RECLAMATION

Managing Water in the West

The Influence of Conservation Pricing and Other Non-Price Factors on Residential Water Demand

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

May 29, 2014

Legal Notice

The Influence of Conservation Pricing and Other Non-Price Factors on Residential Water Demand

This report was prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Denver, Colorado.

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Acknowledgments

This document has benefited immeasurably from the gracious assistance and guidance provided by the following people.

Tim Barr, Metropolitan Water District of Southern California
Joe Beachem, Otay Water District
Doug Bennett, Southern Nevada Water Authority
Tim Blair, Metropolitan Water District of Southern California
Chris Dundon, Contra Costa Water District
Penny Falcon, Los Angeles Department of Water and Power
Terry Feaster, City of Henderson
Dana Friehauf, San Diego County Water Authority
Karly Gaynor, Western Municipal Water District
William Granger, Otay Water District
Richard Harris, East Bay Municipal Utility District
Francie Kennedy, City of San Juan Capistrano
Elizabeth Lovsted, Eastern Municipal Water District
Sophia Marcus, Los Angeles Department of Water and Power
Chris Meenan, Las Vegas Valley Water District
Kyle Okamura, City of Henderson
Bill Plummer, City of Carlsbad
Christine Ruess, City of Carlsbad
Fiona Sanchez, Irvine Ranch Water District
Carolyn Schaffer, Metropolitan Water District of Southern California
Polly Walker, City of Henderson
Debra Whitney, U.S. Bureau of Reclamation, Southern California Area Office

Any errors are the sole responsibility of the author.

Project Funding

This research project was funded by the U.S. Bureau of Reclamation’s Science and Technology (S&T) Program.

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Executive Summary

Municipal and industrial water supply and demand imbalances can be met through investment in water supply expansion, implementation of water conservation techniques, or a combination of both. Lower cost demand side conservation approaches may be preferable when water supply expansion is not a financially viable option. One demand side approach that can be used is conservation pricing. In order to evaluate the potential for conservation pricing to address these imbalances, the response of water users to changes in price and rate structure must be quantified.

This analysis uses individual household data to evaluate the influence of price, rate structure, income, a recession, and other variables on residential water demand. The lagged average cost of water is used as the price variable, which represents the most recent pricing information actually available to the water user. The number of tiers in a water agency's pricing structure is included as a variable influencing the quantity demanded, separate from the impact of price. The time period covered by the data includes a recession, so the potential impact of the recession on water use can be evaluated and the impact of macroeconomic conditions can be considered in the pricing decisions of water agencies.

Previously completed municipal water demand studies have identified important factors that influence household water demand and have estimated municipal water demand relationships. Despite the different approaches used, modeling results have been consistent in terms of the influence of price on the quantity of water used as measured using the price elasticity of demand. Although there is a wide range of estimated elasticities, previous studies indicate a typical range of about -0.20 to -0.60.

The data used to estimate the aggregate household demand models in this analysis included 11 different water agencies in California and Nevada over the period 2000 to 2011. The water agency data includes individual household water use, water bill by household, the rate structure implemented during the period of analysis, household location, and for some agencies the lot size associated with the home. Data obtained from other sources to estimate demand included climate variables (precipitation and temperature), drought conditions, socio-economic data such as median household income and household size, and unemployment rate. Over 614,000 total usable observations were provided by the water agencies, representing over 150 zip codes. Nearly 487,000 observations included lot size information.

The residential demand models estimated in this analysis are based on water use per billing day, the lagged average cost of water per gallon for the billing period prior to the period of use, lot size data when provided by the water agency, and household size when provided by the agency. Additional data were obtained for socio-economic variables obtained at the zip code level and climatic variables. The socio-economic variables included median household income, household size, unemployment rate, median age of the population, and the percentage of single family homes that are detached. The percentage of single family homes that are detached was used as a proxy for lot size when lot size data were not available. Climatic variables included average monthly temperature and precipitation for the weather station nearest the zip code identified for each household and the short-term Palmer Drought Index by month for each region associated with the household location. The modeling results indicate that all of the estimated coefficients were statistically significantly different from zero except for some of the seasonality variables and each variable had the expected sign except for unemployment. The adjusted r-squared for each of the models ranged from .39 to .45, indicating 39% to 45% of the variation in use was explained by the model. The estimated water demand model is based on real prices and income rather than nominal prices. Adjusting the estimated real price elasticities to represent nominal elasticities, results in a range of -0.24 to -0.31. These results are within the range of nominal estimates found in the literature. Similar to the influence of water price on use, a change in income would be expected to influence the amount of water used. An increase in income, other factors remaining constant, would be expected to lead to increased water use. The estimated nominal income elasticity was estimated to range from 0.07 to 0.09.

The estimated models indicate the number of price tiers has a negative effect on water use, holding all other factors constant. A "tier elasticity" could be defined as a measure of how water use would change due to a change in the number of tiers included in the rate structure, separate from the average lagged price. The influence of the number of price tiers on water use was estimated to range from -0.11 to -0.13. This result is important from the standpoint of pricing policy because the influence of the number of tiers on water use can be used to influence water use while theoretically maintaining a stable average cost of water.

Many of the water supply agencies participating in the study indicated that they observed reduced water use during the recessionary period from late 2007 to 2011. Additional aggregate regressions were completed to evaluate the possible effect of the recession on residential water use. The modeling results revealed a structural difference in demand between the 2000 to 2006 pre-recessionary period and the 2007 to 2011 recessionary period. The price elasticity of demand during the pre-recession period was estimated to range from -0.23 to -0.26 while the price elasticity of demand during the recessionary period was estimated to range from -0.26 to -0.30. The estimated price elasticity of demand during the recession was approximately 14% greater than when there was no recession.

The estimated price elasticities of demand should be interpreted as long run elasticities since they are estimated over an 11 year time frame over which water users could respond to price increases by implementing new technologies, removing outdoor landscaping, and other changes that cannot be implemented in the short run. Therefore, the elasticity estimates from this analysis would be most useful in terms of long range planning rather than predicting short run impacts from a rate change.

Introduction

Areas that are experiencing municipal and industrial water shortages can invest in water supply expansion strategies, implement water conservation techniques, or use a combination of both to help balance water supplies and demand in the present and the future. Expansion of water supplies may not be a viable short term option for a variety of financial and engineering reasons, but may be appropriate as part of a long term planning strategy. Water conservation, including installation of water saving devices and conservation pricing, is a demand side approach to water management that avoids the costs associated with water supply expansion and can be implemented in areas that do not have a financially viable supply option.

Previous research has evaluated the price elasticity of demand and the influence of different variables on price elasticity for municipal water in various areas across the United States. Most of these analyses have been aggregate in nature and therefore do not represent the responsiveness of individual households to changes in price or other variables that would be expected to influence quantity demanded. This analysis uses individual household data over an 11 year period to evaluate the influence of price, income, the recession, and other variables on residential water demand. The availability of individual household data allows for increased flexibility in defining the variables that influence water use.

The results of this analysis would be of interest to water agencies for several reasons. First, the variable used to define the price of water is the lagged average cost rather than the cost of water at the actual time of use. The lagged price represents the most recent pricing information provided to the water user through a water bill. Second, the number of tiers included in an agency's pricing structure is included in the model as a variable influencing the quantity demanded, separate from the impact of price. The tier variable provides information on how the rate structure itself affects water use. Third, the data represents a period of time that could be considered a long-run elasticity. Long run elasticities account for potential adjustment in water use through the installation of water saving devices such as low use plumbing fixtures and advanced sprinkler controllers and represent the influence of price in a long term planning context. Last, the period of time of the data includes a recession, so the potential impact of the recession on water use can be evaluated and the impact of macroeconomic conditions can be considered in the pricing decision of a water agency.

