The Potential Effects of Climate Change on Residential Water Demand in Phoenix, AZ

by

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Abstract

Water is a vital component for the continued prosperity and growth of metropolitan Phoenix. Despite that, very little work has been done to examine how potential changes in weather patterns could affect water usage in the coming decades. Newly available data from meteorological agencies around the world on how temperature, precipitation, and other weather variables could evolve until 2100 makes looking at future water demand an area ripe for exploration.

This is one of the first studies to look at water demand in Phoenix using both household level data and extrapolating the demand patterns from the regression of that data to look at different climate scenarios and how they could impact water usage. Panel data are used to model water demand. Then using Intergovernmental Panel on Climate Change (IPCC) data on climate variables in the coming century are used to estimate counter-factual water demands in four Phoenix Communities.

Chapter 1 Introduction

Phoenix is a duck-billed platypus of a city. When people take the time to stop and look at it, no one is sure how it survives or why it's there in the first place. How can a city exist in the middle of the desert? Why would people come to the desert and say to themselves that it is here that they will build a city. The greater Phoenix metro region is home to over 4 million people and the 5th largest city in the nation. Between the years 1990 and 2005, the population of the greater Phoenix metro region, which including Phoenix and other communities including Paradise Valley, Sun City, Sun City West, and Tempe grew 73% according to the Greater Phoenix Economic Council, as compared to 19% for the nation. Being able to forecast with some degree of certainty the residential water demand for Phoenix is and will continue to be a critical tool for urban planners as decisions are made on how to foster continued growth in Phoenix. These plans will become more difficult in the future as climate change affects water usage as well as population growth. Creating a model that takes the effects of climate change into account will be an invaluable tool in water planning for the future. Interest in water demand modeling has been growing, as the importance of a continued uninterrupted flow of water is vital for all continued urban population and economic growth. Most research done on the modeling of water demand attempts to explain current consumption. The next logical step of forecasting water usage into the future has been mostly limited to individual utilities and cities' water planners. Even then, the emphasis is still mostly on short-term forecasting. However, longer term forecasting will be an important part of any plans urban and city planners formulate for continued growth of the southwestern United States.

Despite its desert setting, Phoenix does and has not always utilized its water as if it were a finite resource. Around 30% of homes in Phoenix have a backyard pool, with an average capacity of 16,000 gallons. During the hot summer months, these pools are used to great relief of Phoenicians young and old. However, it is also during these months, when the temperature routinely exceeds 100 degrees, that the majority of the 10,000 gallons that evaporate from each of these pools every year are lost. Phoenix is also odd in the way that it bills its water users. Like many cities, Phoenix uses a step system of payments, where an initial amount of water units are billed at one price while additional units are billed at a higher price. However, if the billing ranking for the 50 largest US cities are compared, with 1 being the least expensive and 50 the most, Phoenix lies in the middle with an initial rank of 21 for the first tier of water, 28 for the second, and 26 for the third. This is compared to 22, 14, and 49 for Tucson and 50, 49, 49 for Seattle (Gammage Jr. et al. 2011). On average Tucson uses about a quarter of the water Phoenix does, and Seattle, which has more expensive water than both, would seem to have a less urgent need to conserve its water resources.

1.1 Purpose of Study

The purpose of this study is twofold. The first is to develop an econometric model of water demand for four different cities within the Phoenix metropolitan area: Sun City, Sun City West, Paradise Valley, and Anthem. Water usage data from individual households has been provided by EPCOR Water Arizona Inc., the local water utility for each of the four cities over the course of a roughly 6-year period. Along with water demand from households, the utility has also provided billing data and the pricing schedules, each different for each community. Once a model has been estimated, the second part of this study is devoted to projecting water usage into the future by presenting counter-factual scenarios of how current residences might react to changes in weather variables owing to climate change. The data for climate change are taken from the Intergovernmental Panel on Climate Change (IPCC).

1.2 Significance of Study

The Phoenix region continues to grow. According to the Morrison Institute for Public Policy at Arizona State University, the greater Phoenix region and the Tucson regions are expected to merge into a megapolitan "Sun Corridor" with 10 million citizens by 2050 (Gammage Jr., Stigler, et al., 2011). Other more conservative estimates place the population growth to 6.3 million by 2030 according to the Greater Phoenix Economic Council. Many who look at the Phoenix region with outsiders' eyes do not understand how a city can survive with annual rainfall in the region so scarce. The truth is that Phoenix exists because of the planning of many individuals in the city's past and present and through their work to bring the water necessary for Phoenix's survival from a variety of sources both in and outside of the state. The region gets its water from three sources: the Colorado River, Arizona ground water sources, and Arizona surface water. A different authority manages each of these sources; the Salt River Project (SRP) is in charge of surface water, the Central Arizona Project (CAP) governs the use of Arizona's allocation of Colorado River water, and the Groundwater Management Act oversees Arizona's ground water.

In the future there will be constraints that could greatly affect the Phoenix metro region's ability to continue to enjoy uninterrupted access to water. The first of these lies in the growth of the population both inside and outside of Arizona. Arizona is allowed 2.8 million acre feet per year from the Colorado River. Currently, 1.2-1.5 million acre feet are conveyed from the Colorado River by CAP to the Phoenix region, with the remainder being used on River. Recently, Arizona for the first time reached it allocation limit. Assuming reaching this limit is not an anomaly, any future growth in the urban population's water demand from this source will have to be met in-state between agricultural and urban use. This may not be a problem, as Arizona still uses the majority of its water (70%) for agricultural purposes and Maricopa County, where Phoenix is located, uses almost half (47%) for agriculture as well. However, while the Colorado River allocation may not be a problem as far as overall supply is concerned, increased urban demand could well mean higher water prices as well as the loss of agricultural jobs, as former farmers instead sell water to the cities.

Population growth outside of Arizona could also adversely affect Arizona's water supply.

Arizona is a junior partner of the Colorado River Compact that divides up the water flowing along the Colorado. Junior rights mean that Arizona only receive its allocation after other states have drawn theirs. Potential climate change effects on the Colorado River could exacerbate the situation. The National Center for Atmospheric Research notes that the Colorado River flow could decrease by 10-20% over the coming decades (Gammage Jr. et al., 2011). This combination of increased usage from other states and the decline of water availability from the Colorado mean that there may not be enough Colorado River water for Arizona's full allocation. Additionally Arizona, through the CAP, would also be the first to be subject to reductions if the Secretary of the Interior were to declare a shortage. This could be important in coming decades since the Colorado River basin has already been in drought conditions for 10 years.

For all of these reasons, being able to forecast water usage is a critical part of securing Arizona's future. This study is the one of the first tentative steps in attempting to bring economic analysis to bear on the effects of climate change on future water consumption. Forecasting future water demand based on current residential water use technology and population is tenuous. Cities in the position of Phoenix, with the great majority of its potable water arriving by manmade aqueducts and originating from long distances away, should plan for future water needs based not just on forecasted population growth but using economic models as well. With almost universal agreement of increasing temperatures in the coming decades, Phoenix must be on the forefront of using a more specialized and in-depth models in order to make the decisions necessary to ensure continued supply. Especially since the necessary water infrastructure is extremely expensive and time consuming to build. Enlarging or building completely new water treatment plants and switching public landscaping from grass and large palm trees into less water-intensive landscaping options such as xeriscaping requires significant investment.

Chapter 2 Literature Review

Despite the importance of water to every facet of human society, relatively little work has been done to assess the price elasticity of water demand and the potential effects that climate change could have on water demand. The work that has been done on the effects of potential climate change has often focused on larger groups of households as individual observations. For example, each census block is treated as a single cross-sectional observation. One of the unique features of this paper is the ability to disaggregate to the individual household and its water usage. However, the articles reviewed below have provided invaluable help in deciding how to model the effects of climate change as well as which climate models to use for predicting future climate variables.

In his 2007 paper, Edwin P. Maurer wrote about the potential hydrologic impact that climate change could have on the Sierra Nevada region. This paper is important even though its focus is on stream flow and runoff rather then residential water. His results show the variation between different climate scenario projections within Global Climate Models (GCM) of future climates and discuss the statistical significance of temperature changes. Within each GCM two emission scenarios are used; each scenario is an alternative view of how the world will grow and change in the future. The differences between the scenarios in each model must be taken into account when trying to project future water usage based on projected climate estimates.

Maurer identifies four factors contributing to the uncertainty in forecasts: (i) the future emission of greenhouse gas; (ii) the response of the GCMs to those emission concentrations; (iii) the added uncertainty inherent in downscaling from larger scale to small-scale geographies; and (iv) how land use could change in the intervening time period.

