Title

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Impact of “Non-Behavioral Fixed Effects” on Water Use: Weather and Economic Construction Differences on Residential Water Use in Austin, Texas

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The purpose of this study is to determine the effects of weather and economic construction factors on residential water consumption in Austin Green Builder homes as the case study. By examining the impact of these "fixed effects" on water use, future water needs can be more accurately predicted and water use policies more effectively developed and implemented. Temperature, rainfall, evaporation, home size, lot size, appraised value, and pools were all significant in the regression model (R^2=0.204), with temperature accounting for 13% of the variation, followed by appraised value (5%). Additionally, small changes in weather factors and if there was a pool resulted in marked differences in water consumption.

Introduction

Many studies have investigated factors affecting residential water consumption in order to better predict future water needs and to determine effective measures for water conservation. A problem with this task is the great geographic and socio-economic variability between areas. In addition, occupant behavior has been a significant influence but can be quite erratic (Baumann, Boland, & Hanemann, 1998) and difficult to measure. Strategies and policies would differ considerably if behaviors primarily determined water use versus the “fixed” effects of weather or geographic variables that are beyond our control. Additional “fixed effects” are home size and price differences that may be associated with differences in water consumption. Although some zoning and land use restrictions affect economic construction differences (e.g., lot size, house size, market value), residential development may simply expand elsewhere in a community or nearby area to accommodate these constraints. These “non-behavioral fixed effects” are easily measurable and can provide a fairly accurate basis for further study of the effects of occupant behaviors and specific home features. What is the impact of these “fixed effects” on water use? In turn, if a significant portion of water consumption is outside our control, what are the subsequent implications for water conservation strategies and policies?

The purpose of this study is to determine the effects of (1) weather (temperature, rainfall and evaporation) and (2) economic construction factors (home size, lot size, appraised value and pools) on residential water consumption, controlling for variation in other geographic factors by selecting one community as the case study. Austin, Texas was selected for this study for two reasons. First, the city has recently faced water crises as the city’s aquifer source experienced greater than average declines. Second, Austin has the oldest and one of the largest Green Building Programs for residential construction in the country. The idea and development of green building programs is spreading quickly across the country with approximately 30 residential green builder programs functioning and others in the development stages (NAHB, 2002; Energy Efficiency, 2003). Building techniques purported by these programs (e.g., xeriscaping, rainwater catchment systems, natural vegetation, modified plumbing and appliances) are expected to significantly reduce water consumption. However, only after determining the “fixed effects” of weather and economic construction differences on water consumption can we isolate policies for green building construction that will truly have an impact on residential water conservation. These "fixed effects" of weather and economic construction differences would be consistent regardless of user behaviors. Thus, the analysis to determine the contribution of these factors in accounting for variation of water use is important not only to better predict water use patterns for future needs but also to isolate those factors beyond our control versus those that can be modified by policies.

Background
Texas Water Consumption

Texas is among the top four water consuming states in the U.S. (Wagner & Kreuter, 2002). Currently, agricultural irrigation accounts for the largest percentage, but by 2050, municipal demand is projected to greatly increase its share from 25% to 35% (an increase from 4.23 to 7.06 million acre-feet/year)(National Wildlife Federation, Environmental Defense, and Lone Star Chapter of the Sierra Club, 2001) (Wagner & Kreuter, 2002). Agricultural demand is expected to drop from 57% to 42% by 2050 (National Wildlife, 2001) due to a gradual decline in the number of irrigated acres and farmers practicing better water conservation techniques (Texas Environmental Profiles, 2005). Over half of municipal water use has been attributed to residential demands (Howe & Linaweaver, 1967). Although residential demands currently represent a fairly small percentage of total water consumption, its percentage is expected to increase. Hence, in the search for conservation alternatives, residential construction will become increasingly important, both in terms of water use and water infrastructure.

With the State's escalating demand for municipal water comes increasing anxiety about water shortages. The Governor's task force in 2000 identified limited water supply as one of the two "most serious natural resource issues facing Texas today" (Wagner & Kreuter, 2002). Part of the reason for this concern is the fact that conventional fresh water supplies in Texas are already 75%-80% developed (Texas Water Development Board, 1995) whereas the population of the state is anticipated to double in the next 50 years (National Wildlife Federation, et al., 2001).

Created in 1997 to address growing demand issues, The Texas State Water Plan recommended a range of actions to ensure water for the future, ranging from conservation measures to dam construction. Related poll results indicated that Texas residents favored conservation efforts as opposed to costly supply side initiatives. This has not, however, been reflected in the plans of the various agricultural, municipal, city and county water groups. Only 21% has included water conservation to any extent in their plans for future supply (National Wildlife Federation, et al., 2001).

