Water Use Characteristics of College Students

Ryan A. Buckley

Abstract The water use characteristics of undergraduate college students are of paramount importance in the effort to save potable water supplies. Although literature describing residential water use and price elasticities of water is available, there are no studies of college students' water use. This study finds how much water college students can save with existing technology by analyzing water audit data self-administered in March and April 2004 by students in an environmental science lecture at the University of California at Berkeley. Students were assigned a graded water audit that collected 29 data points on housing type; basic demographics; and use of faucets, toilets, showers, and clothes washers. Fourteen regressions were run with ten control variables on total water consumption. Data was clustered at residence-specific and residence-type levels. Direct payment of the water bill was found to reduce water consumption by just over 8000 gallons per year and being raised in Los Angeles County contributed approximately 4500 gallons per year. Average water consumption was found to be 80 gallons per person per day. Over half of this water was used in showers, where students spend an average of 15 minutes washing themselves each day. This study finds that there is no significant difference in water use among the three surveyed housing types. This study concludes that residence managers can save over $45 per person per year simply by installing standard low-flow water use devices.

Introduction

The way water is used will continue to gain relevance as populations expand and potable water supplies dwindle. The water use characteristics of undergraduate college students are of particular interest. The consumption habits formed or reinforced during these four or five years as an undergraduate influence the future of American water supplies. It is important, therefore, that consumption patterns of college students are analyzed in order to develop appropriate outreach and implement the proper use of low-flow water devices. In California, one-third of current urban water use (2.3 million acre-feet (AF)) can be saved with existing technology. At least 85% of this (more than 2 million AF) can be saved at costs below what it would cost to tap into new sources of supply (Pacific Institute 2003).

This study narrowed the focus to college students by analyzing the water audit data self-administered in March and April, 2004, by students in Professor Bill Berry's Earth and Planetary Science (EPS) 80 lecture at the University of California at Berkeley. It used this data to make generalizations about water use across three different housing types. It also calculated projected water and cost savings based on implementation of standard low-flow faucet, toilet, and shower devices. Statistical analyses looked at differences in water use characteristics across housing types and regressions found factors that influence water use characteristics.

Our current water supply is bleak and therefore water use characteristics must be studied closely. While California's population may increase by 25% in the next 20 years (CDOF 2002), financial, environmental, political, and social factors will likely prevent any significant expansion of California's water supply (Pacific Institute 2003). This type of problem is common. For example, Somerville and Briscoe (2001) claim that "water systems are under severe strain in many parts of the world with water tables in parts of Mexico, India, China and North Africa declining as much as one meter per year" (p. 2217). Globally, one sixth of the world's six billion people do not have access to safe drinking water (WHO 2003). Water supply in the broader United States, although not as scarce as elsewhere, still concerns members of the scientific and political communities. In 2001, for example, nearly 10% of the population in the United States was not served by community water systems that met all existing health-based standards (US EPA 2002).

Studies about water conservation motives and consumption behaviors will help scientists and activists alike to prevent a water supply crisis. For example, Corral-Verdugo *et al.* studied the effect of perceived externalities (Corral-Verdugo and Frias-Armenta 2002) and found that since the perception of externalities inhibits conservation motives, the resulting effect of perceived externalities on water consumption is positive. This result means that the more people perceive that others waste water, the less they are motivated to conserve, and the more they consume.

This result parallels the theory developed in 1968 by Hardin in his classic text "The Tragedy of the Commons," in which he analyzed the causes and effects of "externalities," or decisions that people make without regard to consequences incurred by others. Hardin suggests that if common water resources are consumed at a rate greater than can be supplied, the cycle is destructive and must be avoided.

Another paper by Corral-Verdugo and Bechtel (2003) explores the effect of environmental beliefs on water use characteristics of residential homes in Mexico, finding that "utilitarian" water beliefs promoted water consumption, while "ecological" water beliefs inhibited that behavior. The utilitarian water beliefs consider water as an unlimited resource to be used by humans in an arbitrary way, while ecological water beliefs conceive water as a limited resource to conserve. In general, the behavior literature shows that the more motivation a person has for saving water, the more she conserves the resource.

Other authors have studied the nature of water demand itself. Dalhuisen *et al*. (2003) studied the variations of price and income elasticities in the literature of residential water demand and found that both the rate system and theoretical microeconomic choice approach are relevant in explaining these differences. In another study, population density, household size, and temperature are not found to significantly influence the estimate of the price elasticity while income, pricing structure, and season do show significant influence (Espey and Espey 1997). Krause *et al*. (2003) combine experimental and survey responses to econometrically estimate water demand for different consumer groups while Williams and Suh (1986) find demand for urban water by consumer class. Buchberger and Wells (1996) does a thorough analysis of 8,000 per capita water demand "pulses" at four single-family residences and finds a reasonable approximation for indoor water demands. A different study finds flaws in the water market, claiming that although residential water demand is normally thought to be market determined, these markets are often restricted, allowing for the possibility that water costs may not accurately reflect the value of water (Brookshire and Burness 2002).