For his analysis he used all the GCMs that had completed at least one simulation of the 20th through the 21st century through 2100, 11 models. Maurer first mapped precipitation and temperature through a historical period (1950-1999) from the National Climatic Data Center Cooperative Observer station data to the GCM data. Citing Wood et al., Maurer argues that this statistical bias-corrected downscaling method performs as well as dynamic downscaling.

His results were summarized over four thirty-year time periods; 1961-'90, 2011-'40, 2041-70, and finally 2071-2100. The temperature projections appear much more consistent with one another while the precipitation values were more variable, though for them as well the majority showed increases over the winter season. As Maurer puts it, "the impact on the flow of these climatic changes is that winter flows increase and late spring and early summer flows decline, with greater disagreement among models during the transition between the two."(Maurer, p. 315)

Temperature increases after the '61-'90 base level were highly statistically significant. He also found that the difference between the amounts that temperature rose between different scenarios was significant as well. Regardless of the emission scenario all models predicted increases in temperature. For precipitation, however, the differences between different emission scenarios were generally not highly significant. But as temperatures rise more precipitation will come as rain instead of snow.

While Maurer used all 11 GCM's with sufficient data, not all the GCMs are equally useful when looking at small geographic areas, such as Phoenix, Arizona. Francina Dominguez, Julio Canon, and Juan Valdes, all of the University of Arizona, conducted an analysis to ascertain which GCMs best represent the climate of the Southwestern United States where Phoenix is located (Dominguez, Canon, & Valdes, 2010).

Because of El Niño weather patterns affect in Southwestern weather, Dominguez et al. were interested in which GCMs best modeled the area's climate. The GCMs use an averaging procedure, which "dampens the spatio-temporal variability in the climate projections…and hamper the analysis of climate variability associated with specific hydroclimatic patterns, such as El Niño Southern Oscillation."(Dominguez et al., p. 500) Because of this dampening not all models could be used with the same degree of confidence in the study of the Southwestern Untied States region. The purpose of their study was to assist water managers in making informed decisions about the future by allowing them to use the models that best fit the Southwest's climate patterns. Being able to accurately measure changes in climate pattern is of particular importance since current projections suggest an increase in temperature and a decrease in precipitation in the region. Barnett & Pierce underline this fear, when they wrote that because of increased water usage, if climate changes as expected and water usage continues to grow apace there is a 50% chance that the storage lakes Mead and Powell will be depleted by 2021 (Barnett & Pierce, 2008).

Dominguez et al. chose data from 24 climate-modeling centers across the globe that generated future projections for temperature and precipitation using the Intergovernmental Panel on Climate Change (IPCC) scenarios. The projections each had three emission scenarios ranging from "B1", which posit "a convergent world with resource-efficient technologies to the "A2" scenario (slow economic growth and ever-increasing population)" (Dominguez, Canon, & Valdes, 2010). Actual daily climate data from the years 1901-

2002 were used to evaluate the models. The actual historical observations were compared to the GCM output in order to verify which of the models most accurately mimicked the real observations. Though most GCM predictions track temperature accurately, they had trouble predicting precipitation variability, "In general, the models have problems capturing the peak summer precipitation associated with the North American Monsoon and all models significantly overestimate winter precipitation."(Dominguez et al., p. 503)

Model predictions were assessed based on two criteria: the performance of the models based on precipitation and temperature. The second measure of the GCMs' performance was based on their ability to measure precipitation changes within the region due to the singular weather patterns the Southwest faces because of the El Niño Southern Oscillation (ENSO). After ranking the models on both criteria, models best representing the region are the German mpi_echam5, the Max-Planck-Institut for Meteorology Model and the United Kingdoms ukmo_hadcm3, from the United Kingdom Meteorological Office (Dominguez, Canon, & Valdes, 2010). These two models with various scenarios will be the ones used to obtain the forecasted temperature, precipitation and evapotranspiration (ET) observations in the present study.

After deciding how to obtain climate forecasts for future years, it is still vitally important to look at how previous studies have modeled water demand. In their 2005 paper, David S. Gutzler and Joshua S. Nims looked at the "Interannual Variability of Water Demand and Summer Climate in Albuquerque, New Mexico". In 1995, the Water Conservation Project was implemented in Albuquerque, New Mexico with the stated goal of lowering water consumption. The paper assesses the success of the conservation project and attempts to predict water demand. This paper is relevant because the city, Albuquerque, and its climate is very similar to Phoenix and its climate.

Gutzler and Nims use a straightforward regression model. The endogenous variable of water demand was monthly metered residential customer accounts. A source of uncertainty with the authors' data that parallels the data in this study, billing cycles are irregular. A bill could cover a "month" even though it starts in the middle of one month and ends in the middle of another. Along with water data, the authors also used census data as in the current study. However, since the census is decennial, the data does not change yearly. The authors chose to interpolate the year-to-year population changes, which is not necessarily how the population varied in reality.

Residential demand peaks in the summer, with almost half, 49%, of water usage occurred between June and September, most likely attributed to outdoor water usage for lawns and pools as well as the use of water in home climate control through evaporative cooling. To control for climate, Gutzler and Nims used precipitation, temperature, and humidity data from the National oceanic And Atmospheric Administration. They also found that over 40% of precipitation also takes place during the four summer months. This is important as they found that the increase in precipitation that starts in the summer with the onset of the monsoon season does correspond to a drop in water demand.

The authors looked at summer climate and water demand covariance using OLS regression. After looking at different permutations of variables including total and per capita demand, the authors chose seasonal precipitation rates and the average of maximum temperatures as climate variables. Interestingly, they found that the r^2 for the simple models where only temperature or precipitation was an explanatory variable were almost the same. However, the r^2 of the combined model was not twice as large.

Gutzler and Nims also looked at the change in water demand from year to year during the summer months, in order to account for the high degree of interannual variability water demand, not related to population growth. This variability could mean that the climate variables would be more influential in the "high-frequency component of the annual time series." To this end, along with using the change in water demand they also use the change in temperature and precipitation from the previous year. When they looked at these models, Gutzler and Nims saw that when they included change in precipitation the models accounted for a much larger part of the demand variance, greater than 60%. They conclude that, in the short term climate induces variability, while in the longer term the impacts of population growth outweigh climate. The authors also found that precipitation was usually the better predictor of the change in water demand than temperature.

Gutzler and Nims found that the conservation efforts implemented by Albuquerque were effective. Also of interest was the difference between looking at modeling water demand during all months as compared to looking at just the summer months. When the authors looked at all water demand, the climate variables provided very weak explanatory results. During the summer months though the climate variables became very good predictors of water demand. Looking forward, they believe that combining the temperature and precipitation observations into a single variable, as evapotranspiration would be, might yield good results as well since they are often related. Finally they note that having actual observations of household demand would allow for a greater degree of spatial differentiation that could lead to more robust results.

This next article, “Sensitivity of residential water consumption to variations in climate: An intraurban analysis of Phoenix, Arizona” deals almost exactly with the topic of this paper. However, while the article is very interesting, it has some areas that this paper may be able to improve upon, along with the ability to project into the future the water demand of residential areas. The authors noted that residents use the majority of their water, from 60-75%, for outdoor purposes. As such, they posit that since such a large percentage is used for outdoor purposes, the water demand may well be more sensitive to climate variations.

Balling et al. obtained water usage by census tract. This data, originally 303 tracts, was obtained from the Phoenix Water Services Department cover 10 years from 1995-2004. It should be noted that just as in Albuquerque, the authors recognize the potential problem of imperfect billing month cycles. After cleaning the data, they were left with 230 tracts. The water use data was then transformed into a percentage of normal use based on monthly means for each tract through the time period. This was done to eliminate the skewing factor of summer usage and better allow variables other than time to show.

The climate variables were obtained from the United States Historical Climatology Network(USHCN), and consisted of temperature, precipitation, and drought data. The temperature data was then transformed into deviations from the mean monthly temperature. The drought data, represented by the Palmer Hydrological Drought Index(PHDI) range from negative to positive. A score of <-4, <-3, and <-2 indicate extreme drought, severe drought, and moderate drought respectively. While a score near zero indicated normal conditions, and >2, >3, and >4, represent respectively moderately wet, very wet, and extremely wet conditions. The PHDI takes into account temperature, precipitation, evapotranspiration, soil runoff, and soil recharge.