Over 600,000 acres of forested wetlands in Texas have already been replaced with deep-water aquatic habitats as a result of reservoir construction (Texas Environmental Profiles, 2003). The 1997 Texas Water Plan proposed the conversion of an additional 52,000+ acres of wetlands to deep-water habitats. Opponents claim this harms existing wildlife and penalizes users downstream with decreased water flow. Alteration also increases costs for water treatment as discharged, water must meet higher standards because it flows into more diluted rivers and streams (Texas Environmental Profiles, 2003).

Texas currently spends approximately $1 billion a year on new water treatment, sewage and drainage (Texas Environmental Profiles, 2003). Additional costs are expected to approximate $65 billion by 2050 for proposed new water treatment, supply and drainage infrastructure (Texas Environmental Profiles, 2003). However, these estimates and past costs did not take into consideration and include conservation alternatives. These alternatives may curb the costs as well as preserve the supply for the predicted increasing demand.

Austin Water Consumption and Conservation

Austin currently has the 10th highest per capita water consumption in Texas - 213 gallons/person/day (National Wildlife Federation, et al., 2001). The average single-family household in the City per year used approximately 120,000 gallons of water. Of this amount, about 45% of summertime water use has been attributed to exterior watering (City of Austin, 2000). Variations in the time of day and season have been shown to significantly affect outdoor water use, raising it to levels several times that of indoor water consumption in arid regions of the country in summer months (Hanke & Mare, 1984). This temperature-dependent increase is attributed to the additional water requirements of lawn irrigation, air conditioning and swimming pools (Hanke & Mare, 1984).

The City of Austin stands out in Texas and nation-wide as a leader in sustainable construction and development that promotes water conservation. The City has developed and accepted a Sustainable Communities Initiative (SCI). The SCI is part of Austin's Transportation, Planning, and Sustainability Department, and program staff report to the City's Sustainability Officer. Since 1996, SCI staff has created plans, performed evaluations and educated city staff and the public to make Austin more sustainable. In addition, Austin also emphasizes sustainable practices through numerous other programs such as the Water Conservation Program, Air Quality Program, Watershed Protection Department, 'Dillo Dirt program, Smart Growth Initiatives, Recycling Programs and the Austin Green Builder Program (The City of Austin's, 2001).

The average Austin household uses 120,000 gallons of water a year; whereas newer homes, built under the requirements of the current plumbing code, use approximately 100,000 gallons (City of Austin Environmental and Conservation Services, 2002). It has been projected that Green Building Program homes could potentially reduce water use to just 36,000 gallons per year. This reduction would be the result of six key water conservation techniques (City of Austin Environmental and Conservation Services, 2002):

1. Efficient fixtures
2. Xeriscape
3. Efficient irrigation systems
4. Rainwater collection
5. Graywater use
6. Landscape designed to prevent run-off

The Green Building Program now offers financial incentives to reduce water usage. A $1,000 per home stipend is available with $600 towards a minimum 25% compost topsoil and $400 for approved low-water use trees and shrubs (City of Austin, 2002). Using a 1-5 star rating system, the Program also awards points for limiting the size of a home below a certain square footage (maximum 1,200 s.f. for a 2-bedroom + 250 s.f. for each additional bedroom) (Austin Green Building Program Single Family, 1998). Additional points are given for incorporating water- and energy-conserving features. These features benefit the occupant by reducing home operating and maintenance costs.

Prior Research on Effects of Weather, Size and Cost in Residential Water Use

Several studies have attempted to determine the effect of weather, residence cost- and size-related factors on residential water consumption. Whereas rainfall and temperature have been shown to significantly affect water use in a number of studies, the patterns have differed (Anderson, Miller, & Washburn, 1980; Morgan & Smolen, 1976; Hansen & Narayanan, 1981). For example, Fourt (1958) found in a survey of 21 large cities that rainfall days, along with average number of people per meter and cost of water were significant factors affecting household water consumption (R^2 of .839) (Grima, 1972). This coefficient of determination (R^2) is defined as "the proportion of the variability in the dependent variable y that is accounted for by the independent variables $x_1, x_2, \ldots x_k$ of the model"(Ott, 1993). This study's high coefficient of determination ($R^2 = .839$) indicates that 84% of the variability in the dependent variable, water consumption, was explained by the independent variables of rainfall days, average number of people per meter and water cost. However, in other studies (Haver & Winter, 1963; Linaweaver, Gyer, & Wolff, 1967; Grima, 1972) climatic factors were not found to be highly significant.