Finally, several papers speak to the effect of water conservation programs on consumer behavior. De Oliver (1999) correlates water consumption with various census data and reveals substantial disparities between survey responses and participants' actual behavior. Punishment for excessive water consumption, however, may induce conservation (Agras and Jacob 1980), compensating for this discrepancy. A study by Geller *et al*. (1983) applies three treatments to promote water conservation and finds that significant water savings occurred only after the installation of low cost water conservation devices. Other authors find that both price and alternative demand management policies were effective in reducing demand. However, the magnitude of the reduction in demand varied among policy instruments such as water allocations, use restrictions, and public education (Renwick and Green 2000).

The Pacific Institute (2003) finds that the residential sector in California is the largest urban water use sector, and it offers the largest volume of potential savings compared with other urban sectors. This study finds that in 2000 Californians used around 60 gallons per capita per day (gpcd) for indoor residential use. However, by replacing inefficient water use devices and reducing the level of leaks, indoor use in 2000 could have been as low as 37 gpcd without any changes in the services actually provided by the water.

While some water districts evaluate details of local residential water use, there are no comprehensive assessments of statewide end use of water in homes (Pacific Institute 2003). Based on preliminary literature searches, this study finds that there are no analyses of water use in the college residences either. College students, however, are the next generation of homeowners, renters, and parents. Researchers need to look at their consumption patterns in order to mold education campaigns that target specific damaging behaviors. Water consumption awareness is imperative in California as population growth increasingly strains water supplies that often must be transported hundreds of miles. In the eastern San Francisco Bay, for example, the East Bay Municipal Utility District (EBMUD) transports water 91.5 miles from the Pardee reservoir through the Pardee Tunnel, Mokelumne Aqueducts, and the Lafayette Aqueducts for use throughout the East Bay (EBMUD 2001).

This study made three hypotheses. First, water use among UC Berkeley students will be highest in the residence halls. The UC Berkeley residence halls, the site of this study, currently have no water use reduction education outreach and students do not directly pay water bills. The effects of price and water conservation outreach differ between residents in different housing types and it is expected that these effects will lower water use of single-family houses and apartments. Furthermore, the effect of perceived externalities on water consumption should be positive; the more people perceive that others waste water, the more they tend to increase their own consumption (Corral-Verdugo and Frias-Armenta 2002). This effect is expected to be most prevalent in residence halls, where many students share restrooms and showers and would be more likely to witness excessive water use.

Second, water use among UC Berkeley students will be higher than the state average. Residences elsewhere in the state typically pay a bi-monthly water bill, allowing consumers to directly see the cost and amount of their water consumption. They also receive information from their utility districts about water conservation. Thus, it was expected that more reckless water use behavior would be seen among students.

And finally, students raised in Los Angeles County will use less water than those who were raised elsewhere. This region is known to be one of the more drought-prone areas in the state, hence it would be expected that drought awareness would be relatively high among Los Angeles County residents. This awareness in turn would nurture water conservation. Thus, water use among students raised in Los Angeles County should be lower than those raised elsewhere.

Methods

Students in the EPS 80 lecture were given the option of surveying their own water consumption and writing a two-page paper about the survey, or doing one of two other surveys. In March and April 2004, the water use survey option generated 68 self-administered audit reports.

The water use survey was originally designed by East Bay Municipal Utilities District (EBMUD) and modified for use in this study. Data is subdivided by several categories, including survey location, demographics, population size, water costs, and appliances including faucets, toilets, showers, and clothes washing machines. Location data includes address, city, and residence description (residence hall, apartment, or single family house). Faucet, toilet, shower, and clothes washing machine information include the flow rates, use rates, and a count of all faucets, toilets, showers, and clothes washing machines. Population data includes the number of men and women in the residence. Demographic information includes residents' years of education, parents' education, locations of childhood residence, use of recycling programs, and education of water issues. Cost information includes the wastewater and agency fees that residents must pay, and whether or not residents make payments directly to their water utility company.

Faucet and shower flow rates were found with a "Shower Flow Gauge" bag that is supplied by EBMUD. Users were instructed to hold the bag beneath a faucet or shower for five seconds. Flow rates were marked on the bag itself. Toilet flow rates were found by looking for markings on the toilet. If no markings were present, students were asked to count the number of seconds it takes for the toilet tank to fill. The number of seconds was multiplied by a standard 0.35 gal/sec. If the toilet had no tank, students were asked to count the number of seconds that the toilet was flushing and make the same calculation. If the calculation exceeded four gallons, EBMUD provided toilet tablets to dye the tank water and check for leaks into the toilet bowl. Students were required to administer pre-designed surveys to find usage frequency of faucets, toilets, and showers among all residents. Demographic information about the residents was also collected by administering these surveys.

Students transfered all survey data to a pre-prepared Microsoft Excel spreadsheet downloaded from the course website. Water use for each device in the spreadsheet was found with equation (1).

$$(TotalPopulation) \times (FlowRate) \times (AverageUseRate) = WaterUse \quad \textbf{(1)}$$

Projected water savings was calculated by subtracting the total water consumption of the residence using standard low-flow flow rates from total water consumption using the students' surveyed flow rates. The standard low-flow rates were: faucets–1.5 gal/min; toilets–1.6 gal/flush; showers–2.5 gal/min; clothes washing machines–35 gal/load. Savings were calculated assuming water use behavior would not change with low-flow water use devices.