The climate predictors were evaluated using both kurtosis and the standardized coefficients of skewness. These values were then compared to a t-value to test whether a statistically significant variation from the normal distribution had taken place. These tests confirmed that precipitation variation time series was skewed, and not normal. A "modified square-root transformation in which the sign of the original value is retained" was instead used to normalize the observations. When the climate variables were compared to one another they were found to be near perfectly independent.

Finally, the authors chose variables to account for land use and socioeconomic status. Using data from a 1998 Landstat Thematic Mapper image, they took as a percentage the amount of land covered in landscaping as a constant. Mean household income and mean household size for each tract taken from the 2000 Census. The average lot size of houses on each tract and percentage of households with pool was taken from the Maricopa County Assessor's Office for the year 2003. Finally, they included the percent "Hispanic" that each census tract was from the Census. The rationale behind this was that Hispanic households might not be able to digest conservation messages as easily or readily because of language barriers. Between these variables, large correlations was found between income and the occurrence of pools, the percentage of Hispanics in a census tract and the average household size and finally between the percent Hispanic and income. These variables were therefore put through a normalization process and "principal components analysis and derived two factors with eigenvalues greater than 1.0".(8)

Balling et al. drew the following conclusions: water usage is significantly related to climate variation, increasing when the temperature goes above the monthly “normal”, when precipitation drops below its “normal” and when the area is in drought. Of the three weather variables, the PHDI best captures the demand for irrigation and the need for pools to be refilled. They also found that the sensitivity to climate varied greatly from tract to tract. A third of all the tracts showed no real sensitivity while at the other end, one census tract showed 72% of its water demand explained by the climate variables. The greater the prevalence of pools, high-income residents, larger lot sizes, and the more irrigated landscaping, the greater the explanatory power of climate variations, which makes perfect sense. While on the other end the higher the percentage of Hispanic residents, the lower their sensitivity. They finally note that while there is a relationship between temperature and precipitation and water usage, it is not nearly as strong as the relationship between the presence of drought and water demand.

Robert C. Balling Jr. has written extensively about water use in Phoenix. This next article is also his, written along with Hermes C. Cubaque, titled “Estimating Future Residential Water Consumption in Phoenix, Arizona based on Simulated Changes in Climate”. It is a follow up to Balling et al.’s 2008 paper discussed previously. While that paper dealt with the immediate past and present water consumption, this paper projects water demand into the future. Balling et al. uses census tract level demand data taken from the City of Phoenix’s Water Services Department for 9 years, 1995 through 2003. These were grouped into census tract level amounts in the same way there were in his previous study, with a final tract count of 282 and the year 2004 eliminated due to anomalous values. The same data used in his previous study was also used here.

The present demand was modeled in two ways in an attempt to eliminate the cycle of within the data; the first was to do twelve regression models for each tract, one for each month. The second method would be to model not the data themselves, but rather transform the variables into "monthly anomalies"(pg 313). Both of these models were run, and gave basically the same results. The first model showed that for every increase in temperature (T) of one degree Centigrade there was an average increase in water consumption (C) of 648 liters per month, with the average temperature coefficient of .22. There was positive and significant correlation between $\Delta C/\Delta T$ and all four of the land use and economic data and absolute consumption of water. Precipitation (P) was also positively and significantly correlated with all four variables, the $\Delta C/\Delta P$ was found to be much smaller, with an average decrease of 530 liters per month of consumption for every 10mm of rain, and an average coefficient of .12.

Balling and Cubaque collected 50 model scenario combinations from the IPCC for a 30-year time period from 2040 until 2069. All of the models used projected a warming trend in the Phoenix area of between 1.33 and 4.46 degrees centigrade with an average of 2.61. There is larger difference between precipitation, with a range from -11.13 to 6.66 mm a month with an average of -2.47.

Using these 50 different models, Balling and Cubaque then switched the actual climate data with the projected, while keeping the other variables constant. Monthly water demand increased on average 3.27% or approximately 1800 liters. Interestingly, almost all of the increase, 96%, could be attributed to temperature while only the remaining 4% is attributed to changes in rainfall. Across these 50 different climate futures, the average standard deviation from the 1800 liters was 491. While this may seem high, approximately ¼ of the average monthly increase, according to the Pearson product-moment correlation coefficient is +.96, which indicates that "the absolute uncertainty is relatively low for small residential consumers and high for larger, more affluent resident water users." (Balling Jr. & Cubaque, 318)

Balling and Cubaque found that climate variables are significantly related to water demand. As the century continues, and temperatures rise and precipitation patterns change, water demand looks to increase. However, the authors also note that conservation methods have already had an impact in Phoenix. From 1980 to 2004 household water consumption dropped 18%, and while it may not be realistic to expect this trend to continue apace it is another indication that conservation methods can indeed make a difference. It is also an important indication that while this paper makes some important conclusions one does need to realize that the models keep all other variables beside climate constant and that needs to be kept in mind when looking at the results.

Moving from the United States to Asia, in their 2009 article, "Identifying the Relationships Between Urban Water Consumption and Weather Variables in Seoul, Korea", Sarah Praskievicz and Heejun Chang looked at how climate change could affect the South Korean capital. Seoul has seen it's average temperature rise more than the world average, and that, coupled with its rising population and consequently the rising heat island effect is expected to lead to increased water usage. The authors quote a 2007 American study of Phoenix by Guhathakurta and Gober that showed that a 1°C increase in temperature led to an additional 1973 liters being consumed per family household in June. One of the main differences between this report and others is their focus on casting the widest possible net of climate variables.

Praskievicz and Chang's study is based on data between the years 2002 and 2007. The daily weather variables were given by the Korean Meteorological Agency. These variables were from a single station located in Seoul. Municipal water usage data was obtained from the Office of Waterworks. For their study, they looked at only total water use for all sectors in the entire municipality of Seoul. The reason that only total water usage is looked at is because that is the smallest spatial unit that has daily observations. That is also the reason that they use only one Climate Station within the city. They chose to only look at the summer months, since the authors felt that the water demand would be more sensitive to weather during those months. Subtracted from the total water usage of each summer month was the December total usage, which had the lowest usage quantity. This was done in order to separate the typical usage from the seasonal usage. As compared to a more sprawling city such as Phoenix, Seoul families live primarily in apartment units. As such the great majority of outdoor usage is for municipal irrigation of landscaping rather than family use.

The authors included a prodigious number of climate variables; maximum and miniature temperature, precipitation, cloud cover, average temperature, wind speed, relative humidity, and daylight length. Of these, cloud cover, precipitation, and wind speed were all logarithmically transformed in order to be of use for linear analysis. The authors then looked at the correlation between these variables and water usage, finding significant correlation between climate variables. They found that all temperature variables along with length of daylight were positively correlated while the rest of the variables had a negative correlation.

Using a stepwise regression process, Praskievicz and Chang ran an OLS model with all the climate variables included in order to determine the extent to which climate affects water usage. Rather than use raw numbers they instead used variance from the mean. After running the model, they found that the explanatory value of the model(R^2) ran from a low of .389 in August to a high of .613 in July. Interestingly, depending upon which month was used, different climate variables played larger or smaller roles. Throughout all summer months, maximum temperature was the most important of the climate variables, with a positive coefficient. However, in June daylight length played a large role as well, but as might not be expected it had a negative coefficient. In August and September, wind speed was significant and negative along with maximum temperature that was significant and positive. When looking at the summer as a whole, both wind speed and daylight length were inversely related to water usage while maximum temperature was positively related.

The authors further developed another model using autoregressive integrated moving average (ARIMA) along with the OLS models for each of the respective time lengths, in order to account for the autocorrelation between variables. Using the water use from the previous day as a variable as well does this. The specific ARIMA model used was selected according to best fit using an iterative approach. After comparing the ARIMA with the OLS it was shown that the ARIMA significantly improved the models R value, explaining between .47 and .76 of the water use variance as compared to .39 and .61.

When discussing their findings, Praskievicz and Chang remark that while climate variables do indeed play a role in water usage, the R-values indicate that there are many non climate variables at play as well. They note that other studies that have not studied exclusively on weather such as Kenney et al. (2008) and Cooley and Gleick (2009) showed that pricing, conservation methods, and socio-economic factors were also related to water usage. Among the articles they mention is the Gutzler and Nims article previously written about above to show how conservation efforts can affect water usage.