Evapotranspiration (ET) has been found in various studies to affect outdoor water consumption (Danielson, et al., 1980; Duble, 1997; Mayer, 1995; Stadjuhar, 1997; Aquacraft, Inc., 1997). In a 1999 study of twelve cities, ET accounted for over half the variation ($R^2 = 0.59$) in outdoor water used when calculated as the amount above an indoor baseload using a data logger. However, when ET was compared to individual residences within each city, much less variation in water use was attributed to this weather factor (R^2 = 0.16) (Mayer, DeOreo, Opitz, Kiefer, Davis, Dziegielewski, & Nelson, 1999).

In a 1989 study of residential water use throughout Texas, Griffin and Chang (1989) found residential and commercial water consumption per capita (R^2= 0.39) was related to climate (number of days without rainfall times average monthly temperature and average annual precipitation from 1951-1980) along with average water price, annual income per capita, and percent of Hispanic origin population. Higher water price, greater proportion of Spanish population, and increased precipitation were associated with lower water consumption while increased income and number of days without rainfall were associated with increased usage (Griffin & Chang, 1989). Similar findings resulted from a study conducted by Hanke and Mare (1982) in Malmo, Sweden where a model was developed (R^2 =0.259) that included rainfall along with household income, number of adults and children per home, age of home, and water price. Rainfall and price were associated with reduced water consumption, whereas all other factors related to increased usage (Hanke & Mare, 1982).

The American Water Works Association recently sponsored a large residential end-use water study of twelve U.S. and 2 Canadian cities, with data comprised of billing records from 12,000 homes, survey information from 6,000 residences, flow trace data from 1,188 homes and weather records from each city (Mayer, et al., 1999). Mayer and others used these data to develop predictive formulas for water use. They found on average, 58% of water was consumed on outdoor purposes, although this number was higher in warmer climates (up to 67%). The mean annual water use for the cities was 146,100 gallons per households per year, with a median of 123,200 gallons. Economic construction factors of home and lot square footage were positively correlated with outdoor water use. Homes with pools were found to use more than twice as much exterior water as those without pools (Mayer, et al., 1999). Although water use was shown to vary between cities in different climate zones, weather factors related to these variations were not examined.

Differences between studies in accounting for water use may be due in part to homeowner behavior. A 1990 Southern California study found that just 11% of households irrigated within +/-10% of what the landscape required, 50% under-irrigated and 39% over-irrigated (Baumann, et al., 1998). These behaviors differed in other cities across the U.S. and Canada, with approximately 22% of the population using less than 10% of a theoretically required water amount, and approximately 17% applying more than needed (Mayer, et al., 1999). Thus, examining “fixed effects” of weather and economic construction differences will help in determining confounding factors in water use patterns in order to isolate behavioral and builder differences that promote water conservation and sustainability.

Review of Methods to Measure and Predict Water Use

Previous studies have used a variety of methods to determine both the end-uses of water and variables that influence consumption. Technological advances have even given researchers the ability to monitor end-use directly as it occurs. One example was a 1990 study conducted in Oakland, California, on a sample of 25 residences where micro-meters were installed on major fixtures and monitored via personal computer. Although precise data was gathered, the cost of this study was almost $10,000 per home (Mayer, et al., 1999). Since then, flow trace analysis tools and software that record and identify the source of water use in a residence have been developed. These data collection tools are considerably less expensive yet can provide similar detail in water use analysis (Mayer, et al., 1999).

Despite these cost reductions, survey and statistical methods are more cost-effective for large-scale studies. One of the earliest construction studies using statistical modeling of water conservation was conducted in 1940 by Roy Hunter in which typical water demands for fixtures were determined using a probability function. The results of Hunter’s study were used for almost 60 years to determine size for water meters and service lines (Mayer, et al., 1999). More recent statistical modeling of water conservation include a 1993 study in Pasadena using household billing records and occupant socio-economic data (Kiefer, Dziegielewski, & Opitz, 1993) and a 1994 study of 494 homes in the Phoenix area (Mayer, et al., 1999).

Austin has used a regression model called WATFORE to forecast extreme water use amounts (Shaw & Maidment, 1987). The parameters in the model include daily water use as the dependent variable, and independent variables of: estimated base winter use, a trend coefficient for seasonal use, and estimated potential water use, which is a function of temperature, and a short-memory recall of water use (Shaw & Maidment, 1987).

These methods and prior research results were considered in designing the current study's methods. Significant parameters of weather and economic construction indicators were identified, along with water use measures that could be efficiently yet reliably collected for a large-scale population. The study population is described below, along with data collection and analysis methods used in this study.