Background and Previous Studies

Previously completed municipal water demand studies have identified factors that influence household and commercial water demand and have estimated municipal water demand curves. While different methodologies were used in these studies, the results from the models have consistently shown the influence of price and income on the quantity of water demanded to be inelastic. The results from previous studies have been consistent even though different variables have been used to estimate the demand for municipal water supplies.

Elasticity is an important concept that is used to describe how the quantity demanded for a good or service reacts to changes in the variables that influence demand. A general definition of elasticity is:

Elasticity = $(\Delta x/x)/(\Delta y/y)$ or the percentage change in x divided by the percentage change in y.

If we are interested in the price elasticity of demand, Price elasticity of demand (ε_d) = $(\Delta Q/Q)/(\Delta P/P)$ where Q is quantity demanded and P is price. In terms of calculus:

$$\varepsilon_d = [\partial Q/\partial P_Q] * [P_Q/Q] \tag{1}$$

The term $[\partial Q/\partial P_Q]$ is equivalent to the coefficient for price in a double log demand equation. In other words, the effect of a change in price on quantity demanded is constant throughout the range of possible prices and quantities.

For a normal good, price elasticity of demand is negative (a higher price results in less of a good purchased) and income elasticity is typically positive (a higher income generally results in purchasing more goods and services). If the calculated absolute value of price elasticity of demand is greater than 1, the good is characterized as being price elastic, meaning that the quantity demanded is very responsive to a change in price. An absolute value of price elasticity less than 1 is an inelastic demand, where a percentage change in price results in a percentage change in quantity demanded that is less than the percentage change in price. An elastic price elasticity of demand implies greater effectiveness of price as a conservation tool.

Most of the previous studies of domestic water demand have estimated an inelastic price elasticity of demand. Given that water does not have any real substitutes and generally represents a small percentage of total household expenditures, demand is expected to be price inelastic. Some previously completed water demand studies and estimated price elasticities are summarized in Table 1. It should be noted that the previously completed studies listed in Table 1 are based on nominal prices. Nominal prices represent the dollar value of a product at the time it was produced. Prices can also be measured in terms of real prices. Real prices are adjusted for changes in the general price level over time, providing a measure of prices for various years as if the value of the dollar was constant.

There are some general observations from previous studies evaluating price elasticity of demand that are interesting to note. First, although there is a wide range of estimated elasticities, previous studies indicate a typical range of about -0.20 to -0.60. Second, the estimated long-run elasticities are consistently greater, in absolute value terms, than the estimated short-run elasticities. This result is expected because water users can adjust to price changes in the long run by adopting new technology or other adjustments in water application and use such as reduced lawn area and different landscape materials. Third, the price variable used in previous water demand studies has included average price, marginal price, or a combination of both. Arguments have been made for the use of both average and marginal price as the relevant price influencing consumer behavior.

Table 1 – Price elasticities estimated in previous water demand studies

Author(s)	**Year of study**	**Price elasticities**	**Geographic region**
Agthe and Billings	1980		Tucson, AZ
- short run		-0.179 to -0.358	
- long run		-0.266 to -0.705	
Agthe, Billings, Dobra, Raffiee	1986		Tucson, AZ
- long run		-0.125 to -0.624	
- short run		-0.019 to -0.364	
Billings and Day	1989	-0.200 to -0.710	Tucson, AZ
Dalhuisen, et al. (meta-analysis)	2003		U.S.
- mean		-0.41	
- median		-0.35	
Espey, Espey, and Shaw (meta-analysis)	1997	-0.51	U.S.
Foster and Beattie	1979		U.S.
- Rocky Mountains		-0.226	
- Southwest		-0.122	
Gottlieb	1963	-0.656 to -0.680	Kansas
Howe and Linaweaver	1967	-0.231	U.S.
Jones and Morris	1984	-0.14 to -0.44	Denver, CO
Martin and Wilder	1992	-0.32 to -0.70	Columbia, SC
Nieswiadomy	1992	-0.17 to -0.45	U.S.
Nieswiadomy and Molina	1989	-0.002 to -0.460	Denton, TX
Nieswiadomy and Cobb	1993		
- increasing block rate structure		-0.64	U.S.
- decreasing block rate structure		-0.46	
Piper	2003	-0.32	U.S.
Renwick and Archibald	1998		Southern CA
- all water users		-0.33	
- less than $20,000 income		-0.53	
- $20,000 to $59,999 income		-0.21	
- $60,000 to $99,999 income		-0.22	
- over $100,000 income		-0.11	
Renwick and Green – all seasons	2000	-0.16	California
- summer months		-0.20	
Schneider and Whitlach	1991		Columbus, OH
- residential		-0.110 to -0.262	
- commercial		-0.234 to -0.918	
- industrial		-0.112 to -0.438	
Weber	1989	-0.202	Oakland, CA
Williams	1985	-0.05 to -1.09	U.S.
Williams and Suh	1986		U.S.
- long run residential		-0.294 to -0.485	
- long run commercial		-0.141 to -0.360	
- long run industrial		-0.438 to -0.735	
Wong	1972		Chicago area
- Cities over 25,000 people		-0.530	
- Cities 10,000 to 24,999 people		-0.817	
- Cities 5,000 to 9,999 people		-0.463	
- Towns less than 5,000 people		-0.257	
Young	1973	-0.41 to -0.60	Tucson, AZ

The study of most interest listed in Table 1 is the Renwick and Green (2000) study of eight California water agencies due to the similarity of the study areas. Three of the eight water agencies included in the Renwick and Green study are included in the analysis described in this paper. Renwick and Green evaluated the effectiveness of price and demand side management policies in reducing urban water demand. They used agency level monthly family water use and cost data over eight years for each of the eight water agencies, resulting in 776 observations. Marginal price at the aggregate agency level was used as the price variable. The alternative demand side management policies evaluated in the analysis included mandatory and voluntary measures. The demand side management policies included:

- Public information campaigns (voluntary)
- Low flow toilet rebate programs (voluntary)
- Distribution of free plumbing retrofit kits (voluntary)
- Water rationing/allocation policies (mandatory)
- Restrictions on certain types of water uses (mandatory)
- San Francisco Water District's compliance affidavit policy (mandatory)

The estimated price elasticities of demand were -0.16 over all seasons and -0.20 during the summer months. Renwick and Green acknowledged that the estimates were somewhat lower than previous studies. Income elasticity was estimated to be 0.25. The average lot size variable was found to be statistically significant and four of the six demand side management policies were statistically significant. The toilet rebate programs and San Francisco compliance affidavit policy were the two variables that were not statistically significant. It was also found that the mandatory water rationing and restrictions on type of use reduced water demand substantially more than voluntary measures.

