Water Use App

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Contents

Executive Summary

In the United States, over 400 billion gallons of water are used each day (USGS 2012). While the primary uses of water in the U.S. are irrigation and agriculture, residential water consumption constitutes a significant share of overall water consumption at 44.2 billion gallons per day (ibid).

We develop models to estimate annual water consumption for residential buildings and commercial buildings. Our models are based on demographic, climate, and demographic variables.

Our analysis found that different urban land use types use different amounts of water, but certain groups of urban land use types do not differ in annual use. For example, single family, duplex, triplex, and fourplex accounts use similar amounts of water in a year. Parks and apartments do as well. However, for other comparisons, significant differences exist.

Our models show the relative contribution of climate, built environment, and demographic variables on urban water use. Climatic variables alone explain very little of the variation in water use for all urban land use types. When built environment variables are added to the models, the model fit improves significantly and the models indicate that variables such as lot size, the number of bedrooms and kitchens, and the year built all significantly affect water use. The larger the lot and size of the building, the more water is used. Demographic variables, surprisingly, contribute very little explanation for water use in any of the urban land use types.

We use the best fitting models for each land use type for application in ET+.

Introduction

In the United States, over 400 billion gallons of water are used each day (USGS 2012). While the primary uses of water in the U.S. are irrigation and agriculture, residential water consumption constitutes a significant share of overall water consumption at 44.2 billion gallons per day (ibid). Increasing population, urbanization and climate uncertainty have driven a plethora of research on residential water consumption across the world.

Residential water consumption has been studied in hundreds of scholarly articles with particular interest in "investigating demand and/or price elasticity's effect on reducing water use, the spread and effect of low-flow appliances, and the effect of bans on certain water practices (Arbués et al, 2003; Rockaway et al. 2011). In this paper, we review residential water consumption models and propose a novel and improved residential water demand model.

The model we develop can be used within the software package Envision Tomorrow Plus (ET+). ET+ is a state-of–the art scenario planning tool being developed by Fregonese Associates and the University of Utah under a HUD Sustainable Communities Grant.

Water Demand Models

Many researchers have developed models that relate water consumption to a variety of independent variables. Ordinary least squares regression, generalized least squares, two and three stage least squares, logit and instrumental variables have all been used to model water use, but ordinary least squares regression "dominates the literature" (Worthington 2008). The general motivation for these researchers is to identify strategies to reduce water consumption, or improve the knowledge of how different factors influence residential water consumption.

Price, income, the number of residents in a dwelling, the availability of a hot water facility; conservation programs; density; average annual precipitation; the number of days when temperature exceeds 90 degrees F; water source; precipitation zone; temperature zone; drought index; housing size; lot value; water using appliance and types; perceptions and habits; water saving devices; family age distribution; family size; household age; region; and policy interventions have all been used as predictors of water use (Hanke and de Mare 1982; Jones and Morris 1984; Lyman 1992; Hewitt and Hanemann 1995; Renwick and Green 2000; Syme et al. 2000; Grafton 2001; Cavanagh et al. 2002; Olmstead et al. 2003; Arbues 2004; Gaudin 2006; Kenney 2008; Jorgenson 2009; Poleblitski and Palmer 2010; Rockaway et al. 2011). We explore many of these variables in detail throughout in the paper.

The models developed based upon these predictors fit water consumption data reasonably well; r^2 values range close to 0.40 (Hewitt and Hanemann 1995; Renwick and Archibald 1998; Pint

1999; Kenney 2008). However, these models indicate that much is still to be investigated and the models to predict residential water consumption can be improved.

Water Price and Elasticity

Water price and elasticity are particularly interesting to researchers because changing water price is a feasible market solution to reduce residential water consumption. In the United States, water pricing usually takes three forms: 1) constant rates; 2) increasing block rates; 3) decreasing block rates. Each of these forms can be accompanied by a fixed water use charge (Cavanagh et al. 2001). Constant rates charge for each unit of volume used, increasing block rates charge higher rates for higher use, and decreasing block structures charge less for higher use (ibid). Researchers have designed experiments that test the effect of changing water price on residential water consumption.

Most studies indicate that water is an inelastic good, that is, an increase in water price does not proportionally decrease water use (Carver and Boland 1980; Thomas and Syme 1988; Barkatullah 1996; Renwick et al. 1998; Martinez-Espinera and Nauges 2004; Worthington et al. 2008; Abrams 2011). For example, Renwick et al. (1998) found that 10% increase in price only reduces water demand by 1.6%-2%. It is thought that water is inelastic because: it is a basic good that everyone needs; there is no substitute for water; water bills constitute a small portion of household expenditures; and price information is delayed or imperfect (Cavanagh et al. 2001; Arbues 2004; Gaudin 2006; Balling 2007).

The elasticity of water may be greater in the long run because water users can adapt to higher prices of water by purchasing water efficient appliances, altering behavior, or planting draught tolerant landscaping (Cavanagh et al. 2001; Arbues et al. 2003). Furthermore, if pricing information was provided to the user more rapidly or clearly, the elasticity of water may be higher (Foster and Beattie 1979; Arbues et al. 2003; Carter and Milon 2005; Gaudin 2006; Kenney 2008). Elasticity may also be higher for homeowners compared to renters and to low income households (Renwick and Archibald 1998; Hoffmann et al. 2006), and at different seasons and in different regions (Howe and Linaweaver 1967; Renwick and Green 2000; Cavanagh et al. 2002; Arbues 2004; Kenney 2008; Polebitski and Palmer 2010).