Energy savings were calculated using only the projected water savings from shower use. Avoided annual shower water heating costs (X) are calculated with equation (2). The 0.8 divisor takes into account the average efficiency (80%) of water heaters.

$$\frac{\left(X \frac{gallons}{year} \times 0.00378 \frac{m^3}{gallon} \times 1 \cdot 10^6 \frac{g}{m^3} \times \Delta 25°C \times 4.2 \frac{J}{g°C} \times 1 \frac{kWhr}{3.6 \cdot 10^6 J} \right)}{0.8} \times \$0.09/kWhr = Savings \quad \textbf{(2)}$$

Avoided utility fees were calculated by multiplying the water savings by $3.50/ccf. This figure includes water charges ($2.00/ccf), wastewater charges ($0.90/ccf), and agency fees ($0.60/ccf).

Regressions were found with STATA software. All regressions accounted for residence-specific effects. Regressions (1) through (6) in Tables 5a and 5b utilized the cluster(id) attribute in STATA. The coefficients in (1) through (6) were the same estimates as ordinary least squares (OLS), but standard errors were adjusted for clustering. These robust standard errors were still reliable when the regression errors were autocorrelated or heteroskedastic. For the purposes of this study, only heteroskedasticity-robust standard errors were used. Regressions (1) through (6) used the model presented by Equation 3.

$$Y_{ij} = \alpha + x_{1ij}\beta_1 + x_{2ij}\beta_2 + ...x_{nij}\beta_n + Z'_j\gamma + \varepsilon_{ij} \text{ where } \varepsilon_{ij} = \lambda_j + e_{ij} \text{ and } E(\lambda_j \bullet \mathrm{X}) = 0 \quad \textbf{(3)}$$

Analysis took into account cluster effects of students living in the same residence. Accounting for clustering assumed that data is not independent within the residence, but is independent across residences. The coefficient, Z', had residual term, λ, to capture these residence effects. Residual term e captured the remainder of the idiosyncratic residuals.

Fixed effects were accounted for in regression (7) in Tables 5a and 5b. This regression added a dummy variable, λ_j, for each residence to capture differences between students in the same residence (Equation 4). This fixed effects regression controlled for resident-specific fixed effects, such as flow rates and peer influence, thus decreasing the risk of omitted variables bias.

$$Y_{ij} = \lambda_j + x'_{1ij}\beta_1 + x'_{2ij}\beta_2 + ...x'_{nij}\beta_n + Z'_j\gamma + e_{ij} \text{ where } E(\lambda_j \bullet \mathrm{X}) \neq 0 \quad \textbf{(4)}$$

Clustering was analyzed both at the individual residence level (Table 5a), such that all data points representing a particular place of residence had the same identification number, and the residence type level (Table 5b), such that all data points representing residence halls, apartments, or single-family homes all had the same identification numbers. The two types of clustering created 31 and 3 clusters, respectively. Regressions (1) through (7) were run with both the residence-specific specifications (Table 5a) and residence-type specifications (Table 5b). An explanation of the controls tested is found in Table 6.

A residence analysis categorizes residences into three categories: residence hall, single family home, and apartment, based on survey information. Statistical differences among the indicators between residence halls and apartments were found via t-tests with equal variances (Tables 1, 2, and 3).

Results

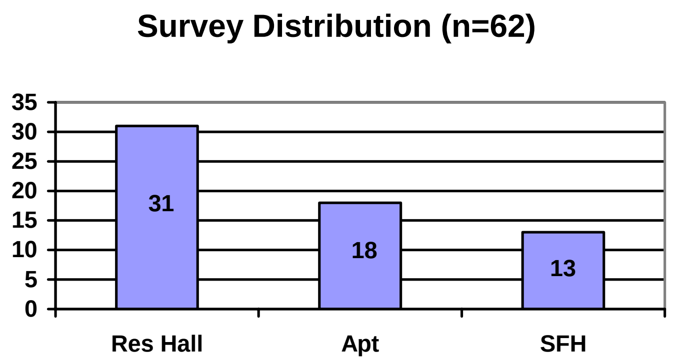

Figure 1 Total distribution of submitted water use surveys in Professor Berry's Spring 2004 EPS 80 lecture.

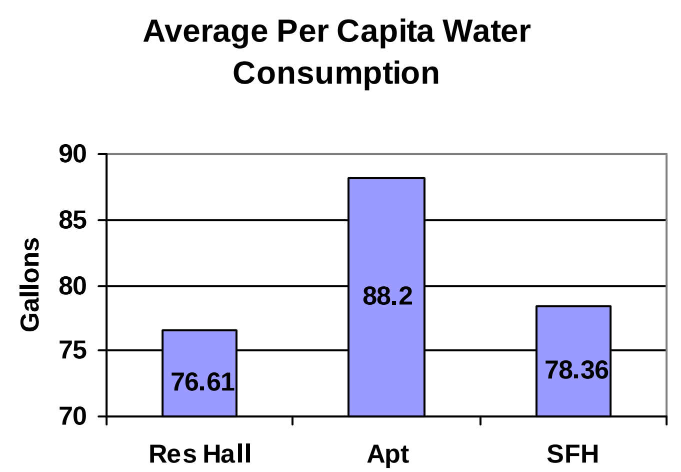

Figure 2 Average total daily water consumption across three housing types in gallons per person per day.