The Renwick and Green study provides results that could be useful to water supply agencies trying to reach water use reduction goals. First, the low price elasticity of demand estimate indicates that although an increase in price will lead to a reduction in the quantity of water used, the reaction to the price increase will be quite small. A 1% increase in price will only lead to a 0.16% reduction in quantity used. If affordability or fairness issues are associated with a price increase, then the use of conservation pricing to meet water use reduction goals may be limited. Second, the study indicates that mandatory non-price conservation requirements are more effective than voluntary approaches. Therefore, it would follow that unpopular mandatory conservation approaches may be necessary to meet future water use reduction goals. Third, marginal price associated with a specific month for an agency is used as the price variable. Marginal price is conceptually the correct measure of price that should be used to measure consumer response to the price of purchasing an additional unit of a good or service. However, the use of marginal price may not be as straight forward as theory would suggest. Given that the marginal price used in the Renwick and Green analysis is representative for aggregate households over a month, it does not represent a marginal price actually imposed on an individual household at any particular time. The marginal price can be thought of as an "average" marginal price imposed on an "average" household. In addition, use of marginal price implies the household understands what the marginal price is and reacts to that price. This issue is addressed later in this paper.

Approach Used in this Analysis

In order to estimate the price elasticity of demand for domestic water and the potential effects of other variables on quantity demanded, a demand relationship must first be estimated. Residential water demand curves can be estimated using time series data, cross-sectional data, or both. Time series data involves the use of data for a single entity over a period of time while cross-sectional data refers to data collected for many entities at one point in time or over a relatively short period of time. It is generally more difficult to obtain a sufficient number of observations to estimate a water demand curve using time series data for a water provider than for cross-sectional data for several water providers. However, time series data potentially allows for a wider range of variation in the factors that affect water use when modeling demand.

The water agency data used to estimate the aggregate household demand models in this analysis are cross-sectional (11 different water agencies in California and Nevada) and time series (2000 to 2011 data). Few 2011 observations were provided. These types of multidimensional data are referred to as panel data. The water agency data includes individual household water use, water bill information by household, the rate structure implemented during the period of analysis, household location, and for some agencies the lot size of the home. In some cases the rate structure implemented by an agency changed over the period of analysis, which was accommodated in the model by simply changing the rate structure variable to reflect the change. This is analogous to changing the price variable to reflect a change in price over time. Data obtained from other sources to estimate demand included climate variables (precipitation and temperature), drought conditions, socio-economic data such as median household income and household size, and unemployment rate. The aggregate model can be used to directly estimate the effect of the policy variables price and rate structure on water use. In addition, a recession occurred during the period of analysis so the effects of a recession on water use can be assessed.

Sources of Data

Individual water use and water rate data were obtained from 11 water agencies in California and Nevada. Each agency was asked to provide data for 500 randomly selected households for the same address over a 10 year period from 2001 to 2010. In some cases, data were provided for 2000 or 2011. Many observations were not included in the analysis because of zero water use or incomplete data across all variables. Additional data such as lot size/landscape area, household size, and climatic variables were provided by some agencies. The following water agencies provided data for the analysis.

- Carlsbad Municipal Water District
- Contra Costa Water District
- East Bay Municipal Utility District
- Eastern Municipal Water District
- City of Henderson
- Irvine Ranch Water District
- Los Angeles Department of Water and Power
- Otay Water District

- Las Vegas Water District
- Western Municipal Water District
- San Juan Capistrano

Over 614,000 total usable observations were provided by the 11 water agencies, representing over 150 zip codes. Not all of these observations included data for landscape area. Nearly 487,000 observations included lot size information. Each observation included the number of days in the billing period and the unit of water use (e.g. 1,000 gallons or cubic feet) so each could be converted into gallons of use per household per day. Water use was provided in terms of use for each price tier so both marginal and average prices can be calculated for each household observation. Average water use and cost information are presented in Tables 2 and 3.

Demand Estimation Issues

There are some general demand estimation issues that need to be addressed in order to derive reliable price elasticity of demand estimates. First, if a water supplier uses a tiered rate structure, the quantity of water used by an individual influences the price of water charged. The use of ordinary least squares to estimate the demand model relationship under this condition would lead to simultaneity bias and would result in inconsistent coefficient estimates. The feedback effect between quantity and price creates the need to use two-stage least squares, indirect least squares, or some other instrumental variable approach to deal with simultaneity. An instrumental variable approach is based on the use of variables that approximate the explanatory variable causing simultaneity issues but are not actually determined simultaneously. Some economists have indicated that the simultaneity problem may be addressed through the use of an average price approximation and then transforming the approximate price into the natural log to estimate demand. This is based on an assumption that consumers are reacting to the approximate average price rather than the rate schedule.

A second issue is choosing the correct price for use in estimating a demand relationship and the timing of price signals. Do residential water users react to current water prices or prices reflected through water bills received for the previous billing period? Theoretically the marginal price of the last unit purchased is the correct price for estimating demand. However, water users may not recognize the marginal price through the current price paid, but may actually react to the average price paid in the latest water bill received. The logic for using previous billing period price is that water users would see their previous month billing period water bill and react to that in the current period. Therefore, the price that water users react to may actually be the average price from the previous month. For example, the average price of water in a June water bill that is received in early July may represent the price that influences water use in July.

Using lagged price as the price also addresses the simultaneity problem created by the interaction of quantity used and price. If the price a water user reacts to in their decision on the quantity of water they wish to use is based on price from a previous time period, then the current price of water is not relevant to the current water use decision. In this case current water use does not influence the relevant price and simultaneity between quantity and price does not exist because price is a lagged endogenous variable.

Table 2 – Average monthly water use per household for those included in analysis

Year	**Carlsbad Municipal Water District**	**Contra Costa Water District**	**East Bay Municipal Utility District**	**Eastern Municipal Water District**	**City of Henderson**	**Irvine Ranch Water District**	**Las Vegas Water District**	**Los Angeles Department of Water and Power**	**Otay Water District**	**San Juan Capistrano**	**Western Municipal Water District**
	Hundred cubic feet (HCF)										
2000	-	-	-	-	-	-	21.80	-	-	22.42	36.91
2001	24.32	10.43	-	25.65	14.26	15.09	21.04	16.87	-	18.90	35.04
2002	25.67	10.51	13.62	27.36	13.98	15.73	20.83	16.04	-	21.92	37.90
2003	23.85	10.36	13.18	25.48	13.67	15.28	19.03	15.68	16.18	21.63	35.10
2004	24.94	10.53	13.64	27.04	12.71	15.58	20.12	15.92	16.72	22.30	36.82
2005	24.99	10.00	10.19	25.67	12.37	15.11	19.62	16.67	16.37	21.45	33.53
2006	25.22	9.74	13.14	26.91	12.84	17.62	20.57	15.42	16.83	21.53	35.84
2007	25.79	10.27	11.07	27.59	12.66	18.46	20.32	15.81	17.26	22.93	38.25
2008	24.60	10.32	12.25	25.22	12.60	17.50	18.96	14.91	16.31	21.18	35.26
2009	21.43	9.34	11.15	21.98	12.23	16.59	19.37	13.73	15.82	20.21	33.02
2010	17.64	8.65	10.75	19.96	11.47	14.95	-	12.03	14.43	18.30	28.26
2011	-	-	-	-	-	-	-	-	12.25	17.75	24.42
Avg.	**23.79**	**10.02**	**12.11**	**25.29**	**12.88**	**16.19**	**20.17**	**15.31**	**15.80**	**20.92**	**33.84**

Table 3 – Average cost of water for those included in analysis (Includes all charges, fixed and variable)