There should not be confusion however as to whether consumers respond to changes in price of water. Even if water is inelastic, consumers will respond to higher prices, but at a rate less than proportionate to the price increase (Renwick and Green 2000; Arbues 2011). Block rates have been found to be effective at reducing water consumption (Billings and Agthe 1980; Niewsiadomy and Mlina 1989; Renwick and Archibald 1998; Pint 1999; Cummings et al. 2005; Strand and Walker 2005; Mazzanti and Montini 2006), and clear marginal price information on water bills has been shown to reduce water consumption (Gaudin 2006).

Income

Income is significant factor in water use, as income rises there is a corresponding increase in water usage (Guhathakurta 2007; Headley 1963; Ferrara 2008). Wealthier households are more likely to have water consuming appliances, swimming pools, and larger lots (Ferrara 2008). Significant differences in personal water habits in households with different incomes have not been found; therefore indoor usage is more of a function of square footage of the dwelling, density, and the size of the household (Polebitski and Palmer 2010; Domene and Sauri 2005; Ferrara 2008). Consequently, income is more significant during the summer months as more water is used for outdoor purposes. (Polebitski and Palmer 2010).

The literature shows that income elasticity is less than one, and ranges from 0.10 to 0.71 (Ferrara 2008). In other words, water consumption does not increase proportionally with an increase in income. Dalhuisen et al. (2003) found in a meta-analysis of residential water demand literature that income elasticity had a mean of 0.43 and a median of 0.24. Though income elasticity is less than one, there is correlation between water usage and income, but not a proportional one.

Renwick and Archibald (1998) estimate that a 10% increase in income led to a 3.6% increase in water with "low-income households are almost five times more responsive to price increases than high-income households"; Renwick and Green (2000) estimate that a 10% increase in income would lead to a 2.5 increase in water use. Again, it is likely that income influences outdoor water consumption more than indoor water consumption.

Home Age

The age of a dwelling can have an effect on water demand, as older homes are more likely to have appliances and fixtures that are less water efficient than newer homes would have. With older appliances and fixtures there is likely to be water leakage because of wear and tear (Guhathakuta 2007; Rockaway et al. 2011).

One explanation is that homes built after 1994 were required to comply with amendments to the Clean Air Act that required more water efficient fixtures and appliances. One study estimated that homes built after 1994 will use 13 gallon per day (gpd) less after controlling for household characteristics and appliances (Rockaway et al 2011). Cavanagh (2011) found that the age of a home and water use is nonlinear and when considering the age of a home the highest water use occurs when the home is between 20 and 40 years old. The older the home is the more likely the home will have replaced their appliances and fixtures.

Lot Size

Larger households on large lots, on average, have higher levels of water use (Abrams 2011). Larger lots have larger lawns, more vegetative cover, more bathrooms and appliances, and therefore lot size has a positive correlation with water use (Renwick and Green 2000; Guhathakurta 2007; Balling 2007; Polebitski and Palmer 2010; Blokker 2010). Guhathakurta (2007) found that controlling for other variables, lot size had the greatest impact on water use, where with each 1,000 square foot increase in average lot size, monthly water use increases by about 1.8%. Renwick and Green (2000) found that with a 10% increase in lot size water demand increases 2.7%.

Household Size

Household size significantly influences water consumption (Gaudin 2006; Wentz and Gober 2007; Arbues et al. 2011). Households with more people use more appliances with greater frequency than smaller households. Arbues et al. 2004 found that as household size increases, water use increases, although it is not a proportional increase. For example, a household with two people use less water than a household with four people, but not half as less. A review of similar studies, the average elasticity of consumption with respect to household size is between 0.734 and 0.868 (Arbues 2004).

In Phoenix, household size was found to be insignificant predictor of water usage (Guhathakurta 2007). This finding does not necessarily contradict findings of other researchers, but rather reflects that interior water use is substantially less than outdoor uses. Household size then may not influence exterior water use, where a house with only one resident may have as much lawn to water as a household with 4 people.
Similarly, Polebitski and Palmer (2010) found that increasing household size was associated with improved interior water efficiency, resulting in a per capita savings despite overall household consumption increasing.

Seasonality/Weather

The seasons and weather are closely related variables and are significant factors in residential water demand. In the summer months as temperatures increase, gardens will dry out more quickly and households will increase outdoor water (Abrams 2011; Worthington 2011). Studies that have considered water use during the summer months have seen increases in water use of 30% to 40% (Kenney 2008; Cavanagh et al. 2001; Gurathakurta 2007). For example, a study in in Phoenix (Gurathakurta 2007) found that two-thirds of residential water uses was for outdoor use during the summer of which irrigation is the largest use. Balling (2007) found that 40% of annual water use occurs during June, July, August, and September. Despite the seasonal fluctuations in residential water demand there are few studies that determine elasticities for variables on a seasonal basis, despite the fact that significant differences may exist (Lyman 1992; Bowman et al. 1997; Polebitski and Palmer 2010).

Maidment and Miaou (1986) found that water demand didn't increase until temperatures were above 70° in the nine U.S. cities they studied. They found in Texas and Florida in their study that when temperatures were above 85-90°, water use increases 3-5 times per degree. However, other studies only consider temperature in their models when the temperature are 90° and above (Gaudin 2006). Rockaway et al. (2011) found that an area that had an average annual temperature between 50-60° used 16% less water than those who lived in a zone that averaged 60°-70°. Polebitski and Palmer (2010) found in Seattle that a 10% increase in monthly temperature in July and August led to a 10% increase in water usage, but in September and October a 10% increase in temperature would lead to a 4% increase in water use. Other studies found that the relationship between temperature and water use was nonlinear (Maidment and Miauo 1986; Gurathakurta 2007).

