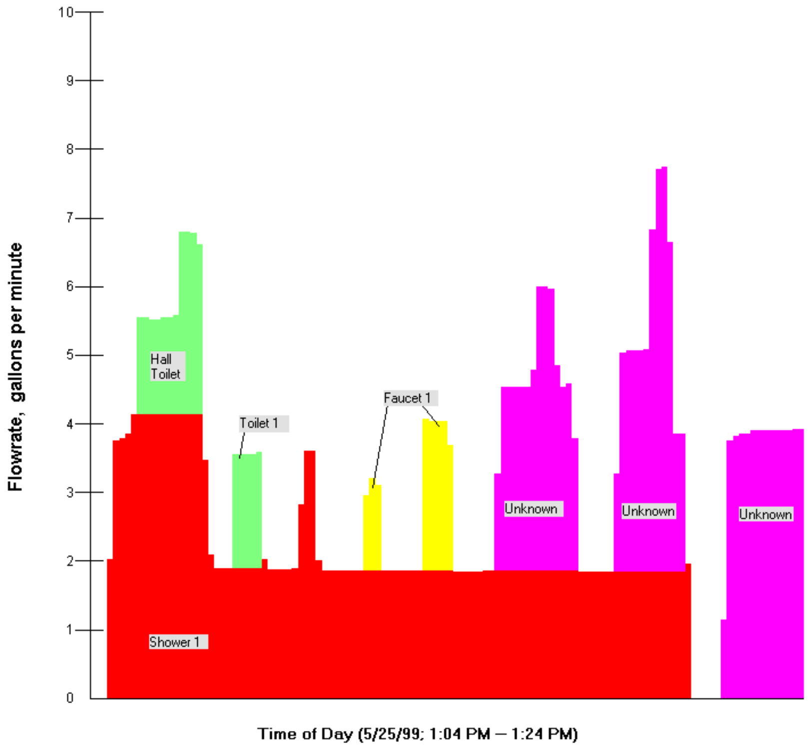


A: Trace Wizard Defined Water-Use Events

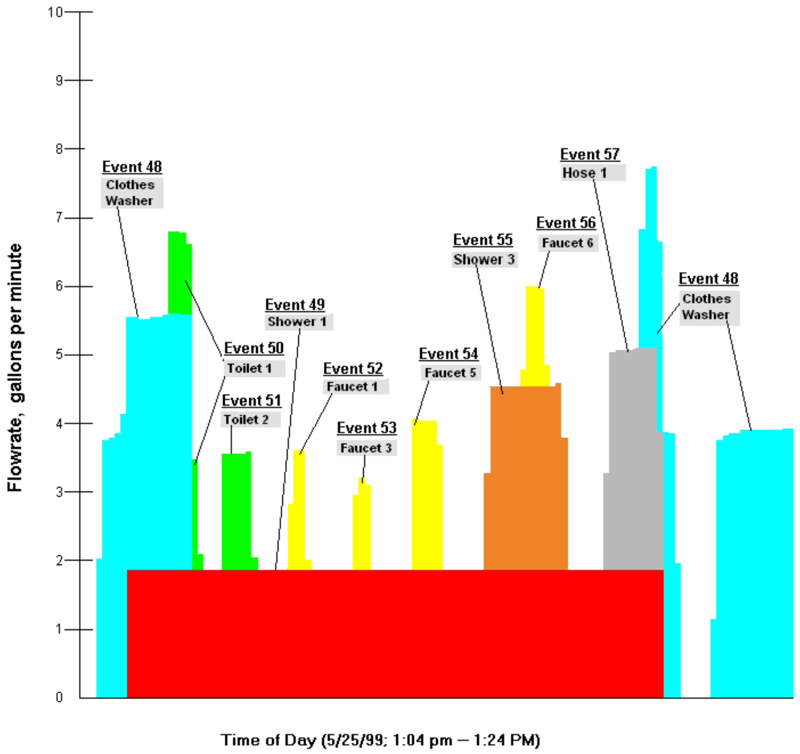


B: Field Data Record of Water-Use Events

Figure A-20. Comparison of Trace Wizard Defined Water Uses and Field Data for Double Water-Use Events: May 25, 11:40 AM – 12:40 PM.

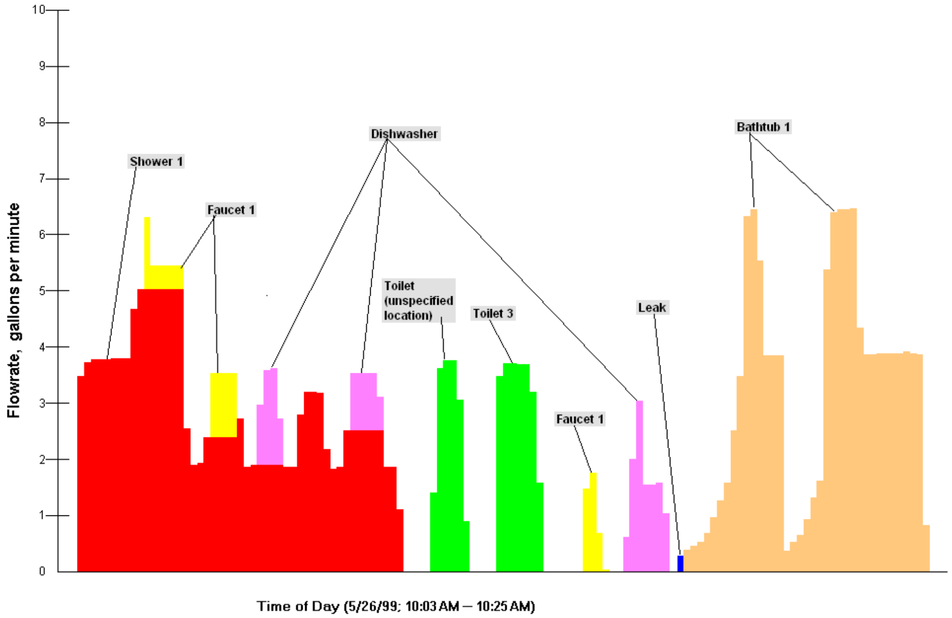


A: Trace Wizard Defined Water-Use Events

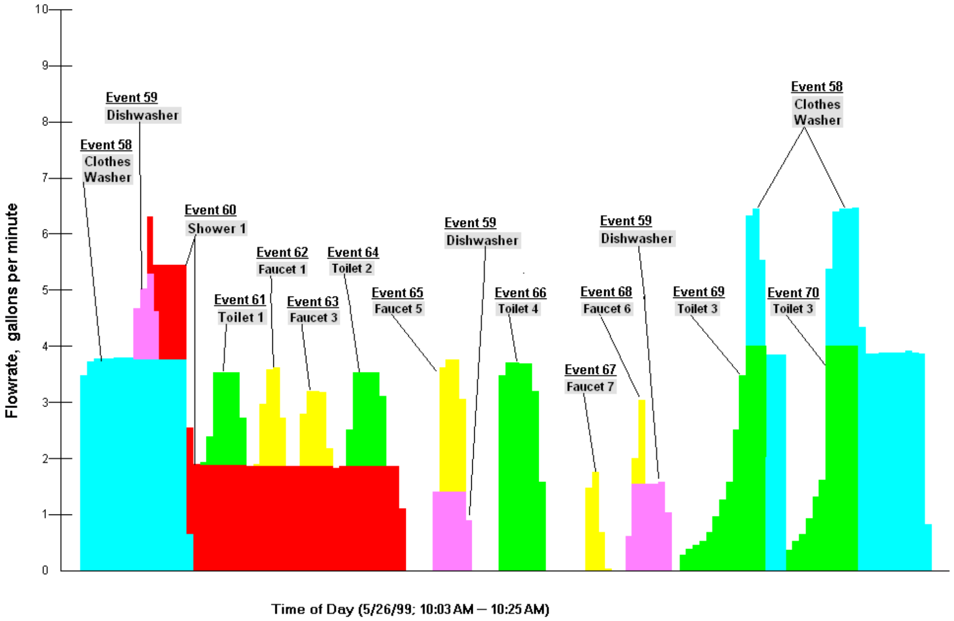


B: Field Data Consistent Record of Water-Use Events

Figure A-21. Comparison of Field Data and Data Logger Record for Triple Water-Use Events: May 25, 1:04 PM – 1:24 PM.



A: Trace Wizard Defined Water-Use Events



B: Field Data Consistent Record of Water-Use Events

Figure A-22. Comparison of Field Data and Data Logger Record for Triple Water-Use Events: May 26, 10:03 AM – 10:25 AM.

A-6 Analysis

This analysis evaluates the ability of Trace Wizard to correctly assign water uses to appropriate appliances for two specific purposes: (1) achieving a clearer understanding of the data that are recorded in REUWS for the purposes of estimating household water use as a function of appliance and demographic variables, and (2) understanding the value of using the data logger to assist in identifying water-use behavior during exposure studies.

A-6.1 Analysis of Appliance Assignment

To achieve the above objectives, this analysis compares the Trace Wizard assigned water-use parameters with the actual water-use activities that were conducted during the field study. To make this comparison, each field water use is assigned one of four classifications as follows:

Exact Match:	An event is assigned an "Exact Match" classification if Trace Wizard correctly identified water-use parameters reasonably similar to the values recorded in the field for the given appliance use.
Category Match:	An event is assigned a "Category Match" classification if Trace Wizard correctly identified the type of water use (e.g. toilet, faucet, shower, etc.), but did not correctly identify the exact appliance (e.g. toilet 1 specified when water use was toilet 2). For an event to be classified as a Category Match, Trace Wizard must also identify water-use parameters reasonably similar to the values recorded in the field for the given appliance use.
Partial Match:	An event is assigned a "Partial Match" classification when part of the water use is assigned to either the correct appliance or the correct appliance type, but either a portion of the water use is assigned to another appliance or a portion of another appliance's water use is assigned to this event.
No Match:	An event is assigned a "No Match" classification when it does not fall into any of the above categories.

The water-use parameters assigned by Trace Wizard were judged to be reasonably similar if the total duration, start and end times were all within 30 seconds of the field values, and where measured, if the volume was within 5% of the measured volume.

The "Category Match" classification is used in our analysis to assess the reliability of the REUWS data. A population based water-use behavior study, such as REUWS, requires knowledge of types of appliances being used and their water-use parameters, but knowledge of the exact appliance is irrelevant. The "Exact Match" classification is used in our analysis to assess how reliable Trace Wizard is in making an "exact" assignment to a given water-use appliance for the purposes of an exposure study. An exposure study requires knowledge of the exact water appliance, as its proximity to the person affects his or her exposure. Therefore, water uses assigned to "Partial Match" and "No Match" are considered to be misclassified.

A-6.1.1 Calibration Draws

The calibration draws are shown in Figure A-8. Three of the four calibration draws resulted in a ratio between 1.03 and 1.04 between the field measure volume and the meter measured volume. The forth had a ratio of approximately 1.06. These calibration draws were used by Trace Wizard to estimate actual volumes throughout the study by adjusting the meter readings by this ratio.

A-6.1.2 Results from Appliance Comparison

The water uses executed as a part of this study are shown in Figures A-9 through A-22 and in Table A-5. In the figures, the actual field uses are compared to the Trace Wizard assignment. These results are summarized in Table A-5, the actual water-use appliances are compared with Trace Wizard's identification of the appliance. The water uses are identified as either single water-use events (where only one appliance was used at a time), double water-use events (where two events overlapped), and triple water-use events (where three events overlapped). The "Type of Match" for each water-use event is listed, categorizing the event comparison as either "Exact", "Type", "No" match as discussed above.

The results of the appliance comparison study are presented in Table A-6. For the single water-use events, Trace Wizard identified the correct type of appliance used, with either an "Exact Match" or a "Category Match" 83% of the time. However, Trace Wizard was not very accurate in identifying the particular appliance location (e.g. shower 2 or shower 3), producing an "Exact Match" only 33% of the time. Considering a "Partial Match" and "No Match" to be misclassified, Trace Wizard misclassified 17% of the single water-use events.

Table A-6. Source Matches for Single, Double and Triple (Overlapping) Water Uses

	Total Number of Events	Exact Matches	Category Matches	Partial Match	No Match
Single Water-use Events	18	6 (33.3%)	9 (50.0%)	0 (0%)	3 (16.7%)
Double Water-use Events	21	2 (9.5%)	3 (14.3%)	2 (9.5%)	14 (66.7%)
Triple Water-use Events	9	0	0	3 (33%)	6 (66.7%)

When water uses overlapped, Trace Wizard was much less able to assign the water use to the correct appliance. For the double water-use events, Trace Wizard correctly identified the type of appliance (Exact or Category Matches) only about one quarter of the time (24%) and the exact appliances 10% of the time. Trace Wizard misclassified 76% of the double water-use events. When three water-uses overlapped (Triple water-use events), Trace Wizard displayed much more difficulty in isolating the water-use events and identifying the type of appliance. It misclassified 100% of the triple water-use events.