Lily A House-Peters and Heejun Chang wrote an extremely interesting, comprehensive, and in my case, helpful article published in 2011 about the current literature of urban water demand. Titled "Urban Water Demand modeling: Review of Concepts, Methods, and Organizing Principles", it does exactly what its title suggests and provides an invaluable source of information. House-Peters and Chang first note the complex interactions that account for urban water demand starting from the individual water user "microscale" patterns up into "macroscale" of municipal and regional patterns (House-Peters & Chang, 2011). These interactions between individuals and areas are further not static but rather change across temporal ranges, which can in turn feed back into and change future patterns. As an example, strong water demand across a given time period could lead to the lowering of the aquifer leading to demand ceiling imposed across regional areas. It is therefore extremely difficult to model these behaviors since the existence of chaotic and unforeseen occurrences rises as the time period and complexity of the modeled area increases.

Growing along with the realization of the importance of modeling water demand is the amount of literature devoted to it. From 1978 through 1994, House-Peters and Chang note that on average less than 5 papers were published each year. However, that number had grown to 15 in 2003 and to almost 45 in 2010. The growth in the publishing the authors attribute to the growing awareness of climate, the growing availability of datasets, the refinement of how these datasets are gathered, and the computing power available to create and process new models. These new advances allow for better methodology to deal with "methodological advances: (1) scale, (2) uncertainty, (3) nonlinearity, and (4) dynamic processes."

Scale can be either temporal or spatial and in either case is very important to modeling water demand. At first, water data was typically citywide, only later was household level data obtainable. The availability of time scaled data allowed for researchers to test the significance of variables such as weather and climate variables, along with economic variables. For example, changing price or price structures or the imposition of new conservation promotions or fees. Block price structuring of water usage is prevalent across the world and the ability to gauge the effectiveness of different schemes is invaluable to future estimation. Time series models can suffer from serial autocorrelation. Additionally, simultaneous equation bias can also exist when looking at elasticity estimates, though a solution to minimize it might be by using simultaneous equations for both the short and long run.

Another issue that is part and parcel of water demand modeling is what "price" to use as an independent variable. After all, economic theory would most likely point to marginal price as the variable to use. However, this is complicated by the pricing structure that water usage takes. Water pricing usually uses a block-pricing schedule. Indeed, in Paradise Valley, one of the areas of study, there are five blocks. One school of thought to deal with this is to use the average price per unit per billing cycle, this was used most recently by Palmer and Polebitski (2010). A second would be to use marginal price of the last unit used along with a second variable of the fixed service charge. Finally, Lyman (1992) suggested also using a lagged price specification in the model. This added lagged price has been popular with dynamic panel modeling.

The use of panel models has shown to produce more efficient and consistent estimators than simple ordinary least square models. Using household level data, Arbues et al. (2004) with dynamic panel data showed that the observed households responded to an average lagged price. Going more in depth with the type of model to use, Palmer and Polebitski tested both fixed and random-effect panel models along with OLS and found that the panel models perform better.

Spatial scale is another issue in water demand. The data for different spatial scales has improved over time, and at a finer resolution. The ability to add variables such as metering household irrigation, or land cover classification into demand models has produced better results. Census data in particular has been used heavily to attempt to account for different characteristics of areas. Wentz and Gober used Geographically Weighted Regression (GWR) in order to account for spatial autocorrelation by

> "interpolating spatial phenomena at unknown locations using random variables…Wentz and Gober [2007] identified varying degrees of the GWR coefficient for the household size variable, suggesting different sensitivity of water consumption with an increase in household size across different census tracts in the City of Phoenix. If such spatial dependence in explanatory variables is not taken into account, OLS regression model parameters are either overestimated or underestimated…" (House-Peters & Chang, 2011, p. 8)

Perhaps the most immediate question that modeling the effect of future climate change on water demand is that of uncertainty. The climate modeler themselves freely admit they do not know how the future will be shaped, and as such each can have several different values based on the type of technological and economic progress the world makes. Further, when attempting to downscale to a region and look at climate change at the micro scale can include new uncertainties that were not been present when attempting to model the macroclimate change.

House-Peters and Chang gathered and explicitly listed the most commonly used variables for modeling water usage. Of the climate variables: temperature, precipitation, wind speed, and evapotranspiration, evapotranspiration is used in the present study because the ET equation includes wind speed, temperature, humidity and solar radiation. The water price and/or rate structure are also listed. As mentioned above, there are different ways to attempt to use these, either using an average or a marginal as well as including lagged values. Socioeconomic variables for the water users are also in abundance. Income, age, education, ethnicity are all listed. Household characteristics, such as household size, house size, yard size and presence of pool are also used.

Chapter 3.1 Model

There are currently several different estimation methods used in water demand analysis. The simplest is OLS, which has been widely used in the past as much for its simplicity as for any theoretical reason. Before the advent of new software and hardware to run better models, the OLS model was the norm.

OLS models were used despite the fact that because of simultaneity present in the block structure of water pricing, OLS assumptions were violated. Multiple regression panel model and geographically weighted regression (GWR) are two of the more recent models that capitalize on the availability of more powerful computers and more disaggregated data to model water demand. The benefit of GWR is that it takes spatial correlation in explanatory variables. Accounting for spatial correlation could be useful when modeling water demand as normal linear models could mask neighborhood correlation.

There is good reason to think there are spatial differences that would change the reactions that different areas have to changing prices, temperature, and other variables. GWR also accounts for spatial autocorrelation. The presence of a Home Owners Association (HOA), different lot sizes, or clustering of people of similar socioeconomic backgrounds could lead one area to behave differently than another.

While GWR could be very useful, the type of data available for this study lends itself more to panel modeling. The water data used as the basis of this study is panel data, following customers over a six-year period of monthly water demand. Using panel methods differences in space, as in the GWR, as well as temporal changes can be accounted for. Using this method lagged average price is included as an explanatory variable, simultaneity between current average price and quantity consumed is minimized. The general format of the model is

$$(3.1)\quad q_{i,t} = \beta_1 + \beta_2 AvgP_{i,t-1} + \beta_3 ET_{it} + \beta_4 G_i$$

where AvgP is average price, ET is monthly evapotranspiration and G are exogenous time invariant variables.

3.2 Functional Form

There is no apparent consensus on the appropriate functional form of the water demand function. The often-used linear demand form has an intuitive appeal to it. Using the linear demand form the lower the price, the less sensitive households are to it. On the other hand, it also implies that the marginal effect will always be the same no matter what the price is.

The semi-log form also has some advantages. First, the distribution of water demand is rightly skewed, but also has extreme values to the left. Taking the log of demand would therefore tend to make the distribution more symmetric. Second, by taking the log of demand you are theorizing that the change in quantity of water demanded differs even if the absolute amount of price change is the same depending upon whether the starting price is low or high. The elasticity equations below of both the linear, equation 3.3, and the semi-log functional form, equation 3.2, implies that the price elasticity of water is not constant.

$$(3.2)\quad e_{avgp} \Rightarrow \frac{\partial q}{\partial p} \cdot \frac{p}{q} = \hat{\beta}(\frac{p}{q})$$

$$(3.3)\quad e_{avgp} \Rightarrow \frac{\partial \log{(q)}}{\partial p} \cdot \frac{p}{q} = \hat{\beta}(p)$$

It makes intuitive sense that customers become more sensitive to the price changes the higher the initial price is. Problems arise with using the semi-log model when usage is zero, since you cannot take the natural log of 0. Both the semi-log and the linear form are used in the literature. Since the water bill usually comprises such a small part of households overall expenses the reaction of a household upon seeing a high water bill is probably fairly uniform no matter how high it is so long as it is past a certain threshold that qualifies it as "high" to the household. That being the case a linear form makes the most sense.

Economic theory is very clear that fully informed people respond to marginal prices. It is when marginal prices equal marginal benefit that the literature agrees the quantity demanded exists. In the case of water demand, the reality of water billing violates the assumption of perfectly informed consumers. While it is true that customers are given their total bill, marginal price, total usage, etc. at the end of each month, between bills they have no way of tracking their water usage. Even if they could track how much water they had been using, how they could use that information to adjust non-discretionary water use is not clear. Water is charged per 1,000 gallons so that a customer trying to conserve water usage at that magnitude would have to know at what marginal rate water is currently and how much until it will change. While such knowledge is conceivably available, the amount of time necessary to deduce the information is very likely far more than any customer would be willing to spend. If the customer does not live alone, every person in the household would need to know and track the information in order for consistent changes in water use.