Rainfall plays a role in water usage though when it occurs and the intensity determines the impact on residential water use (Maidment and Miauo 1986). Similarly, Polebitski and Palmer (2010) found that when it rains plays a role in water usage, a 10% increase in rain in May and June led to a 2.5% decrease in total water usage. They found that rainfall in July and August had very little effect, but it may be because the area they were studying sees very little rainfall during those months. Kenney (2008) found that for every inch of annual precipitation, water use decreases by 4%.

Weather variables such as temperature and rainfall drive short-term fluctuations in demand rather that underlying changes (Abrams 2011). The magnitude of the temperature and the depth of rainfall largely determine water use response (Maidment and Maiuo 1986). Yet, finding the right combination of weather variables can be challenging and the impact of weather may be difficult to distinguish from "the broad spectrum of non-price management tools that are most frequently (and/or aggressively) employed during the hottest and driest seasons" (Kenney 2008). An additional problem facing researchers is that they are likely constrained by available water usage data that is only available on a monthly basis while weather changes daily (Kenney 2008).

Conservation/Non Price Strategies

Conservation, or non-price strategies, normally take three different approaches: 1) Public education programs such as public awareness campaigns and clearly marked water bills; 2) Technology improvements such as low flow fixtures and shower heads, and water efficient appliances; 3) Water restrictions that restrict the hours that water can be used for irrigation

(Grafton et al. 2011). Though non-price strategies can reduce water usage, it is difficult to differentiate between different programs as there often multiple non-price programs happening at the same time (Michelsen et al. 1999; Kenney 2008).

Research on non-price programs have found that mandatory water restrictions to be an effective method of reducing water usage; sometimes over 30% (Lee 1981; Lee and Warren 1981; Shaw and Maidment 1987, 1988; Renwick and Green 2000; Kenney et al. 2004; Kenney 2008). Analysis of water restrictions in Santa Barbara and Goleta found that the average household used 16% less water in Santa Barbara and 28% less water in Goleta (Renwick and Archibald 1998). The authors go on to argue that to achieve reductions of water demand of 15% or more, water restrictions or large price increases are necessary.). Espineira and Nauges (2004) found one hour of water restrictions per day was similar to a 9% increase in the price of water. However, another study in Corpus Christi, Texas found there was no significant effect in water usage when the water restrictions were imposed during a drought (Schultx et al. 1997; Cavanagh et al. 2001).

Because of the population growth in the arid Southwest and the strain it has put on water resources, many studies in the United States have focused in that region (Hart 2009, Rockaway et al. 2011). A survey of three cities in New Mexico found that when the respondents were made aware of water conservation they were 13% more likely to adopt a landscape that was more water efficient. Nieswiadomy (1992) found that public education was statistically significant in the arid West, but when you take all four regions of the United States together, non-price programs were not significant. One analysis of the effect of conservation programs on water use in California found landscape programs and watering restrictions significant, but indoor conservations efforts and low-flow fixtures not significant (Corral 1997).

Methods

For our analysis, we created a database that includes climatic, built environment, and demographic variables for 77,235 parcels in Salt Lake City, Utah, in 2011. The following sections describe the data we use, our measures, and the statistical techniques we employed.

2.2. Data

We were able to collect climate, demographic, and built environment data at the parcel level for Salt Lake City, Utah, in 2011. Our database includes the following:

1. The Salt Lake City Public Utilities database provides monthly water use for all customers of the Salt Lake City public utility (n=88,245). We aggregated accounts to each parcel level because the parcel is our unit of analysis. Included in this database are household locations (addresses), type of service (single family, apartment, industrial, industrial, restaurant, triplex, duplex, fourplex, business) and monthly water use.

2. The Salt Lake County Assessors database provides built environment and demographic variables for parcels in the Salt Lake City Public Utilities database. We joined information tables from this database to the public utilities database based on matching parcel numbers.
3. The PRISM Climate Group Data (PRISM Climate Group 2004) provides climate variables for the Salt Lake City region. The PRISM (Parameter-elevation Regressions on Independent Slopes Model) Climate Group developed a database that uses point measurements of precipitation, temperature, and other climatic factors to produce continuous, digital grid estimates of monthly and yearly climatic parameters. We assume that temperature and precipitation vary across the Salt Lake Valley and therefore we need continuous measures of temperature and precipitation. We re-projected the PRISM database in Salt Lake City to 200' pixels in GIS. This value was chosen as it roughly matches the spatial grain of parcel data. We then transferred pixel values to parcel centroids using the ArcGIS. V. 10.0 "add surface information" geoprocessing tool.
4. Remote Sensing Data which we used to calculate turf and tree cover for each parcel. The data is based on the Utah Automated Geographic Reference Center (AGRC) which provides 4-band (red, green, blue, and near-infrared) aerial photography of Salt Lake City at one meter resolution. The data was collected by the National Agricultural Imagery Program (NAIP) during summer 2011. In addition, using Python programming to interpret Light Detection and Ranging (LiDAR) data gathered by AGRC in 2006, the Salt Lake City GIS Coordinator provided tree canopy cover vectors for Salt Lake City. This data, based on the difference between first and last returns with a two meter height threshold, facilitated a finer-grained land cover classification that could distinguish tree cover from turf cover.

2.3. Measures

Our dependent variable for this study is annual water use for each parcel in Salt Lake City in 2011. We measure the effect of the following variables on annual water use.

Climate Variables: The seasons are significant factors in residential water demand. In the summer months as temperatures increase, lawns and gardens dry out more quickly, and households increase outdoor watering (Abrams 2011; Worthington 2011). We thus examine average use in the summer compared to average use in winter use to evaluate the effect of seasonality on water use.

Precipitation also plays a role in urban water use (Maidment and Miauo 1986), where more precipitation is negatively correlated with water use. Accordingly, we measure rainfall as the average annual precipitation from the PRISM Climate Group data. Temperature drives short-term fluctuations in demand (Abrams 2011), and we measure temperature as the mean maximum annual temperature. Notably, lower elevations in the Salt Lake Valley have higher maximum annual temperature than higher elevations along the mountains.