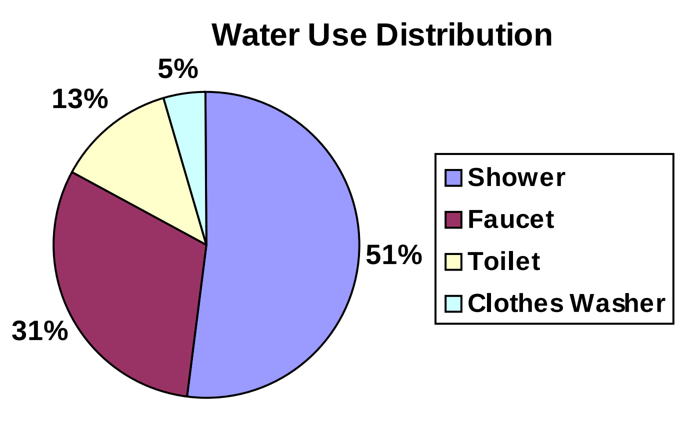

Figure 3 Total aggregate distribution of water use among all housing types.

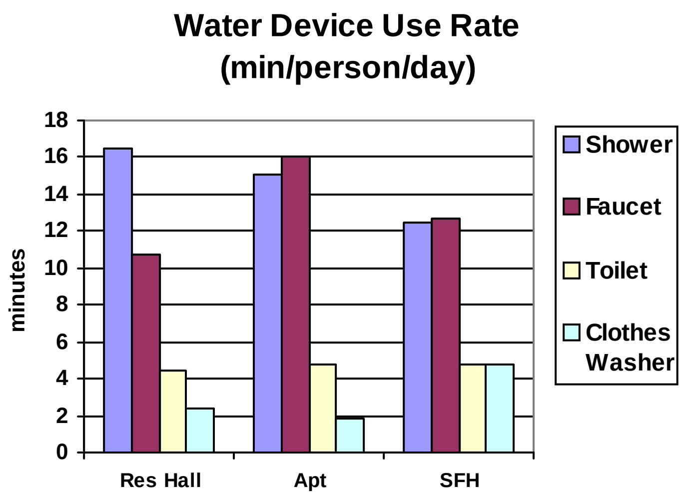

Figure 4 All indoor water device use for three surveyed housing types in ccf/person/year.

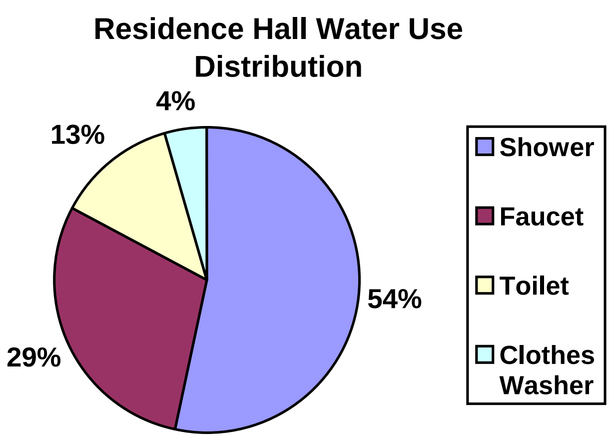

Figure 5 Distribution of water use in the UC Berkeley residence halls.

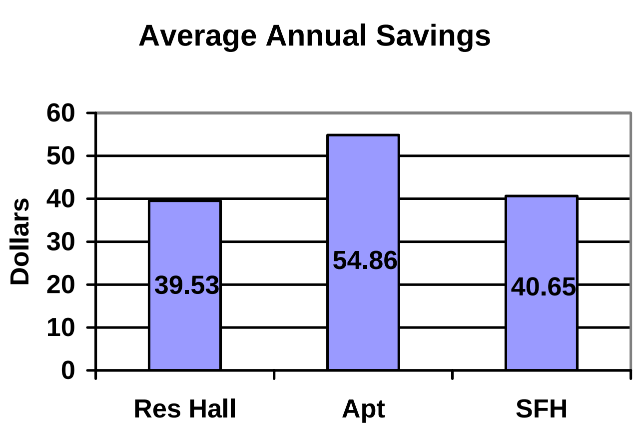

Figure 6 Average total yearly potential savings across three housing types in dollars per person per year.

	Res Hall	Apartment
Mean	76.66	88.20
Variance	765.34	3267.70
Observations	32	18
P-value	0.17	

Table 1 T-test results (equal variances, H_0=0) of the difference in per capita water consumption between residence halls and apartments.

	Res Hall	Apartment
Mean	10.78	16.06
Variance	16.44	157.39
Observations	32	18
P-value	0.01	

Table 2 T-test results (equal variances, H_0=0) of the difference in faucet use rate between residence halls and apartments.