Another problem with using the standard economic theory when discussing price is the problem of endogeneity that could result because of simultaneity between marginal price and quantity demanded. Marginal price is not fixed in any of the communities under this study but instead steps higher the more water consumed along the increasing block price schedule. Because of this there is a simultaneity bias present within the model if marginal price is used as the pricing variable. There is no consensus among economists about the best way to correct for this. The Nordin specification has been put forward, which uses both the marginal price as well as a price difference specification variable. The price difference variable is the amount of money a customer saves over what they would have paid had the marginal price been the same across all units of water consumed. Lagged average price seems a reasonable alternative. By lagging price simultaneity is potentially avoided because the average price of the previous month has already been determined prior to the current monthly price. It also seems more likely that a customer would calculate average price rather than trying to use the Nordin specification even if they happened to know what it was, especially considering how little time the average customer probably spends looking at the water bill.

The water usage data used in this study is given at a household level, which is about as fine a spatial level possible. There are only two theoretical improvements to this data, one having to do with usage and the other with customer identity. Because of the nature of how EPCOR collects data it is possible that two or more different customers lived at the same house over the sample period but were counted as the same customer. While the chance that this happens often enough to bias the results is small it should be noted. The only other improvement for water usage collection would be if there were ways to differentiate explicitly between indoor and outdoor usage. It could be thought that outdoor water usage is more discretionary and could therefore have a different elasticity to price and climate than indoor water usage. While this is a potential area of improvement, the fact is that one can still get a rough idea of that difference simply by looking at peak water demand in the summer months versus the winter months. The vast majority of the difference between peak and off-peak demand is because of discretionary outdoor usage. However, because outdoor water use cannot be explicitly disaggregated from total water usage, being able to measure both separately year round would be a helpful improvement.

In order to proxy for household income/lifestyle, household-level county assessor data was collected from 2010. The only improvement could be if there were actual household incomes available on a year-by-year basis. As assessed value, lot size, and pool size do not change over time it will be necessary to use a random effects model. The assessor data also includes lot size, pool size and house size in square feet. While the house size and pool size are used as is, it is by taking the difference between the lot size and pool size that we get a proxy for the size of the household's yard size. The problem with taking the house size from the lot size as was done originally was that because of multistory houses this would often lead to negative values.

There are several potential areas for improvement in yard size variable that were not feasible in this study. It would have been useful to have actual yard size, or the actual area given over to landscaping. Going even further, some studies have used GIS mapping software in concert with infrared satellite imaging to also map the type of landscaping for each household. This would be doubly useful both in getting more exact numbers for yard size and by allowing the type of landscaping to also be a variable in the model, xeriscaping taking less water than a full lawn and non-desert trees. Finally, the type of irrigation method each household has would also be very useful in order to better model demand. Some households use drip irrigation with rain sensors, others use sprinklers, while still others have their lawns flooded on a semi regular basis.

Demographic data is included in almost every study done on water demand, and is of course included in this study as well. Several different household demographic factors potentially have an impact on water demand. The number of people within each household could well impact indoor water use, potentially even more than the size of the house. After all, two people living in vastly different sized houses on average will most likely use around the same amount of water for indoor purposes. Put another way, when modeling water demand it doesn't matter how many showers someone has, but how many they take. The ethnicity or language spoken at home could also be a factor. Especially when non-economic public service announcements or even news articles are written about water conservation, if you are unable to understand or read them then you may be less likely to reduce water usage.

Age of household members is another demographic variable that could affect water demand. Households with children may use more water in the summer months as children may spend more time outdoors than the elderly, or the elderly may have more time to devote to their landscaping hobbies. In a perfect world, this data would be available at a household level as well. As it is, unless house-by-house surveys were completed this is not feasible and instead data from the 2010 decennial Census and the 2009 Census American Community Survey were used instead. The downside of this is twofold. The first is that the numbers are static throughout the sample time period. This small disadvantage might be expected as there may not be many long-run changes within each neighborhood unless large parts of the households move out or are replaced. The second disadvantage is larger, that is that the data is not at household level but rather at block, or in the case of education, tract level. Barring the survey option, Census data remains probably the best option when it comes to demographic data.

After obtaining the estimated coefficients of the model for the current period the job is only half done. The next step is to create the counter-actual scenarios using future predicted climate. The new usage totals are obtained by stripping out the current period climate data and the current period usage but keeping in place the current period non-climate variables and their coefficients.

$$\widehat{Usage}_{it} = \hat{\beta}_1 Climate_{it} + \hat{\beta}_x X_{it} \tag{3.4}$$

$$\widehat{Usage}_{iFUTUREt} = \hat{\beta}_1 Climate_{iFUTUREt} + \hat{\beta}_x X_{it} \tag{3.5}$$

This will be done with both IPCC models and all available scenarios, creating a plethora of counter-factual water usage data.

In practice this method is probably as good as can be found, though there are several areas that could be improved upon but are not empirically feasible. First the method assumes that prices will remain static into the future. In reality prices are very likely to change, not only in the event of water supply changes, but also because looking at the current period data we see that there price changes in all communities over a 6-year period there is almost no chance that prices would remain static out into decades of the future. In Paradise Valley, for example, the pricing schedule changed multiple times. This same problem is present in all other variables as well. There is an argument that neighborhood characteristics change slowly over time so that there may be minimal issues with using static variables for socioeconomic and demographic characteristics over the current data period. However, that argument becomes weaker the further into the future the climate predictions are.

Finally, this method assumes that there is not some breaking point in water. Much like gasoline reaching $4.00 a gallon, there could conceivably be a point where water becomes so expensive that usage is drastically curtailed much more so than might be predicated using the coefficients estimates obtained from the model. Alternatively, and perhaps more likely, water usage could also be given a sharp curb because of rationing which would render the counter-factual usage examples mute. These are the main reasons that the new usage numbers might be better termed counter-factual rather than forecasts or predictions, though they can most certainly be used as something of a weather gauge.

Chapter 4 Data

The data used for this paper are composed of three parts. The first is, of course, the water usage data. For this study, the water usage data is comprised of household level monthly billing data. This data come from EPCOR and covers the metropolitan regions of Anthem, Paradise Valley, Sun City and Sun City West. The billing periods are for a roughly 5-year period starting in late 2004 and until the end 2010. It is important to note that cleaning and normalizing the water usage was necessary before it could be used. Individual customers dropped out or came into the data before it ended and after it began. Also, there would be no way to ascertain from the data whether the same person owned the house throughout the study period.

All of these areas are serviced using standard water meters. Therefore, an EPCOR employee must individually check them. Since the population of these cities is so large-21,700 for Anthem, 37,499 for Sun City, 26,300 for Sun City West and 12,820 for Paradise Valley-the manual meter readings cannot always be on the same day each month. Accordingly billing cycles can vary widely; the shortest billing cycle was 1 day and the longest was over 300 days. According to EPCOR, despite these outliers a normal billing cycle is anywhere from 25 to 35 days. Another complication is the existence of multiple meters at the same address. Houses, especially in Paradise Valley, can be very large. In some cases there may be a meter for the water used in the house itself and a different meter for the water used for outdoor/yard uses. This problem was further compounded by the fact that in some instances the beginning and ending billing dates for the two meters did not coincide.