A-6.1.3 Comparison of Appliance Identification

For discussion, we will examine Figures A-21A and A-21B more closely. Figure A-21A displays the graphical presentation produced by the Trace Wizard software of the water-use events for 5/25/99 from 1:04 PM to 1:24 PM. Figure A-21B is an adjusted drawing for the same time interval, with the events corrected to match the actual events that occurred in the field study.

During this time period multiple events occurred simultaneously. Clearly Trace Wizard had difficulty disaggregating the individual events. In many cases, Trace Wizard combined and mislabeled the various water-use events.

In this graph, it is apparent that the software incorrectly assessed the shower and the Hall Toilet events. The shower signatures (see Table A-5) indicate that the peak water flows for the showers range from 1.93 gpm (Shower 1) to 2.69 gpm (Shower 4), yet in Figure A-21A, it is shown that Trace Wizard assigned an event with a peak flow of over 4 gpm to the Shower. Furthermore, the event that Trace Wizard assigned to "Toilet 3", clearly does not match the signature profile of a toilet.

The first event during this time period is actually the first clothes washer water draw. Once this event signature is properly identified and isolated, it becomes clear that the shower is a long rectangular event, and the turret on the top of the clothes washer event displays the Toilet. The Trace Wizard "Unknowns" are actually combinations of the Shower 1, with simultaneous Shower 3 and Faucet 6, and the second unknown is actually the Shower 1 with a hose use and the second clothes washer water draw. The third unknown is the third clothes washer water draw alone. This graph displays the complexity and difficulty in the task of water-use differentiation.

A-6.1.4 Determination of Device Locations Using a Simple Algorithm

Trace Wizard defined all showers and faucets as Shower 1 and Faucet 1, respectively, because the program was unable to discern between the various locations (e.g. Showers 1, 2, 3, and 4). As an exercise, we tested a simple algorithm to see if it would help in determining the exact appliance used during single water-use events. Then the mode of event was compared to the signature modes of all the events. Then the use was assigned to the device whose signature mode was equal to or greater than the current (event in question) mode with a 3% latitude. In other words, the use was assigned to the device with a signature mode that is greater to or equal to 0.97 multiplied by the mode of the event in question.

The results from this exercise are displayed in Table A-7. This table includes the 22 events that were successfully isolated by Trace Wizard (with approximate matches of start and end times), not including the signature events, which were used as references. From the Trace Wizard database, there were 8 correct "exact" matches out of the 22 events. Using this algorithm, the "exact" matches increased to 17 out of 22. (This does not include the cases where two or more devices were equally viable). This is an increase in accuracy from 36% to 77%. This exercise is meant to demonstrate that the algorithms employed by Trace Wizard could be dramatically improved.

A-6.2 Start and End Time Comparisons

The water-use start and end times for each event recorded by the field personnel were compared to the start and end times recorded by Trace Wizard to assess Trace Wizard's performance in determining actual start and end times. This comparison involved only the data for the single water-use events (including signature events) occurring on 5/23/99, 5/24/99 and until 11:32:30 AM on 5/25/99. These events are exhibited in Table A-8. For this analysis, each clothes washer fill is compared separately, since each fill (wash and rinses) was timed in the field as well as by Trace Wizard. The single water uses were chosen for this analysis because these events were clearly isolated, whereas when events overlapped, many times events were not disaggregated properly. Note that in the two cases where the water draw was immediately switched from the bathtub to the shower (events 11 & 12, and events 35 & 36), Trace Wizard combined the bath/shower into one event. For this analysis of start and end times, events 11 and 12 are analyzed as a single event, as are events 35 and 36.

The Meter-Master recorded water flows at 10-second intervals. Therefore, a 10-second difference between field data and Trace Wizard data is considered a match.

Out of 40 water draws, the start times recorded in the field and those recorded by Trace Wizard differed by 10 seconds or less in all but three of the events. In other words, 93% of the events had actual starting times within 10 seconds of the Trace Wizard record. Out of the three differing start times, one differed by approximately 20 seconds, and the other two (dishwasher and clothes washer 2nd water draw) were a little over one minute in difference and probably attributable to the field personnel not being able to tell exactly when the water began to flow. Overall, Trace Wizard did an excellent job in accurately capturing the start times of the events.

The end time data between the field records and the Trace Wizard records also matched relatively well, though not as well as the start times. There were 18 events out of 37 where the end times differed by 10 seconds or less. Of the remaining, only 4 events differed by greater than 20 seconds. Therefore, 49% of the events had ending times within 10 seconds of the Trace Wizard record. And, 89% of the events had ending times within 20 seconds of the Trace Wizard record.

Table A-7. Determination of Water-Using Device Through Algorithm

	First Occurrence (Signatures)						Second Occurrence							Third Occurrence						
Actual Device	Event No.	Date	Actual Start Time	Peak Flow	Mode	Trace Wizard Device[A]	Event No.	Date	Actual Start Time	Peak Flow	Mode	Trace Wizard Device[A]	Device[B] selected with Algorithm	Event No.	Date	Actual Start Time	Peak Flow	Mode	Trace Wizard Device[A]	Device[B] selected with Algorithm
Shower 1	1	5/23/99	10:54:00	1.93	1.89	Shower 1	28	5/24/99	16:04:00	1.96	1.88	Shower 1	Shower 1	39	5/25/99	11:46:02	3.56	1.86	Shower 1	Shower 1
Shower 2	8	5/23/99	11:11:00	2	1.98	Shower 1	31	5/24/99	20:06:30	2.13	2.06	Shower 1	Shower 2	43	5/25/99	11:49:35	2.06	2.03	Faucet 1	Shower 2
Shower 3	12	5/23/99	11:21:59	9.12	2.87	Shower 1	36	5/25/99	11:18:27	5.2	2.83	Shower 1	Shower 3	[C]						
Shower 4	15	5/23/99	11:32:15	2.69	2.66	Shower 1	22	5/24/99	14:49:15	2.67	2.67	Unknown	Shower 4							
Faucet 1	3	5/23/99	11:00:41	1.86	1.82	Faucet 1	25	5/24/99	15:21:20	1.86	1.86	Faucet 1	Faucet 1 or Faucet 7	41	5/25/99	11:47:54	1.68	1.68	Faucet 1	Faucet 2 or Faucet 6
Faucet 2	4	5/23/99	11:03:12	1.79	1.79	Faucet 1														
Faucet 3	5	5/23/99	11:04:47	1.43	1.43	Faucet 1	29	5/24/99	16:18:45	1.41	1.41	Faucet 1	Faucet 3	53	5/25/99	13:11:23	1.34	1.34	Faucet 1	Faucet 3
Faucet 4	9	5/23/99	11:16:15	8.23	8.23	Faucet 4	32	5/24/99	20:26:45	7.99	7.99	Clothes Washer 1	Faucet 4							
Faucet 5	10	5/23/99	11:18:30	2.26	2.26	Faucet 1	34	5/25/99	11:07:45	2.27	2.24	Faucet 1	Faucet 5	54	5/25/99	13:13:02	2.2	2.17	Faucet 1	Faucet 5
Faucet 6	14	5/23/99	11:30:00	1.64	1.64	Faucet 1	23	5/24/99	15:04:30	1.65	1.65	Faucet 1	Faucet 6							
Faucet 7	17	5/23/99	11:38:15	1.82	1.82	Faucet 1	37	5/25/99	11:29:15	1.76	1.76	Faucet 1	Faucet 2	67	5/26/99	10:16:11	1.76	1.76	Faucet 1	Faucet 2 or Faucet 6
Toilet 1	2	5/23/99	10:59:00	1.76	1.76	Toilet 1	27	5/24/99	15:35:40	1.79	1.76	Toilet 1	Toilet 1							
Toilet 2	6	5/23/99	11:06:35	1.79	1.79	Toilet 1	26	5/24/99	15:25:40	1.79	1.79	Toilet 1	Toilet 2	51	5/25/99	13:07:41	1.69	1.66	Toilet 1	Toilet 1 or Toilet 2
Toilet 3	13	5/23/99	11:26:30	3.03	3.03	Toilet 3	24	5/24/99	15:11:20	3.06	3.06	Toilet 3	Toilet 3							
Toilet 4	16	5/23/99	11:36:30	3.72	3.68	Toilet 4	38	5/25/99	11:31:00	3.72	3.72	Toilet 4	Toilet 4	66	5/26/99	10:14:00	3.7	3.7	Toilet 4	Toilet 4

A. Trace Wizard did not label the appliances with the same numbering system as was done in the field. Therefore, for consistency purposes, the Trace Wizard labels were adjusted to match the Field Study labels. Using the unique appliance signatures, appliance identifications were matched up and the following changes were made: Trace Wizard “Utility Faucet 1” was relabeled as Faucet 4, Trace Wizard “Toilet 2” was relabeled as Toilet 3; Trace Wizard “Toilet 3” was relabeled as Toilet 4. These changes were maintained throughout our analysis.

B. This table presents an exercise in determining the actual water-using device used. The device is chosen using the following algorithm: Choose the device whose signature mode is equal to or greater than the current mode with a 3% latitude (signature mode is >= 0.97 * current mode).

C. The third occurrence of Shower 3, Event 55, was not disaggregated by Trace Wizard, therefore an assignment was not attempted.

Table A-8. Comparison of Start and End Times

Event No.[A]	Actual Device	Actual Start Time	Trace Wizard Observed Start Time	Actual End Time	Trace Wizard Observed End Time	Difference Between Start Times (Seconds)	Difference Between End Times (Seconds)
1	Shower 1	10:54:00	10:54:00	10:57:30	10:57:40	0	10
2	Toilet 1	10:59:00	10:59:00	10:59:49	10:59:50	0	1
3	Faucet 1	11:00:41	11:00:40	11:01:44	11:02:00	1	16
4	Faucet 2	11:03:12	11:03:10	11:03:59	11:04:10	2	11
5	Faucet 3	11:04:47	11:04:50	11:05:51	11:06:00	3	9
6	Toilet 2	11:06:35	11:06:40	11:07:27	11:07:30	5	3
7	Bathtub 1	11:08:50	11:08:50	11:09:55	11:10:10	0	15
8	Shower 2	11:11:00	11:11:00	11:14:45	11:14:50	0	5
9	Faucet 4	11:16:15	11:16:20	11:17:22	11:17:30	5	8
10	Faucet 5	11:18:30	11:18:30	11:19:35	11:19:50	0	15
11/ 12	Bathtub 2/ Shower 3	11:20:45	11:20:50	11:25:11	11:25:20	69	9
13	Toilet 3	11:26:30	11:26:50	11:28:36	11:28:40	20	4
14	Faucet 6	11:30:00	11:30:00	11:31:11	11:31:20	0	9
15	Shower 4	11:32:15	11:32:20	11:35:38	11:35:50	5	12
16	Toilet 4	11:36:30	11:36:30	11:37:37	11:37:40	0	3
17	Faucet 7	11:38:15	11:38:10	11:39:15	11:39:20	5	5
18	Clothes Washer	21:41:30	21:41:30	21:44:05	21:44:20	0	15
18	Clothes Washer	21:57:03	21:57:00	21:58:04	21:58:20	3	16
18	Clothes Washer	21:59:09	21:59:00	22:01:34	22:01:50	9	16
19	Dishwasher	22:33:00	22:34:20	Unknown	22:35:30	80	Unknown
20	Hose 1	6:34:00	6:34:00	6:37:00	6:37:20	0	20
21	Hose 2	6:50:00	6:50:00	6:53:00	6:53:10	0	10
22	Shower 4	14:49:15	14:49:20	14:51:33	14:51:40	5	7
23	Faucet 6	15:04:30	15:04:30	15:04:55	15:05:00	0	5
24	Toilet 3	15:11:20	15:11:30	15:13:20	15:13:40	10	20
25	Faucet 1	15:21:20	15:21:20	15:21:55	15:22:00	0	5
26	Toilet 2	15:25:40	15:25:40	15:26:31	15:26:50	0	19
27	Toilet 1	15:35:40	15:35:40	15:36:28	15:37:00	0	32
28	Shower 1	16:04:00	16:04:00	16:10:15	16:10:20	0	5
29	Faucet 3	16:18:45	16:18:50	16:19:15	16:19:20	5	5
30	Bathtub 1	16:25:30	16:25:30	16:26:22	16:26:40	0	18
31	Shower 2	20:06:30	20:06:30	Unknown	20:13:50	0	Unknown
32	Faucet 4	20:26:45	20:26:50	20:27:05	20:27:20	5	15
33	Clothes Washer	7:26:10	7:26:10	7:28:49	7:29:50	0	61
33	Clothes Washer	7:41:24	7:42:30	Unknown	7:43:40	66	Unknown
33	Clothes Washer	7:44:27	7:44:30	7:47:04	7:47:10	3	6
34	Faucet 5	11:07:45	11:07:50	11:09:03	11:09:20	5	17
35/ 36	Bathtub 2/ Shower 3	11:18:11	11:18:20	11:23:09	11:23:30	9	21
37	Faucet 7	11:29:15	11:29:20	11:29:41	11:30:00	5	19
38	Toilet 4	11:31:00	11:31:10	11:32:07	11:32:30	10	23

A. This analysis was conducted on only single water uses that were both recorded in the field and correctly disaggregated by Trace Wizard. Trace Wizard combined events 11 & 12 into a single event, and events 35 & 36 into a single event, therefore, they are considered single events for this analysis. This analysis does not include the single events 66 and 67.