	Res Hall	Apartment
Mean	16.53	15.05
Variance	15.45	84.26
Observations	32	18
P-value	0.22	

Table 3 T-test results (equal variances, H_0=0) of the difference in shower use rate between residence halls and apartments.

	California*	UC Berkeley	95% confidence
Showers	6.23	18.8	± 2.65
Faucets	5.32	12.53	± 2.27
Toilets	9.22	4.80	± 0.58
Washing Machines	4.15	1.55	± 0.54
TOTAL	24.93	37.72	± 4.27

Table 4 Comparison of UC Berkeley and California indoor water use characteristics in ccf per person. *Calculated by the author using Pacific Institute population and residential indoor water use data.

Control Full Name	Abbreviation	Regressions						
		(1)	(2)	(3)	(4)	(5)	(6)	(7) F.E.
		total_cons	total_cons	total_cons	total_cons	total_cons	total_cons	total_cons
Pays for water directly?	PAY_WATER?	-8205.51**	-8555.24**	-9130.20**	-9281.86**	-9069.46**	-12801.72**	
		(2481.82)	(2512.49)	(2256.36)	(2120.79)	(2172.34)	(4255.61)	
Parents have an advanced degree?	ADVANCED?	-4844.29**	-1242.14	-1697.50	-1778.22	-1991.81	-1865.10	675.19
		(1253.71)	(3065.38)	(3017.57)	(3110.33)	(3034.40)	(2904.20)	(3253.29)
Raised in Los Angeles?	LA?	4463.03*	4345.61+	4703.57*	4693.91*	4643.22*	4776.85*	3591.51*
		(2179.84)	(2169.67)	(2290.94)	(2294.22)	(2189.45)	(2208.07)	(1577.63)
Parents have up to a Bachelor's degree?	BACHELORS?		4872.08	4638.05	4585.09	4454.29	4493.70	4320.97
			(3596.91)	(3590.75)	(3583.22)	(3573.67)	(3460.67)	(3365.49)
Parents have up to a high school diploma?	DIPLOMA?		3699.86	3640.84	3601.32	3431.19	3506.79	3650.60
			(3328.27)	(3319.44)	(3500.95)	(3361.99)	(3223.69)	(3295.30)
Born outside the USA?	OUTSIDE_USA?		-1379.40	-1342.64	-1294.44	-1281.11	-1274.30	-819.56
			(1226.60)	(1179.77)	(1159.65)	(1162.80)	(1107.66)	(1514.17)
Actively use recycling programs?	RECYCLE?			3125.39+	3059.61+	3180.72+	3420.68+	1144.60
				(1773.28)	(1788.11)	(1829.41)	(1906.87)	(1410.98)
Received environmental education?	ENVIRO_ED?				1055.35	1024.30	675.12	446.08
					(1728.29)	(1769.06)	(1697.89)	(1253.85)
Percent of women in residence	WOMEN					-879.67	-798.12	
						(4806.99)	(5071.33)	
Live in a residence hall?	RES_HALL?						-4285.65	
							(3694.86)	
Constant		25407.11**	22142.41**	20343.71**	19856.03**	20545.32**	24146.94**	20144.52**
		(1457.81)	(2594.63)	(3149.20)	(3342.40)	(5044.24)	(5405.10)	(3293.72)
Observations		283	280	280	279	279	279	279
R-squared		0.07	0.08	0.10	0.10	0.10	0.11	0.46

Robust standard errors in parentheses

+ significant at 10%; * significant at 5%; ** significant at 1%

Table 5a Robust regression results on total water consumption for clusters at the residence level. Measured in gallons per person per year.

Control Full Name	Abbreviation	Regressions						
		(1)	(2)	(3)	(4)	(5)	(6)	(7) F.E.
		total_cons	total_cons	total_cons	total_cons	total_cons	total_cons	total_cons
Pays for water directly?	PAY_WATER?	-8205.51**	-8555.24**	-9130.20**	-9281.86**	-9069.46*	-12801.72**	-7218.64
		(522.21)	(540.62)	(557.71)	(904.87)	(1353.19)	(848.22)	(8348.52)
Parents have an advanced degree?	ADVANCED?	-4844.29	-1242.14	-1697.50	-1778.22	-1991.81	-1865.10	-1718.17
		(2755.79)	(3185.37)	(3181.59)	(2719.18)	(2243.09)	(2044.35)	(3656.40)
Raised in Los Angeles?	LA?	4463.03**	4345.61*	4703.57**	4693.91**	4643.22**	4776.85**	4684.09**
		(396.32)	(507.69)	(87.86)	(100.59)	(249.98)	(329.05)	(1758.91)
Parents have up to a Bachelor's degree?	BACHELORS?		4872.08+	4638.05+	4585.09*	4454.29**	4493.70**	4553.83
			(1236.69)	(1109.63)	(603.48)	(339.51)	(327.20)	(3854.28)
Parents have up to a high school diploma?	DIPLOMA?		3699.86**	3640.84**	3601.32+	3431.19	3506.79	3741.71
			(289.29)	(333.22)	(845.95)	(1220.62)	(1459.44)	(3770.36)
Born outside the USA?	OUTSIDE_USA?		-1379.40*	-1342.64*	-1294.44*	-1281.11*	-1274.30**	-1393.03
			(186.16)	(236.95)	(218.77)	(195.11)	(99.29)	(1742.47)
Actively use recycling programs?	RECYCLE?			3125.39*	3059.61+	3180.72+	3420.68+	3234.45*
				(577.63)	(778.80)	(1055.41)	(877.64)	(1570.43)
Received environmental education?	ENVIRO_ED?				1055.35	1024.30	675.12	774.03
					(2760.56)	(2821.36)	(2461.43)	(1468.33)
Percent of women in residence	WOMEN					-879.67	-798.12	-681.27
						(1910.22)	(2055.62)	(2542.47)
Live in a residence hall?	RES_HALL?						-4285.65*	
							(734.75)	
Constant		25407.11**	22142.41*	20343.71*	19856.03**	20545.32**	24146.94**	20254.07**
		(2096.93)	(2473.41)	(2919.23)	(968.98)	(529.42)	(1727.67)	(4247.45)
Observations		283.00	280.00	280.00	279.00	279.00	279.00	279.00
R-squared		0.07	0.08	0.10	0.10	0.10	0.11	0.11
Robust standard errors in parentheses								
+ significant at 10%; * significant at 5%; ** significant at 1%								