Figure 4.1: Four Cities Monthly Average Water Usage

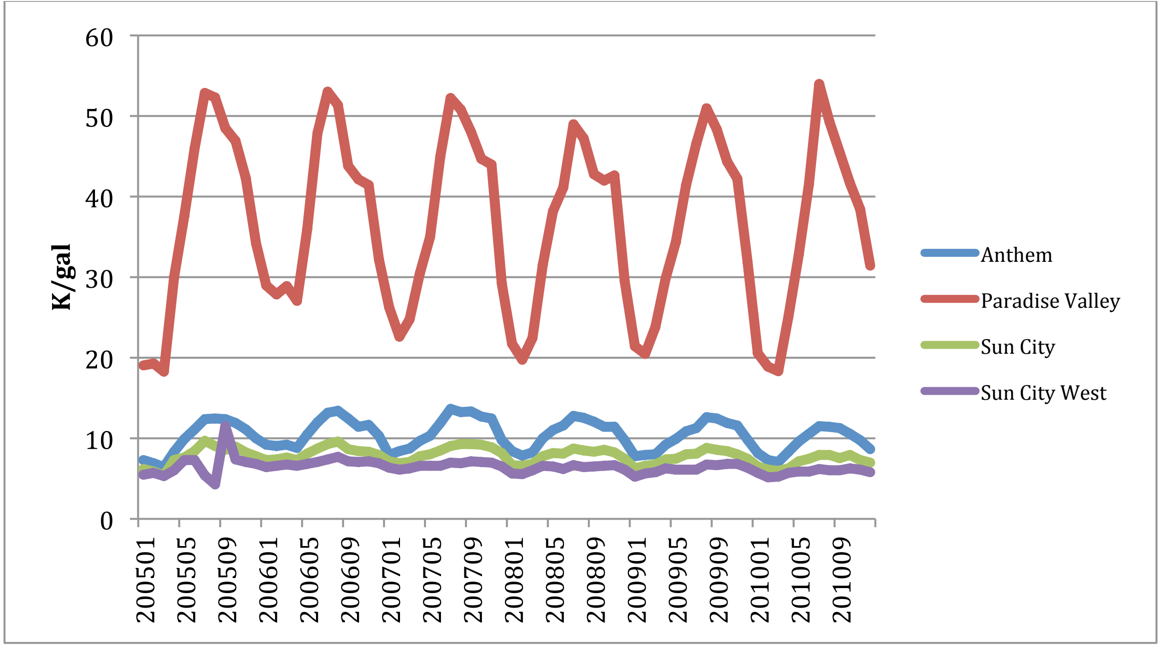
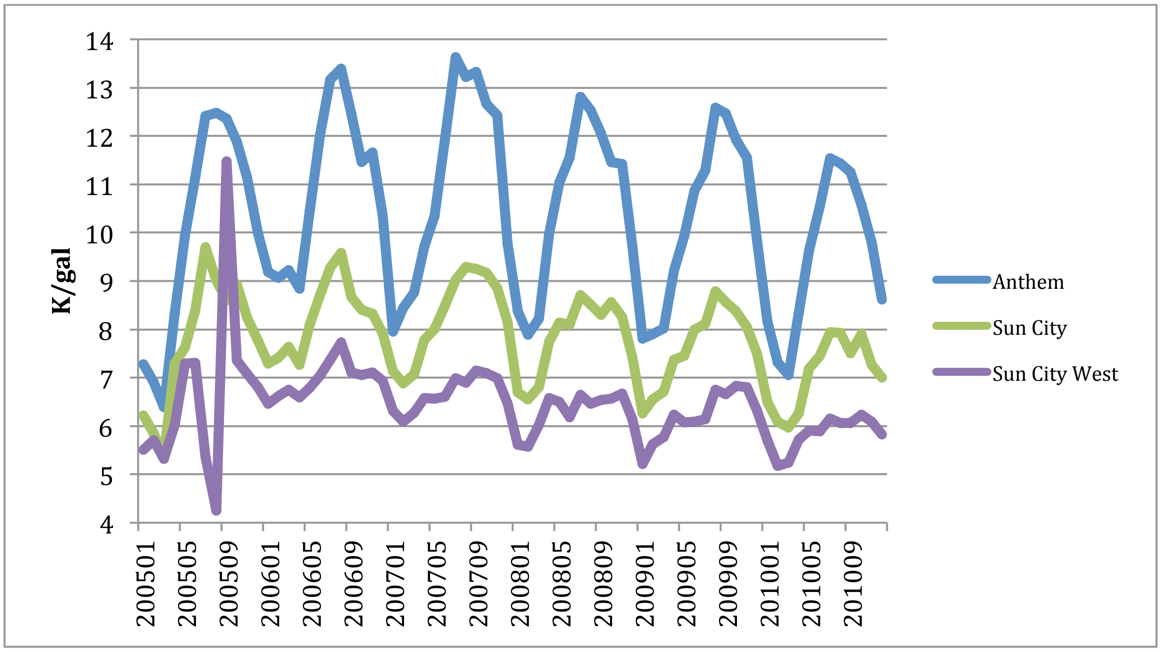


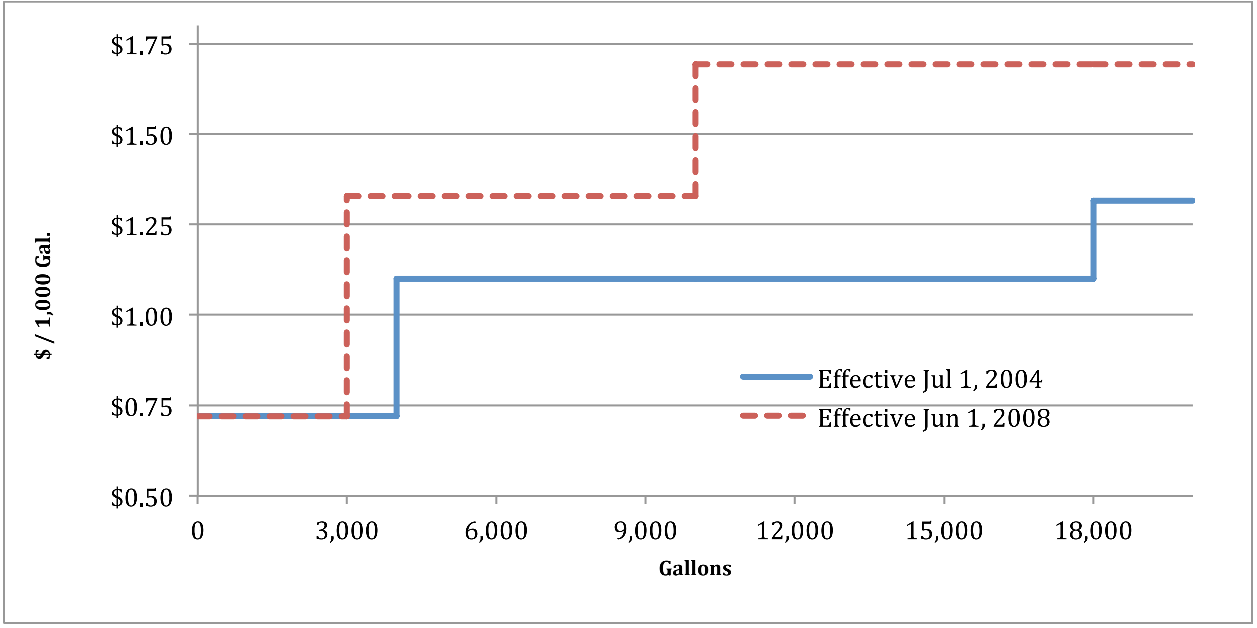
Figure 4.2: Monthly Average Water Usage without Paradise Valley



The water pricing schedules for the four communities were not uniform, with each city having its own. None of the communities had the same billing schedule throughout the entire time period from January 2005 to December 2010, an example of which can be seen in Figure 3. Each monthly bill is comprised of two or three components, the bill for the actual water used, sundry surcharges depending on the city, and a fixed monthly fee for the hookup. All the communities use increasing block rate pricing for water usage. Under block rate pricing, customers are charged different pricing depending upon the amount of water being used. For example, the Sun City pricing schedule in Figure 3 we can see that in the initial pricing scheme, users were charged approximately $ .72 per 1,000 gallons up to the first 4,000 gallons. After that point each additional 1,000 gallons would instead cost users approximately $1.10 for the next 14,000 gallons used. Past 18,000 gallons used in a month, each additional 1,000 would cost roughly $1.32. This pricing scheme was changed in June of 2008.

4.1 Price Variable

Figure 4.3: Sun City Pricing Schedule



One of the potential issues with block pricing schedules is marginal price is difficult to ascertain unless the customer has full knowledge. In most cases the customer most likely does not know the marginal price and this must be taken into account when choosing what price variable to use in the model. A few different alternative prices have been put forward, besides just using the marginal price itself. Many articles have been written that argue against the marginal price as the only price variable to include, or even if it is the best one. Since the marginal price is related to the amount of water consumed, using marginal price would lead to simultaneity bias. One possible contender would be a price difference variable (Nordin, 1976). Though Nordin was commenting on Taylor's paper written about electricity pricing, the increasing block price structure of electricity pricing being analyzed is the same as in water pricing. Nordin suggested in addition to using marginal price instead of also using average price for all other blocks before the final block or the total cost of all the blocks before the final, the difference between the actual bill and what it would have been had all units been purchased at the marginal price (Nordin, 1976).