A-6.3 Leaks

Throughout the database, Trace Wizard isolated numerous short events and labeled them as “leaks.” Table A-9 presents the Trace Wizard record of water draws during the time periods during which field monitoring occurred. This analysis includes water uses This table includes only single-water-use events that were recorded by the data logger around the time periods during which field monitoring occurred. However, please note that the volume was not measured in the field during all these events. The grayed rows indicate single events that were separated by Trace Wizard into multiple events that included one or more leaks.

Table A-9. Single Water Uses Including Leaks

Actual Field Data				Trace Wizard Data							
Event No.[A]	**Device**	**Start Time**	**End Time**	**Device[B]**	**Date**	**Start Time**	**Duration (seconds)**	**End Time**	**Peak (gpm)**	**Volume (gallons)**	**Mode (gpm)**
1	Shower 1	10:54:00	10:57:30	Shower 1	5/23/99	10:54:00	220	10:57:40	1.93	6.64	1.89
2	Toilet 1	10:59:00	10:59:49	Leak 1	5/23/99	10:57:40	80	10:59:00	0.01	0.01	0.01
				Toilet 1	5/23/99	10:59:00	50	10:59:50	1.76	1.33	1.76
				Leak 1	5/23/99	10:59:50	10	11:00:00	0.24	0.04	0.24
3	Faucet 1	11:00:41	11:01:44	Faucet 1	5/23/99	11:00:40	80	11:02:00	1.86	1.93	1.82
4	Faucet 2	11:03:12	11:03:59	Faucet 1	5/23/99	11:03:10	60	11:04:10	1.79	1.35	1.79
5	Faucet 3	11:04:47	11:05:51	Faucet 1	5/23/99	11:04:50	70	11:06:00	1.43	1.52	1.43
6	Toilet 2	11:06:35	11:07:27	Leak 1	5/23/99	11:06:30	10	11:06:40	0.24	0.04	0.24
				Toilet 1	5/23/99	11:06:40	50	11:07:30	1.79	1.47	1.79
7	Bathtub 1	11:08:50	11:09:55	Bathtub 1	5/23/99	11:08:50	80	11:10:10	8.85	9.18	8.85
8	Shower 2	11:11:00	11:14:45	Shower 1	5/23/99	11:11:00	230	11:14:50	2	7.43	1.98
9	Faucet 4	11:16:15	11:17:22	Leak 1	5/23/99	11:16:10	10	11:16:20	0.28	0.05	0.28
				Faucet 4	5/23/99	11:16:20	70	11:17:30	8.23	8.8	8.23
10	Faucet 5	11:18:30	11:19:35	Faucet 1	5/23/99	11:18:30	80	11:19:50	2.26	2.43	2.26
11	Bathtub 2	11:20:45	11:21:59	Shower 1	5/23/99	11:20:50	270	11:25:20	9.12	20.09	2.87
12	Shower 3	11:21:59	11:25:11								
13	Toilet 3	11:26:30	11:28:36	Leak 1	5/23/99	11:26:30	20	11:26:50	0.17	0.03	0.17
				Toilet 3	5/23/99	11:26:50	110	11:28:40	3.03	3.19	3.03
14	Faucet 6	11:30:00	11:31:11	Faucet 1	5/23/99	11:30:00	80	11:31:20	1.64	1.93	1.64
15	Shower 4	11:32:15	11:35:38	Leak 1	5/23/99	11:32:10	10	11:32:20	0.28	0.05	0.28
				Shower 1	5/23/99	11:32:20	210	11:35:50	2.69	9.02	2.66
16	Toilet 4	11:36:30	11:37:37	Toilet 4	5/23/99	11:36:30	70	11:37:40	3.72	3.66	3.68
				Leak 1	5/23/99	11:37:40	10	11:37:50	0.07	0.01	0.07
17	Faucet 7	11:38:15	11:39:15	Faucet 1	5/23/99	11:38:10	70	11:39:20	1.82	1.82	1.82
18	Clothes Washer	21:41:30	21:44:05	Clothes Washer 1	5/23/99	21:41:30	170	21:44:20	3.86	9.72	3.8
18	Clothes Washer	21:57:03	21:58:04	Clothes Washer 2	5/23/99	21:57:00	80	21:58:20	3.79	3.8	3.79
18	Clothes Washer	21:59:09	22:01:34	Clothes Washer 1	5/23/99	21:59:00	170	22:01:50	3.85	9.41	3.85
	[C]			Leak 1	5/23/99	22:26:00	10	22:26:10	0.1	0.02	0.1
				Faucet 1	5/23/99	22:29:50	20	22:30:10	0.69	0.19	0.69
19	Dishwasher	22:33:00	Unknown	Dishwasher 1	5/23/99	22:34:20	70	22:35:30	1.62	1.6	1.6
				Dishwasher 1	5/23/99	22:42:20	60	22:43:20	1.58	1.38	1.58
				Leak 1	5/23/99	22:43:20	10	22:43:30	0.28	0.05	0.28
				Dishwasher 1	5/23/99	22:47:20	120	22:49:20	1.57	1.58	1.57
				Dishwasher 1	5/23/99	23:32:20	50	23:33:10	1.58	1.13	1.55
				Dishwasher 1	5/23/99	23:36:20	60	23:37:20	1.57	1.43	1.57
				Dishwasher 1	5/23/99	23:40:20	70	23:41:30	1.57	1.42	1.57
20	Hose 1	6:34:00	6:37:00	Outdoor Hose	5/24/99	6:34:00	200	6:37:20	3.41	10.16	3.37
				Leak 1	5/24/99	6:49:10	20	6:49:30	0.07	0.02	0.07
21	Hose 2	6:50:00	6:53:00	Outdoor Hose	5/24/99	6:50:00	190	6:53:10	5.06	14.96	5.01

Table A-9. *(Continued)*

Actual Field Data				Trace Wizard Data							
Event No.[A]	Device	Start Time	End Time	Device[B]	Date	Start Time	Duration (seconds)	End Time	Peak (gpm)	Volume (gallons)	Mode (gpm)
22	Shower 4	14:49:15	14:51:33	Unknown	5/24/99	14:49:20	140	14:51:40	2.67	6.11	2.67
				Leak 1	5/24/99	14:51:40	90	14:53:10	0.03	0.02	0.01
				Leak 1	5/24/99	14:54:50	10	14:55:00	0.18	0.03	0.18
				Faucet 1	5/24/99	14:55:00	10	14:55:10	0.69	0.12	0.69
	[C]			Faucet 1	5/24/99	14:59:50	30	15:00:20	1.65	0.78	1.65
				Leak 1	5/24/99	15:00:20	10	15:00:30	0.21	0.04	0.21
23	Faucet 6	15:04:30	15:04:55	Faucet 1	5/24/99	15:04:30	30	15:05:00	1.65	0.65	1.65
				Leak 1	5/24/99	15:05:00	10	15:05:10	0.21	0.04	0.21
24	Toilet 3	15:11:20	15:13:20	Toilet 3	5/24/99	15:11:30	130	15:13:40	3.06	3.27	3.06
25	Faucet 1	15:21:20	15:21:55	Leak 1	5/24/99	15:20:10	70	15:21:20	0.01	0.01	0.01
				Faucet 1	5/24/99	15:21:20	40	15:22:00	1.86	1.04	1.86
				Leak 1	5/24/99	15:22:00	10	15:22:10	0.21	0.04	0.21
	[C]			Leak 1	5/24/99	15:23:10	30	15:23:40	0.07	0.02	0.03
				Faucet 1	5/24/99	15:23:50	10	15:24:00	0.62	0.1	0.62
				Leak 1	5/24/99	15:24:00	10	15:24:10	0.28	0.05	0.28
26	Toilet 2	15:25:40	15:26:31	Toilet 1	5/24/99	15:25:40	70	15:26:50	1.79	1.5	1.79
	[C]			Leak 1	5/24/99	15:30:00	10	15:30:10	0.21	0.04	0.21
				Toilet@[D]	5/24/99	15:30:10	170	15:33:00	2.07	2.75	2.07
27	Toilet 1	15:35:40	15:36:28	Toilet 1	5/24/99	15:35:40	80	15:37:00	1.79	1.38	1.76
				Faucet 1	5/24/99	15:52:00	10	15:52:10	1.52	0.25	1.52
28	Shower 1	16:04:00	16:10:15	Shower 1	5/24/99	16:04:00	380	16:10:20	1.96	11.8	1.88
				Leak 1	5/24/99	16:10:20	10	16:10:30	0.3	0.05	0.3
29	Faucet 3	16:18:45	16:19:15	Faucet 1	5/24/99	16:18:50	30	16:19:20	1.41	0.68	1.41
				Leak 1	5/24/99	16:19:20	90	16:20:50	0.21	0.05	0.01
30	Bathtub 1	16:25:30	16:26:22	Faucet 4	5/24/99	16:25:30	70	16:26:40	8.92	7.55	8.85
31	Shower 2	20:06:30	Unknown	Shower 1	5/24/99	20:06:30	440	20:13:50	2.13	13.97	0
				Faucet 1	5/24/99	20:16:10	20	20:16:30	2.48	0.49	0
32	Faucet 4	20:26:45	20:27:05	Clothes Washer 1	5/24/99	20:26:50	30	20:27:20	7.99	2.67	0
33	Clothes Washer	7:26:10	7:28:49	Clothes Washer 1	5/25/99	7:26:10	220	7:29:50	3.82	9.98	3.8
33	Clothes Washer	7:41:24	Unknown	Leak 1	5/25/99	7:42:20	10	7:42:30	0.07	0.01	0.07
				Clothes Washer 2	5/25/99	7:42:30	70	7:43:40	3.82	3.87	3.79
33	Clothes Washer	7:44:27	7:47:04	Clothes Washer 1	5/25/99	7:44:30	160	7:47:10	3.86	9.55	3.86
34	Faucet 5	11:07:45	11:09:03	Faucet 1	5/25/99	11:07:50	90	11:09:20	2.27	2.87	2.24
	[C]			Leak 1	5/25/99	11:10:40	10	11:10:50	0.14	0.02	0.14
				Toilet 3	5/25/99	11:10:50	130	11:13:00	3.05	3.27	3.05
	[C]			Leak 1	5/25/99	11:17:10	20	11:17:30	0.14	0.03	0.14
35	Bathtub 2	11:18:11	11:18:27	Shower 1	5/25/99	11:18:20	310	11:23:30	5.2	14.89	2.83
36	Shower 3	11:18:27	11:23:09								
37	Faucet 7	11:29:15	11:29:41	Faucet 1	5/25/99	11:29:20	40	11:30:00	1.76	0.75	1.76
38	Toilet 4	11:31:00	11:32:07	Leak 1	5/25/99	11:31:00	10	11:31:10	0.21	0.04	0.21
				Toilet 4	5/25/99	11:31:10	80	11:32:30	3.72	3.6	3.72

A. This table includes only single-water-use events that were recorded by the data logger around the time periods during which field monitoring occurred. This analysis includes water uses appearing on the data logger between the following time periods: on 5/23/99 from 10:54:00 to 11:39:20 and 21:41:30 to 23:41:30; on 5/24/99 from 6:34:00 to 6:53:10 and 14:49:20 to 16:26:40 and 20:06:30 to 20:27:20; on 5/25/99 from 7:26:10 to 7:47:10 to 11:07:50 to 11:32:30. The grayed rows indicate single events that were separated by Trace Wizard into multiple events that included one or more leaks.