Methods

Study Population and Data Collection

The study population consisted of all green homes in the Austin area registered with the Austin Green Building Program from January 1998 to March 2001 (N=830 homes by 33 builders, with available matching data for water consumption and appraisal information). Five datasets were merged to determine the effect of weather and economic construction factors on residential water consumption: 1) Austin Green Builder Program (AGBP) list of qualified homes, January 1998-March 2001; 2) National Weather Service Southern Regional Headquarters listing of temperature and rainfall in the Austin area, March 2001 to March 2003; 3) U.S. Army Corps of Engineers, Ft. Worth District's Reservoir Control Office measurements of evaporation data for Lake Travis/Marshall Ford Dam in the greater Austin Area from March 2001 to March 2003; 4) Travis County Appraisal District Office for data on the existence of a pool, appraised value and square footage of home and lot; and 5) Austin Energy Department for monthly residential water consumption records.

Monthly water consumption records (gallons per month per household) were obtained for each registered Austin Green Builder home from data available from March 2001 to March 2003. Current square footage of each home and lot, appraised value and the existence of a pool was obtained at the Travis County Appraisal District Office. Monthly data on mean temperature (degrees Fahrenheit), total rainfall (inches), and mean evaporation (inches) in the Austin area was calculated to correspond with the water consumption study period and attributed to all homes in the study population. The various sources of data were merged by green-built home address, then converted to reflect the unit of analysis of monthly water consumption per household during the 2-year study period (830 households x 24 months = 19,920 eligible cases of monthly household water use).

Statistical Analysis

First, univariate analyses were used to describe the characteristics of the study population. Next, bivariate correlations were conducted to investigate relationships among these characteristics, followed by testing for multicollinearity of the independent variables using the Variance Inflation Factor (VIF). As no VIF values were over 10, this was not considered problematic (Neter, Kutner, Nachtsheim, & Wasserman, 1996). Lastly, multivariate stepwise regression was used to determine statistically significant relationships ($p < .05$) of temperature, rainfall, evaporation, home square footage, lot square footage, appraised value and pool data accounting for variation in monthly household water consumption. Cases with missing values of any one variable were deleted in the multivariate analysis, with the majority of these missing lot square footage data (revised N=16,605). To control for equal variance, only those cases in which the absolute value of the residuals was +/-4 were included because it is common statistical practice to consider residuals as outliers in large data sets if their absolute value is 4 or more (Neter, et al. 1996). This process reduced the number of cases by less than 1% (N = 16,4755 for multivariate analysis).

Results

Description and Correlation of Weather and Economic Construction Factors

Weather

Weather factors were measured as mean monthly temperature, rainfall, and evaporation in the Austin area for the 24-month study period of March 2001 through March 2003, then compared to long term patterns reported for the Austin area by the National Weather Service. Monthly average temperatures (^{o}F) in the Austin area ranged from 50^{o} to 87^{o} during the study period (Table 1). Both mean and median monthly temperatures were 69^{o}, similar to the average of 68^{o} recorded by the National Weather Service from 1854-2002. Because of this close similarity to patterns for over a century, findings of temperature factors should not be biased by abnormal patterns.

Table 1.
Description of Weather, Economic Construction and Water Use Patterns in the Study Population

	Water Use in Gallons Per Month	Monthly Avg. Temp. ^{0}F	Monthly Rainfall Inches	Monthly Avg. Evap. Inches	Appraised Value $	Home S.F.	Lot S.F.
Mean	10,148.60	68.57	3.32	0.19	223,986.56	2,186.40	8,277.10
Median	7,900.00	69.50	2.46	0.16	225,000.00	2,279.00	7,680.00
Std. Deviation	7,876.67	12.91	2.63	0.10	106,632.47	773.65	2,653.12
Minimum	100.00	49.60	0.34	0.07	42,365.00	451	3,300.00
Maximum	57,700.00	87.20	10.00	0.39	952,004.00	4,853.00	30,056.00

Total monthly rainfall ranged from 0.3 to 10.0 inches, with a monthly mean of 3.3 inches compared to the median of 2.5 inches (Table 1). This slightly skewed distribution indicates a few months during the study period that had much greater rainfall. In fact, this study period was wetter than usual overall, with approximately 1/2" above the monthly average for Austin recorded from 1856 to 2002 by the National Weather Service. Prior studies have found that outdoor watering decreases with increased monthly rainfall (Tinker & Woods, 2000; Campbell, Larson, Johnson, & Waits, 1999). However, other studies have found little variance in outdoor watering with increased rain due to large variances in watering habits (Heaney, DeOreo, Mayer, Lander, Harpring, Stadjuhar, Courtney, & Buhlig, 2005).

Monthly average evaporation rates ranged from 0.07 to 0.39 inches, with a mean of 0.19 inches, approximately equivalent to the median of 0.16 inches (Table 1). This was very close to mean evaporation rate of 0.18 in Austin for the 10 years prior to the study period (1991-2000). Hence, findings regarding evaporation should be typical and appropriate to apply to patterns over time.