*Built Environment Variables:*Larger lot sizes correspond with higher levels of water use (Abrams 2011). Larger lots generally have larger lawns, more vegetative cover, more bathrooms and appliances, and therefore have a greater capacity to use water (Renwick and Green 2000). We measure lot size as the number of acres for each parcels from the assessors database. The age of a dwelling can affect water demand, as older homes are more likely to have less water-efficient appliances and fixtures than newer homes. With older appliances and fixtures, there is likely to be water leakage because of wear and tear (Guhathakuta 2007; Rockaway et al. 2011). We measure the age of a dwelling as the year built from the assessor's database. From the assessor's database, we also measure the number of bathrooms and kitchens, the number of units and the number of stories. These measures provide additional resolution on the built characteristics of the parcel.

The amount of turf and canopy cover is a likely indicator of outdoor water use. We measure tree and turf fraction for all parcels in our database from remote sensing data. We assembled and cropped 2011 NAIP tiles in Geographic Information Systems (GIS) software ArcMap (version 10.0) for our study area. Next we used ArcMap to create training data (spectral signature ranges) for seven land cover categories: turfgrass, tree canopy, concrete, asphalt, roofs, bare soil, and water (approximately 3,000 pixels per training class). This training data informed a supervised maximum likelihood land cover classification of the whole study area, performed using Environment for Visual Images (ENVI) remote sensing software. Our initial classification aggregated the seven land cover categories into vegetated land cover (turf and canopy) and non-vegetated land cover (impervious surfaces, dirt, and water). We then used the LiDAR-based tree canopy vectors, provided by the Salt Lake City GIS coordinator, to disaggregate vegetation into canopy cover (every pixel initially classified as vegetation that overlapped the processed LiDAR data) and non-canopy vegetation (every pixel initially classified as vegetation that did not overlap the processed LiDAR data). We labeled this non-canopy category as turf cover.

With the study area classified as turf, trees, or non-vegetated landscape, we used the intersect tool in ArcMap to assign land cover vector data to parcel centroids (when necessary we also removed cases with no data and used the dissolve tool to aggregate partial polygons). In this process, the original polygons take on the new geometry of the overlapping parcel, retaining the parent cell's values and inheriting the parcel-ID. Thus, we could determine the turf cover and canopy cover of every parcel both in acres and as a fraction of the total lot size. These fractions represent our measurement of turf and canopy cover for all parcels in our database.

Demographic Variables: Income has been found to be a primary influence on residential water use; water usage and income correlate positively, where higher income residents use more water (Baumann et al., 1998; Dalhuisen et al., 2003; Domene and Sauri, 2006; Guhathakurta 2007; Ferrara 2008). Wealthier households are more likely to have water consuming appliances, swimming pools, and larger lots (Ferrara 2008). Similarly to Arbues et al. (2004), we measure income as the final value of a parcel from Salt Lake County Assessors database. The final value of a parcel is the land value plus the value of the building. We assume that if parcel is valued higher, the owner has a higher income than the owner of a low valued parcel.

Household size significantly influences water consumption (Gaudin 2006; Wentz and Gober 2007; Arbues et al. 2011). Variations in internal water consumption have been found to depend on household size and households with more people use more appliances with greater frequency than smaller households. (Loh and Coghlan 2003; Gregory and Di Leo 2003; Domene and Sauri, 2006). We measure household size as the number of bedrooms per household from the assessor's database. A direct count of household size at the parcel level was unavailable. We do use the number of families, and whether the household is owner occupied as demographic measures from the assessor's database.

2.4. Modeling

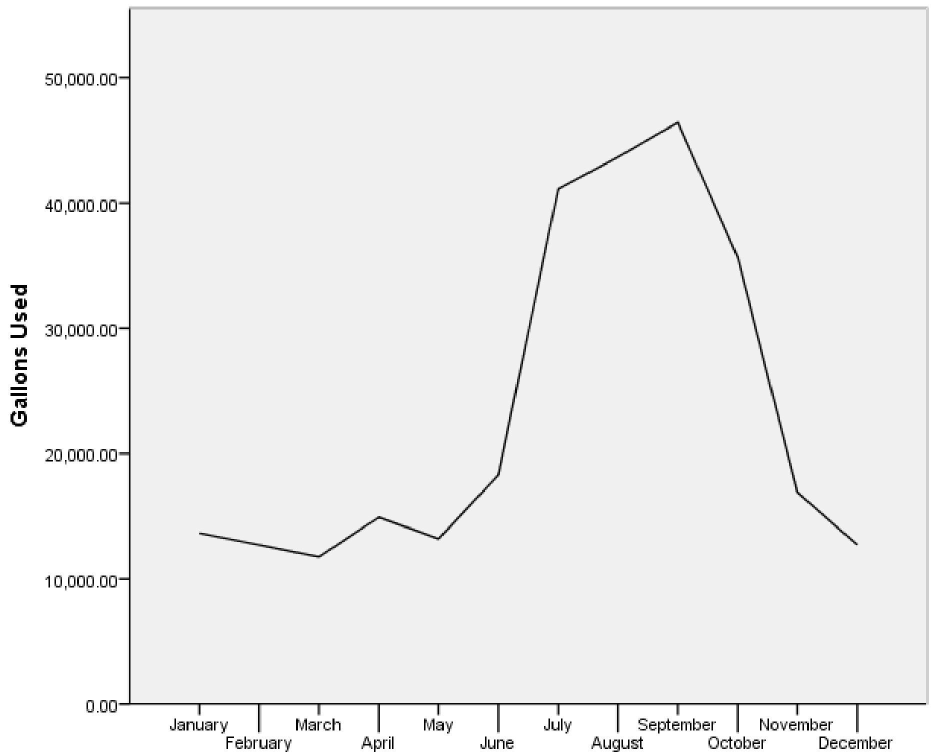
We developed models for four types of urban land use; single family residential, semi-attached housing (duplex, triplex, and fourplex), apartments, and commercial (businesses and restaurants). We isolate the contribution of climate, built environment, and demographic variables by presenting three models per land use type. For example, model 1= climate only, model 2 = climate + built environment; model 3 = climate + built + demographics. We used Ordinary Least Square Regression (OLS) to develop our models. We include both significant and not significant variables to show the importance of the variable. We try to minimize collinearity in our models when possible, and tolerance values reflect the degree of collinearity in the models, where high values (on a scale of 0 to 1) indicate that no collinearity exists.