B. Trace Wizard did not label the appliances with the same numbering system as was done in the field. Therefore, for consistency purposes, the Trace Wizard labels were adjusted to match the Field Study labels. Using the unique appliance signatures, appliance identifications were matched up and the following changes were made: Trace Wizard "Utility Faucet 1" was relabeled as Faucet 4, Trace Wizard "Toilet 2" was relabeled as Toilet 3; Trace Wizard "Toilet 3" was relabeled as Toilet 4. These changes were maintained throughout our analysis.

C. The data logger was left on the house for a number of days, however, only a small portion of water uses were monitored as part of this field study. The water uses labeled with the "C" in this table were recorded by the data logger, but were not monitored by the field personnel.

D. Toilet@ was the label used by Trace Wizard to indicate a Toilet use, where the specific appliance was unknown.

During these time periods examined, Trace Wizard indicated 25 leaks. All of these leaks are recorded as less than or equal to 0.05 gallons in volume. Many of these leaks may be attributable to small water draws such as the icemakers in refrigerators, or a drinking-water filter. However, some of these leaks clearly are part of the preceding or succeeding water-use event. Figures A-9, A-10, A-11, A-13, A-15, A-16, A-18, and A-19 graphically display the water uses from the Trace Wizard analysis where uses that were part of an appliance use are mislabeled as leaks. It is likely that a significant percentage of the water uses reported as leaks in REUWS are in fact portions of other uses. The "leak" events that clearly seem to be part of the adjacent larger water-use events are shaded in gray on Table A-9. Out of the 10 toilet uses in the time frames displayed, seven of them had adjacent leaks defined by Trace Wizard. Overall, 22 of the 25 leaks were clearly part of an adjacent water-use event. The connection of these leaks to water-using events is further discussed in the following section on Volume Comparisons.

A-6.4 Volume Comparisons

During the study, the field personnel measured the volumes of water in 31 water-using events in order to assess the capability of the Meter-Master to accurately measure volumes. Table A-10 displays a volume comparison of the 15 events for which the volume was measured in the field and where Trace Wizard matched the field data nearly exactly in start and end times. Only these 15 events are chosen for this analysis, since volume is integrally related to the duration of the event. The Trace Wizard observed volumes differ from the field-measured volumes from between 0.2% error for a seven-minute shower to 7.1% error for a very small volume faucet use (approximately 25 seconds). The percent error values are plotted against the actual volume in Figure A-23.

The Meter-Master volumes as reported by Trace Wizard compared very well to the field-measured volumes for single water-using events. For multiple overlapping water-use events, the Meter-Master accurately measured the total volumes of the combined water-use events, but Trace Wizard was unable to accurately assign the volumes to the appropriate appliances. For example, on 5/25/99 (Figure A-20), the Toilet 1 usage at 11:46:20 (Event 40) was not noted by Trace Wizard, however Trace Wizard's volume for the Shower 1 (Event 39) that occurred simultaneously from 11:46:02 to 12:00:28 was reported as approximately 3 gallons over that volume that was measured for the shower by the field personnel. Trace Wizard failed to identify the individual water use of the toilet, but correctly reported the volume usage during that time for the combined water uses, as it lumped the toilet water-use volume into the volume of the shower use. Similarly, The shower (Event 49) that occurred on 5/25/99 (Figure A-21) from 13:05:00 to 13:19:55 was recorded by Trace Wizard to have a volume 9.45 gallons over the actual shower volume measured by the field personnel. The difference of 9.45 gallons was due to misassigning portions of the clothes washer event (Event 48) and Faucet 1 (Event 52) to the shower.

The difference between the measured field and the Meter-Master observed volumes may be due to several factors. Some of these factors can be attributed to the water meter and the Meter-Master data logger. The Meter-Master records the number of revolutions of the impeller over a fixed interval. In their study, a 5 second interval was used, while in the study upon which the REUWS database is based, a 10-second interval was used. The interval can affect Trace Wizards ability to disaggregate uses, since uses will appear to overlap if they occur during the same interval even if they don't actually occur simultaneously. In addition, partial revolutions of the water meter impeller are not recorded, leading to a small meter-dependent error with a magnitude of the volume of one rotation.

Table A-10. Volume Comparison Including Leaks

Event No.[A]	Actual Device	Leaks Observed by Trace Wizard	Date	Actual Start Time	Trace Wizard Observed Start Time	Actual End Time	Trace Wizard Observed End Time	Actual Volume (gal)	Trace Wizard Observed Volume (gal)	Trace Wizard Volume incl. leaks (gal)	Difference in Volume (gal)	Percent Error in Volume (Diff/Act)	Difference in Volume incl. leaks (gal)	Percent Error in Volume incl. leaks	Volume Ratio (Obs/Act)	Volume Ratio incl. leaks (Obs/Act)
22	Shower 4		5/24/99	14:49:15	14:49:20	14:51:33	14:51:40	6.26	6.11	6.13	0.15	2.4%	0.13	2.1%	0.976	0.979
		Leak 1	5/24/99		14:51:40		14:53:10		0.02							
23	Faucet 6		5/24/99	15:04:30	15:04:30	15:04:55	15:05:00	0.70	0.65	0.69	0.05	7.1%	0.01	1.4%	0.929	0.986
		Leak 1	5/24/99		15:05:00		15:05:10		0.04							
25	Faucet 1	Leak 1	5/24/99		15:20:10		15:21:20		0.01							
			5/24/99	15:21:20	15:21:20	15:21:55	15:22:00	1.09	1.04	1.09	0.05	4.6%	0.00	0.0%	0.954	1
		Leak 1	5/24/99		15:22:00		15:22:10		0.04							
28	Shower 1		5/24/99	16:04:00	16:04:00	16:10:15	16:10:20	11.90	11.80	11.85	0.10	0.8%	0.05	0.4%	0.992	0.996
		Leak 1	5/24/99		16:10:20		16:10:30		0.05							
29	Faucet 3		5/24/99	16:18:45	16:18:50	16:19:15	16:19:20	0.72	0.68	0.73	0.04	5.5%	-0.01	-1.4%	0.944	1.014
		Leak 1	5/24/99		16:19:20		16:20:50		0.05							
30	Bathtub 1		5/24/99	16:25:30	16:25:30	16:26:22	16:26:40	7.97	7.55		0.42	5.3%			0.947	
31	Shower 2		5/24/99	20:06:30	20:06:30		20:13:50	14.00	13.97		0.03	0.2%			0.998	
32	Faucet 4		5/24/99	20:26:45	20:26:50	20:27:05	20:27:20	2.79	2.67		0.12	4.3%			0.957	
33	Clothes Washer		5/25/99	7:26:10	7:26:10	7:28:49	7:29:50	10.25	9.98		0.27	2.6%			0.974	
33	Clothes Washer	Leak 1	5/25/99		7:42:20		7:42:30		0.01							
			5/25/99	7:41:24	7:42:30		7:43:40	4.04	3.87	3.88	0.17	4.2%	0.16	4.0%	0.958	0.960
33	Clothes Washer		5/25/99	7:44:27	7:44:30	7:47:04	7:47:10	9.89	9.55		0.34	3.4%			0.966	
34	Faucet 5		5/25/99	11:07:45	11:07:50	11:09:03	11:09:20	2.92	2.87		0.05	1.7%			0.983	
35	Bathtub 2 /Shower 3[B]		5/25/99	11:18:11	11:18:20	11:23:09	11:23:30	16.24	14.89		1.35	8.3%			0.917	
37	Faucet 7		5/25/99	11:29:15	11:29:20	11:29:41	11:30:00	0.78	0.75		0.03	3.8%			0.962	
48	Clothes Washer		5/25/99	13:21:28	13:21:30	13:23:58	13:24:10	9.80	9.44		0.36	3.7%			0.963	

A. This table includes only those events for which the volume was measured in the field and where Trace Wizard matched the field data nearly exactly in start and end times.

B. These two events were combined into one volume measurement for comparison purposes. The water switched from the bath faucet to the showerhead.

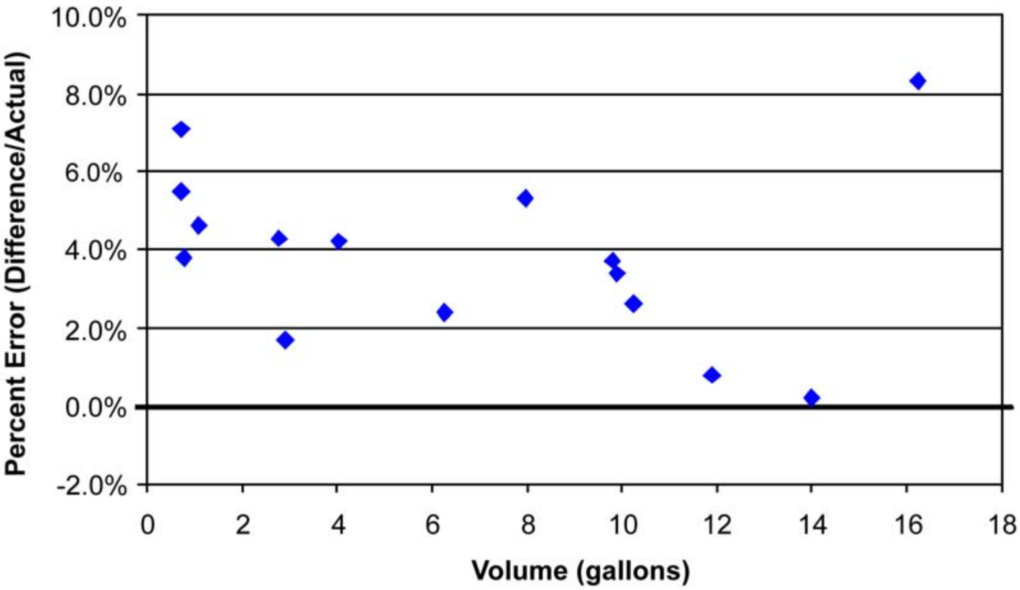


Figure A-23. Water Event Volume versus Accuracy in Meter-Master Measurements.

Note: Percent Error is difference between actual volume and observed volume divided by actual volume.

Another factor influencing the accuracy of the volume observation is that Trace Wizard erroneously labels as “Leaks” many short events that are actually part of an adjacent water-use event. If these mislabeled “Leak” events are combined with the appropriate adjacent water-use event, the volumes more closely approach those measured in the field. For example, Faucet 6 (Event 23) was field measured to have a volume of 0.7 gallons. Trace Wizard observed it to have a volume of 0.65 gallons, and this event was followed directly by a leak of 0.4 gallons. Adding the leak to the observed volume results in 0.69 gallons, which nearly matches the field measured data. Similarly, Faucet 1 (Event 25) was measured with a volume of 1.1 gallons, yet the observed volume was 1.04 gallons, preceded and succeeded by leaks of 0.01 and 0.04, respectively. Adding these two adjacent leaks to the faucet event results in an exact match with the measured data. The Shower 1 (Event 28) and the Faucet 3 (Event 29) events also follow this pattern of the leaks serving to correct the observed volume to closely match the measured. The other two events, Shower 4 (Event 22) and the Clothes Washer (Event 33), are not as significantly affected by the addition of their adjacent leaks. It appears that in the cases when the “Leak” is directly adjacent to the event, its volume (and duration) should be added to the volume of the event.

A-7 Discussion

This analysis was conducted for two specific objectives: (1) to evaluate the accuracy of the Meter-Master data logging equipment, and (2) to evaluate the ability of the Trace Wizard water-use-analysis software to accurately characterize the individual water uses. The capabilities of both the Meter-Master and Trace Wizard are evaluated in the context of providing useful water-use information as inputs for analysis of exposure to water-borne contaminants. This requires consideration of both the quality of the Meter-Master’s ability to provide useful whole-house water-use (volume and flow rate) information as well as Trace Wizard’s ability to disaggregate the uses into individual water uses and assign the uses to the appropriate appliances.

<u>Start and End Times</u>

The Meter-Master data logger proved very successful in documenting a continuous record of the start/end times and volumes of household water uses (e.g. faucet, shower, toilet) during single water-use events (where there was only one appliance used at a time). In reference to these single use events, Trace Wizard's recorded event start times were no more than 10 seconds off from the actual 93% of the time. These are nearly exact matches since the Meter-Master device took measurements every 10 seconds. Trace Wizard's recorded end times matched the actual end times 49% of the time, yet matched by no more than 20 seconds 89% of the time. The volumes also matched quite well, when the start and end times matched well. Total volumes also appeared to be correct in cases where two events were combined (not disaggregated), and when the "leak" volumes were added to the volumes of the adjacent.

