conservation

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Residential water use trends in North America

FOR UTILITIES TO BOTH ENCOURAGE CONSERVATION AND HAVE SUFFICIENT FINANCIAL RESERVES FOR MAINTENANCE AND GROWTH, IT IS NECESSARY TO UNDERSTAND HOW WATER USE PATTERNS HAVE CHANGED DURING THE PAST 30 YEARS.

Water utilities across North America are experiencing declining water sales among their residential customers (single-family households). Typically, utility officials attribute the decline in water use to several possible factors, including wetter weather, new water-conserving appliances, changing demographics, and classification anomalies; however, there is no clear understanding of the ratio of use each of these factors contributes to the overall decline. Without a clear understanding of the driving forces behind changing water use patterns, it is difficult to develop appropriate pricing structures that will both recoup costs and provide resources for the future.

This study investigates trends in household water use in North America during the past 30 years and draws preliminary conclusions on the magnitude and causes of declining residential use. To assist utilities in adapting to changing use, the study focuses on (1) understanding residential water use patterns and trends; (2) assessing the effect of those patterns on water utility operations; and (3) providing data to be correlated with future trends for planning purposes. The study concludes that the decline in the number of individuals per household and the increased use of low-flow appliances are the primary contributors to the observed decline in water use among single-family households.

OLD WAYS OF ESTIMATING WATER USE DON'T WORK ANYMORE

Water utilities are finding it increasingly difficult to accurately manage their finances in the face of changing residential water use patterns. Many utilities have reported a gradual erosion of residential water sales on a per-household basis and are uncertain of the causes of the observed trends (Fig-

A full report of this project, *North American Water Usage Trends Since 1992* (4031), is available for free to Water Research Foundation subscribers by logging on to www.waterrf.org.

ure 1). A variety of explanations has been proposed, including wetter weather, new water-conserving appliances, changing demographics, and misclassification of multifamily residents as single-family residents. Although each of these factors may contribute to the decline, it is unknown to what degree. It is clear, however, that old rules of thumb, such as assuming households consume 100 gpd per person (KBCWSO, 2009), are no longer sufficient. New water use predictions must take into account a variety of individual factors that may drive water use either up or down. For example, fewer people per housing unit or more water-conserving appliances in the housing market lead to less water use per household. Rising incomes, larger homes, and more landscaping, however, lead to increases in household water use. Further complicating the issue, water use is also dependent on geographic location, climate, housing stock, pricing, and local conservation policies.

Although reduced residential water use and "water conservation" are generally portrayed as positive in water-poor regions challenged by restricted water supplies, the observed gradual attrition in residential consumption may force utilities to raise rates to cover basic operating costs and maintain sufficient revenues for expanding service and replacing old water mains and equipment (Beecher et al, 1994). For utilities to both encourage conservation and have sufficient financial reserves for maintenance and growth, it is necessary to understand how water use patterns have changed during the past 30 years, what factors influence use, and how these individual factors affect single-family household use patterns.

SEEKING CLUES FROM A REVIEW OF THE LITERATURE

Understanding water use patterns has been of interest for many years as water utility managers have contended with decreasing supplies and/or increasing demands from growing populations (Kenny et al, 2009). Within the United States, many of the water use studies have focused on the arid Southwest, which has experienced significant population growth and subsequently strained water resources (Hart, 2009). This interest has led to hundreds of scholarly and practitioner articles on topics such as investigating demand and/or price elasticity's effect on reducing water use, the spread and effect of low-flow appliances, and the effect of bans on certain water practices (Arbués et al, 2003).

Declining residential water use has also been noted by utilities in communities not commonly associated with arid or water-poor regions. For example, the city of Cleveland, Ohio, which uses Lake Erie as its source, found a drop of 17% in overall consumption from 2004 to 2009 (Sundheimer et al, 2007). Similarly, the American Water Works Company, in Voorhees, N.J., also reported customer consumption has fallen, causing a decline in water revenues and subsequent budget shortfalls (AWWC, 2007). Although the observed declining use trends have been similar, the factors driving the decline are likely more attributable to a combination of changing household demographics and increased household efficiency, rather than active conservation or education programs.

Water use studies conducted in the international community focus on residential classification issues and household demographics to provide a basis for understanding water use patterns. Randolph et al (2007) conducted a study in Sydney, Australia, using actual household-level data to understand gross per capita water demand trends, the effect of socioeconomic variables, and water supply forecasts over time. Arbués et al (2003) used cross-sectional, time-series data to investigate the consumer demand of water in Zaragoza, Spain, using actual data collected at the household level in a microseries study. These kinds of empirical studies provide more reliable information about water demand trends and the effects of pricing, climate, income, household size, and household appliances.

Historically, water use studies analyzed water demand through models based on seasonal variations without breaking out data based on customer classification or demographics. When detailed customer studies are performed, they have typically focused only on a specific locality and short-term trends (Domene & Sauri, 2005; Martinez-Espiñeira, 2002; Hanke & de Mare, 1982; Danielson, 1979). This paucity of research is most likely caused by a lack of accurate, consistent data collection across states and regions and the costliness of collecting disaggregated residential water end-use information.

With new data acquisition techniques and increased access to public databases, more detailed household end-use studies have been possible. The benchmark 1999 Water Research Foundation–sponsored study "Residential End Uses of Water" (Mayer et al, 1999) was able to link specific customer information to specific consumption. In this manner, the study was able to monitor actual water use in statistically representative households and then control for housing, demographic, economic, and behavioral variables that affect water use.

Although many water use studies have been conducted, most have been performed for arid regions or

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for highly localized communities. Few water use studies have been performed to assess the underlying cause of the declining water use trends in relatively water-rich areas. This research differs from previous water use study approaches in that it first identifies the temporal trend for single-family household water use at a national level and subsequently determines the influence of critical variables on single-family household water use in a water-rich community.