Year	**Carlsbad Municipal Water District**	**Contra Costa Water District**	**East Bay Municipal Utility District**	**Eastern Municipal Water District**	**City of Henderson**	**Irvine Ranch Water District**	**Las Vegas Water District**	**Los Angeles Department of Water and Power**	**Otay Water District**	**San Juan Capistrano**	**Western Municipal Water District**
	Dollars per hundred cubic feet (HCF)										
2000	-	-	-	-	-	-	1.43	-	-	1.76	2.21
2001	2.59	4.62	-	1.93	1.88	1.33	1.39	2.47	-	1.89	2.26
2002	2.49	4.55	2.95	1.84	1.83	1.21	1.35	2.31	-	1.95	2.17
2003	2.43	4.58	2.94	1.87	1.82	1.31	1.37	2.34	3.98	2.09	2.26
2004	2.39	4.53	3.03	1.90	1.90	1.48	1.88	2.33	4.35	2.43	2.18
2005	2.32	4.62	3.11	1.98	1.87	1.66	1.78	2.48	4.59	3.07	2.41
2006	2.29	4.52	3.29	1.97	1.83	2.19	1.73	2.25	4.57	3.28	2.35
2007	2.29	4.42	3.33	1.95	1.71	2.25	1.71	2.43	4.98	3.20	2.21
2008	2.50	4.37	3.81	2.19	1.75	2.46	1.99	2.75	5.60	3.64	2.59
2009	3.17	5.14	4.15	2.45	1.81	2.69	1.96	3.11	6.26	3.78	3.14
2010	4.13	5.05	4.54	2.49	2.02	2.89	-	4.00	6.98	6.21	3.76
2011	-	-	-	-	-	-	-	-	7.86	7.16	4.28
Avg.	**2.66**	**4.64**	**3.46**	**2.06**	**1.84**	**1.94**	**1.66**	**2.65**	**5.46**	**3.37**	**2.65**

Variables Used to Estimate Demand

The residential demand models estimated in this analysis are based on water use per billing day, the lagged average cost of water per gallon for the billing period prior to the period of use, lot size data when provided by the water agency, and household size when provided by the agency. Those agencies which use water budgets to determine water bills have lot size and household size data as part of their water budget calculation. Additional data were obtained for socio-economic variables obtained at the zip code level and climatic variables. The socio-economic variables included median household income, household size, educational attainment as defined by a B.S. degree or higher, unemployment rate, median age of the population, median single family home value, and percentage of detached single family homes. A detached home is a building that does not share an inside wall with any other house or dwelling. Ultimately educational attainment was not included as an explanatory variable due to a high correlation with income. The median single family home value and percentage of single family homes that are detached were considered as proxy variables for lot size when lot size data were not available. The median home value is a poor proxy for lot size because many characteristics unrelated to lot size influence home values while the percentage of detached homes is more closely correlated to lot size. Therefore, the percentage of detached homes was selected as the proxy for lot size. Climatic variables included average monthly temperature and precipitation for the weather station nearest the zip code identified for each household and the short-term Palmer Drought Index by month for each region associated with the household location.

The Palmer Drought Index (PDI) is used by the National Oceanic and Atmospheric Administration (NOAA) to measure the duration and intensity of long-term drought-inducing circulation patterns. Since long-term drought is cumulative, the intensity of drought during the current month is dependent on the current weather patterns as well as cumulative patterns of previous months. Weather patterns can change quickly from a long-term drought pattern to a long-term wet pattern, so the PDI can respond fairly rapidly. That is why the PDI was used as an explanatory variable in this analysis.

The variation in socio-economic data results from both cross-sectional differences and differences over time. Most of the zip code level socio-economic data were available only from the 2000 Census, although some demographic data (household size and age) are available from the 2010 Census. American Community Survey data single year estimate data were available for some of the larger communities and all counties for 2000 through 2010. For the smaller communities, 3 year and 5 year estimates were available for the years between 2000 and 2010. The community level data were used to estimate proportional changes in the socio-economic variables over time for the 2000 zip code data. The community data were applied to all zip codes within that community. This approach was used to account for changes in economic and social conditions over the 2001 to 2010 time period. All price and income data were converted into base year 2000 real prices.

The average precipitation and temperature climatic variables are annual averages for each month. Therefore, the variation between observations is the result of the cross-sectional nature of the data. The PDI drought variable represents a change in conditions over time.

The number of price tiers was included in the model to represent differences in the price structure for each water agency. Other influences considered to be important in evaluating the influence of pricing structures on use are the "width" of the tier (usage included in each tier) and the "height" of the tier (price associated with each tier). However, these factors are correlated with the number of tiers and average price so they were not included as separate variables.
The use of panel data creates a unique problem because the effects associated with differences between different groups must be differentiated from effects over time. Each water agency has unique characteristics that may influence household responses to changes in price. A fixed effects model can be used to account for these unique characteristics while evaluating the effect of variables that influence water use over time. The term fixed effects is used because the model is raising or lowering the estimated regression line (intercept) by a fixed amount for each individual agency. One method that can be used to account for fixed effects is to simply include dummy variables for the different agencies, where the dummy variable takes on a value of 1 or 0 to indicate the observation does or does not represent a specific water agency. Dummy variables were specified for each agency except Los Angeles. The total number of dummy variables must be equal to the total number of agencies minus 1, to avoid perfect multicollinearity, so a dummy variable must be excluded for one of the agencies. As a result, Los Angeles can be thought of as the base case where all of the dummy agency variables take on a value of zero. Failure to account for fixed effects would result in biased regression estimates.

Average cost/price is used to estimate demand in this analysis based on the theoretical discussion above and as a result of preliminary modeling results and small group interviews described below regarding water bill formats. Preliminary modeling indicated marginal price was not a good predictor of water use, based on incorrect coefficient signs and lack of statistical significance, based on several variations of marginal price and price differentials. In addition, two-stage least squares results from preliminary modeling were relatively poor due to instrumental variables that were poor predictors of price used in the first-stage equation that corrected for simultaneity. If the instrument is poor, the two-stage least squares results will also be poor.

The average price of water from the previous billing period is used in this analysis as the price variable for the current month of use. It is assumed that households will not be reacting simultaneously to current price, but will instead react to the most recent price information available to them from their water bills for use in the previous billing period. Preliminary models were run using the price for the month of use and for the price for the month prior to use. The lagged price generated better results in terms of statistical significance and expected coefficient signs as well as having theoretical validity. The results of the small group interviews described below also supported using lagged price as the relevant price variable.

Additional Information: Water Bill Format

In order to get a better idea of how water users might interpret the price of water portrayed in a water bill and the influence of the water bill format on use, two small groups of 4 people each were asked to evaluate the water bill format for each of the participating agencies. We wanted to evaluate the importance of the appearance of the water bill on use, what information is actually understood by those looking at the water bill, and how the information influences water use behavior. When evaluating water bills, the following questions were asked:

1) How would you determine total water use for the period?
2) What is the total amount charged for water for the period?
3) What is the average cost of water per unit used?
4) What is the cost of the last unit of water used?
5) How does this month's water use compare to the same month for other years (last year)?
6) How does this month's water use compare to other months of use on average?
7) Does the bill format encourage water conservation?

The questions were followed up with a general discussion. The general results of the group answers and discussion are summarized below.

- Only 1 person could answer the marginal cost question for all bills (A maximum of five minutes was allowed on each bill, most took much less)
- All but two could answer average cost.
- The tier information was "interesting," but the total bill was consistently the main focus.
- Having sewer on the bill confused two on total cost.
- All agreed that they would use the information presented in the most recent water bill as a measure of current price.

The results of the small group discussions provide additional support for the use of average lagged cost per unit of water as the measure of water price.