However, while economic theory argues that customers do indeed use the marginal price of an item as well as the rate premium of Nordin, consumer response to marginal price assumes perfect information, in practice consumers are often unaware of marginal price since they do not spend the time looking at the water bill to find it (Hoffman & Worthington, 2008) Further, some water bills only give the marginal price for the last block used. A third variable put forward is simply to use average price. There seems to be no real agreement on how to measure price. Perhaps more importantly, however, is that when these different types of price specification have been used, the resulting price elasticity values are negative and relatively similar in value. For models using the Nordin Specification the price elasticity ranged from -0.12 to -0.86. The marginal price models the range was -0.003 to -1.24 and for average price from -0.2 to -0.96. (Arbues et al., 2003)

For this study, lagged average price is chosen as the price variable for two reasons. First, there is a simultaneity problem when determing current price and current quantity with increasing block prices. Lagging the price should help to counter the simultaneity because the previous month's quantity is already determined. Second, marginal price can be both difficult to figure out in water bills and are not the only part of the bill that is important. There is also a fixed charge that is added every month to the bill as well as additional fixed surcharges. The billing cycle is not the same as the calendar month. In addition, water is charged per 1,000 gallons, which would be very difficult for the customer to measure at the faucet. Accordingly there is no way for the customer to know when they are on the verge of moving up to a higher block price. With these complications, the idea of customers adjusting water use to marginal price to look at their bill seems far fetched. If customers were paying close attention to their marginal price and by extension their water usage, one would expect to see "bunching" around the water usage cutoffs between the different blocks (Borenstein, 2009). None of the communities show much bunching as can be seen from the average percentage of customers who fall within +/- 5% of any tier limit in any given month in Table 2. Even though each community had a different number of tiers the small percentage is still a good indication that customers are not trying to stay within a tier level.

Table 4.1: Bunching Percentage Monthly Average

	m	se Valley	ity	ity West
ly Avg		.6%		3%

4.2 Census Data

Socioeconomic variables were taken from the Census Bureau, both the 2010 Decennial Census and the 2005-09 American Community Survey (ACS). Matching between Census designations and addresses as done using the GIS website[1] of the University of Southern California which returned 2000 Census designations. Because the data used are from the 2010 Census, these designations were then matched to their 2010 counterparts. In order to examine how differences between communities and customers affect water usage, several of these variables were used. While the usage data is at a household level, the socio-demographic characterisitcs are not. Many previous studies have used census data in their analysis, with most ranging in detail from Census tract, with a population range

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[1] Goldberg DW, Wilson JP. 2012. USC WebGIS Services. Available online at https://webgis.usc.edu

of 1,200 to 8,000 to Census Designated Place(CDP) which is a contiguous metro region. For this study the most used classification is the Census Block, the smallest census designation by population. The average total population of blocks varies between communities as can be seen in Table 4.3 below.

Table 4.2: Average Number of Households per Census Block

Anthem	radise Valley	Sun City	n City West
82.82	34.01	45.81	41.06

The only exception is for Educational Attainment, which is taken from the Census ACS and is at the tract level. The other demographic data--average household size, percentage of population of different ethnicicites, and percentage of population of different ages--are given at the block level.

4.3 Weather Data

The effects of weather on water usage will be accounted for using evapotranspiration (ET) and the number of rainy days in a bill cycle, rather than simply using temperature and precipitation. ET is most simply defined as the amount of water lost from the ground to the atmosphere. The name comes from the combination of evaporation, the water lost from the ground itself, and transpiration, which is water lost from plants rather than the ground itself. ET is measured in millimeters or inches and the equation most widely used method to calculate ET is the Penman-Monteith equation. The equation includes daily average temperature, relative humidity, wind speed and solar radiation (Allen, Pereira, Raes, & Smith, 1998). Using ET is done for a few reasons. The first is that temperature and precipitation tend to be correlated, with lower temperatures going along with higher levels of precipitation. Second is that ET measures more accurately how much water plants need than temperature or precipitation alone.

Assuming that indoor water use is fairly constant month to month, the huge variations seen in Figure 1 and 2 were most likely due to outdoor water use such as the irrigation of yards and maintaining swimming pools. ET will better pick up the changes in the amount of water needed to keep lawns and other yard features alive as well as better account for the need to refill swimming pools over the summer because of evaporation. Current ET, that is the ET levels taken during the billing cycle, were calculated from the Arizona Meteorological Institute (University of Arizona). These were daily observations, summed across each individual customer's monthly bill cycle and then normalized for a 30-day month.

Future ET is taken from two models from the Intergovernmental Panel on Climate Change (IPCC), the Max-Planck Institute for Meteorology Model and the United Kingdoms Meteorological Model. Both of these models forecast monthly ET up to the year 2099. The forecasted ET have been downscaled to each of the four cities, and then least squares was used to predict back to 1950. Figure 4.4 below shows the ratio of predicted ET to Actual ET per month. The average ratio value for the a2 scenario was .9 and for b1 .91.

Figure 4.4: Ratio of Historic Predicted ET to Actual Monthly ET, Sun City

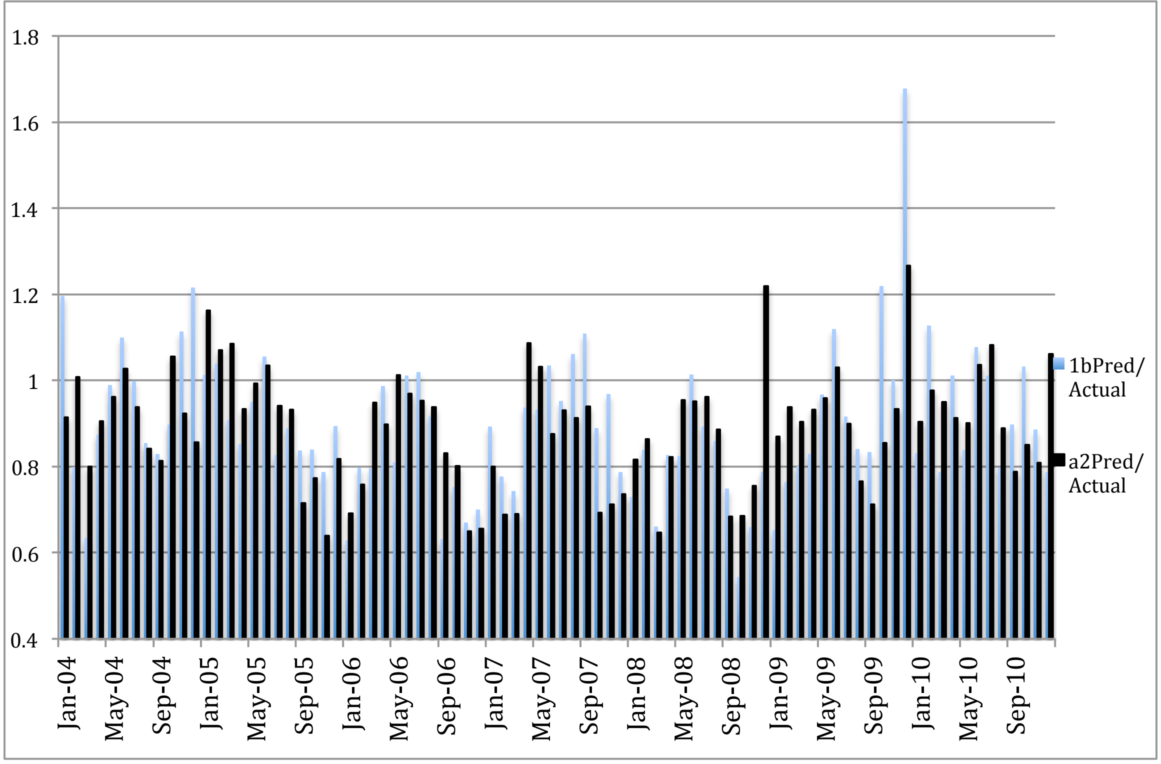
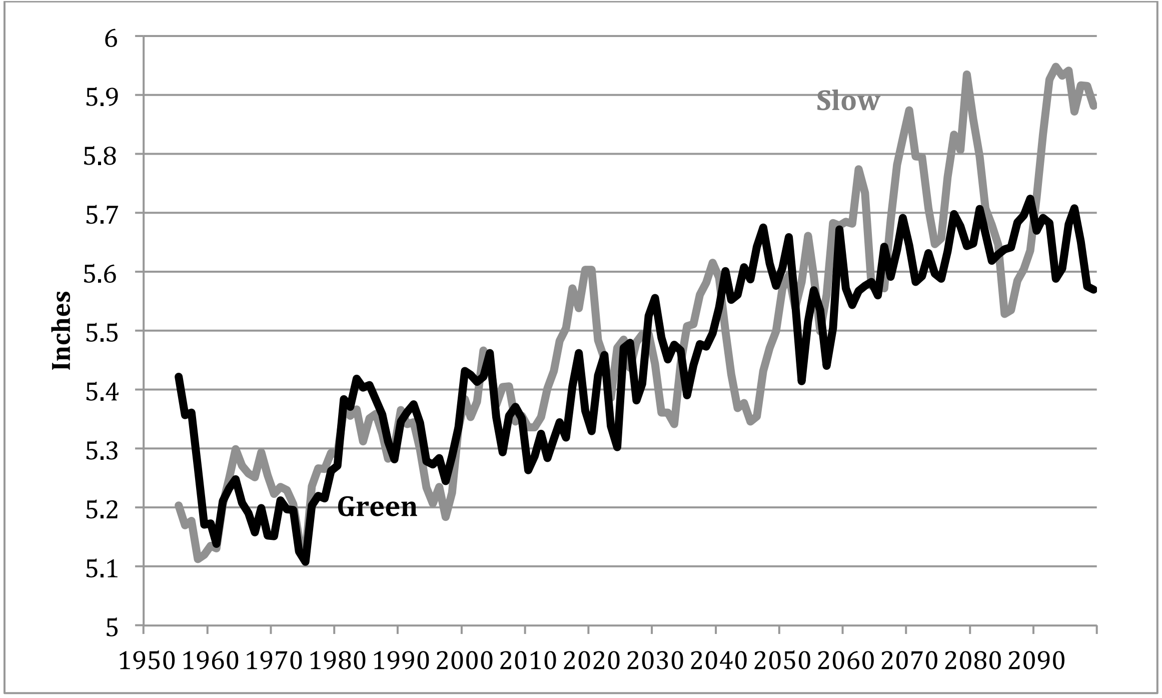