DETAILS OF THE PROJECT DESIGN

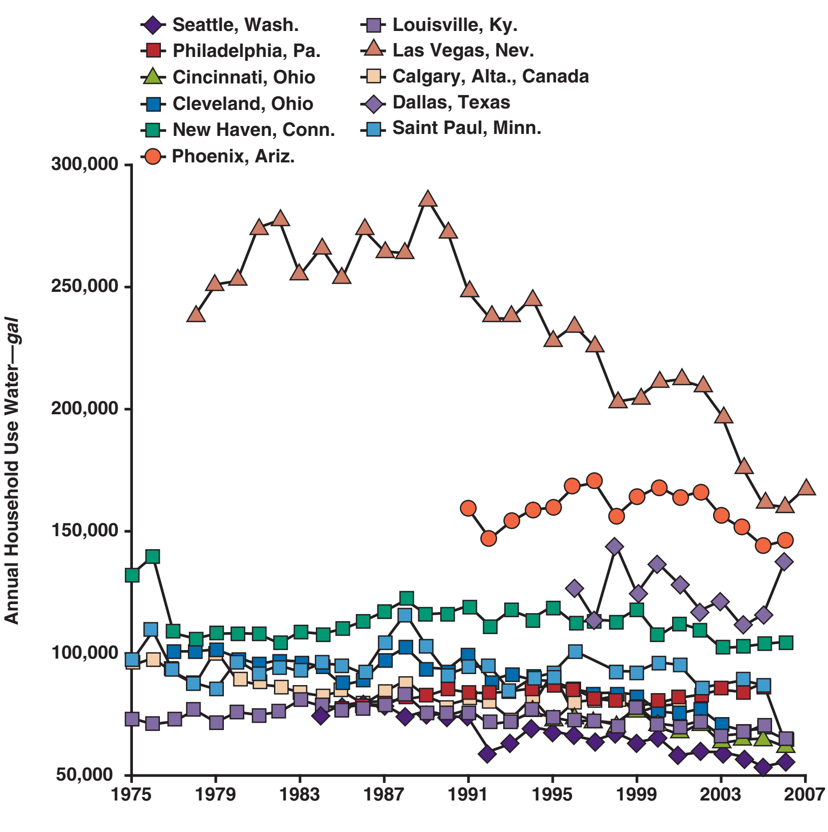
To appropriately evaluate residential water use changes across North America, the study relied on data assembled at the national, regional, and local levels. In this way, the research progressed from a macro view of the issue to a micro view. This also facilitated a greater understanding of both geographic and demographic variations as the study progressed.

The national trends (i.e., macro) component of the study analyzed the historical databases of 43 utilities. The analysis estimated the statistical relationships among six variables over time: utility size, water source, ownership type, precipitation zone, temperature zone, and drought indexes.

The regional component of the study examined the specific experiences reported by 11 partner utilities that provided background information and data. These data also estimated the statistical relationships among the same six variables addressed in the national study. In these instances, however, the researchers factored in specific conditions and aspects particular to each utility, such as conservation initiatives, billing practices, and government oversight.

The local (i.e., micro) component of the study, based on the methods of Mayer et al (1999), assessed the independent effects of water conservation fixtures and household demographics on water consumption at the household level. To avoid the natural tendency of self-reporting subjects to underestimate their water use, electronic data loggers were installed on 65 statistically representative homes in the Louisville (Ky.) Water Company (LWC) service area. The device captured flow signatures and accurately differentiated among various types of water use. For example, it could discern whether water was being used by a person taking a shower, flushing a toilet, or doing laundry. The participating households were surveyed to determine their socioeconomic characteristics as well as their inventory of indoor and outdoor water-using fixtures. The data were combined with demographic and economic factors to provide an assessment of water use patterns within a community. Finally, researchers analyzed the national, regional, and local components of the study to draw conclusions.

FIGURE 1 Overview of 11 regional partner utilities' water use



Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. **North American Water Usage Trends Since 1992.** *©2010 Water Research Foundation. Reprinted with permission.*

CREATING A METHOD OF ANALYZING THE DATA

Statistical models. To statistically measure water use trends, the study used ordinary least-squares (OLS) regressions and fixed-effects statistical models. The OLS regression model fits a linear equation that minimizes the sum of squared errors from the observed data, with annual water use per residential customer as the dependent variable. It is a relatively simplistic model that can quantify general data trends, but it cannot provide specific information on the importance of multiple variables contributing to the trend.

To capture information on competing variables contributing to observed trends, such as demographic, topographic, and climatic differences, a fixed-effects statistical model was used. This is a common regression technique for panel data when time-invariant place characteristics are observed over time for a constant set of locations. This model provides users with the ability to control for all stable characteristics of the identified variables in the study, thereby eliminating potentially large sources of bias. Thus, by exploring the dataset with both the OLS and fixed-effects models, it was possible to assess overall trends and the importance of each identified variable in the final outcome.

Addressing water use measurement issues. Water use data maintained by utilities reflect information captured for billing and metering purposes, not for economic or forecasting analyses. As such, much of the information necessary for a detailed economic analysis is simply not available. Some of the issues that complicate consistent collection and analysis of household water use data over time and across utilities are:

- Some utilities do not meter water use. Rather, they simply charge each customer a flat fee per month and supply all the water the customer chooses to use. The random sample of 200 utilities included at least three (South Lake Tahoe, Calif.; Saint George, Utah; and Juneau, Alaska) that did not meter use.
- Some utilities do not distinguish water use by customer type. They meter water use on a monthly, bimonthly, or quarterly basis, but they do not differentiate between residential, commercial, industrial, public use, or other types of customers. Thus, historical data on use per customer reflect patterns across many customer types. The random survey included two utilities (Bristol, Conn., and Sonora, Calif.) that did not distinguish by customer type.
- In databases of water customers, there is no standard way to treat single-family and multifamily residential units. Some utilities break these out carefully; others treat both simply as part of a residential total; still others measure housing units inconsistently. This is an important issue because apartment complexes may contain dozens or hundreds of housing units, use individual or group metering, and may have very different demographic characteristics than single-family homes. In some cases, a user is deemed a residential customer if the building's water supply pipe is below a certain diameter, for example, $^5/_8$ inch, and a commercial customer if the pipe is larger. In this case, a large apartment complex will have many households but will be treated as a single commercial customer.
- Few utilities maintain time-series data longer than 5–10 years. Longer time series are necessary for analysis of use patterns because weather conditions can cause major year-to-year fluctuations in use per customer. Moreover, a utility's service territory can frequently change as exurban developments are annexed, as wholesale customers are converted to retail customers, or as utilities are merged or acquired.
- The water industry does not have a standardized methodology for customer billing classification. Academic researchers and industry officials acknowledge that most water companies group customers according to similar "use characteristics"—such as amount of water consumed, topographic constraints, and service type—rather than actual property use (Dziegielewski & Opitz, 2002). This approach poses a problem when water consumption patterns are analyzed based on economic and demographic models.

Although utilities often had extensive information available, it was not all usable for analysis. This study worked with utilities to clarify classifications and merge select datasets when necessary for analysis. When data were not sufficiently detailed or did not fit defined parameters, they were excluded. The study focused on those datasets that were robust and detailed enough to provide a reliable foundation for analysis.

Declining residential water use has also been noted by utilities in communities not commonly associated with arid or water-poor regions.