As expected, the three weather measures were significantly correlated ($p < 0.05$), but not as strongly as expected (Table 2). Although temperature and evaporation were highly correlated ($R=0.927$), rainfall was not as strongly associated with temperature or evaporation as expected. However, the Variance Inflation Factor (VIF) for temperature and evaporation was less than 10 when analyzed using regression, indicating that multi-co-linearity was not significant. Hence, each was included in the analysis to isolate its effect on residential water consumption.

Table 2.
Correlation Among Weather and Economic Construction Factors

	Weather Factors			Economic Construction Factors		
	Temp	Rain	Evap	Home S.F.	Lot S.F.	Value
Weather Factors						
Temp	-					
Rain	.017*	-				
Evap	.927****	-.096****	-			

Economic Construction Factors						
Home S.F.	-.005	-.002	-.005	-		
Lot S.F.	-.003	.000	-.003	.370****	-	
Value	-.006	-.002	-.006	.877****	.468****	-

*p≤.05 **p≤.01 ***p≤.001 ****p≤.0001

Economic Construction Factors

Three economic construction factors were measured for all homes in the Austin Green Built Program registered from January of 1998 to March of 2001 – appraised value, house square footage, and lot square footage. Appraised market values ranged from approximately $42,000 to over $950,000 (Table 1) with a mean of $224,000 (median = $225,000). Almost 50% of the homes were valued between $200,000 and $300,000 and only 14% of homes were valued below $100,000. Although there were some extremely high values, 99% of homes in the study population cost $500,000 or less. Home value distributions are shown in Figure 1.

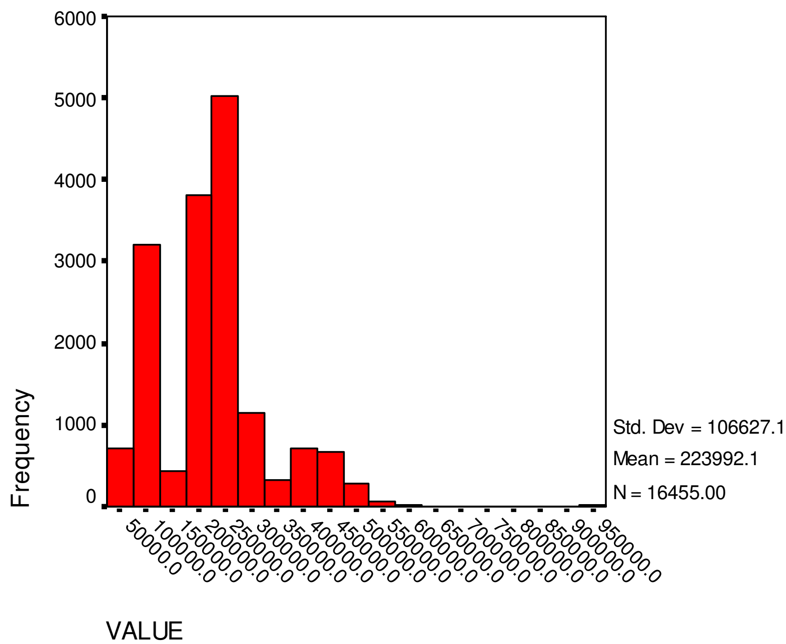

Figure 1. Distribution of home values for green homes.

As shown in Figure 2, home sizes were widely distributed, thus representing a diverse study population. Home size ranged from approximately 450 sf to over 4,800 sq.ft., averaging approximately 2,190 sq.ft., with an equivalent median of 2,280 sq. ft. (Table 1). Only 2% of houses in the study were below 1,000 sq.ft. and less than 2% were above 3,500 sq.ft. Lot sizes varied even more, with an approximate 10-fold difference across the study population ranging from 3,300 to over 30,000 sq. ft. This distribution was slightly skewed by the few cases with largest lot sizes, shown by the difference between the mean size of approximately 8,280 sq.ft. compared to the median of 7,680 sq,ft. Despite this wide range, almost two-thirds of lot square footages fell within the 6,000-9,000 range with just 3% above 14,000 and approximately 2% under 5,400. Thus, the study population was likely to be representative of a wide range of homes throughout the Austin area.