Results

3.1. Results

For all types of urban land use, average water use in Salt Lake City was highest in the summer months starting in June, peaking in September and declining in November. Winter use was stable and lower than the summer months (Figure 2). This is expected given its high desert alpine climate regime.

Figure 2. Water Use by Month in 2011 (all urban use types).



We find that industrial accounts have the highest mean annual use, averaging over 16 million gallons a year. Hospitals were the next greatest user of water at over 14 million gallons a year followed by schools, churches, and charities at almost 4 million gallons per year. Single family residences had the lowest mean annual use averaging about 148,000 gallons per year, but had the greatest cumulative contribution to water use in Salt Lake City, using more than 9 billion gallons of water in 2011. Businesses and restaurants were also intensive water users, with high mean annual use per are and high total use.

Table 1. Water Use by Service Type

	Annual Use							
Service Type	Total Use	Mean	Maximum	Std. Error	Total N	Mean Acres	Mean Use Per Acre	Std. Error
Apartment	2141627972	2057279.5	41566360	122242.8	1041	1.12	17611006.2	3544176.8
Business	4513105124	1034167.0	153956352	55294.5	4364	1.84	2474115.0	504957.9
Duplex	722573984	166070.7	1445136	1625.8	4351	0.18	1073564.2	23333.0

Triplex	94803764	192299.7	990352	5251.6	493	0.17	1347180.1	84978.7
Fourplex	285424832	283722.5	1594736	5645.1	1006	0.20	1845281.1	214604.2
Hospital	175891452	14657621.0	81163236	6890535.1	12	1.35	5767841.6	4284912.1
Hotel or Motel	513283584	6038630.4	77989472	1159145.0	85	0.47	8953966.7	2413292.6
Industry	1397566192	16063979.2	596449216	8039106.7	87	3.62	2645368.6	1745813.0
Miscellaneous	705702096	3898906.6	204342380	1221161.7	181	4.80	8287810.6	2826905.3
Parks & Municipals	204588472	1636707.7	31936608	351776.6	125	6.77	1796323.5	427544.1
Restaurant	139834112	852647.0	4648820	71163.0	164	0.43	5255241.6	1201944.4
School/Church	1220271492	3987815.3	452985060	1563515.3	306	2.86	29667261.1	25253326.7
Single Residence	9593345344	147496.8	4627876	459.6	65041	0.22	798923.3	6037.7

An analysis of variance (ANOVA) test reveals that mean annual water use is significantly different among various urban land use types (F 307.738; p= <0.001). The variance between groups was homogenous (Levene Statistic= 763.198; p= <0.001), so we use Bonferroni Post Hoc tests to identify which urban land use types had statistically significant different annual water use. Apartments and parks had no statistically significant differences in mean annual water use, nor did businesses and restaurants. Duplexes, triplexes, fourplexes and single family residences did not have statistically significant mean annual water use and hospital and industrial users did not have statistically significant mean annual water use. Other comparisons of urban land use types indicated significant differences among mean annual water use.

Single Family Residential Models: We use ordinary least squares regression to determine the key drivers of water use for single family residences. These models show the contribution of climate, built environment and demographic variables on single family residential annual use (Table 2). Almost all variables are significant, and we have tried to minimize or prevent collinearity. Whether the single family residential parcel is owner occupied was not significant in any of the models. The F statistic in each model is significant. Climate variables had a small effect on water use, and the built environment variables substantially improved the model’s fit to the data. The number of bedrooms, number of kitchens and bathrooms, and the higher the fraction of turf and trees all increased water use. The greatest effect on water consumption for single family residences is the size of the lot (acres), where the larger the lot size the greater the water use. Income significantly influenced water use, with higher income associated with higher water use. The year the building was built indicated that the more recent the building, the higher the water use.

Table 2. Water Demand Models for Single Family Residences

Variable	B	St. Error	Sig	Tolerance
	Climate			
Constant	611810.485	60577.898	0.000	0.430
Temperature Max	-418.061	26.458	0.000	0.430
Precipitation	113.046	4.629	0.000	0.430
R2				0.144
	Climate with Built Environment			
Constant	-601816.939	53435.701	0.000	0.736
Temperature Max	225.500	26.849	0.000	0.331
Precipitation	127.122	5.95	0.000	0.309
Owner Occupied	1127.895	2510.503	0.653	0.965
Number of Bedrooms	5947.822	672.130	0.000	0.586
Number of Kitchens	765.822	3621.338	0.833	0.980
Total Bathrooms	20473.756	870.191	0.000	0.472
Turf Fraction	48012.989	4989.070	0.000	0.827
Tree Fraction	11518.162	4082.458	0.005	0.915
Acres	232177.732	6475.891	0.000	0.629
R2				0.381
	Climate with Built Environment and Demographics			
Constant	-474022.429	93357.614	0.000	
Temperature Max	95.115	27.801	0.001	0.298
Precipitation	70.614	6.376	0.000	0.259
Owner Occupied	428.586	2468.547	0.862	0.962
Number of Bedrooms	5670.770	660.108	0.000	0.586
Number of Kitchens	8623.141	3571.204	0.016	0.971
Total Bathrooms	8610.955	997.790	0.000	0.346
Turf Fraction	52936.376	4911.916	0.000	0.910
Tree Fraction	14340.994	4018.142	0.000	0.910
Acres	143476.606	7388.865	0.000	0.466
Final Value	0.141	0.006	0.000	0.283
Year Built	93.928	35.274	0.008	0.525