A LOOK AT THE NATIONAL TRENDS

A key component of this study was investigating national trends in water use patterns and learning whether declining use was pervasive geographically or limited to certain regions or types of utilities. A random sample of water utilities was compiled and stratified by size, climate variables, ownership type, primary water source, and customer base. The utilities were requested to participate in a survey and provide historical use data. The study's statistical model of single-family residential customers' water use estimated the relationship among six variables: utility size, water source, ownership type, precipitation zone, temperature zone, and a drought index. The primary objective of the national survey of water providers was to determine the consumption trends per single-family residential customers throughout North America.

Details of the sample design. The national trends analysis began with a comprehensive database of water utilities comprising all respondents to the AWWA 1999 Financial/Revenue Survey (AWWA, 2001). The database contained information for approximately 4,000 water utilities. However, there were many inconsistent entries and blank fields in the database, limiting the sample to 602 viable utility entities. The study used interval measurements for population size and percentage of water sales to industrial customers and used these along with binary variables for water source and ownership type. The utilities were further coded by climate characteristics and precipitation and temperature zones, as set by the National Oceanic and Atmospheric Administration (NOAA) and Environment Canada. The zone numbers correspond to increasing precipitation and temperature and thus were ideal for inclusion in the regression analysis.

The six measures of utility and climate characteristics were used to stratify the 602 utilities. A random sample of 200 of these utilities was selected for inclusion in the survey, and 43 elected to participate. Although limited in size, the responding utility group was statistically representative of the full sample. The 43 responding utilities were located across 22 states, two Canadian provinces, seven precipitation zones, and five temperature zones. They represented all utility types and size classes. Collectively, they provided 605 annual observations on water use per single-family residential customer for just more than 14 years of use data. Table 1 summarizes the distribution of those observations across the six variables. Figures 2 and 3 summarize the climate characteristics of the sample utilities.

On average, each utility provided 14 years of data for the national trend survey. The average single-family household water use varied widely among the participating utilities. The mean was 84,387 gallons per year, with a standard variation of 44,092 gallons. Carpinteria, Calif., reported the highest average use, 160,345 gallons, whereas the Gold Heart Water District in Fairbanks, Alaska, reported the lowest average use, 47,024 gallons.

Analysis of the model. The variable of most interest in this study was the time trend (Table 2). With the OLS model, the estimated coefficient of –200.5 indicated that, on average, single-family households have been reducing their water use by 200.5 gallons per year over the past three decades. However, the large standard error indicated that the coefficient estimate was imprecise and further study was needed.

The fixed-effects model estimated an even more pervasive decline in water use per single-family household across the United States and Canada over the past three decades than the OLS model. The fixed-effects model estimated an annual decline of 388 gallons per year over the past 30 years. Although this estimated decline in use may be viewed as negligible, the long-term consequences are important. A household in the 2008 billing year used 11,678 gallons less water annually than an identical household did in 1978.

The effects of climate variables. The three climate variables of average precipitation, average temperature, and Palmer drought severity index measures were all statistically important in explaining water use. Through the nine zones, annual residential water use fell as precipitation rose, ranging from almost no rain to more than 80 inches per year. This pattern presumably reflects that lawn and landscape irrigation

TABLE 1 Categorization of survey respondents

Partner Utilities	Annual Temperature Zone*—°F	Annual Precipitation Zone†—*in.*	Ownership	Primary Water Source	Population Size	Industrial Percentage of Total Water Sales—%
> 30			41 (public)	17 (groundwater)	26 (> 50,000)	12 (> 1)
30–40		1	2 (private)	20 (surface water)	5 (50,001–150,000)	7 (> 5)
40–50	1	0		6 (purchased water)	7 (150,001–500,000)	10 (5–20)
50–60	0	16			5 (> 500,001)	6 (20–40)
60–70	5	17				2 (> 40)
70–80	2	8				6 (unknown)
> 80	11	1				
	11	0				
	12					
	0					
	0					
	1					
	0					

Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. *North American Water Usage Trends Since 1992*. ©2010 Water Research Foundation. Reprinted with permission.

*From Figure 2
†From Figure 3

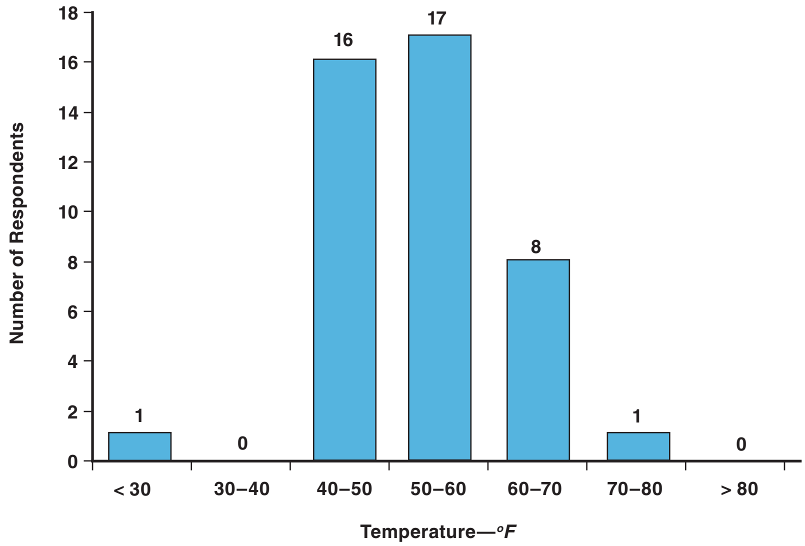
are not needed in the rainiest climates, and conversely, outdoor watering is heavily used in arid climates. A valid, if rough, interpretation is that a household located in a zone receiving 36–45 inches of precipitation per year would use an average of 15,233 more gallons than the same household in a zone receiving 45–63 inches per year. This difference in consumption amounts to 17.4% of the average customer's use in the sample.

Additionally, average temperatures were strongly correlated with water use. The interval scale showed that a customer living in a zone with average temperatures between 60 and 70º would use on average 14,514 more gallons than a customer living in a zone where temperatures averaged between 50 and 60º. This difference amounts to 16% of the average customer's use in the sample. This difference in consumption can be attributed to the increased outdoor water use demand associated with higher temperatures.

The drought index is geographically more specific to each utility than the broad regional precipitation and temperature zones. As was the case with the other two climate measures, the estimated coefficient was statistically significant. For example, a movement in the average annual drought index from a value of –1 (mild drought) to a value of –2 (moderate drought) increased average water use by 646 gallons per year. The drought index, although statistically significant, cannot be taken at face value. Although dry conditions encourage more water use, mandatory restrictions may reduce water use.