Table 5b Robust regression results on total water consumption for clusters at the residence type level. Measured in gallons per person per year.

Control coefficient	Type	Level	Description
Pays for water directly?	Binary	Residence	Flagged affirmative if the residence pays its water bill directly, instead of through a landlord or housing manager
Parents have an advanced degree?	Binary	Resident	Flagged affirmative if parents of the resident received a graduate degree
Raised in Los Angeles?	Binary	Resident	Flagged affirmative if resident spent a majority of his/her childhood in Los Angeles County
Parents have up to a Bachelor's degree?	Binary	Resident	Flagged affirmative if parents of the resident received an undergraduate degree and received no more formal education
Parents have up to a high school diploma?	Binary	Resident	Flagged affirmative if parents of the resident graduated from high school and received no more formal education.
Born outside the USA?	Binary	Resident	Flagged affirmative if resident was born in a country other than the United States of America
Actively use recycling programs?	Binary	Resident	Flagged affirmative if resident actively utilizes campus or city recycling programs
Received environmental education?	Binary	Resident	Flagged affirmative if resident has received formal environmental education beyond basic high school biology
Percent of women in residence	Continuous	Residence	Ratio of women to total population of residence
Live in a residence hall?	Binary	Residence	Flagged affirmative if residence is a campus residence hall

Table 6 Information regarding type, level, and description of each of ten controls run in regressions (1) through (7) in Tables 5 and 5b.

Water Savings	Total Per Capita Savings		
Water Savings per Capita (gal/person/day)	Charged and Waste Water Savings ($)	Energy Savings from Shower ($)	Total Cost Savings ($/year)
18.77	$23.71	$21.90	$45.61

Table 7 Potential savings using standard low-flow water use devices assuming constant behavior. Savings in dollars per residence per year.

Shower Savings	Total Per Capita Savings Per Year		
10% use rate reduction (gal/day)	Charged and Waste Water Savings ($/year)	Energy Savings from Shower ($/year)	Total Cost Savings ($/year)
4.0	$5.05	$13.40	$18.45

Table 8 Potential savings from a ten percent reduction in shower use. Savings in dollars per person per year.

	Res Hall	Apt	SFH	All
total consumption (gal/year)	23266.62	28244.30	15910.36	23528.71
	(691.26)	(2736.92)	(2020.16)	(671.78)
total consumption (gal/day)	86.17	104.61	58.93	87.14
	(2.56)	(10.14)	(7.48)	(2.49)
total population	26.24	3.30	4.64	23.12
percent women	0.65	0.60	0.85	0.65
actively use recycling programs?	0.65	0.58	0.64	0.64
received environmental education?	0.55	0.67	0.82	0.57
advanced degree?	0.51	0.45	0.55	0.51
some college?	0.18	0.21	0.09	0.18
some HS?	0.26	0.27	0.36	0.26
no HS?	0.06	0.06	0.00	0.06
faucet use rate (min/day)	12.56	21.26	9.64	13.36
toilet use rate (flush/day)	4.45	4.94	4.45	4.50
shower use rate (min/day)	18.27	19.06	12.91	18.17
clothes washer use rate (load/month)	2.72	1.70	8.55	2.82
faucet flow rate (gal/min)	2.20	1.87	1.96	2.16
toilet flow rate (gal/flush)	2.33	1.88	1.8	2.26
shower flow rate (gal/min)	2.43	2.55	1.69	2.42
clothes washer flow rate (gal/load)	32.99	10.90	28.72	30.55
los angeles?	0.24	0.22	0.00	0.23
potential cost savings ($/person/yr)	40.84	56.63	42.47	46.22
sample size	274	33	11	318

Table 9 Means and standard errors of measured data.

Students submitted a total of 67 surveys from 31 residence halls, 18 apartments, 13 single family homes, and 5 fraternities or sororities (Fig. 1). The fraternities and sororities were not used in housing type analysis because of their limited representation in the sample.