<u>Appliance Type Identification</u>

The purpose of this study, as stated in the objectives, is to evaluate Trace Wizard's ability to disaggregate the total water flows into individual water uses and to correctly assign the uses to either the correct appliance or to the correct appliance type. In this particular study, the ability of Trace Wizard to successfully match the "type" (e.g. faucet, toilet, shower) of appliance during **83%** of the singly occurring events provides an estimate of the ability of the software to assign a water use to the correct type of appliance when only one water use is occurring. When the two water uses occurred simultaneously in this study, Trace Wizard correctly identified the "Type" of appliance 24% of the time. When three water uses occurred simultaneously in this study, Trace Wizard was unable to identify the appliance types. However, these scenarios of triple water uses (see Figures A-21 and A-22) represent very confusing water usage configurations and it was not unexpected that Trace Wizard would have difficulty disaggregating the water flows.

There are a few specific examples in the study that warrant further discussion. They are as follows:

- <u>Bathtub versus Utility Faucet</u>. In Event #30, Trace Wizard classified a "Bathtub 1" faucet use as the "Utility Faucet" (Faucet 4). The signature peak flow of Bathtub 1 was 8.85 gpm and the signature peak flow of Faucet 4 was 8.23 gpm. However, event #30, with a peak flow of 8.92 gpm, was assigned as Faucet 4. Thus, an assignment was made to an appliance for which its signature maximum flow rate was significantly less. It is clear that a flow of 8.92 gpm could not have come from faucet 4, and therefore this event should have been assigned to another appliance. It is likely that Trace Wizard and/or the analyst assumed that the water usage was not a bathtub use because of its short duration (not enough water to fill a bathtub). The implication is that Trace Wizard may have difficulty properly classifying water uses that do not conform to typical behavioral patterns.

  In the case of Event #40, also a "Bathtub 1" use classified as "Utility Faucet" (Faucet 4), the assignment was more ambiguous. This event occurred during a series of double water uses where a constant shower underlies a variety of other events. The total flow occurring at that time period was greater than 10 gpm. Trace Wizard had difficulty identifying the correct parameters of the underlying shower, which makes assigning the appropriate parameter to the other simultaneous water uses very difficult. Consequently, the flow rate of event #42 was underestimated and misclassified as Faucet 4.

- <u>Bathtub/Shower Combination Appliances</u>. Events #35 and #36 were meant to simulate a person taking a shower in a bathtub/shower appliance. The first part of the water use (Event #35), which had a higher flow rate through the bathtub faucet, was meant to simulate the period when the user adjusts the temperature and flow rate of the water prior to starting the shower. The second part of the water use (Event #36) simulates the user switching the waterflow from the bathtub faucet to the showerhead and then taking a shower. Together these two events (#35 and #36) can be viewed as one showering event, which was how Trace Wizard classified them. This classification technique was further borne out in the signature phase when Trace Wizard classified the usage of the same bathtub/shower combination appliance (Events #11 and #12) as a single event. (See Table A-5). Our analysis assumed that this was correct classification.

- Clothes Washer and Dishwasher Water Draws. Clothes washers are mechanical devices that repeat the same water-use patterns during each use with some modifications for user settings. In this study, the clothes washer had three distinct water draws, which were not altered during this study by changing the settings. As such, the clothes washer should have been viewed by the software as a series of water draws. In signature Event #18, single water-use Event #33, and double water-use Event #46, Trace Wizard classified the three water draws of the single clothes washer load as Clothes Washer 1 (CW1), Clothes Washer 2 (CW2), and Clothes Washer 1, respectively. The Trace Wizard software did not recognize the clothes washer event a series of more than two related water draws, but rather as independent events. Similarly, this occurred with the dishwasher as well. In the signature dishwasher Event #19, each of the six dishwasher water draws for the single dishwasher event was labeled Dishwasher 1. As a result, every clothes washer event in the study was reported as two events, and each dishwasher event was reported as six events. The implication is that Trace Wizard is likely to significantly over report the frequency of clothes washer and dishwasher use.

Appliance Identification for Human Exposure Assessment
In order for the Meter-Master and Trace Wizard to be effective tools in human activity pattern and exposure research, it is desirable that the technology to adequately identify the exact locations of the devices in use. Trace Wizard was somewhat more successful in identifying the mechanical appliances (e.g. toilet, dishwasher, clothes washer, etc.), as mechanical-type flows usually have distinct signatures that are easier to identify. However, manual-type flows (e.g. faucets, showers, baths, etc.) were more difficult to identify because their use characteristics are not consistent as they depend on how far the faucet is opened, vary from use to use, and often one faucet acts very similar to another.

The field study provided Trace Wizard with appliance signatures for use in identifying the exact appliance for each water-use. With the exception of 3 pairs of appliances (toilets 1 and 2; showers 1 and 2; and faucets 1 and 2), the signatures of the appliances were unique and exact appliance identification should have been possible. However, Trace Wizard was only able to achieve “Exact Matches” **33%** of the time for single events, 10% of the time for double events. This level of accuracy is not adequate for the purpose of estimating personal exposure to water use in the home. The basic criteria for an exposure study are to know which sources the person is in contact with (or in close proximity to) and for how long. Therefore, the analytical capabilities of the software are not presently adequate. Furthermore, Trace Wizard misclassified a significant number of small water uses as “leaks.” Frequently, these small uses were the leading or trailing remnant of a larger water use. For this reason, uses classified as “leaks” in the REUWS database are unreliable.

In an attempt to determine whether exact appliance identification could be achieved through better algorithms, a simple algorithm was tested (see Table A-7). This algorithm involved selecting the device whose signature mode was greater than or equal to 97% of the mode of the event in question. This method increased the accuracy of device identification for the events tested from 36% to 77%. This method was extremely simple, and was likely not the optimal algorithm. However, the results demonstrate that alternative algorithms have a potential for far greater success and highlight the shortcomings in the Trace Wizard analysis. Still, there may be problems with matching faucet and shower uses when the spigots are not fully opened. Throughout this study, the field personnel fully opened the showers and faucets to maintain a level of consistency, however, in real-life scenarios, this may not be the case, especially with faucet uses.

Water-Use Event Volumes
Figures A-24, A-25 and Table A-11 provide a comparison of the actual volume of water used in the house as a function of appliance type compared to the Trace Wizard assignment of volumes. The most obvious difference between the actual and assigned uses is the assignment of the unknowns and leaks, which comprise 10.5% of the total volume. In general, this leads to an underreporting of all the other appliances. The exceptions to that are the shower and faucets, which are slightly over reported. The most under reported water use was the clothes washer, which was reported as 50.2 gallons, but was field measured as 94.2 gallons. This large under reporting of the clothes washer is somewhat surprising since it is a

mechanical-type water use. This discrepancy should be correctable by improving Trace Wizard's algorithms.

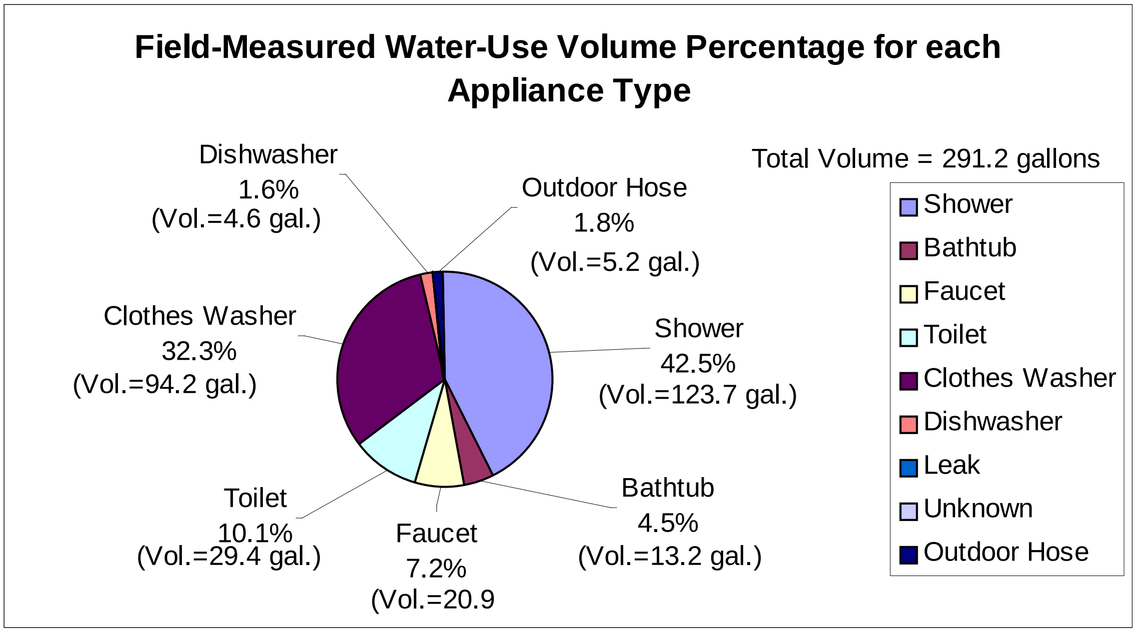


Figure A-24. Field-Measured Water-Use Percentage for Each Appliance Type.

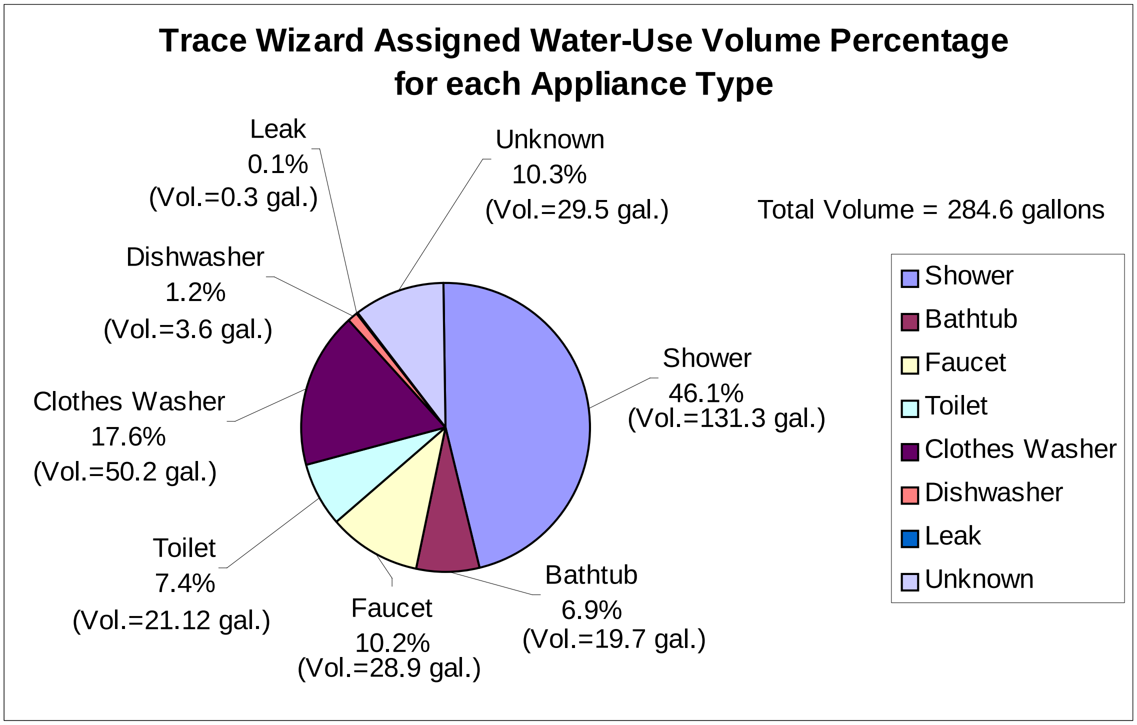


Figure A-25. Trace Wizard Assigned Water-Use Percentage for Each Appliance Type.

Table A-11. Volume Comparison between Actual Water Uses and Trace Wizard Assigned Water Uses by Appliance Type

Appliance Type	Volume of Actual Recorded Water Uses during Study (gallons)	Volume of Trace Wizard Assigned Water Uses during Study (gallons)	Ratio between Trace Wizard and Actual Volumes
Shower	123.68	131.31	1.0617
Bathtub	13.24	19.71	1.4887
Faucet	20.95	28.94	1.3814
Toilet	29.36	21.12	0.7193
Clothes Washer	94.18	50.19	0.5329
Dishwasher	4.56	3.55	0.5329
Outdoor Hose	5.19	0	NA
Leak	0	0.31	NA
Unknown	0	29.45	NA

Conclusions

In conclusion, the Trace Wizard and Meter-Master technologies are extremely useful in monitoring durations and volumes of household water uses, and in determining the “type” of appliance in use, particularly for singular events. However, the software needs improvements in disaggregating multiple events. In addition, for exposure assessment studies, the software needs improvement in determining the “exact” appliance. Other methods, including alternative strategies for determining when an appliance is in use and manual analysis of the water-use record are preferable. A possible means of using these tools in exposure studies would be to supplement the Meter-Master and Trace Wizard analyses with some sort of personal location detector. For example, the persons under study could wear a type of location badge. Their location could be determined either by some sort of large field coordinate system, or by a room-by-room receiver that records when persons enter and exit. This type of location technology could be coupled with the Meter-Master/Trace Wizard such that when Trace Wizard indicates that a shower is in use, the location detector will discern which shower. Another approach would be to use appliance specific sub-metering.