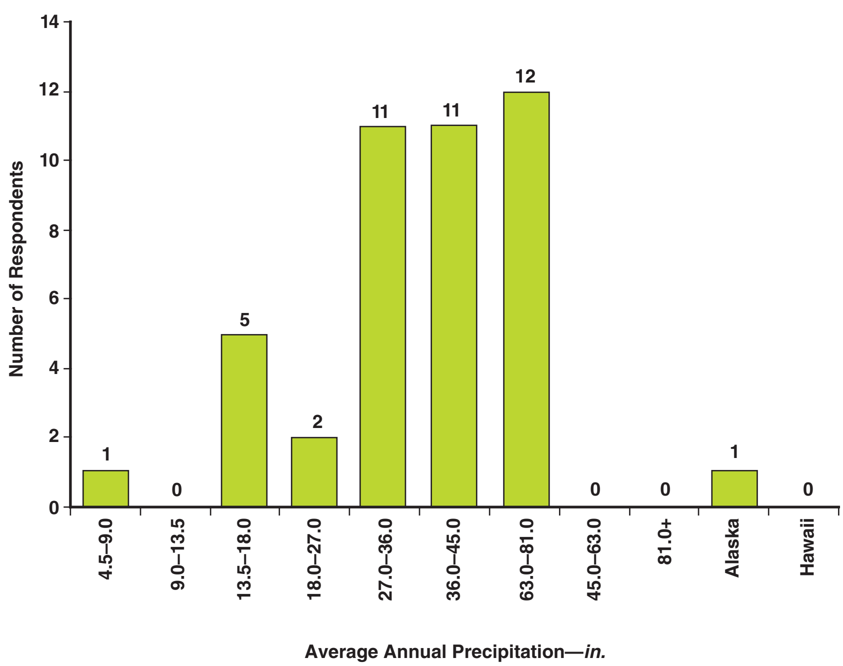
Number of accounts and type of ownership variables' impact. The OLS model estimated a negative and statistically significant relationship between the number of residential accounts and residential water use per customer (Table 2). A growth of 1,000 single-family households was associated with a decline in use of 88.7 gallons per customer annually. This pattern

FIGURE 2 Distribution of average annual temperature by survey respondents, 1971–2000



Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. North American Water Usage Trends Since 1992. *©2010 Water Research Foundation. Reprinted with permission.*

FIGURE 3 Distribution of precipitation zone by survey respondents, 1971–2000



Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. North American Water Usage Trends Since 1992. *©2010 Water Research Foundation. Reprinted with permission.*

could plausibly be interpreted as a measure of urbanization. Large cities tend to have higher population density, higher land prices, smaller yards, and fewer people per household. Smaller water districts often are dominated by suburban households and rural communities, which use more water per household. The OLS model estimated that the type of utility ownership did not have a statistically significant effect on single-family household use.

National survey summary. The national trend survey found that there has been a pervasive decline in water use among single-family, residential customers across the United States and Canada. However, the aggregate data did not indicate which factors caused the decline.

REGIONAL CHARACTERISTICS BROKEN DOWN

To identify and characterize regional variations in water use trends, the study developed partnerships with 11 utilities in nine US states and one Canadian province. Study participants provided aggregate annual residential use data and participated in in-depth interview sessions. Nearly all reported a long-term decline in water use among single-family residential customers, but the analysis showed considerable variation among utilities.

Details of the sample design. The study requested 30 years of annual account and use data from each partner. The period of data that was provided varied according to the utility's specific recordkeeping protocol and the availability of historical records. All partners provided a minimum of 11 years of residential use data. Water use data for other customer classes (multifamily, commercial, and industrial) were requested but were not available in all cases.

To gain further insight into the relationship among the utility's specific characteristics, customer behaviors, and historic consumption trends, each partner participated in an interview to explore its customer classification practices, rate structures, conservation practices, and water quality issues. The qualitative information gathered was not used for the statistical modeling process but was intended to provide case studies for other utilities. The case studies allow utilities to access information from others facing experiences similar to their own. Utility managers may extrapolate from the data the most salient points to assist them with making more informed planning decisions.

As in the national analysis, the regional analysis used climate measurements—the annual precipitation and temperature averages for each partner were obtained from NOAA and Environment Canada. The partner utilities were located across seven precipitation zones and four temperature zones.

The partners were publicly owned utilities serving urban communities with populations of more than 350,000 people. All partners except for New Haven (Conn.) and Saint Paul (Minn.) Regional Water Services served populations greater than 500,000 people. All partners used surface water (lakes and rivers) as their primary water source. One utility, Las Vegas (Nev.) Valley Water District, relied on a purchased water supply. Many of the partner utilities indicated they used groundwater to supplement their primary water supply or to meet peak demands.

The period of data provided by the partners varied, so descriptive analysis focused on the use data from 1996 through 2005. For this period, average single-family household water use varied widely among the partner utilities. The mean was 102,985 gallons, with a standard variation of 21,544 gallons. Las Vegas reported the highest average use at 203,483 gallons. Seattle, Wash., reported the lowest use at 61,593 gallons. Table 3 shows a statistical summary of the annual single-family use per account for each partner from 1996 through 2005. Figure 1 provides an overview of the regional partners' residential use.

How the regional data were analyzed. As with the national survey, two statistical models were used to

TABLE 2 Average annual water use per single-family residential customer

Variable	Ordinary Least-squares Regression (Standard Error)	Fixed-effects Model (Standard Error)	
		Number of Customers Included	Number of Customers Excluded
Precipitation zone	–15,233* (1,003)		
Temperature zone	14,514* (1,516)		
Ownership type	3,821 (6,869)		
Water source	7,923* (3,018)		
Number of customers	–0.0887* (0.0296)	–0.0155 (0.122)	
Percent industrial	–4,908* (1,121)		
Drought index	–2,256* (695.8)	–738.8† (333.5)	–741.3† (332.6)
Drought index squared	536.7† (237.3)	123.0 (113.4)	122.7 (113.3)
Time	–200.5 (176.4)	–380.8* (111.0)	–388.5* (93.15)
Constant	138,650* (9,068)	96,758* (3,547)	96,411* (2,269)
Observations	605	605	605
R^2	0.484	0.038	0.038

Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. *North American Water Usage Trends Since 1992*. ©2010 Water Research Foundation. Reprinted with permission.