Average per capita water consumption was highest in apartments at approximately 88 gallons per person per day, ten gallons higher than water use in residence halls and single-family houses (Fig. 3). The average per capita water consumption across the three housing types was 80.34 gallons per person per day. No significant difference in per capita water consumption between residence halls and apartments was found (Table 1). There was, however, a significant difference in faucet use rates between these two housing types (Table 2).

Half of all water used by college students is consumed in the shower. Faucet use made up nearly one third of total water consumption, with toilet use and clothes washing machine use making up for the remaining fifth of total consumption (Fig. 3).

Shower use varied across the three housing types, with the longest showers taken in residence halls and shortest in single-family houses (Fig. 4). Shower use in the UC Berkeley residence halls accounts for 54% of total water use (Fig. 5). No significant difference in shower use rates between residence halls and apartments was found (Table 3).

The greatest potential savings was found to be in the apartment housing type, at $55 per person per year (Fig. 6).

Indoor residential water use at UC Berkeley is found to be higher, on average, than California at large (Table 4).

Robust regression results show that direct payment of the water bill reduced water consumption by just over 8000 gallons per year. Being raised in Los Angeles County contributed approximately 4500 gallons per year, while participating in recycling programs also signified a 3000-gallon per year contribution to total water consumption. (Tables 5a and 5b).

Implementation of low-flow water use devices would save $45 on average per person per year (Table 7). UC Berkeley residence halls would save $18 per resident per year (Table 8) from an outreach campaign to reduce shower use by 10%.

Discussion

Hypotheses The water use characteristics of college students have not previously been studied. This report sought to describe these water use characteristics by testing three hypotheses.

This first hypothesis suggested that water use among UC Berkeley students was highest among those living in the residence halls. It was believed that the effect of perceived externalities and cost distribution would entice residents to take extended showers and not be considerate of faucet use. Instead, water use per capita was lowest in residence halls and highest in apartments. This difference, however, was not significant. This finding may best be explained by the fact that neither group of students pays their water bills directly. Only students living in single-family houses paid their water bills directly. This price effect may be the best indicator of water use awareness. Further study will be required to test how college students react to water pricing.

Another explanation of the difference in average per capita water consumption may be the difference in flow rates. The study found, for example, that shower flow rates were lowest in the residence halls. With shower use composing half of college students' water consumption, it follows that residence hall per capita water use should be relatively low. Use rates for faucets were also significantly lower in residence halls than in apartments. Lower flow rates and use rates would lead inevitably to lower per capita water consumption.

The second hypothesis suggested that water use among college students was higher than the California state average. As shown in Table 4, the average per capita water consumption in the state fell within the 95% confidence interval of the per capita consumption of the student population. Therefore, the difference in consumption between UC Berkeley students and the rest of California was not found to be significant. However, this study found that the way water is used differed significantly between these two populations. For example, UC Berkeley students used nearly twice the amount of shower water per capita than the rest of California, and the California average fell well below the 95% confidence interval of the student shower use average. The average shower flow rate at UC Berkeley was 2.42 gal/min (Table 9), a low figure, so students must have a much higher shower use rate. If this high use rate remains unchanged as students grow older and move out off campus, the water use characteristics of California at large may change as well, further increasing the strain on water supplies. Faucet water use per capita of college students was nearly twice the state average and, again, reflects a higher use rate among students because the average flow rate is quite low at 2.16 gal/min (Table 9). Toilet and washing machine water use per capita was probably higher statewide because flow rates were found to be low for both devices in students' residences.

The third hypothesis suggested that students who grew up in drought-prone regions conserve more water than those who did not. Due to lack of regional drought data and inconsistencies in survey responses, the author chose Los Angeles County as the only drought-prone region.

Tables 5a and 5b each present seven ordinary least squares robust regression specifications that analyze the effect of ten factors on total water consumption, as measured in gallons per person per year. These robust regression results found that if Los Angeles County is a representative drought-prone region, then the hypothesis was false. Instead of using less water, regression results show that students who spent a majority of their adolescences in Los Angeles County use significantly more water than those who did not.

A negative relationship coefficient would be expected for this binary variable, however, because it would seem logical that students raised in an area prone to drought, where it is common knowledge that water resources are strained and should be conserved, should use less water than students raised elsewhere. A total of 68 students, roughly one fifth (Table 9), responded that that they spent a majority of their adolescence in Los Angeles County. Instead of a negative result, Tables 5a and 5b showed the coefficient of LA? to be positive. Students used over 4000 gallons more per year if they were raised in Los Angeles County. This coefficient is substantial, considering that the average annual consumption was approximately 23,000 gallons (Table 9).

This result is surprising, but may be explained by income effects and survey discrepancies. In contrast to what was explained earlier, wealth may induce students to use more water, since the price of water is low enough to be insignificant. It can be assumed that students were successful enough in high school to attend UC Berkeley because their parents were supportive and there were no major financial problems to overcome during their adolescence. It may be true, therefore, that most students coming from Los Angeles County were not burdened by needing to work part-time to supplement their parents' incomes, and thus could focus on schoolwork and extracurricular activities required to attend UC Berkeley. Therefore, although there are many poor families in the Los Angeles area, it may be suspected that most of the students who are accepted into UC Berkeley are not from that poor demographic. If being raised in Los Angeles County can be used as a proxy for wealth, then what was seen by this significant and high positive coefficient was an income effect, and not an ignorance of the drought phenomenon common in the region.