Model Estimation

Several different types of functional forms could be used to estimate a model of municipal and industrial water demand. The simplest model is a linear model. Two important characteristics of the linear model are: 1) the model has a constant slope and 2) the elasticities of the explanatory variables vary according to the quantity of goods and services purchased. In some cases the linear form may be overly simplistic. The model that is most frequently used to estimate water demand relationships is the log-log or double log model. In a double log model the water use and water cost variables are transformed using the natural log and the transformed variables are then used in model estimation. Transforming the water use and water cost variables into natural logs leads to a constant price elasticity of demand. Therefore, the coefficients for water cost can be interpreted as a price elasticity of demand. The estimated aggregate water use model is:

$$
\begin{aligned}
lnUse = \; & \beta_0 + \beta_1\, ln\text{Price} + \beta_2\, ln\text{Income} + \beta_3\, ln\text{Tiers} + \beta_4\, ln\text{Precip} + \beta_5\, ln\text{Temp} + \beta_6\, \text{Drought} \\
& + \beta_7\, ln\text{HHsize} + \beta_8\, ln\text{Age} + \beta_9\, \text{Unemp} + \beta_{10}\, ln\text{Lot/Detach} + \beta_{11}\, \text{Sin3} \\
& + \beta_{12}\, \text{Sin6} + \beta_{13}\, \text{Cos3} + \beta_{14}\, \text{Cos6} + \beta_{15}\, \text{Carlsbad} + \beta_{16}\, \text{Contracosta} \\
& + \beta_{17}\, \text{Eastern} + \beta_{18}\, \text{EBMUD} + \beta_{19}\, \text{Henderson} + \beta_{20}\, \text{IrvineRanch} \\
& + \beta_{21}\, \text{LasVegas} + \beta_{22}\, \text{Otay} + \beta_{23}\, \text{SanJuanCap} + \beta_{24}\, \text{Western} + \beta_{25}\, \text{Trend} \qquad (2)
\end{aligned}
$$

Where:

lnUse:	The natural log of household water use measured in gallons per household per day.
*ln*Price:	The natural log of real water cost in the previous billing period measured in dollars per gallon.
*ln*Income:	The natural log of real median household income.
*ln*Tiers:	The natural log of the number of tiers included in the rate structure.
*ln*Precip:	The natural log of average monthly precipitation in inches, plus 1.
*ln*Temp:	The natural log of average monthly temperature in degrees Fahrenheit.
Drought:	Palmer Drought Index, where extreme or severe drought is represented by a 2, a moderate drought is a 1, and mid-range or moist conditions are a 0.
*ln*HHsize:	The natural log of average household size.
*ln*Age:	The natural log of average age in years.
Unemp:	Annual unemployment rate.
*ln*Lot/Detach:	The natural log of lot size in square feet or, when lot size data are not available, the percentage of single family homes that are detached.
Sin3, Sin6, Cos3, Cos6:	Sine and cosine harmonics representing seasonality.
Carlsbad, Contracosta, Eastern, EBMUD, Henderson, IrvineRanch, LasVegas, Otay, Western, SanJuanCap:	0, 1 Dummy variables were used to represent each water agency in the fixed effects model.
Trend:	A monthly time trend variable, ranging from 1 to 144.

Not all of the variables shown for the general model (2) above were included for all of the estimated equations. Lot size data were not available for Contra Costa, EMBMUD, and Otay so only the models estimated using the variable Detach included these three agencies. The expected effect of each of the variables on water use is discussed below.

Water Use per Household

Water use for each agency is converted into gallons per household per billing day. This conversion allows for comparable use figures regardless of billing period. It is assumed that one residential connection represents one household.

Real Price/Cost of Water

Economic theory suggests that for normal goods people will demand less of a good or service as the price of the good or service increases, assuming other factors such as income and the price of other goods remains constant. Therefore, the price/cost coefficient is expected to be negative. The natural log of real average price/cost per gallon from the previous billing period (lagged) was used in the models. Real prices were estimated using the consumer price index.

Real Household Income

Income is included in the model to capture the financial resources available for water users to purchase water and other goods and services that may contribute to water consumption. The natural log of real median household income was used as the income variable. A higher income would be expected to contribute to greater water use, all other factors held constant. Real income is estimated using the consumer price index.

Number of Tiers
The number of tiers is hypothesized to lead to a reduction in water use if all other factors such as the price of water and income are held constant. It is generally believed by most water agencies that increasing the number of tiers provides an incentive for water users to limit use to avoid moving into higher priced tiers. Therefore, a greater number of tiers will tend to discourage water use as a variable separate from the influence of price.

Average Monthly Precipitation and Temperature
The average annual precipitation and temperature variables are an indication of average climatic conditions and are useful for capturing differences between locations. Previous research results have shown that there is a statistically significant relationship between water use in a geographic region and climate in that region. Average monthly temperature and precipitation are climate variables that can be used to capture the influence of weather on primarily outdoor water use. The natural log of precipitation plus one was used as the precipitation variable and is expected to have a negative influence on water use. The natural log of average monthly temperature is expected to have a positive influence on water use, where higher temperatures would tend to create a greater demand for landscape irrigation

Drought
Measures of climatic conditions over time are needed to capture variability in conditions from the average. The Palmer Drought Index measures the balance between moisture demand (evapotranspiration driven by temperature) and moisture supply. The Palmer Z Index used in this analysis describes moisture conditions for a specific month. The Index includes extreme drought, severe drought, moderate drought, mid-range, and various levels of moist conditions. Extreme or severe drought was given a rating of 2, moderate drought a rating of 1, and mid-range or moist conditions a rating of 0. A higher rating should lead to greater levels of water use.

Household Size
It is expected that larger household size translates into greater water use.

Median Age
There is no prior expectation for the effect of age on water use. However, age is frequently included in demand models as a potentially relevant demographic variable.

Unemployment
It is expected that higher unemployment levels would have a negative effect on water use since unemployment represents reduced economic resources and expectations.

Lot size or Percentage of Detached Single Family Homes
Lot size data were provided by eight of the participating water agencies. It is expected that lot size will have a positive impact on water use because it takes more water to irrigate more square footage, assuming other characteristics such as the type and coverage of landscape materials are held constant. In the absence of lot size data, the percentage of homes that are detached is used as a proxy for the area that needs to be watered. The percentages of detached single family

homes were obtained from Census data by zip code. It is expected that the percentage detached and home value will have a positive impact on water use.

Seasonality
Seasonality was included in the model through biannual and quarterly sine and cosine harmonics. Dummy variables could also be used to represent seasonality, but would likely cause multicollinearity problems with the climatic variables.

Trend
A trend variable is included to account for factors that may change over time but are not accounted for by the other explanatory variables. For example, drought experiences and an improved understanding of water supply constraints may change attitudes towards water use over time. Another example could be changes in the number of households that have gardens or participate in activities that require water use. The expected sign of the trend variable is unknown because many factors that have a positive or negative effect on water use are included in the trend.

Aggregate Modeling Results

Four different aggregate water demand models were estimated. Two models included lot size as an explanatory variable and two models included the percentage of single family detached homes as a proxy for lot size. There were approximately 23% more observations for the models that included the percentage of single family detached homes as a proxy for lot size compared to the models using lot size. Outlier observations were removed from the data for two models. Outliers are defined in terms of water use, where observations with use of less than 12 gallons of water per household per day or greater than 5,000 gallons per household per day were removed. Summary modeling results are shown in Tables 4 through 7.