*$p > 0.01$
†$p > 0.05$

National-level regression results, 43 water utilities, mixed time ranges, 1975–2006 assess the regional level data (Table 4). First, OLS was used to run a simple regression of average water use against climate, water source, size, drought, and trend variables. Second, a fixed-effects model served to identify the time-invariant place characteristics of each utility. In this regional study, the categorical variables were more similar than they were in the national survey.

The estimated coefficients on the time-trend variable used to estimate residential water use decline were large and statistically significant in both models. The coefficient estimate was –427.9 in the OLS model and –381.9 in the fixed-effects model, a difference of only 46 gallons per year. Clearly, both models show that the partner utilities have experienced similar declines in water use among residential customers. The degree of the decline was of similar magnitude as that estimated for the national component of the study. The average annual residential use for the complete partner data set was 86,012 gallons per year. Thus, the estimated annual decline for the utility partners was between 0.44 and 0.50% annually, or between 13 and 15% if compounded over 30 years. The OLS and fixed-effects model results are shown in Table 4.

What the regional survey trends indicate. The results of the regional study were similar to those in the national study. The estimated coefficient on the regional time variable (–381.0) in the fixed-effects model was almost identical to that in the national model (–388.5), providing some confidence that the annual trend in water use is indeed pervasive and of similar magnitude throughout the United States and Canada.

LOOKING AT LOCAL BEHAVIOR

The national and regional trend surveys found that there has been a pervasive decline in water use among single-family residential customers across the United States and Canada. However, the aggregate data did not show which factors caused the decline. To help identify underlying causes of the decline in relatively water-rich communities, a local-level water use analysis was performed in cooperation with the LWC. This study built on the results of the 1999 Mayer et al study.

Within the Louisville community, water use for the average single-family household peaked late in 1988 at around 7,000 gallons per month per household. By 2004, water use was just 5,600 gallons per month per household, a decline of 20% (Figure 4). Suggested explanations for the decline include wetter weather, new water-conserving appliances, declining number of people per residence, measurement problems (deteriorating meters), and classification anomalies. Classification anomalies include multifamily residences variously considered commercial or residential accounts and sometimes reclassified during periodic inspections. These factors would cause data to show a decline in water use per residence, but the relative magnitude of each effect was unknown.

To assess the relative magnitude of the demographic factors and other characteristics of individual households, a two-stage assessment program was implemented. First, a 48-question survey was mailed to a stratified random sample of 1,002 LWC households. The survey included questions about the type and number of water-using appliances in the home, types of outdoor water use, characteristics of the housing structure, number and ages of residents, and education of the primary wage-earner. This survey

TABLE 3 Descriptive statistics—*gallons per year*

Regional Partner*	Mean	Standard Error	Median	Standard Deviation	Sample Variance	Range	Minimum	Maximum
Calgary, Alta. (6)	79,525	939	79,742	2,301	6,792	75,815	82,606	477,151
Cincinnati, Ohio (10)	69,822	1,489	70,723	4,710	14,272	63,242	77,514	698,217
Cleveland, Ohio (10)	77,341	2,059	76,783	6,510	16,984	68,481	85,465	773,410
Dallas, Texas (10)	124,147	3,312	123,048	10,474	33,126	111,070	144,197	1,241,472
Las Vegas, Nev. (10)	203,483	6,816	206,883	21,555	73,189	161,167	234,357	2,034,831
Louisville, Ky. (10)	71,236	1,046	71,076	3,307	12,067	66,364	78,431	712,363
New Haven, Conn. (10)	109,558	1,693	110,943	5,353	15,877	102,274	118,152	1,095,575
Philadelphia, Pa. (10)	82,764	919	82,505	2,906	9,448	78,431	87,879	827,637
Phoenix, Ariz. (10)	160,844	2,712	163,860	8,576	26,032	143,988	170,020	1,608,439
Saint Paul, Minn. (8)	92,526	1,820	92,636	5,146	15,355	85,815	101,169	740,208
Seattle, Wash. (10)	61,593	1,418	61,559	4,484	13,837	53,634	67,471	615,933
Average (9)	102,985	2,202	103,614	6,848	21,544	91,844	113,387	984,112

Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. *North American Water Usage Trends Since 1992.* ©2010 Water Research Foundation. Reprinted with permission.

*Numbers in parentheses indicate the number of records.

information was then paired with water billing records and real estate assessment information to form a rich data set for assessing the influence of demographic factors, house vintage, home value, water-using appliances, behavioral patterns, lot size, significant water features, and types of irrigation on water use.

The second stage of the local water use assessment included a field study in which data loggers were attached to 65 residences to record water-using activities. With assistance from a private company,[1] data loggers were installed on meters outside the homes for 14 days to record water flows into the home at 10-second intervals. The resulting use record was matched to the inventory and flow signatures of water-using appliances in the home, enabling a detailed breakdown of how and when customers used water. By focusing on the daily use patterns of actual customers, the study could record and measure the effects of demographics, water-conserving appliances, and other factors.

Performing the local-level study in a two-stage process enabled the development of a robust database that combined water use and demographic information with publicly available information from census tracts and tax records. With this combined information, it was possible to measure the independent effects of

- weather—local temperature, precipitation, and soil moisture,
- demographic factors—the number of people in the home and their ages,
- housing vintage—age of home, as one measure of water infrastructure,
- home value and size—as a proxy for income of household,
- water-using appliances in home—inventory of number, type, and vintage,
- seasonal behavioral patterns—snowbirds leaving for winter, students returning from college, holidays,
- lot size, housing footprint on lot—a measure of potential lawn and landscape watering, and
- significant water features—such as swimming pools and fountains.

What the model analysis showed. Similar to the national and regional findings, the LWC has also seen a reduction in water use per residential customer. An OLS statistical model was developed to investigate the independent effects of weather, demographics, economics, indoor appliances, and outdoor water features. The model was estimated in stages, progressively adding groups of variables, to reveal any sensitivity to coefficient estimates as the model broadened. The results of the local behavior model are shown in Table 5 and discussed in detail later.

The combination of demographic information and consumption data provided the opportunity to assess actual water use for each home by type of appliance, timing, length, and frequency of use. The model showed that household demographic and economic factors contribute to changing water use trends. Fewer people per household decreased water use, and the amount used varied according to the ages of the residents. Specifically, in Table 5, model 6 estimates that each adult contributes about 36 gpd to household water demand, while each teenager contributes 32 gpd. Each grade-school aged child adds about 18 gpd to household water demand, while a preschooler adds about 10 gpd. Contrary to Lyman's (1992) work, the model estimates that the number of babies and toddlers in the home has no independent effect on household water use in the Louisville market.