This result implies that water education may not be effective in Los Angeles County. Los Angeles County is one of the more commonly recognized drought-prone regions in California, and its residents, therefore, should be conscious of their water use. The result demonstrated the opposite to be true. One explanation might be income effects on water consumption. Future studies will be required to find the truth with certainty.

Study Errors Any original data collection presents challenges. Some of these challenges are unexpected, while others can be planned for. The survey design, for instance, could have been improved before its administration. The survey layout may have been misleading to some students who though the example responses included on the survey itself were the three choices. Students who wrote "N/A" or left the question blank may have done so because their most educated parent had a degree other than the there listed as examples. Thus, it is not clear what students whose parents either hold Bachelor's degrees or did not complete high school should have written. Although some students wrote "BA" or "BS" to signify completion of an undergraduate college degree, it cannot be assumed that every student reacted this way. Another questionable response was no response. This response was interpreted to mean incompletion of high school or college. Other responses, such as "JD" and "MBA," were clustered with "Master's" and "PhD" to form the binary variable ADVANCED?. There is still a possibility that some students who wrote N/A or wrote nothing chose to do so despite having parents with advanced degrees.

There were a number of other problems with the survey. First, many survey respondents confused "county" for "country" when asked which county they lived in longest. Approximately one third of responses were not included in the regressions because they were inappropriate. Second, many students spent a majority of their adolescence outside of California or even outside the country, confounding the effects of living in drought-prone regions. As a result, Los Angeles County was chosen as a representative drought-prone region, a decision that carries with it bias. For example, water use behavior in Los Angeles County could be explained by other characteristics of the region, including income. It was not possible, however, to request family income information as a control for the income effect because of the sensitive nature of the information. Getting the proper approval proved to be too time consuming for the purposes of this project. Still, permission may be granted by the UC Berkeley human subjects committee if a more formal survey were produced. This information would be compelling and should be investigated further.

While this study demonstrated compelling results, selection bias in this study is another factor that cannot be disregarded. Preference for participation in this water survey involves several layers of bias. First, students self-select into this Earth and Planetary Science lecture, attracting those students who might already have an interest in the environment and water issues. The class is also known to be fairly easy and therefore caters to a certain type of student. Second, students self-select to complete the water survey used in this study. As explained, students were able to choose between this water survey and two other assignments. This water survey was offered before the other assignments were due, catering to students who might prefer to get ahead and choose not to procrastinate. These attitudes will influence the mean water use characteristics as well.

However, not all students surveyed are enrolled in the EPS 80 lecture or are acquaintances of the student administering the survey. Due to selection of roommates in apartments and single-family homes, however, there may be similar bias among the surveyed residents as well. Residence hall assignments are random and the sample of students filling out water use surveys, therefore, will also be random.

Policy Implications Managers can save over $45 per resident per year simply by installing low-flow devices in their homes (Table 7). Apartment managers have the greatest potential per capita savings, at $55 per person (Fig. 6). Over half of this savings will accrue from low-flow showerheads alone, since the cost of energy required to heat the shower water will also be saved. Also, a ten percent reduction in shower use (1.5 minutes) will save approximately four gallons per person per shower, or well over 1,200 gallons per year. This shower use rate reduction translates to approximately $18 per student per year (Table 8). In a residence hall system of 5,000 students, this small use rate reduction could translate into $90,000 in annual avoided water heating costs. It is advised, therefore, that residence hall managers consider low-flow showerhead installation and shower use rate reduction a high budgeting priority.

Also, if water were paid at a per gallon rate, students might be compelled to conserve. In order to implement such a policy, however, better tracking systems are needed. For example, water flows into individual residence halls are not currently tracked, so residence hall managers have no way of pin-pointing leaks or particularly wasteful residence halls. Technologies that are able to track flow rates without cutting pipes currently exist and would supplement the lack of information about water use in the residence halls at little additional cost. With this information, an interactive, real-time website could be developed that would track total water consumption, calculating the cost to each resident and their per capita water use in gallons per day. Students would then have the opportunity to reduce their fees by conserving water and energy. As stated, targeted outreach at shower use alone could save thousands of dollars each year.

Outside of the residence halls, municipalities could ask that landlords not charge flat water rates, tempting residents to conserve water. Regression models clearly show that such a policy will reduce consumption. Also, it appears that higher education has beneficial effects on the water use characteristics of offspring, so improved access to graduate degrees would help state water experts manage our resources. Unfortunately, this study was not able to conclude that environmental education will decrease water consumption, hence no policy recommendations can be made for students' education (Tables 5a and 5b).

Still, it is important to realize that indoor residential use accounts for only one-third of total urban water consumption (Pacific Institute 2003). Although the college population is growing and will continue to grow into the next decade, there are many other non-residential water uses that were not covered in this study. It is important to learn as much about water use characteristics now, when the water crisis in at a minimum. If we wait too long, it may be too late.

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