The results presented in Tables 4 and 5 include lot size as an explanatory variable and have outliers removed (Table 4) and have all data included (Table 5). The results presented in Tables 6 and 7 include the percentage of single family detached homes as an explanatory variable and have outliers removed (Table 6) and have all data included (Table 7). The modeling results are shown for four different models to provide full information on effect of excluding very low and high use observations and including lot size as an explanatory variable. Generally, the model with lot size data and outliers removed (Table 4) is considered to be the theoretically best model. However, since three agencies are not included in the lot size models, the model using the percentage of detached single family homes is also useful in terms of geographic coverage. EViews 8 was the econometric software used to estimate the models (HIS Global Inc., 2013).

It should be noted that while several different functional forms and different combinations of explanatory variables were initially estimated, the elasticity estimates and significance of the explanatory variables were very stable and consistent across all models. It should also be noted that although the choice of average lagged cost of water was chosen as the price variable for theoretical reasons, preliminary models were estimated using several variations of marginal price/cost and price differentials for both lagged and current marginal price/cost as well as current average price/cost. None of these other models performed well in terms of statistical

Table 4 - Modeling results including a lot size variable and removing outliers

ln Use/HH/Day = -7.9338 – 0.9023 ln lagged price + 0.1101 ln income - 0.1272 ln tiers
(-381.43)* (23.36)* (-26.22)*

- 0.0919 ln Precip + 1.1250 ln Temp + 0.0055 Drought + 0.1875 ln hhsize + 0.4645 ln Age
(-30.59)* (121.37)* (5.03)* (23.83)* (47.21)*

+ 0.0034 Trend + 0.3445 Unemploy + 0.0220 ln Lot Size + 0.6883 Carlsbad + 0.5230 Eastern
(95.48)* (7.11)* (51.11)* (113.60)* (86.82)*

- 0.0936 Henderson + 0.5168 Irvine Ranch + 0.3023 Las Vegas + 0.8247 Western
(-15.86)* (74.17)* (48.43) * (141.51)*

+ 0.9023 San Juan Cap - 0.0135 Sin(3) – 0.0108 Cos(3) – 0.0065 Sin(6) + 0.0132 Cos(6)
(155.36)* (-10.31)* (-8.19)* (-4.70)* (9.83)*

Observations = 483,065
Adjusted R^2 = .39
F Statistic = 14,148.9*
*Significant at the 1% level of confidence

Table 5 – Modeling results including a lot size variable and using all observations

ln Use/HH/Day = -8.4730 – 0.9618 ln lagged price + 0.1153 ln income - 0.1346 ln tiers
(-406.06)* (23.82)* (-27.08)*

- 0.0932 ln Precip + 1.1399 ln Temp + 0.0046 Drought + 0.1969 ln hhsize + 0.4795 ln Age
(-30.18)* (119.57)* (4.14)* (24.36)* (47.46)*

+ 0.0036 Trend + 0.4921Unemploy + 0.0220 ln Lot Size + 0.6744 Carlsbad + 0.4900 Eastern
(98.73)* (9.90)* (49.87)* (108.36)* (79.21) *

- 0.1182 Henderson+ 0.5026 Irvine Ranch + 0.2719 Las Vegas + 0.8240 Western
(-19.45)* (70.27)* (42.41)* (137.70)*

+ 0.9133 San Juan Cap - 0.0130 Sin(3) – 0.0115 Cos(3) – 0.0063 Sin(6) + 0.0116 Cos(6)
(152.86)* (-9.65)* (-8.53)* (-4.42)* (8.39)*

Observations = 486,802
Adjusted R^2 = .40
F Statistic = 15,021.0*
*Significant at the 1% level of confidence

significance and expected coefficient signs. In addition, two-stage least squares results for the current price models were relatively poor due to a poor fit for estimating the instrumental variable used for price/cost to correct for simultaneity as was discussed above in the section Variables Used to Estimate Demand.

Table 6 – Modeling results using a detached single family home variable and removing outliers

ln Use/HH/Day = -9.4962 – 0.9590 ln lagged price + 0.2571 ln income - 0.1059 ln tiers
(-450.50)* (57.56)* (-22.88)*

- 0.1002 ln Precip + 1.0672 ln Temp + 0.0054 Drought + 0.2905 ln hhsize + 0.4533 ln Age
(-41.56)* (122.94)* (5.44)* (39.13)* (50.97)*

+1.1505 Unemploy + 0.0053 Detached + 0.6887 Carlsbad + 0.6499 Contra Costa
(28.42) * (0.62)* (119.26)* (97.11)*

+0.4981 Eastern + 0.5350 EBMUD - 0.1349 Henderson + 0.3611 Irvine Ranch
(83.43) * (103.98)* (-22.42)* (51.04) *

+ 0.2692 Las Vegas +1.1287 Otay + 0.8174 Western + 0.8301 San Juan Cap
(44.48) * (157.66)* (140.75)* (147.39)*

- 0.0110 Sin(3) – 0.0101 Cos(3) – 0.0011 Sin(6) + 0.0153 Cos(6) + 0.0028 Trend
(-9.60)* (-8.86)* (-0.91) (12.96)* (90.54)*

Observations = 595,766
Adjusted R^2 = .43
F Statistic = 18,107.5*
*Significant at the 1% level of confidence

Table 7 – Modeling results using a detached single family home variable and including all observations

ln Use/HH/Day = -10.0463 – 1.0266 ln lagged price + 0.2615 ln income - 0.1112 ln tiers
(-485.57)* (57.07)* (-23.44)*

- 0.1021 ln Precip + 1.0779 ln Temp + 0.0046 Drought + 0.3033 ln hhsize + 0.4628 ln Age
(-41.23)* (120.80)* (4.59)* (39.82)* (50.79)*

+1.3161 Unemploy + 0.0157 Detached + 0.6777 Carlsbad + 0.6539 Contra Costa
(31.74) * (1.78)** (114.25)* (95.36)*

+0.4615 Eastern + 0.5317 EBMUD - 0.1661 Henderson + 0.3450 Irvine Ranch
(75.26) * (100.59)* (-26.85)* (47.51) *

+ 0.2321 Las Vegas +1.1674 Otay + 0.8134 Western + 0.8411 San Juan Cap
(37.34) * (158.58)* (136.43)* (145.18)*

- 0.0098 Sin(3) – 0.0107 Cos(3) – 0.0009 Sin(6) + 0.0141 Cos(6) + 0.0030 Trend
(-8.39)* (-9.12)* (-0.74) (11.69)* (94.78)*

Observations = 601,591
Adjusted R^2 = .45
F Statistic = 19,751.1*
*Significant at the 1% level of confidence

All of the estimated coefficients were significantly different from zero at the 1% level of significance, except for some of the seasonality variables, and each variable had the expected sign except for unemployment. The unemployment variable may move in a pattern similar to other variables that have a positive influence on water use. The unemployment variable was left in the model to avoid potential omitted variable bias. The F statistic indicates the overall model is significant in explaining the variation in household water use. The adjusted r-squared ranged from .39 to .45, indicating 39% to 45% of the variation in use was explained by the model. Although more than half of the variation is not explained by the model, the statistical significance of the individual coefficients and the overall model indicates the model is useful for describing the effects of various factors on household water use.