R2	0.403

Semi-Attached Residential Models: We developed demand models for semi-attached residential parcels such as duplexes, triplexes, and fourplexes (Table 3). The climate variables are significant but temperature does exhibit the anticipated sign of the coefficient and the two variables do not explain the data well. When built environmental variables were added, the number of acres of the parcel size significantly increases water use, as do the number of kitchens and bedrooms. The fraction of the parcel covered with turf is not significant in the built environment and climate variables model, but is significant when demographic variables are included. Whether a semi-attached residential unit was owner occupied was not significant. The number of families on each parcel is significant, and the more families, the greater the water use. Finally, income is a significant variable, with water use increasing as the final value increases. The F statistic in each model is significant at $p<0.001$.

Table 3. Water demand models for Semi-Attached Residential

Variable	B	St. Error	Sig	Tolerance
	Climate			
Constant	1454844.229	251590.096	0.000	
Temperature Max	-656.466	133.426	0.000	0.524
Precipitation	-101.411	22.118	0.000	0.524
R2				0.010
	Climate with Built Environment			
Constant	-1239686.831	333418.696	0.000	
Temperature Max	386.425	120.695	0.001	0.390
Precipitation	59.837	24.222	0.014	0.368
Number of Bedrooms	11050.006	1622.937	0.000	0.841
Number of Kitchens	10837.892	3551.591	0.002	0.909
Year Built	259.589	111.423	0.020	0.926
Turf Fraction	30308.362	19281.063	0.116	0.866
Tree Fraction	-31617.632	13352.271	0.018	0.926
Acres	455466.030	35533.717	0.000	0.780
R2				0.182
	Climate with Built Environment and Demographics			
Constant	-489406.578.216	167149.523	0.003	
Precipitation	-27.064	16.172	0.094	0.576
Number of Bedrooms	7871.101	1542.680	0.000	0.666

Number of Kitchens	9135.977	3558.133	.0.10	0.644
Year Built	260.913	92.241	0.005	0.691
Turf Fraction	65383.607	16100.810	0.000	0.882
Tree Fraction	-22648.843	11339.919	0.046	0.914
Acres	259882.353	32956.236	0.000	0.661
Owner Occupied	-3768.800	3646.760	0.301	0.925
Number of Families	14415.391	3588.047	0.000	0.602
Final Valuation	0.265	0.027	0.000	0.496
R2				0.210

Apartment Demand Models: We also used OLS to determine the relative contribution of climate, built environment, and demographic variables on water use. Again, the climate variables are significant, though temperature did not exhibit the anticipated direction of effect. Alone, the climate variables do not explain more than four percentof the variance in the data. When built environment variables are added to the model the model fit improves substantially. The number of units and number of stories are both significant, with greater water use associated with more units and more stories. Newer apartments also use more water. When demographic variables are considered, the final value of the parcel is significant, but the higher the final value the lower the water use.

Table 4. Water demand models for Apartments

Variable	B	St. Error	Sig	Tolerance
	Climate			
Constant	76932983.68	18759873.38	0.000	
Temperature Max	-39330.492	9765.838	0.000	0.512
Precipitation	-5491.686	1868.073	0.003	0.512
R2				0.04
	Climate with Built Environment			
Constant	-601816.939	53435.701	0.000	
Precipitation	-1295.477	857.462	0.132	0.969
Number of Units	9455.128	498.185	0.000	0.919
Number of Stories	328361.585	81611.416	0.00	0.976
Year Built	9742.122	2932.757	0.001	0.921
R2				0.627
	Climate with Built Environment and Demographics			
Constant	-474022.429	93357.614	0.000	
Precipitation	-1396.561	843.402	0.099	0.968
Number of Units	11449.890	773.416	0.000	0.368

Number of Stories	361337.340	80829.309	0.000	0.961
Year Built	10210.915	2886.230	0.000	0.919
Final Value	-0.101	0.030	0.001	0.367
R2				0.634

Commercial Water Demand Models: We use OLS on all business and restaurant accounts to derive estimates for water demand for commercial buildings (Table 5). The climate variables are similar to the other models, but do not explain the variation as well. Built environment variables explain almost all of the variation in water use (R^2=0.93), where the largest parcels with a many lots are associated with higher water use. Neither turf nor tree fraction were significant in these models. When demographic variables are added, water use for commercial buildings increases as the final value of a parcel increases and the direction of effect of lot size changes.