As discussed earlier, this study was designed and implemented as a preliminary study with one of the objectives being to better understand the meaning of the data contained in the REUWS database. The REUWS data was compiled using the Trace Wizard, Version 2.1, Water Use Analysis Software. Thus, the analysis and conclusions presented in this report pertain to Trace Wizard, Version 2.1. A newer version of Trace Wizard (Version 4.0) with enhanced capabilities is now available. No review of version 4.0 has been conducted to determine if the issues raised by this study have been addressed. However, since the data in the REUWS database was compiled using version 2.1, this study appropriately addresses issues related to the database.

This study evaluates Trace Wizard’s capabilities based on a small set of water uses, and therefore, variations in classifications of individual events have the potential to significantly alter the apparent accuracy of its classification algorithm. Clearly, this study was conducted on one household with one set of appliances, and therefore, its relationship to general appliances in the REUWS database is unknown. Given that there are nearly two million water use events in the REUWS database that are based on a technique that has not been evaluated, the results of this study raises concerns that need to be further investigated.

Given that this analysis is the only evaluation study conducted on the techniques used to compile the REUWS database, it is clear that a more in-depth study that examines the Trace Wizard assignment of water uses to appliance types would be beneficial. Such a study would need to provide a means for separately data logging each appliance in the household, such that the actual water uses can be compared to the Trace Wizard analysis. In addition, the study would need to include a significant number of households to properly represent the variability inherent in water uses and appliance types. For this study to be useful in interpreting the REUWS data, the same methods and software would need to be employed in the validation study as those used to compile REUWS. The results of such a study would be very valuable in understanding the data contained in the database as well as in designing future studies.

The REUWS database provides a wealth of water use data that is potentially very useful in estimating exposure to waterborne contaminants. However, given the reliability of classification by Trace Wizard discussed above, an exposure assessor should be aware of the uncertainties associated with the data. Considering that Trace Wizard achieved a correct "type" match 83% of the time during single water-use events, and 24% of the time for double or overlapping water-use events, the impact on the data could be minor or enormous. No studies have been identified that quantify the amount of household water-uses that falls into the single water-use category, but given the relative low frequency of water uses throughout the day, it is expected for there to be more single use events. Also, given constraints used to eliminate "unreasonable" records in REUWS, the analysis for volumetric usage is likely to be reasonable, and is certainly the best currently available data.

Recommendations for Improving Trace Wizard

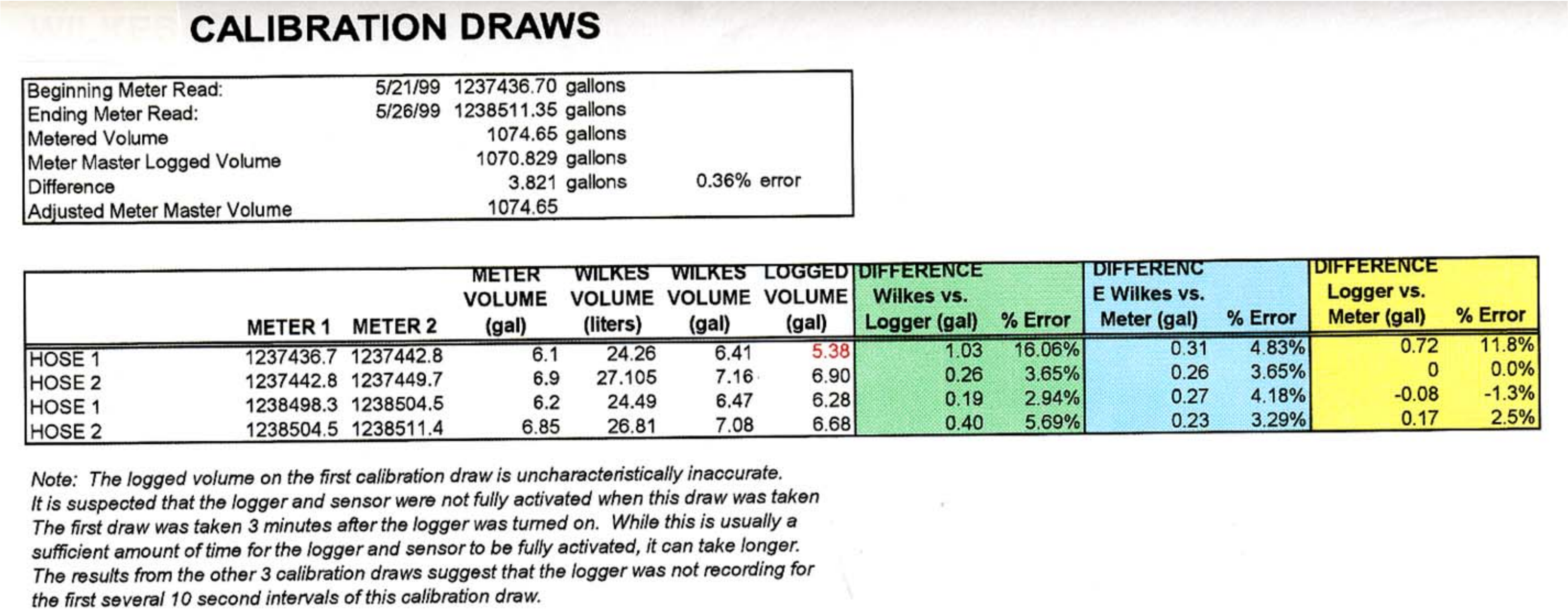
After analysis, we offer a few recommendations for improving the Trace Wizard software. First, Trace Wizard should incorporate checks to test for reasonableness, similar to those discussed in the various sections of the water-use report (e.g. see Table 7-13). For example, Trace Wizard should develop "reasonable" criteria for clothes washer operations based on published experimental and manufacturer data. Furthermore, the software should connect the various portions of dishwasher and clothes washer events. For example, each fill in a clothes washer event is not an individual water-use event, but part of the overall event. Thereby, Trace Wizard should expect initial wash water draws to be followed by rinse water draws, and it should label each as portions of the single whole event. Trace Wizard should also be improved in its analysis of very small water draws (previously labeled as "leaks"), in order to determine if the "leaks" are actually the leading or trailing edges of a larger water-use event. Misclassifying water uses as leaks may lead to ill-conceived programs by water utilities attempting to minimize these fictitious leaks. Finally, it would be useful if the software incorporated some "expert" knowledge into its algorithms. For example, toilet usage is frequently followed by a small faucet use as the user washes his/her hands.

A-8 References

DeOreo, W.B., J.P. Heaney, and P.W. Mayer. 1996. "Flow Trace Analysis to Assess Water Use." *Journal of the American Water Works Association*. Vol. 88, No. 1.

A-9 Select Results Supplied by Aquacraft

The tables, figures (A-26 through A-32), and accompanying analyses included in following pages were submitted by Aquacraft, Inc., to Wilkes Technologies on June 21, 1999 along with the finalized Trace Wizard Database resulting from the analysis of the field study from 5/23/99 to 5/26/99. The handwritten notes were written by Aquacraft, Inc.



CALIBRATION DRAWS

Beginning Meter Read:	5/21/99	1237436.70	gallons		
Ending Meter Read:	5/26/99	1238511.35	gallons		
Metered Volume		1074.65	gallons		
Meter Master Logged Volume		1070.829	gallons		
Difference		3.821	gallons	0.36%	error
Adjusted Meter Master Volume		1074.65			

	METER 1	METER 2	METER VOLUME (gal)	WILKES VOLUME (liters)	WILKES VOLUME (gal)	LOGGED VOLUME (gal)	DIFFERENCE Wilkes vs. Logger (gal)	% Error	DIFFERENC E Wilkes vs. Meter (gal)	% Error	DIFFERENCE Logger vs. Meter (gal)	% Error
HOSE 1	1237436.7	1237442.8	6.1	24.26	6.41	5.38	1.03	16.06%	0.31	4.83%	0.72	11.8%
HOSE 2	1237442.8	1237449.7	6.9	27.105	7.16	6.90	0.26	3.65%	0.26	3.65%	0	0.0%
HOSE 1	1238498.3	1238504.5	6.2	24.49	6.47	6.28	0.19	2.94%	0.27	4.18%	-0.08	-1.3%
HOSE 2	1238504.5	1238511.4	6.85	26.81	7.08	6.68	0.40	5.69%	0.23	3.29%	0.17	2.5%

Note: The logged volume on the first calibration draw is uncharacteristically inaccurate. It is suspected that the logger and sensor were not fully activated when this draw was taken The first draw was taken 3 minutes after the logger was turned on. While this is usually a sufficient amount of time for the logger and sensor to be fully activated, it can take longer. The results from the other 3 calibration draws suggest that the logger was not recording for the first several 10 second intervals of this calibration draw.

Figure A-26. Analysis of Calibration Draws as Provided by Aquacraft, Inc., Boulder, Colorado.