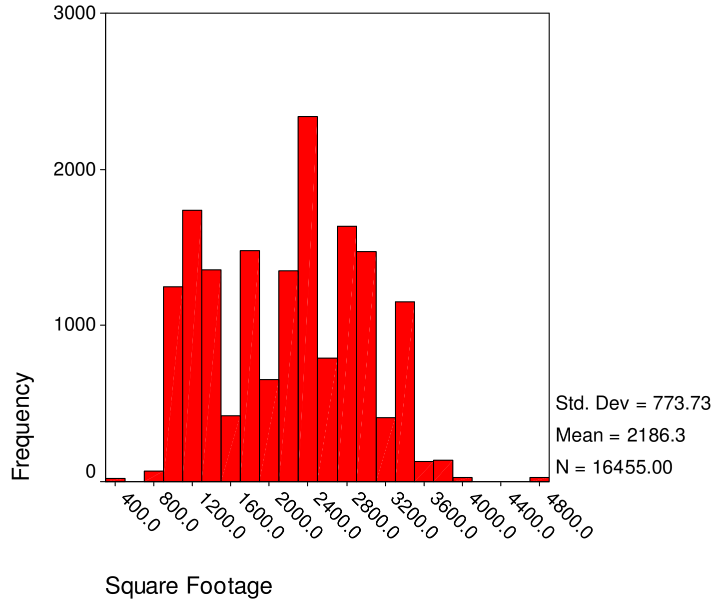

Figure 2. Distribution of home square footages for green homes.

As shown in Table 2, these economic construction factors were highly correlated ($p<0.0001$). Appraised value was most strongly associated with house square footage. Interestingly, lot square footage was not as tightly correlated with value or house square footage as anticipated. Although appraised value and home square footage were highly correlated ($R=0.873$), the VIF was less than 10, indicating that multicollinearity was not significant. Each economic construction measure was included to determine specific relationships with water consumption, particularly to differentiate inside and outside water use according to house versus lot size.

Swimming Pool

Approximately 2% of Green Program homes had a pool. Home value was significantly larger for homes with pools ($p<0.0001$). Appraised value was over $100,000 greater on the average for homes with a pool ($329,654) than those without ($220,010). Although it is not known what contribution a pool would make in the appraised value, homes with a pool were significantly larger ($p < 0.0001$). Those with a pool averaged 2,907 sq.ft. compared to those without a pool averaging 2,571 sq.ft. Homes with pools tended to also have larger lots (10,022 sq.ft.) than those without (8,206 sq.ft), but these differences were not significant ($p > 0.05$). Unfortunately, patterns of pools for Austin housing overall was not known.

Water Consumption

Water use was recorded from water utility billing data sources, measured as total use per household per month (N=16,690 household-months). There was a remarkable range of residential water usage in the study population, from a minimum of 100 gal/mo. to as much as 57,700 gal/mo. (Table 1 and Figure 3). Two percent of green-built homes used less than 1,000 gallons per month and 50% used 7,900 gallons or less per month. Mean monthly use was approximately 10,150 gallons per household, skewed by 1% of households that used 37,000 gallons or more per month. Although it was not known if the extremely high amounts of use among the study population were due to filling pools or, perhaps, leaks in household water lines, these values were included in the analysis as they were valid measures of water consumption that could occur in any broader population.

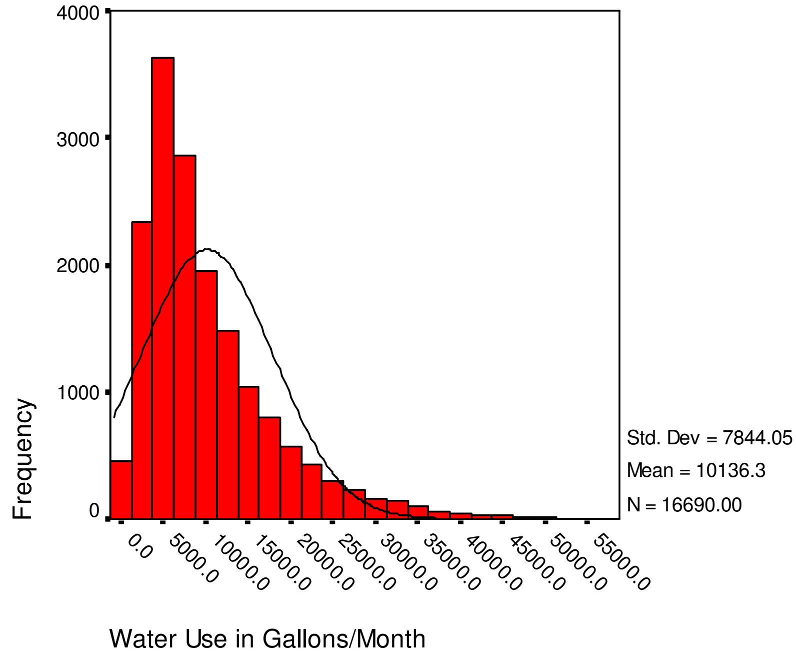

Figure 3. Distribution of water usage in gallons per month.