Although newer homes in the study had higher daily use than older homes, this was shown to be a function of demographics. Certain types of neighborhoods tend to attract residents with common lifestyles, and those lifestyles affect use. New subdivisions tend to attract families with school-age children, which results in larger household sizes and higher daily household water use. On the other hand, neighborhoods full of older homes tend to attract artists, students, and small households. As shown in Table 5, model 6 estimates that homes built after the 1994 amendments to the Clean Water Act imposed uniform water efficiency standards actually use about 13 gpd less than those built before 1994, after controlling for household demographic, household size and value, indoor water-

TABLE 4 Average water use per single-family residential customer

Variable	Ordinary Least-squares Regression (Standard Error)	Fixed-effects Model (Standard Error)
Precipitation zone	–7,195* (–844.3)	
Temperature zone	16,682* (–1818)	
Water source	–54,852* (–2956)	
Number of customers	–0.0401 (–0.0110)	–0.0463* (0.0182)
Drought index	–2,375* (–698.7)	–1.562* (245.9)
Drought index squared	291.3 (230.2)	101.7 (78.51)
Time	–427.9* (–151.2)	–381.9* (61.70)
Constant	154,502 (7,973)	103,830* (3,371)
Observations	264	237
R^2	0.614	0.37

Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. *North American Water Usage Trends Since 1992*. ©2010 Water Research Foundation. Reprinted with permission.

*$p > 0.01$
†$p > 0.05$

Regional partner utilities regression results, 11 large urban water utilities, mixed time ranges, 1975–2007 using appliances, and outdoor watering practices and features. In other words, if one family lived in an older home and an identical family lived in a home built after 1994, the family in the newer home would use less water.

Homes in the sample ranged in value from $28,800 to $628,520, and the estimated coefficient implies that the most expensive home consumed 100 gpd more than the least expensive home. Homes in the sample varied between 494 and 5,687 square feet, and the largest home used 86 gpd more water than the smallest home, after controlling for value. This finding likely reflects the additional appliances and outdoor watering habits of higher-income customers, which offset the more efficient appliances in newer homes.

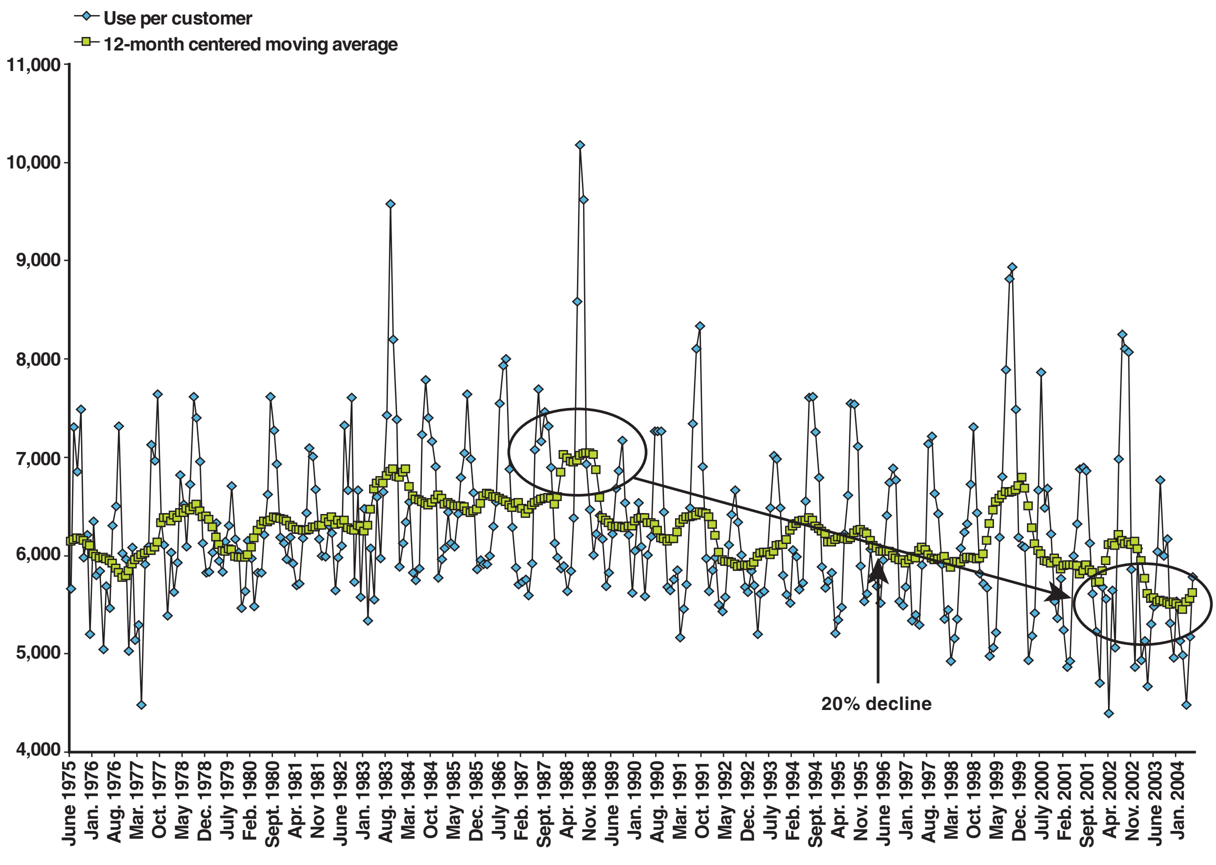
The influx of water-efficient fixtures and appliances into the market is the other major determinant in household water use. Toilets, showers, and washing machines are the largest indoor users of water. In the Louisville sample, 17% of the homes contained ultralow-flush (ULF) toilets, 79% contained low-flow showerheads, and 12% contained efficient washing machines. Table 6 compares water use of homes with and without these water-conserving fixtures.

The installation rates from the household sample can be applied to the universe of LWC residential customers to make an inference about how much water households would be using if there were no low-flow appliances. In 2007, LWC had 245,729 residential customers, with an average daily use of 194.9 gallons. Removing the estimated effect of the low-flow appliances would raise average daily water use to 210.8 gallons, an increase of about 8%. This translates into an average "conservation" effect of 0.63% per household per year.

Although it is estimated that the low-flow showerheads have saturated the Louisville market with a 79% installation rate, the same cannot be said of the ULF toilets or washing machines. As ULF toilets and efficient washing machines replace older ones, the LWC can expect continued reduction in daily household water use.