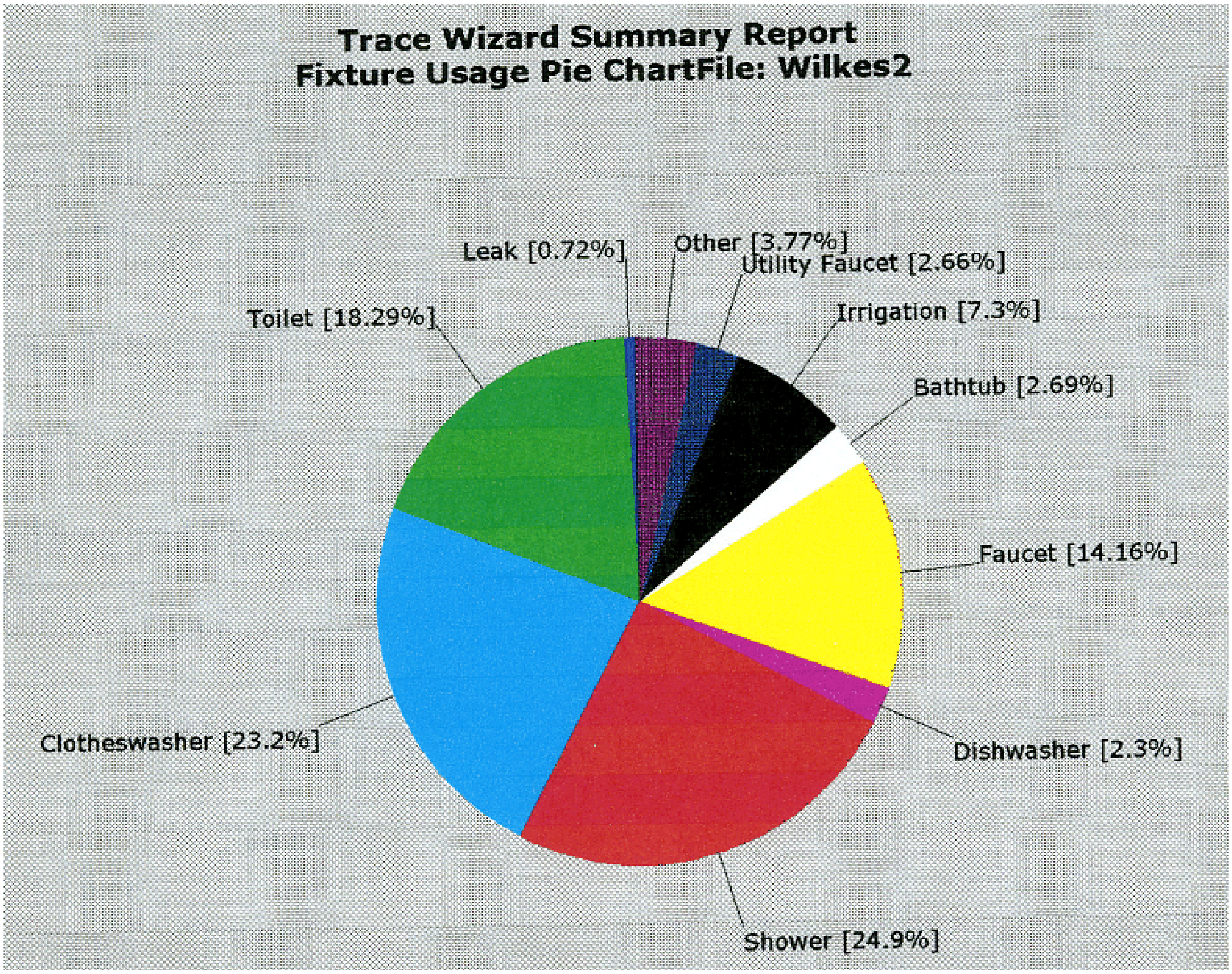
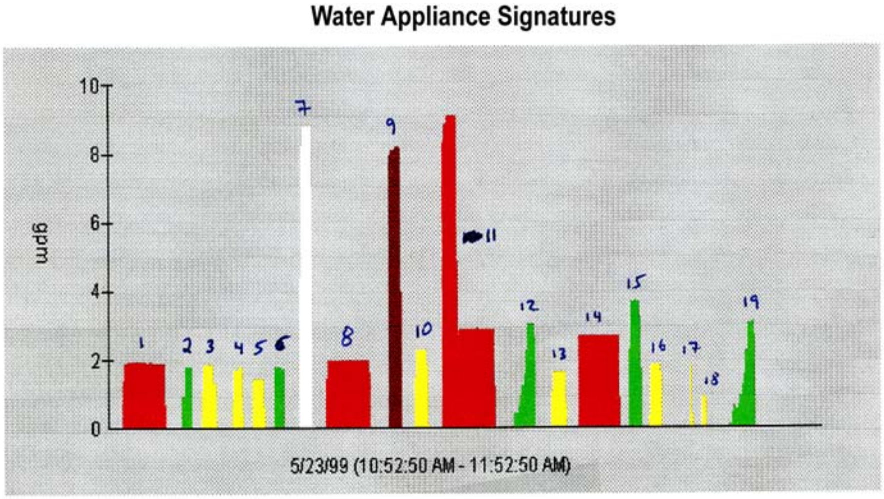
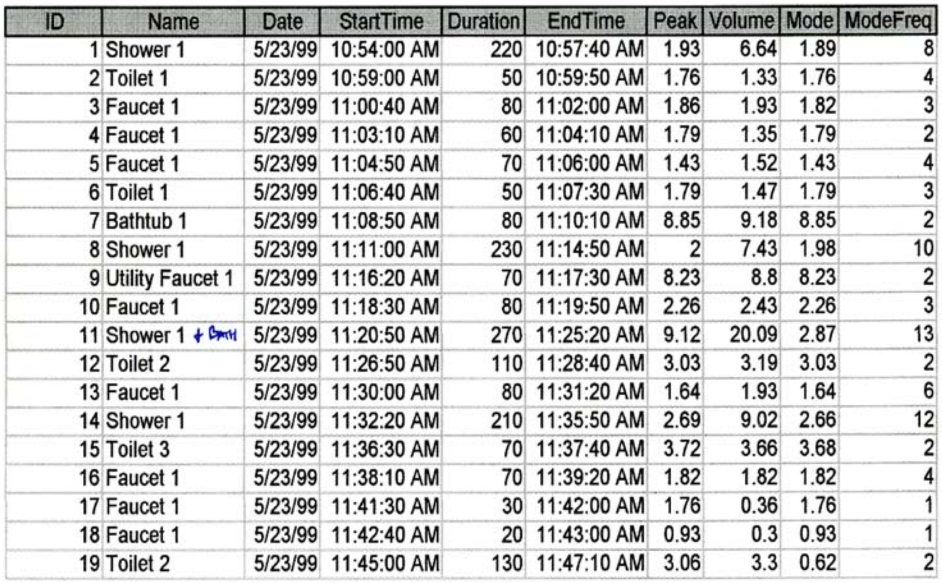


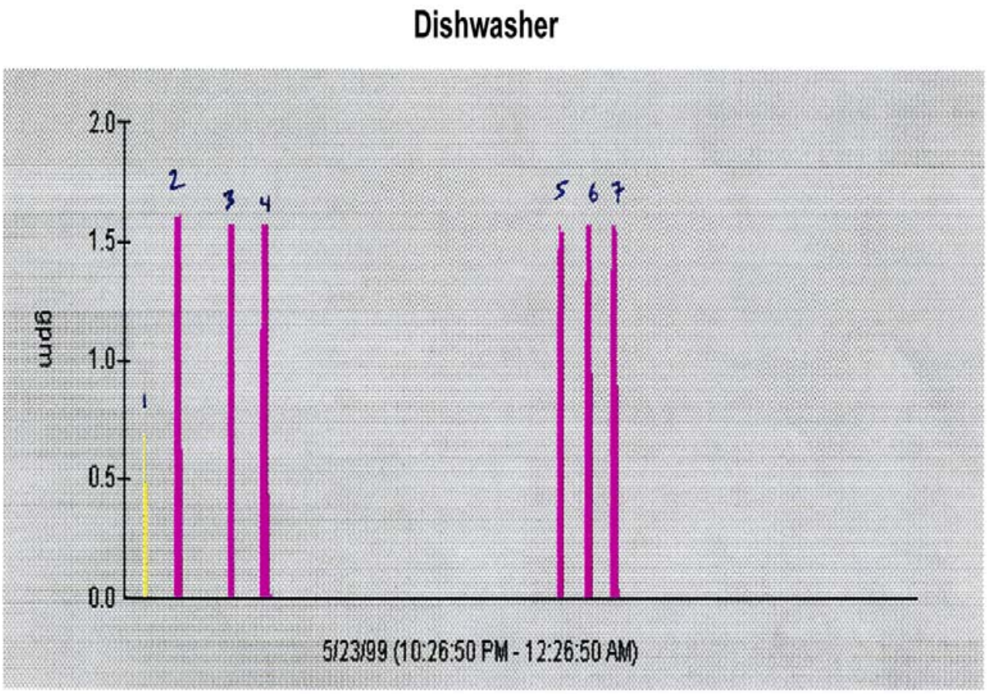
Figure A-27. Trace Wizard Fixture Water Usage as Provided by Aquacraft, Inc., Boulder, Colorado.

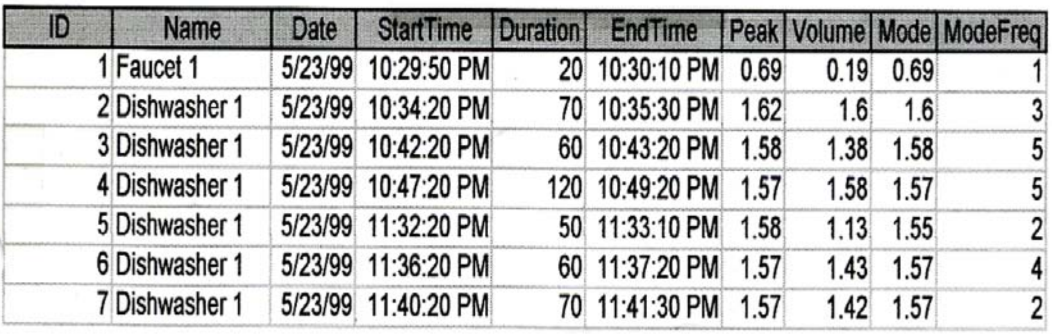




ID	Name	Date	StartTime	Duration	EndTime	Peak	Volume	Mode	ModeFreq
1	Shower 1	5/23/99	10:54:00 AM	220	10:57:40 AM	1.93	6.64	1.89	8
2	Toilet 1	5/23/99	10:59:00 AM	50	10:59:50 AM	1.76	1.33	1.76	4
3	Faucet 1	5/23/99	11:00:40 AM	80	11:02:00 AM	1.86	1.93	1.82	3
4	Faucet 1	5/23/99	11:03:10 AM	60	11:04:10 AM	1.79	1.35	1.79	2
5	Faucet 1	5/23/99	11:04:50 AM	70	11:06:00 AM	1.43	1.52	1.43	4
6	Toilet 1	5/23/99	11:06:40 AM	50	11:07:30 AM	1.79	1.47	1.79	3
7	Bathtub 1	5/23/99	11:08:50 AM	80	11:10:10 AM	8.85	9.18	8.85	2
8	Shower 1	5/23/99	11:11:00 AM	230	11:14:50 AM	2	7.43	1.98	10
9	Utility Faucet 1	5/23/99	11:16:20 AM	70	11:17:30 AM	8.23	8.8	8.23	2
10	Faucet 1	5/23/99	11:18:30 AM	80	11:19:50 AM	2.26	2.43	2.26	3
11	Shower 1 + Bath	5/23/99	11:20:50 AM	270	11:25:20 AM	9.12	20.09	2.87	13
12	Toilet 2	5/23/99	11:26:50 AM	110	11:28:40 AM	3.03	3.19	3.03	2
13	Faucet 1	5/23/99	11:30:00 AM	80	11:31:20 AM	1.64	1.93	1.64	6
14	Shower 1	5/23/99	11:32:20 AM	210	11:35:50 AM	2.69	9.02	2.66	12
15	Toilet 3	5/23/99	11:36:30 AM	70	11:37:40 AM	3.72	3.66	3.68	2
16	Faucet 1	5/23/99	11:38:10 AM	70	11:39:20 AM	1.82	1.82	1.82	4
17	Faucet 1	5/23/99	11:41:30 AM	30	11:42:00 AM	1.76	0.36	1.76	1
18	Faucet 1	5/23/99	11:42:40 AM	20	11:43:00 AM	0.93	0.3	0.93	1
19	Toilet 2	5/23/99	11:45:00 AM	130	11:47:10 AM	3.06	3.3	0.62	2

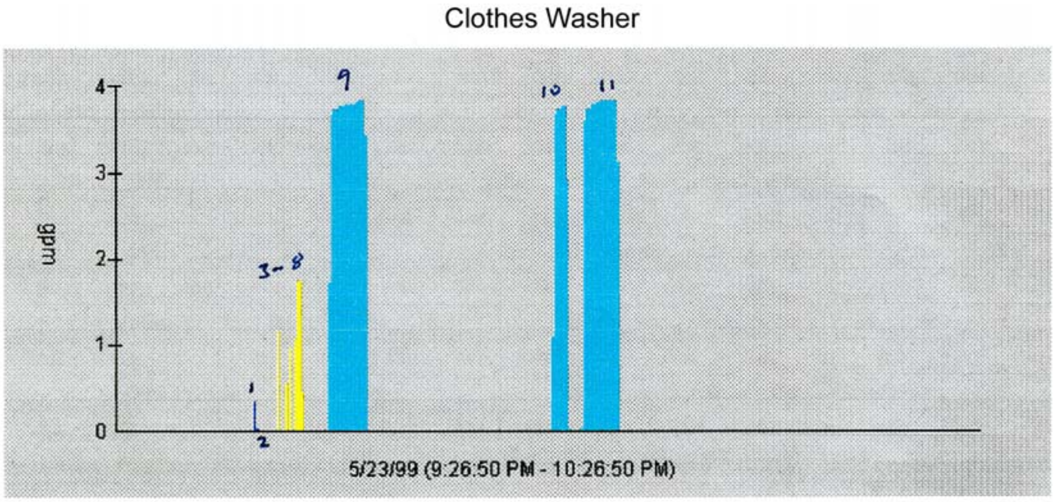
Figure A-28. Water Appliance Signatures as Provided by Aquacraft, Inc., Boulder, Colorado.

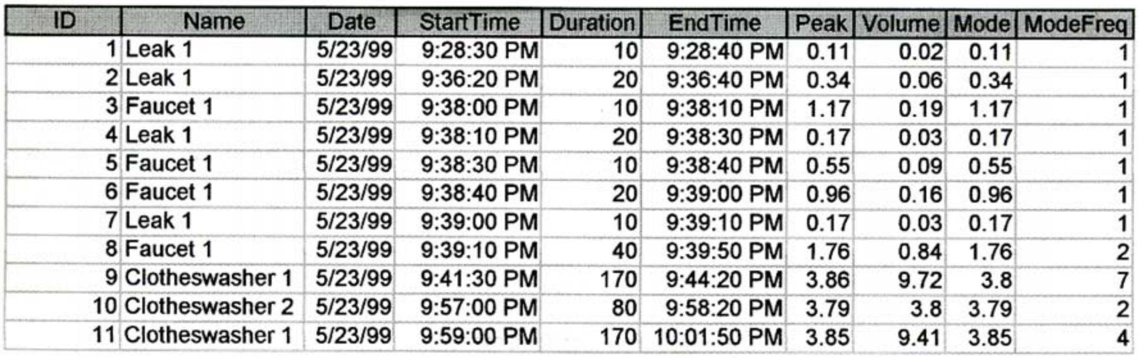




ID	Name	Date	StartTime	Duration	EndTime	Peak	Volume	Mode	ModeFreq
1	Faucet 1	5/23/99	10:29:50 PM	20	10:30:10 PM	0.69	0.19	0.69	1
2	Dishwasher 1	5/23/99	10:34:20 PM	70	10:35:30 PM	1.62	1.6	1.6	3
3	Dishwasher 1	5/23/99	10:42:20 PM	60	10:43:20 PM	1.58	1.38	1.58	5
4	Dishwasher 1	5/23/99	10:47:20 PM	120	10:49:20 PM	1.57	1.58	1.57	5
5	Dishwasher 1	5/23/99	11:32:20 PM	50	11:33:10 PM	1.58	1.13	1.55	2
6	Dishwasher 1	5/23/99	11:36:20 PM	60	11:37:20 PM	1.57	1.43	1.57	4
7	Dishwasher 1	5/23/99	11:40:20 PM	70	11:41:30 PM	1.57	1.42	1.57	2

Figure A-29. Dishwasher Signature as Provided by Aquacraft, Inc., Boulder, Colorado.