The mean water use of the study population from 2001 to 2003 (10,148 gallons per month) was equivalent to that for Austin's overall yearly average of 120,000 gallons in 2000 (City of Austin, 2000). However, almost two-thirds (62%) of the Green Program homes had lower average water use when compared to Austin averages overall. This bias in distribution of water use, along with selection of the more conservation-conscious green homes for the study population, may indicate more conservative water use behaviors.

Model of "Fixed Effects" for Residential Water Consumption

Each weather and economic construction factor was significant ($p<0.0001$) in explaining residential water consumption (Table 3). As no VIF's were at or above 10, multicollinearity was not considered a problem. The model of these "fixed effects" accounted for approximately one-fifth ($R^2 = 0.204$) of the variation in water use in the study population.

$$Y = -9{,}986.862B_o(\text{constant}) + 171.876\text{Temp.} + 0.005\text{Value} + 345.176\text{Rain} + 0.253\text{LotSF} + 3{,}733.066\text{Pool} + 1.273\text{HomeSF} + 6{,}388.239\text{Evap.}$$

Table 3.

Regression Coefficients and P-values for Significant Variables

Variable	Regression Coefficient	P-value	Stepwise Step: Adjusted R^2
Constant	-9,986.862	<0.0001	
Temperature	171.876	<0.0001	#1: 0.128
Value	0.005	<0.0001	#2: 0.179
Rainfall	345.176	<0.0001	#3: 0.190
Lot Square Footage	0.253	<0.0001	#4: 0.195
Pool	3,733.066	<0.0001	#5 0.200
Home Square Footage	1.273	<0.0001	#6: 0.203
Evaporation	6,388.239	<0.0001	#7: 0.204

Weather Factors

Temperature was the most important factor in the model, accounting for almost 13% of the variation (R^2 = 0.128). For every 1°F increase in temperature, water consumption was predicted to increase approximately 170 gal/mo per household. Rainfall was third to enter the stepwise model, accounting for another 1% of the variation in water use (R^2=0.011). However the direction of this relationship was contrary to what was expected. For every 1 in. of rainfall there was an increase of 345 gal/mo per household. After controlling for all other factors, evaporation was seventh and last to enter the model, accounting for only 0.1% of variation (R^2 = 0.001). However, the impact of evaporation was quite notable, with almost 6,400 gal/mo increased use for every 1 inch of evaporation. The combination of these weather factors accounted for a sum of 14% of the variation in water consumption.

Economic Construction Factors

Appraised household value was second in significance in the stepwise model, accounting for approximately 5% of the variation in residential water consumption. Although this was an important factor in the model, the effect of change was limited to almost 50 gal/mo increase in use for every $10,000 increment increase in house value. Lot size was fourth to enter the stepwise model, accounting for less than 1% of the variation. For every 1,000 sq.ft. of lot size, there was approximately 250 gal/mo increase in household water consumption. This converts to an expected increase of approximately 11,000 gallons/month for each additional acre. Having a pool was fifth to enter the model. Although having a pool only accounted for less than 1% of the variation, there was approximately 3,700 gal/mo greater water use in households with a pool than those without, after controlling for the other weather and economic factors. House size was the sixth factor to enter the stepwise model, also accounting for less than 1% of the variation in water use. There was slightly over a 1 to 1 ratio of house square footage to gallons of water use/mo.; i.e., for every 100 sq.ft. increase there was 127 gallon increase in monthly household water use. The four economic construction factors accounted for a sum of 6.4% of variation in water use by the study population.

Discussion and Conclusions

Austin, like many other cities throughout the USA, is planning and implementing conservation strategies to prevent a water shortage. For over a decade, Austin has continued to develop the Sustainable Communities Initiative (SCI). The Green Builder Program is part of this effort to make the city more sustainable. Whereas green planning and construction programs are rapidly developing across the U.S., their impact is just beginning to be examined. To better plan cost-effective strategies, it is important to isolate factors that can be influenced by planning and policy versus those that remain outside our control – i.e., weather and economic construction differences. The findings of this study present evidence of these “fixed effects” on residential water use in one location, Austin, Texas.