Implications from the model. With the development of the water use model specific to the LWC, it is possible to assess and interpret the influence of the variables with respect to local conditions. Historically, water

FIGURE 4 Water use per residential customer of the Louisville (Ky.) Water Company, 1975–2000



Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. **North American Water Usage Trends Since 1992.** *©2010 Water Research Foundation. Reprinted with permission.*

use per customer in the Louisville area peaked in the late 1980s, with a subsequent negative trend (Figure 4). After adjusting for weather, demographics, and housing variables, the average LWC household water use fell from 208 to 187 gpd between 1990 and 2007. This amounts to a 21-gpd reduction in use per single-family account over the 17 years shown, a decline of 10%. Table 7 shows a breakdown of the key factors and their estimated influence on LWC households.

During this same period, the average number of people per household in Jefferson County, Ky., fell from 2.52 to 2.38. The 2007 water use model shows the average person using about 36 gpd. This reduction in household size would lead to a decline in average daily household water use of 5 gallons [(2.52–2.38) × 36] over the period. Demographic changes

TABLE 5 Ordinary least-squares models of average daily water use from 293 randomly selected residential customers of the Louisville (Ky.) Water Company

		Model Number					
	Parameter	**1**	**2**	**3**	**4**	**5**	**6**
Bin 1	Average monthly precipitation—*in.*	–0.0380 (0.565)	–0.0740 (0.510)	–0.0729 (0.500)	–0.0882 (0.495)	–0.0718 (0.475)	–0.0962 (0.459)
	Average monthly temperature—*°F*	0.767† (0.308)	0.750* (0.278)	0.745* (0.273)	0.737* (0.270)	0.739* (0.259)	0.728* (0.251)
	Palmer Modified Drought Index—*–4 to +4*	–2.554* (0.496)	–2.589* (0.448)	–2.613* (0.439)	–2.612* (0.435)	–2.594* (0.417)	–2.599* (0.403)
Bin 2	Total number of residents		35.55* (0.742)				
	Adults			45.72* (1.124)	43.29* (1.234)	38.09* (1.207)	36.37* (1.205)
	Teens			48.83* (2.097)	46.90* (2.081)	34.48* (2.062)	32.24* (2.039)
	Grade-schoolers			28.60* (1.827)	24.13* (1.843)	20.69* (1.777)	18.69* (1.737)
	Preschoolers			5.919 (3.975)	7.629‡ (3.957)	13.22* (3.822)	10.62* (3.727)
	Babies, toddlers			2.107 (2.774)	–3.168 (2.775)	–4.436‡ (2.686)	1.113 (2.620)
Bin 3	Number of workers				5.404* (1.093)	6.694* (1.055)	6.521* (1.035)
	Education level				7.883* (0.666)	3.400* (0.660)	3.593* (0.654)
	Year home built					0.226* (0.0515)	0.176* (0.0529)
	Built after 1994—no, yes					–11.66* (3.492)	–10.42* (3.503)
	Assessed value of home					0.181* (0.0324)	0.105* (0.0338)
	Square footage of home					20.34* (2.871)	23.96* (2.822)
Bin 4	Bathtubs with showers—*number*						–2.891 (1.806)
	Bathtubs only, no shower—*number*						11.91* (2.140)
	Showers only, no bathtub—*number*						–7.622* (1.948)
	Top-loading washing machine—*no, yes*						9.635† (4.126)
	Front-loading washing machine—*no, yes*						–0.814 (4.339)
Bin 5	Water outdoor landscaping—*no, yes*						9.684* (1.666)
	Swimming pool—*no, yes*						65.19* (2.982)
	Outdoor spa—*no, yes*						13.62* (3.828)
	Constant	109.5* (13.03)	29.22† (11.88)	13.09 (11.71)	–11.35 (11.78)	–484.5* (100.8)	–394.1* (103.4)
	Observations	10,146	10,146	10,146	10,146	10,146	10,146
	R^2	0.036	0.214	0.246	0.260	0.318	0.364

Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. *North American Water Usage Trends Since 1992*. ©2010 Water Research Foundation. Reprinted with permission.

*$p > 0.01$
†$p > 0.05$
‡$p > 0.1$

Standard errors in parentheses; all models include monthly dummy variables, not shown.

thus explain approximately one fourth of the total 21-gallon decline in use per household.

Although changing demographics can account for a portion of the declining water use, other variables contribute to rising water use. Within the Louisville area, there has been a slow but steady increase in educational attainment since 1990, raising the value of the education index from 2.45 to 2.81. Multiplied by the coefficient in model 6 (Table 5), this implies a rise in daily water use of 1.3 gallons.

Similarly, home values in Jefferson County have risen from $120,100 to $144,600 (in constant 2007 dollars) over the period, implying an increase in water use of 3.5 gpd. There is no direct local measure of home square footage over time; however, the US Census Bureau provides a national measure. It shows that the average square footage for a single-family home increased from 2,155 to 2,581 between 1990 and 2007. Applying the regression coefficient from model 6 yields a growth in average daily water use of 0.6 gallons as a result of the larger home size. Thus, income-related measures suggest that the average household has increased water use by 5.4 gpd.

The decline in number of residents per household is also an important factor in falling water consumption per residential customer. However, this decline appears to be more than offset by higher household incomes. Higher incomes have led to larger homes, with more water-using appliances and more landscape irrigation. This study attributes the remaining estimated net decline in water consumption, about 19 gpd, to the increased use of low-flow appliances in the Louisville market (Table 7).

A COMPARISON OF LOCAL STUDIES

Although there have been several studies that physically measured the type and volume of water use in individual homes (Denver Water, 2006; Mayer et al, 1999; Brown & Caldwell, 1984), there have been few end-use studies conducted in the water-rich regions of the United States. The LWC end-use study enables a comparison between the experiences of water-poor regions with those of a water-rich region. The most recent data from the Denver Water (2006) study provided a particularly relevant comparison (Figure 5).

Both the Denver Water (2006) end-use study and the Louisville study exhibited a decline in daily household use from the baseline established with the Residential End Use Water Study (REUWS; Mayer et al, 1999). In the Louisville study, households used consistently less water (151 gpd) than those in the REUWS (177 gpd) baseline. The Denver Water study showed a similar decline in daily household use (155 gpd). In both cases, the decline is attributed to two factors—the lower number of people per household and higher installation rates of low-flush toilets in the Denver and Louisville housing markets.

In both studies, the average number of people per household was fewer compared with the REUWS average of 2.7. As shown in Table 8, Denver households averaged 2.5 people per household, whereas the Louisville households averaged 2.24 people.