Additional Econometric Issue: Nonstationarity in Time Series Data

An issue that can occur when using time series data is spurious correlation, which means that a specified model may show statistically significant results due to a consistent trend of the model variables over time rather than the independent variables actually explaining the change in the dependent variable. If prices and quantities used of a good or service are constantly increasing over time, then a model could be estimated which appears to show prices and income are positively correlated when in fact they are following the same time trend.

A test that can be completed using EViews8 to evaluate potential problems associated with trends over time that create spurious correlation is a unit root test based on an augmented Dickey-Fuller test. A unit root test, tests whether a time series variable is non-stationary. If a series is stationary, then the underlying probability distribution of the variable is not changing over time and spurious correlation is not indicated. If a series is non-stationary, then the distribution is changing over time and spurious correlation is a problem and the estimated model is biased. If a series has a unit root, it is non-stationary. The augmented Dickey–Fuller test statistic is a negative number and the more negative the statistic is, the stronger the evidence that the series is stationary. The results of the Dickey-Fuller test rejected the hypothesis that the time-series data are non-stationary.

A couple of things should be noted regarding the data used in this analysis. First, all prices and costs are converted into real terms, which helps reduce the potential for non-stationarity. The real price/cost of water and water use per household over time and for different tiered pricing structures are presented in Tables 8 and 9. These Tables indicate that there is variation over the 11 year time period, but that it is not a strong consistent trend that would be found for nominal prices. Second, a time trend variable was included in the model to account for potential changes in use over time from factors that are not captured in the model, such as changing attitudes about water use.

Table 8 – Average real water cost and use over time

Year	Average real cost per 1,000 gallons	Thousands of gallons used per household per year
2000	$2.56	282.2
2001	$2.90	208.8
2002	$3.03	210.8
2003	$3.17	188.7
2004	$3.33	195.7
2005	$3.36	199.0
2006	$3.43	186.0
2007	$3.29	204.0
2008	$3.87	192.0
2009	$4.33	167.4
2010	$5.20	150.4

Table 9 – Average real water cost and use by rate structure, number of tiers

Tier	Average price per 1,000 gallons	Thousands of gallons used per household per year
1	$3.67	207.1
2	$3.23	191.9
3	$4.47	193.9
4	$3.67	188.0
5	$3.16	161.1

Interpretation of the Results – The Effect of Using Real Prices and Income

The estimated water demand models in this report are based on real prices and income rather than nominal prices (it is assumed when using real prices that there is no money illusion effect). As a result, the price and income elasticities of demand estimated by the models reflect the effect of an increase in real price or income on water use. Therefore, the percentage change in nominal price required to achieve the percentage change in quantity indicated by these models is greater than the percentage change in real price. This can be illustrated using a simple example. Suppose that the current price of a good is $5.00 and the rate of inflation over the next year is 3%. In this example, the nominal price of the good increases to $5.15 ($5.00*1.03). The increase in price is accounted for by inflation, so the real price next year of a nominal $5.15 is still the original $5.00. However, if the real price of the good that currently costs $5.00 increases by 1% next year, the real price next year would be $5.05. Converting the 1% real increase in price to a nominal price increase, assuming the same 3% inflation rate, results in a nominal price increase to approximately $5.20 ($5.05*1.03). So, a 1% real price increase is equivalent to about a 4% nominal price increase in this hypothetical example.

It is important to correctly interpret the estimated price elasticity of demand as a real price elasticity because the observed nominal price change must be considerably higher than the real price change (assuming inflation occurs) in order to achieve the increase or decrease in quantity demand predicted by the real price demand model. If the price elasticity of demand is -0.6 for real prices, a 1% increase in real prices would result in a 0.6% decrease in the quantity demanded. However, a larger than 1% nominal price increase would be needed to achieve a 0.6% decrease in quantity demanded.

The following assumptions are used to convert the real dollar elasticities estimated for the aggregate models into nominal dollar elasticities.

- 16,550 gallons of water used per household each month (this is equivalent to 22.13 hundred cubic feet per month).
- A nominal base price of $6.00 per hundred cubic feet.
- An assumed annual 2.72% rate of inflation.
- An assumed annual *real* increase in the price of water of 1% to $6.06. This translates into a nominal price of approximately $6.225 at a 2.72% rate of inflation.

The assumed water use and price is roughly the average values for the data used to estimate the aggregate models that included data for all 11 water agencies. It should be noted that the assumed base use and base price has no effect on the conversion from a real price elasticity to a nominal price elasticity. The assumed 2.72% inflation rate is based on the simple average percentage increase in the Consumer Price Index (CPI) for Los Angeles-Riverside-Orange County, San Francisco-Oakland-San Jose, and San Diego areas over the 2000 to 2011 time period for which data was provided. A separate CPI was not available for the Las Vegas area and was therefore not included in the average inflation calculation. The assumed 1% real price increase is conventionally used to measure price elasticity. The conversion results are shown below in Table 10.

Clearly the effect of a nominal price change on quantity demanded is much less than the effect of a change in real price because the nominal change in price includes inflation. The nominal -equivalent elasticities are most likely to be of interest to water suppliers. Those making decisions regarding future price changes will be looking at the nominal price they charge rather than the real price. In other words, based on the aggregate model results, an increase in the nominal price of water from $6.00 to $6.225 per hundred cubic feet (a 3.75% nominal price increase which is equivalent to a 1% real price increase) will lead to a 0.90% to a 1.15% decrease in the quantity of water used, all other factors held constant. It should be noted that results of the nominal equivalent elasticities are well within the range of elasticities discussed above in the review of previously completed studies.

Table 10 – Estimated nominal elasticities from aggregate modeling results

Estimated Model	**Real price elasticity of demand estimated from model**	**Estimated use with a 1% increase in real price**	**Equivalent nominal price elasticity of demand**
All observations, with lot size	-0.9618	21.92	-0.2567
Data prior to recession, with lot size	-0.9580	21.92	-0.2557
Data during recession, with lot size data	-1.0906	21.89	-0.2910
Outliers removed, with lot size	-0.9023	21.93	-0.2408
Outliers removed, prior to recession, with lot size	-0.9012	21.93	-0.2405
Outliers removed, during recession, with lot size	-1.0234	21.90	-0.2731
All observations, no lot size data	-1.0266	21.90	-0.2740
Data prior to recession, no lot size data	-1.0205	21.90	-0.2723
Data during recession, no lot size data	-1.1549	21.87	-0.3082
Outliers removed, no lot size data	-0.9590	21.92	-0.2559
Outliers removed, prior to recession, no lot size	-0.9565	21.92	-0.2553
Outliers removed, during recession, no lot size	-1.0809	21.89	-0.2885

The Influence of the Number of Tiers on Water Use

The modeling results presented in Tables 4 through 7 indicate the number of price tiers have a negative effect on water use when all other factors held constant. The estimated coefficients or the number of tiers are shown in Table 11.

Table 11 – Estimates for the coefficients for the number of tiers

Aggregate model	**Coefficient for the natural log of the number of tiers**
Includes lot size data and all observations	-0.1346
Includes lot size data and outliers removed	-0.1272
Does not include lot size data, all observations	-0.1112
Does not include lot size data, outliers removed	-0.1059

A “tier elasticity” could be defined as a measure of how water use would change due to a change in the number of tiers included in the rate structure, separate from the average lagged price. This result is important from the standpoint of pricing policy because the influence of the number of tiers on water use can be used to influence water use while theoretically maintaining a stable average cost of water. In other words, the number of pricing tiers could be potentially used as a policy variable itself, while maintaining revenue neutrality, to help achieve a reduction in water use per household.