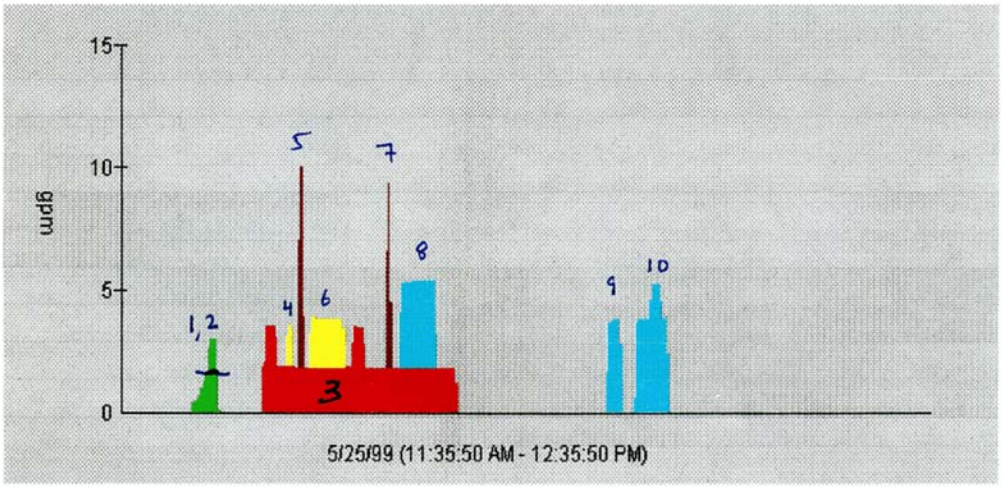


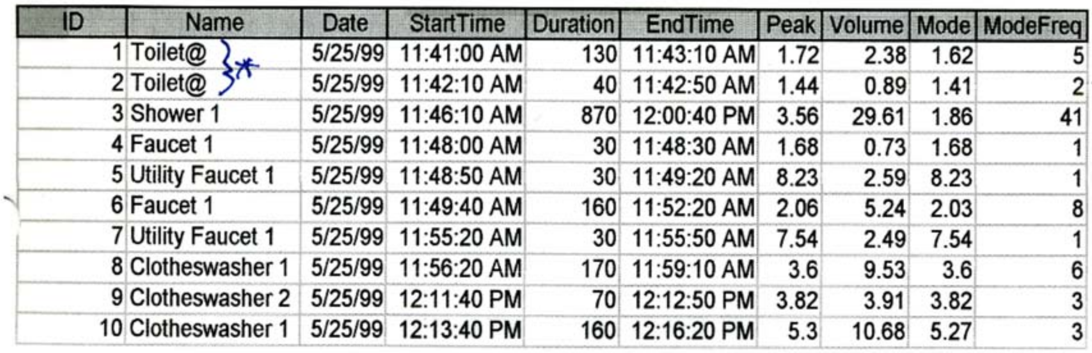


ID	Name	Date	StartTime	Duration	EndTime	Peak	Volume	Mode	ModeFreq
1	Leak 1	5/23/99	9:28:30 PM	10	9:28:40 PM	0.11	0.02	0.11	1
2	Leak 1	5/23/99	9:36:20 PM	20	9:36:40 PM	0.34	0.06	0.34	1
3	Faucet 1	5/23/99	9:38:00 PM	10	9:38:10 PM	1.17	0.19	1.17	1
4	Leak 1	5/23/99	9:38:10 PM	20	9:38:30 PM	0.17	0.03	0.17	1
5	Faucet 1	5/23/99	9:38:30 PM	10	9:38:40 PM	0.55	0.09	0.55	1
6	Faucet 1	5/23/99	9:38:40 PM	20	9:39:00 PM	0.96	0.16	0.96	1
7	Leak 1	5/23/99	9:39:00 PM	10	9:39:10 PM	0.17	0.03	0.17	1
8	Faucet 1	5/23/99	9:39:10 PM	40	9:39:50 PM	1.76	0.84	1.76	2
9	Clotheswasher 1	5/23/99	9:41:30 PM	170	9:44:20 PM	3.86	9.72	3.8	7
10	Clotheswasher 2	5/23/99	9:57:00 PM	80	9:58:20 PM	3.79	3.8	3.79	2
11	Clotheswasher 1	5/23/99	9:59:00 PM	170	10:01:50 PM	3.85	9.41	3.85	4

Figure A-30. Clothes Washer Signature as Provided by Aquacraft, Inc., Boulder, Colorado.

Simultaneous Shower and Clothes Washer



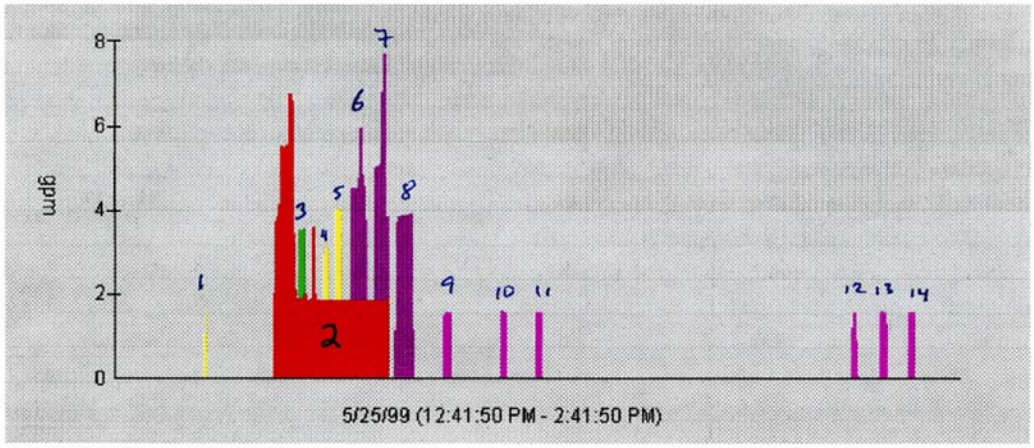


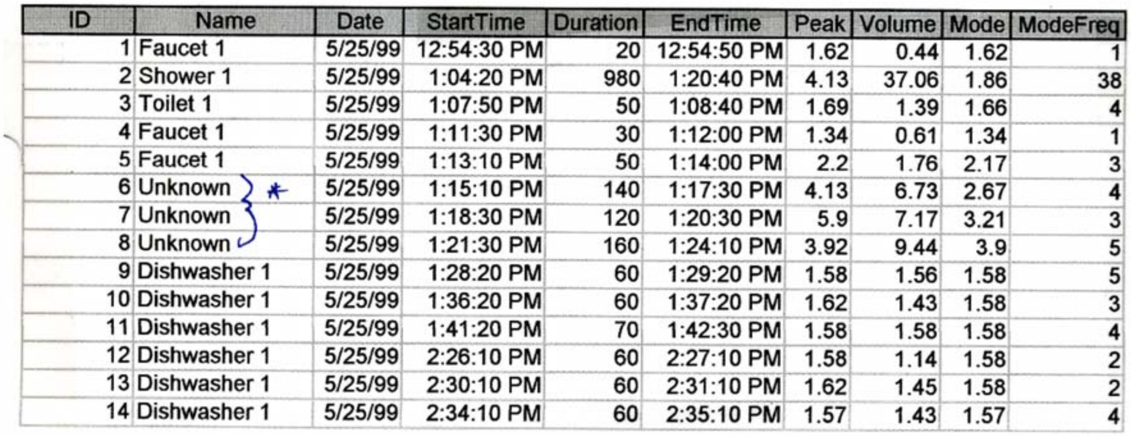
ID	Name	Date	StartTime	Duration	EndTime	Peak	Volume	Mode	ModeFreq
1	Toilet@ }*	5/25/99	11:41:00 AM	130	11:43:10 AM	1.72	2.38	1.62	5
2	Toilet@	5/25/99	11:42:10 AM	40	11:42:50 AM	1.44	0.89	1.41	2
3	Shower 1	5/25/99	11:46:10 AM	870	12:00:40 PM	3.56	29.61	1.86	41
4	Faucet 1	5/25/99	11:48:00 AM	30	11:48:30 AM	1.68	0.73	1.68	1
5	Utility Faucet 1	5/25/99	11:48:50 AM	30	11:49:20 AM	8.23	2.59	8.23	1
6	Faucet 1	5/25/99	11:49:40 AM	160	11:52:20 AM	2.06	5.24	2.03	8
7	Utility Faucet 1	5/25/99	11:55:20 AM	30	11:55:50 AM	7.54	2.49	7.54	1
8	Clotheswasher 1	5/25/99	11:56:20 AM	170	11:59:10 AM	3.6	9.53	3.6	6
9	Clotheswasher 2	5/25/99	12:11:40 PM	70	12:12:50 PM	3.82	3.91	3.82	3
10	Clotheswasher 1	5/25/99	12:13:40 PM	160	12:16:20 PM	5.3	10.68	5.27	3

* Because of the slowly combined flow pattern of this toilet (Toilet 3 from your signature), it was often split into 2 events by Trace Wizard. When this happened, these flushes were designated Toilet@.

Figure A-31. Simultaneous Water Signatures as Provided by Aquacraft, Inc., Boulder, Colorado.
Note: Handwritten notes provided by Aquacraft have been transcribed into typed text.

Simultaneous Use Events





ID	Name	Date	StartTime	Duration	EndTime	Peak	Volume	Mode	ModeFreq
1	Faucet 1	5/25/99	12:54:30 PM	20	12:54:50 PM	1.62	0.44	1.62	1
2	Shower 1	5/25/99	1:04:20 PM	980	1:20:40 PM	4.13	37.06	1.86	38
3	Toilet 1	5/25/99	1:07:50 PM	50	1:08:40 PM	1.69	1.39	1.66	4
4	Faucet 1	5/25/99	1:11:30 PM	30	1:12:00 PM	1.34	0.61	1.34	1
5	Faucet 1	5/25/99	1:13:10 PM	50	1:14:00 PM	2.2	1.76	2.17	3
6	Unknown *	5/25/99	1:15:10 PM	140	1:17:30 PM	4.13	6.73	2.67	4
7	Unknown	5/25/99	1:18:30 PM	120	1:20:30 PM	5.9	7.17	3.21	3
8	Unknown	5/25/99	1:21:30 PM	160	1:24:10 PM	3.92	9.44	3.9	5
9	Dishwasher 1	5/25/99	1:28:20 PM	60	1:29:20 PM	1.58	1.56	1.58	5
10	Dishwasher 1	5/25/99	1:36:20 PM	60	1:37:20 PM	1.62	1.43	1.58	3
11	Dishwasher 1	5/25/99	1:41:20 PM	70	1:42:30 PM	1.58	1.58	1.58	4
12	Dishwasher 1	5/25/99	2:26:10 PM	60	2:27:10 PM	1.58	1.14	1.58	2
13	Dishwasher 1	5/25/99	2:30:10 PM	60	2:31:10 PM	1.62	1.45	1.58	2
14	Dishwasher 1	5/25/99	2:34:10 PM	60	2:35:10 PM	1.57	1.43	1.57	4

* These events were classified as "Unknown" because it was not possible to distinguish them with any confidence. The analyst felt there were 3 possibilities: (1) bathtub fixture, (2) utility sink, or (3) outside hose. These three uses were often similar in character.

Figure A-32. Simultaneous Water Use Events Signatures as Provided by Aquacraft, Inc., Boulder, Colorado.
Note: Handwritten notes provided by Aquacraft have been transcribed into typed text.

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