In both studies, households also showed a higher installation rate for water-efficient appliances and fixtures than the REUWS households. The REUWS, released in 1999, reported only 9% of households contained ULF toilets (< 2.0 gpf). Within the Louisville sample, the installation rates measured for ULF toilets (≤ 2.0 gpf), low-flow shower heads (2.5 gpm), and water-efficient washing machines (30 gallons per load) were measured at 17, 79, and 12%, respectively. These rates were similar to those observed in the 2006 Denver Water study, which were 19.8% for ULF toilets and 19% for water-efficient washing machines. The installation rates for low-flow showerheads were not included in the Denver Water study, although the average shower flow rate was 2.21 gpm, indicating a high incidence.

SUMMARY AND CONCLUSIONS

This research investigated trends in household water use in North America. When controlling for weather and other variables, the evident decline in residential use was pervasive among the national and regional components of the study. A household in the 2008 billing year used 11,678 gallons less water annually than an identical household did in 1978.

TABLE 6 Comparison of water use for homes with and without water-conserving fixtures

Fixture/appliance	Households Using Low-flow Fixtures/Appliances—%	Number of People per Household		Fixture/Appliance Use Events per Day		Water Use per Household per Day—*gal*	
		Low Flow	Other	Low Flow	Other	Low Flow	Other
Toilets	17	2.3	2.2	10.4	11.7	18.5	43.6
Showers	79	2.4	2	1.5	1.5	21.8	26.6
Washing machines	12	2.1	2.3	1.2	0.08	26.7	33.9

Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. *North American Water Usage Trends Since 1992.* ©2010 Water Research Foundation. Reprinted with permission.

TABLE 7 Breakdown of Louisville (Ky.) Water Company residential water decline between 1990 and 2007

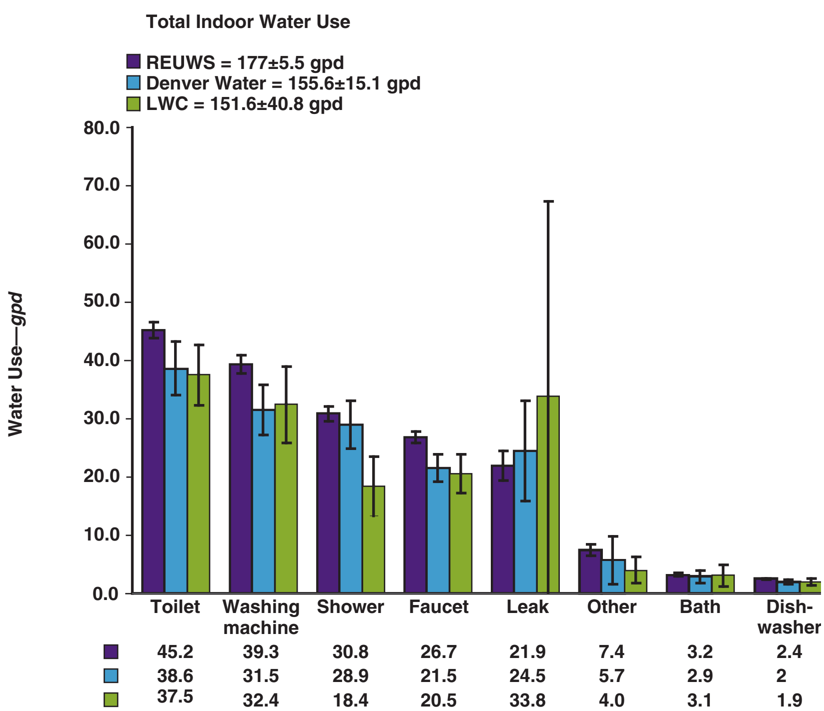
Parameter	1990	2007	Allotment—*gpd*
Household use—*gpd*	208	187	–21
PMDI	0.29	0.75	–2.6
People per household	2.52	2.38	–5
Educational index	2.45	2.81	+1.3
Average home value—*$*	$120,100	$144,600	+3.5
Home size—*sq ft*	2,155	2,281	+0.6
Total			–18.8*

Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. *North American Water Usage Trends Since 1992.* ©2010 Water Research Foundation. Reprinted with permission.

PMDI—Palmer Modified Drought Index

*Remaining decline in household water use attributed to installation of water-efficient fixtures and appliances

FIGURE 5 Comparison of average daily household indoor water use



Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein.* North American Water Usage Trends Since 1992. *©2010 Water Research Foundation. Reprinted with permission.

LWC—Louisville (Ky.) Water Company, REUWS—Residential End Use Water Study

Data compiled from LWC (2007), Denver Water (2006), and Mayer et al (1999).

TABLE 8 Comparison of average number of people per household for three studies

Study	Year	Number of People Per Household
REUWS	1998	2.7
Denver Water	2005	2.5
Louisville Water Company	2007	2.24

Source: Coomes, P., T. Rockaway, J. Rivard, and B. Kornstein. *North American Water Usage Trends Since 1992.* ©2010 Water Research Foundation. Reprinted with permission.

REUWS—Residential End Use Water Study

To investigate the causes of this decline, a local study of statistically representative households of the LWC was conducted in Louisville. Adjusting for weather, water use per LWC customer fell from 208 to 187 gpd between 1990 and 2007, a decline of 21 gallons. Data-logging devices were installed at participating homes, and the data were incorporated into statistical models to examine possible causes and the relationships among socioeconomic factors, demographic factors, water-using appliances, behavior patterns, significant water features and types of irrigation, and residential water consumption. Demographic factors can account for a decline of 5 gallons, whereas income-related factors suggest an increase of about 5.4 gallons. This study attributes the remaining estimated net decline, about 19 gpd, to the increased installation of low-flow appliances in the Louisville market (Table 6).

Although there has been a clear trend of declining residential customer water use over the past 25 years, this trend may begin flattening over the next 20 years. There are some indications that the two main factors driving this decline—declining household size and increased efficiency appliance standards—may not have as strong an impact on water use in the future. Both of these trends have theoretical limits on how low they can go.

First, census data show that between 1950 and 2000 the average household size fell from 3.38 to 2.59 (Bianchi & Casper, 2000). Average household size was projected to experience a slow decline to 2.53 by 2010 as it began to flatten out. Instead, the census numbers show the average household size increased to 2.63, a small but significant rise. The increase is attributed to demographics, high unemployment, and cultural shifts (Nasser, 2010). It is unknown whether this rise will be temporary or if average household size will eventually resume its flattening trend.

Second, there is a limit to how efficient a water-using appliance can become. Although new efficiency standards are becoming more stringent, the percentage change will be smaller than the landmark 1992 Energy Policy Act (AWR, 2008; USEPA, 2008).

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FOOTNOTE

[1]Aquacraft, Boulder, Colo.

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