The Influence of Income on Water Use

Similar to the influence of water price on use, a change in income would be expected to influence the amount of water used. An increase in income, other factors remaining constant, would be expected to lead to increased water use. The income coefficients in the estimated models represent income elasticities because the models are double log models. The real income elasticities can be converted into nominal elasticities in the same way as described above for price elasticity. The income elasticity results are shown in Table 12.

Table 12 – Estimated real and equivalent nominal income elasticities

Aggregate Model	**Estimated income elasticity**	
	Nominal Equivalent	**Real**
Includes lot size data and all observations	0.2801	0.0747
Includes lot size data and outliers removed	0.2640	0.0705
Does not include lot size data, all observations	0.3298	0.0880
Does not include lot size data, outliers removed	0.3202	0.0854

Income elasticities are positive as expected and very income inelastic, meaning a change in income will have a very small impact on water use. The income elasticity results are of limited usefulness for water agencies since the agencies have little influence on household income.

An Additional Consideration: Effect of the Recession on Water Demand

Many of the water supply agencies participating in this study indicated that they observed reduced water use during the recessionary period from late 2007 to 2011. Additional aggregate regressions were run to evaluate the possible effect of the recession on residential water use. It was generally expected that households would be more affected by changes (primarily increases) in the cost of water during recessionary periods as a result of the overall desire to reduce household expenditures. If this is the case, then the price elasticity of demand would be expected to be higher during periods of recession and the effect of price on use could be overstated.

According to the National Bureau of Economic Research, the U.S. Recession began in December of 2007 and ended in June of 2009. For the purposes of this analysis it was assumed that the effects of the recession in the study area continued through February 2011, the latest information available from the data set. A Chow test was used to test for a structural difference between pre-Recession and Recession water demand. A Chow Test examines whether the parameters of one group are different from those of other groups. In other words, the test can be used to test for break points or structural changes in the relationship being modeled. Intuitively, the test is based on separating the data into two groups, estimating separate models for each data group, and comparing the results to determine if they are statistically different from one another. In terms of hypothesis testing, the null hypothesis (H_0) is that the model coefficients are equal to each other for each subset of observations and for the entire set of observations and the alternate hypothesis is that they are not equal. Rejection of H_0 supports the notion that there is a structural difference between the two groups of data. The Chow test is based on an F test of overall model significance. The potential impact the recession on water use was evaluated in this analysis by dividing the data sets into pre-recession (2000 to November 2007) and recession (December 2007 to 2011) time periods. The results of the Chow test are shown in Table 13.

Table 13 – Chow test results

Aggregate model	**Calculated F statistic**	**Critical F statistic**	**Recession and pre-recession modeling results are statistically different**
Includes lot size data and all observations	310.87	1.88	Yes
Includes lot size data and outliers removed	285.18	1.88	Yes
Does not include lot size data, all observations	390.00	1.81	Yes
Does not include lot size data, outliers removed	353.25	1.81	Yes

The critical F value at the 1% level of significance is 1.88 for the models that include the lot size variable and 1.81 for the models that do not include lot size. The calculated F value for each of the models is greater than the critical F value so the null hypothesis that the pre-recession and Recession models have the same estimated coefficients is rejected. In other words, there appears to be a structural difference in the household water demand relationship during the recession compared to before the recession. The lagged price coefficient was consistently more negative for the recession year model than for the pre-recession year model. This result is expected because households would likely react more to price changes during a recession than when there is no recession because they are more aware of household budget constraints and may want to try and save money as much as possible. A comparison of price elasticities of demand for each of the four aggregate models is presented in Table 14.

Table 14 – Comparison of pre-recession and recession elasticities

	Pre-Recession elasticity		**Recession elasticity**	
Aggregate Model	**Nominal**	**Real**	**Nominal**	**Real**
Includes lot size data and all observations	-0.9218	-0.2460	-1.0514	-0.2806
Includes lot size data and outliers removed	-0.8648	-0.2308	-0.9859	-0.2631
Does not include lot size data, all observations	-0.9893	-0.2640	-1.1276	-0.3009
Does not include lot size data, outliers removed	-0.9252	-0.2469	-1.0548	-0.2815

In each case the estimated price elasticity of demand during the recession was approximately 14% greater than when there was no recession. This was very consistent across all models.

Summary and Policy Implications

This analysis contributes to the existing knowledge of price and non-price factors that influence household water use. The unique features of this analysis include:

- Availability of a large number of individual household observations for the same residence over a large cross-section of locations.
- The time series aspect of the individual household data provided allows for the use of a lagged price variable at the household level. Average real cost per gallon for each household from the previous billing period is used as the price variable which households respond to when making water use decisions.
- The 2000 to 2011 data period allows for calculation of long run price elasticities of demand.
- A recession occurred during the 2000 to 2011 period of analysis, which allows an evaluation of the potential impact of an economic downturn on the responsiveness of households to the price of water.
- The number of tiers is included as an explanatory variable separate from the price variable as an indication of how water users respond to the known rate structure.

The nominal equivalent price elasticities estimated from the modeling results presented in this paper are very similar to previous estimates, indicating the price elasticity of demand for household water is very price inelastic. However, there are several possible water policy inferences that could be taken from the results of this analysis.

The statistical significance of the lagged average cost variable combined with the overall modeling results and input from small group discussions indicates that average cost from the previous billing period is the relevant price signal influencing water use. This could be due to the relatively small proportion of overall household expenses represented by water bills until very high average costs are reached. In addition, the marginal cost of water may be difficult to interpret from many water bills, while the average or total cost is much easier to understand. It should also be noted that as automatic billing systems become more predominant, water pricing signals may become even more confusing.

Another interesting inference from the modeling results is that the statistical significance of the tier variable and the tier "elasticity" estimates indicate the rate structure (as defined by the number of tiers) used by a water supply agency has an impact on water use that is separate from the effect of the price of water. Therefore, a neutral price change in rate structure, where tiers are implemented but average cost remains the same, could potentially lead to a reduction in water use. Therefore, the use of a tiered rate system can help accomplish water use reduction goals while avoiding the adverse economic and financial impacts of an increase in water costs to households.

The estimated price elasticities of demand should be interpreted as long run elasticities since they are estimated over an 11 year time frame over which water users could respond to price increases by implementing new technologies, removing outdoor landscaping, and other changes that cannot be implemented in the short run. Generally, long run elasticities would be expected to be greater (in absolute terms) than short run elasticities because there are fewer options to reduce water use in the short run. Therefore, the elasticity estimates from this analysis would be most useful in terms of long range planning (for example, over a 10 year period) rather than predicting short run impacts from a rate change. Based on theory, the short term change in water use would be much less than the long run impacts.

The modeling results indicate that an increase in income will lead to an increase in water use. However, the income elasticity of demand is very inelastic, so an increase in income will have a relatively small impact on water use. Even though income is not a water agency policy variable, except to the extent that water agencies can offer rebates or other types of incentives that have a positive influence on disposable income, it is important for water suppliers to understand the influence of income on use so policy decisions can account for these factors. For example, if the goal is to maintain a relatively constant quantity of water use and it is anticipated that future incomes will rise, then pricing decisions can be made to counteract the expected change in the future. The same process could be applied to home lot size, household size, age, etc.

Finally, the influence of price is greater during economic downturns. Therefore, rate setting decisions during recessionary times need to account for this sensitivity. Otherwise, a rate increase could have a greater than expected impact on water demand and, therefore, revenues.

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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.