Table 5. Water Demand Models for Commercial Buildings

Variable	B	St. Error	Sig	Tolerance
	Climate			
Constant	46320481.08	7346983.513	0.000	
Temperature Max	-25658.731	4141.964	0.000	0.788
Precipitation	-1488.050	487.448	0.002	0.788
R2				0.017
	Climate with Built Environment			
Constant	6277567.205	9018636.376	0.491	
Temperature Max	-4402.937	5362.307	0.417	0.423
Precipitation	657.339	348.978	0.067	0.620
Acres	754417.339	59297.282	0.000	0.456
Number of Lots	11207.623	2046.708	0.000	0.869
Turf Fraction	212116.852	213947.020	0.328	0.593
Tree Fraction	-197183.779	256314.486	0.446	0.937
R2				0.930
	Climate with Built Environment and Demographics			
Constant	34918724.17	26818846.62	0.199	
Temperature Max	-19212.44	15600.163	0.224	0.581
Precipitation	-1982.113	1199.954	0.105	0.713
Acres	-1035110.661	260792.402	0.000	0.389
Number of Lots	23744.258	8765.186	0.009	0.874
Turf Fraction	1903593.904	779539.499	0.018	0.741

Tree Fraction	400178.904	981839.273	0.685	0.869
Final Value	2.918	0.144	0.000	0.497
R2				0.926

Conclusion

Our study uses a uniquely rich database to analyze urban water use in Salt Lake City, Utah, for the year 2011 from which we assert generalizations can be made. We compare water use by urban land use type, and develop models that related the climatic, built environment, and demographic variables to water use. Not surprisingly, we find that seasonality is the greatest driver of water use, where in the summer, outdoor irrigation increases average water use for all urban land use types. Accounting for this, however, we find that certain urban land use types used more water than others, where industrial users and hospitals use the most water. Single family residential units show the least mean annual water use, but their cumulative use as a land use group shows the highest total water use.

Our analysis proceeded to find that different urban land use types use different amounts of water, but certain groups of urban land use types do not differ in annual use. For example, single family, duplex, triplex, and fourplex accounts use similar amounts of water in a year. Parks and apartments do as well. However, for other comparisons, significant differences exist.

Our models show the relative contribution of climate, built environment, and demographic variables on urban water use. Climatic variables alone explain very little of the variation in water use for all urban land use types. When built environment variables are added to the models, the model fit improves significantly and the models indicate that variables such as lot size, the number of bedrooms and kitchens, and the year built all significantly affect water use. The larger the lot and size of the building, the more water is used. Demographic variables, surprisingly, contribute very little explanation for water use in any of the urban land use types.

We use the best fitting models for each land use type for application in ET+.

References

Abrams, Barry. "An Econometric Assessment of Pricing Sydney's Residential Water Use*: Pricing Sydney's Residential Water Use." Economic record (2011): 89-105.

Arbues, F., Garcıa-Valinas, M. and Martınez-Espineira, R. (2003) Estimation of residential water demand: a state of the art review. *Journal of Socio-Economics* 32: 81–102.

Arbués, Fernando. "Price impact on urban residential water demand: A dynamic panel data approach." Water resources research 40.11 (2004)

Balling, Robert C. "Climate Variability and Residential Water Use in the City of Phoenix, Arizona." Journal of applied meteorology and climatology 46.7 (2007):1130-1137.

Barkatullah, N. (1996) OLS and instrumental variable price elasticity estimates for water in mixed-effects model under multiple tariff structure, Report No. 226, Department of Economics, University of Sydney.

Billings, R. B. and D. E. Agthe (1980), "Price Elasticites for Water: A Case of Increasing Block Rates", *Land Economics*, 56 (February), 73-84.

Blokker. "Simulating Residential Water Demand with a Stochastic End-Use Model." Journal of water resources planning and management 136.1 (2010):19.

Carter, D.W. and J.W. Milon, 2005. Price Knowledge in Household Demand for Utility Services. Land Economics 81(2):265-283.

Carver, P. and Boland, J. (1980) Short run and long run effects of price on municipal water use. *Water Resources Research* 16: 609–616.

Cavanagh, Sheila M., Hanemann, W. Michael and Stavins, Robert N., Muffled Price Signals: Household Water Demand under Increasing-Block Prices (June 2002). FEEM Working Paper No. 40.2002. Available at SSRN: http://ssrn.com/abstract=317924 or http://dx.doi.org/10.2139/ssrn.317924

Corral, L.R. (1997), Price and Non-Price Influence in Urban Water Conservation, Unpublished Ph.D. Dissertation, University of California at Berkeley, Berkeley, CA

Cummings, R., J. Hill, B. Thompson and D. Wilson (2005), "Conservation Pricing of Household Water Use in Public Water Systems in Georgia's Coastal Communities: A Preliminary Exploration", Working Paper # 2005-007.

Dalhuisen, J., Florax, R. de Groot, H. and Nijkamp, P. (2003) Price and income elasticities of residential water demand: a meta-analysis. *Land Economics* 79: 292–308.

Domene, E., and D. Sauri (2005), "Urbanisation and Water Consumption: Influencing Factors in the Metropolitan Region of Barcelona", *Urban Studies,* 43(9), 1605-1623.

Ferrara, I. (2008), Residential water use: A literature review, In Household Behaviour and Environment: Reviewing the Evidence, pp. 153–180. Org. for Econ. Coop. and Dev., Paris.

Foster, H. S., and Beattie, B. R. (1979). "Urban residential demand for water in the United States." *Land Econ.,* 55(1), 43–58.

Grafton, R Q., Michael B. Ward, Hang To, and Tom Kompas. "Determinants of residential water consumption: Evidence and analysis from a 10-country household survey." Water resources research 47.8 (2011)

Gaudin, S. "Effect of price information on residential water demand." Applied economics 38.4 (2006):383-393.

Guhathakurta, Subhrajit. "The Impact of the Phoenix Urban Heat Island on Residential Water Use." Journal of the American Planning Association 73.3 (2007):317-329.

Hanke, S.H. and L. de Mare, 1982. Residential Water Demand: A Pooled Time-Series Cross-Section Study of Malmo, Sweden. Water Resources Bulletin 18(4):621-625.

Hart, A., 2009. U.S. Water Use Declines, But Points to Troubling Trends, Says USGS Report. www.circleofblue.org/ waternews/2009/world/u-s-water%20 use-declined-from-2000-to-2005-part-of- growing-trend-usgs-report-finds/ (accessed Feb. 22, 2010).