Discussion of “Fixed Effect” Model

A fifth of variation in residential water consumption over a 2-year period was accounted for by weather and economic construction factors, namely temperature, rainfall, evaporation, appraised value, house size, lot size and having a pool (R^2=0.204). Temperature alone accounted for approximately 13% of variation in water use, with other weather factors accounting for another 1% after controlling for temperature. Slight changes in weather factors were predicted to effect large changes in water consumption. The direct relationship of water use with temperature and evaporation corresponds with previous studies (Danielson, et al., 1980; Duble, 1997; Mayer, 1995; Stadjuhar, 1997; Aquacraft, Inc., 1997; Griffin & Chang, 1989; Anderson, Miller, & Washburn, 1980; Morgan & Smolen, 1976; Hansen & Narayanan, 1981). It was surprising in this Austin case that water consumption actually increased in months with higher total rainfall amounts. Others argued that increased rainfall reduced outdoor water use in other climatic zones (Griffin & Chang, 1989; Fourt, 1958; Hanke & Mare, 1982). Perhaps controlling for the effect of lot size and pools in this study modified the effect of outdoor use, resulting in rainfall’s positive effect. Whereas other studies have shown that number of months without rainfall is associated with increased outdoor water use, little remains known about use during months with variations in rainfall. Thus, the unexpected relationship found in this Austin case warrants future study.

Measures of home value, home size, lot size, and pool were shown in this study as well as others to directly affect residential water use. Although significant, house and lot size contributed less than 1% in accounting for variation in water consumption. The effect of house size may be more a function of number of occupants, which has been shown to effect water consumption in previous studies (Fourt, 1958; Hanke & Mare, 1982). Unfortunately, number of occupants in this study population could not be obtained for confidentiality reasons. But future studies should examine number of occupants in terms of number of adults and children while controlling for house square footage.

Larger lot size associated with increased water would be an indicator of greater outdoor water use. The effects on probable outdoor water use by rainfall, lot size, and temperature would have implications for landscape design. This remarkable effect by weather variables supports efforts to encourage native vegetation and xeriscaping. Other sustainable strategies such as rainwater collection or graywater use may or may not work in other locations with drought conditions.

Thus, planning models and policy decisions about water conservation should take into account seasonal and weather trends having a significant impact on the pattern and amount of water use. Only after isolating these effects can the true impact of sustainable construction and conservation behaviors and policies be determined.

Implications of "Fixed Effects" for Planning & Policy

This study's findings indicate the tremendous variability in water consumption between households, based on the variation in water use accounted for by seasonal and economic factors investigated. While it may be conjectured that one or several key factors were not included, past studies have had fairly low R^2 's for water consumption models even with the factors of number of residents or income included. Inclusion of this information in this study was not possible due to assurance of resident confidentiality.

This study also confirms what others have found regarding the direct relationship of temperature on water use. The question is, if this is the case, what can be done to curb water consumption in warmer periods? Rainfall during warm months (May – September) was above normal for this study period. It would therefore make sense to use rainwater collection devices as sole or supplemental supply the offset increased needs in these warmer months. Even if rainfall had not been higher than normal, collection from cooler months could be stockpiled to meet the increased demands of summer watering. Price increases could also be implemented to help curb consumption in this period. Such increases have been found to be effective (Renwick, Green & McCorkle, 1998; Cuthbert & Lemoine, 1996). Additionally, more sustainable planning could be applied, such as low-water use vegetation, xeriscaping, more permeable surfaces, smaller lots and other water reducing measures.

Rainfall and evaporation also had a large impact on water consumption among the green builder homes. As evaporation is related to temperature, this seems logical and again, plans can be made to curtail water consumption in the warmer months when evaporation is greatest. However, the direct relationship with rainfall and water use in this study must be investigated further due to its inconstancy with other studies. In future studies, different and longer time periods could be studied to test this hypothesis.

Controlling for these readily available weather and economic construction data to predict residential water use will help to isolate other factors such as behavioral and price differences to better predict water consumption and develop sustainable planning and policies for future demands. Additionally, the effects of sustainable practices and incentives could be more accurately isolated and measured, thus allowing more effective cost/benefit analyses and decision-making. Hence, models that attempt to explain residential water use are greatly enhanced.

Recommendations

Future research should attempt to not only gather information for particular water conservation program groups, but also compare findings between green programs and other groups. Thus, studies with Austin Green-rated homes and non-rated homes in the Austin area should be conducted so that green construction can be assessed more reliably. Water price should also be investigated, ideally before and after a price change to determine impact, and between regions with different rate structures. Additionally, if possible, surveys should be conducted that assess issues not available in public databases such as the number of people per household, watering habits and attitudes, vegetation types and shade cover. These factors might offer additional clues that would help explain more of the variability in residential water consumption and lead to more accurate predictive models.

Similar studies should be conducted nationwide to determine the varying effect of climate and economic variables by region. Because climates differ by area, separate models should be derived for each region to ensure applicability. Finally, a longer time period of study could be beneficial to help overcome the affects of unusual weather patterns. With proper determination of regional fixed effects, research studies can then be conducted to isolate the value of sustainable programs, cost incentives and consumer education.

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