Hewitt, J. and Hanemann, W. (1995) A discrete/continuous choice approach to residential water demand under block rate pricing. *Land Economics* 71: 173–192.

Hoffmann, M., Worthington, A., Higgs, H., 2006. Urban water demand with fixed volumetric changing in a large municipality: the case of Brisbane, Australia. The Australian Journal of Agricultural and Resource Economics 50, 347–359.

Howe, C. W., and Linaweaver, F. P. (1967). “The impacts on residential water demand and its relation to system design and price structure.” *Water Resour. Res.,* 3(1), 13–32.

Kenney, D.S., R.A. Klein, and M.P. Clark, 2004. Use and Effective- ness of Municipal Water Restrictions During Drought in Colo- rado. Journal of the American Water Resources Association 40(1):77-87.

Kenney, D., Goemans, C., Klein, R., Lowery, J., Reidy, K., 2008. Residential water demand management: lessons from Aurora, Colorado. Journal of American Water Resources Association 44, 192–207.

Kenny, J.F., Barber, N.L., Hutson, S.S., Linsey, K.S., Lovelace, J.K., and Maupin, M.A., 2009, Estimated use of water in the United States in 2005: U.S. Geological Survey Circular 1344, 52 p.

Jones, C.V. and J.R. Morris, 1984. Instrumental Price Estimates and Residential Water Demand. Water Resources Research 20(2):197-202.

Jorgensen, Bradley, Michelle Graymore, Kevin O’Toole. "Household water use behavior: an integrated model." Journal of environmental management 91.1 (2009):227.

Lee, M.Y., 1981. Mandatory or Voluntary Water Conservation: A Case Study of Iowa Communities During Drought. Journal of Soil and Water Conservation 36(4):231-234.

Lee, M.Y. and R.D. Warren, 1981. Use of a Predictive Model in Evaluating Water Consumption Conservation. Water Resources Bulletin 17(6):948-955.

Lyman, R. A. (1992). “Peak and off-peak residential water demand.” *Water Resour. Res.,* 28(9), 2159–2167.

Martınez-Espineira, R. and Nauges, C. (2004) Is really all domestic water consumption sensitive to price control? *Applied Economics* 36: 1697–1703.

Mazzanti, M. and A. Montini (2006), “The Determinants of Residential Water Demand: Empirical Evidence for a Panel of Italian Municipalities”, *Applied Economics Letters*, 13(2), 107-111

Maidment, D.R. and Miaou, S.P. (1986) Daily water use in nine cities. *Water Resources Research* 22: 845–851.

Michelsen, Ari M., J. Thomas McGuckin, and Donna M. Stumpf, 1998a. Effectiveness of Residential Water Conservation Price and Nonprice Programs. American Water Works Association Research Foundation, Denver, Colorado.

Nieswiadomy, M. L. and D. J. Molina, Comparing residential water demand estimates under decreasing and increasing block rates using household demand data, *Land Econom. 65*, 280-289 (1989).

Olmstead, S.W., M. Hanemann, and R.N. Stavins, 2003. Does Price Structure Matter? Household Water Demand Under Increasing-Block and Uniform Prices. NBER Research Paper, March, Cambridge, Massachusetts.

Pint, E. (1999) Household responses to increased water rates during the California drought. Land Economics 75: 246–266.

Polebitski, Austin S., Richard N. Palmer "Seasonal Residential Water Demand Forecasting for Census Tracts." Journal of water resources planning and management 136.1 (2010):27.

Renwick, M.E., Archibald, S.O., 1998. Demand side management policies for residential water use: who bears the conservation burden? Land Economics 74, 343–360.

Renwick, Mary E. & Green, Richard D., 2000. "Do Residential Water Demand Side Management Policies Measure Up? An Analysis of Eight California Water Agencies," Journal of Environmental Economics and Management, Elsevier, vol. 40(1), pages 37-55, July.

Renwick, M., Green, R. and McCorkle, C. (1998) Measuring the price responsiveness of residential water demand in California's urban areas. Report prepared for the California Department of Water Resources, May. Available at: http://rubicon. water.ca.gov/

Rockaway, Thomas D.; Coomes, Paul A.; Rivard, Joshua; Kornstein, Barry, 2011. Residential Water Use Trends in North America. Journal AWWA, Vol. 103 Iss. 2, February 2011, Page Range 76-89, 14 Pages

Schultz, M.T., S.M. Cavanagh, B. Gu and D.J. Eaton (1997), The Consequences of Water Consumption Restrictions During the Corpus Christi Drought of 1996, Draft Report (LBJ School of Public Affairs, University of Texas at Austin).

Shaw, D.T. and D.R. Maidment, 1987. Intervention Analysis of Water Use Restrictions, Austin, Texas. Water Resources Bulletin 23(6):1037-1046.

Strand, J. and I. Walker (2005), “Water Markets and Demand in Central American Cities”, *Environment and Development Economics*, 10(3), 313-335.

Syme, G., Nancarrow, B. and Seligman, C. (2000) The evaluation of information campaigns to promote voluntary household water conservation. *Evaluation Review* 24: 539–578.

Thomas, F. and Syme, G. (1988) Estimating residential price elasticity of demand for water; a contingent valuation approach. *Water Resources Research* 24: 1847–1857.

Wentz, E., and P. Gober, 2007: Determinants of small-area water consumption for the city of Phoenix, Arizona. *Water Resour. Manage.,* doi:10.1007/s11269-006-9133-0.

Worthington, Andrew C. "An Empirical Survey Of Residential Water Demand Modelling." Journal of economic surveys 22.5 (2008):842-871.