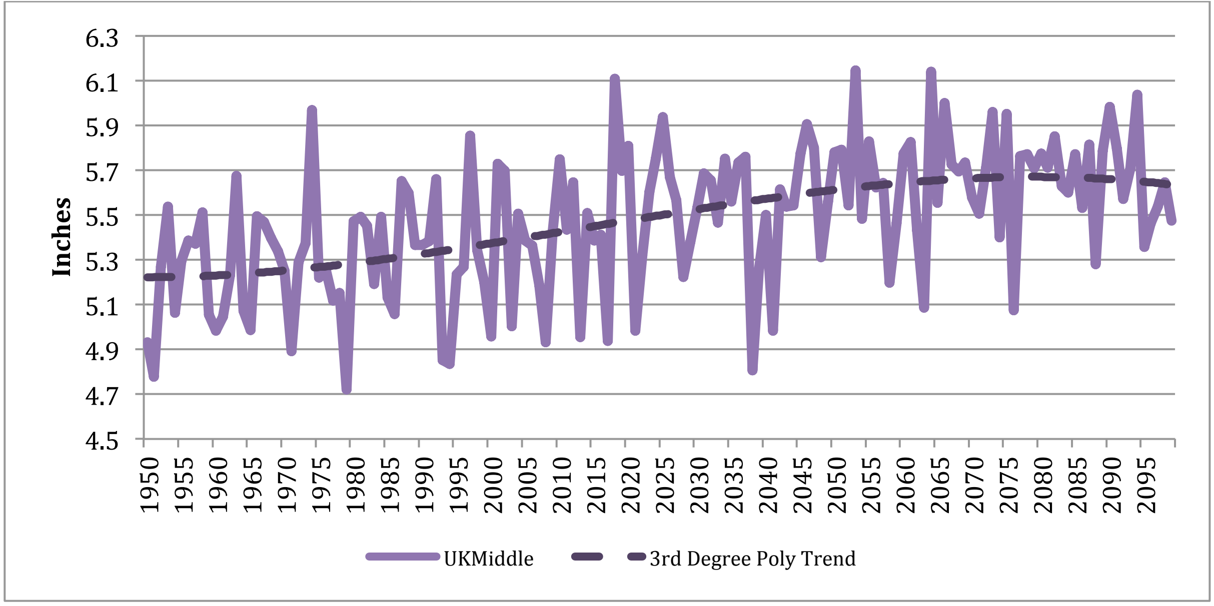
Figure 4.5: 6-Year Moving Average of ET in Max Planck Emission Scenarios



Both Max Plank and The UK Meteorological Model have different sub-models to account for the different potential effects that “human systems” may have on climate in the future. Each sub-model has different assumptions of how human population and technological advancements would affect climate. A1B, the middle emissions scenario, assumes rapid economic growth and a population of 9 billion by 2050, along with 3rd world countries' income coming closer to those of the first world. B1, the low emissions scenario, switches to a more ecologically inclined world with more concerted effort among countries to introduce clean energy. Economic growth is still rapid but concentrated in information and service jobs and the population growth also reaches 9 billion. Finally, the A2 world is more divided: this high emission scenario also has an increasing population, but the divided countries mean less holistic, slower economic growth. A look at 6-year moving average Paradise Valley ET projected using the different scenarios can be seen in Figure 4.5.

Because the billing cycles do not conform to calendar months as the IPCC models do, it was important to check whether there was a large difference between summing daily ET for the exact billing cycle compared to taking the proportional ET from the monthly ET values, e.g. if a billing cycle fell between two months taking 50% of the ET for each month and adding those values together. When these two numbers were compared for Sun City, only 10% of all observations had a difference between the daily ET and the proportional ET greater than 20%. Because of this small difference, proportional values from the projected future IPCC values are used.

Figure 4.6: Yearly Average of ET for UK Middle Emission Scenario



The number of rainy days was collected from the Maricopa County Flood Control District, using the cutoff of .1 inches precipitation to qualify as a "rainy day". Future rainy days presented an issue, as the UK model did not have the data available. For Max Planck, daily precipitation was only available for two models, the slow growth and middle model. Data was collected from all available projected years, 2046-2065 and 2081-2100 for both emission scenarios.

4.4 Assessor Data

Finally, data was also collected from the Maricopa County Assessors Office for tax year 2011.

The assessed value of the property is used as a proxy for income. This may well be important as the higher the income of a household, the less likely they may feel compelled to conserve water as the impact of water on the household finances gets increasingly smaller. The Assessors data coupled with the household-level billing data allowed us to also include other household-level variables. The existence and size of pools are included, since during the summer months especially, pools must be kept filled and can account for a significant portion of water usage.

The Assessors data also included both lot and house size in square feet. Pool size was subtracted from lot size and this difference was used to estimate yard size. Household size can be expected to lead to an increase in water usage, as the square footage increases, but the effect may be small. For example, an additional bathroom may not necessarily mean much more water usage if the demand is the same but simply spread amongst more faucets. In the summer months especially, outdoor water usage can account for 50% or more of water use. By having an estimate of yard size separate from lot size may lead to better estimates for how property size affects water demand. There are likely systematic differences in landscaping across the four communities. Anthem, for example, has a home owners association that enforces landscaping being native or near native in nature.

Chapter 5:Results

When merging Census data to the water usage data a problem arose in two of the four community datasets. While Sun City and Paradise Valley were successfully geocoded, Sun City West and Anthem were not. Instead of giving each address a different Census block and tract designation the same one was given for every address within Sun City West and Anthem.

Figure 5.1: Address to Census Process

Because of this geocoding problem, two sets of models were run, one without census data that includes all four communities, Equation 5.1, and one with census data that was run for using only Sun City and Paradise Valley, Equation 5.2.

$$(5.1)\ Use_{it} = \beta_1 + \beta_2 Livgarea_i + \beta_3 Yard_i + \beta_4 Homevalue_{it} + \beta_5 Pool_i + \beta_6 AvgPrice_{i,t-1} + \beta_7 ET_{it} + \beta_8 Precip_{it}$$

$$(5.2)\ Use_{it} = \beta_1 + \beta_2 Livgarea_i + \beta_3 Yard_i + \beta_4 Homevalue_{it} + \beta_5 Pool_i + \beta_6 AvgPrice_{i,t-1} + \beta_7 ET_{it} + \beta_8 Precip_{it} + \beta_9 \%Latino_i + \beta_{10} \%BachDegree_i + \beta_{11} \%GradDegree_i + \beta_{12} AvgHousePop_i$$

A second problem arose when trying a slightly different model to interact ET with both the pool size and yard size of households. When ET*Pool and ET*Yard were used in the model, no standard error for the coefficient for Yard*ET could be estimated. The reason for this error is high collinearity and with this result, the models treat ET, yard size, and pool size as separate variables.

5.1 Empirical Results

Table 5.1: Model Estimated Coefficients

ent Variable:	ized Monthly Usage					
	Anthem	Paradise Valley		un City		n City West
dent Variable		Census	Census	ensus	Census	
t	.92***	63.1***	.85***	.27***	.93***	1.26***
	(.301)	(84.7)	(1.08)	(0.38)	(0.10)	(0.12)
rea	.001***	.0002***	0003***	002***	0002***	0.0004***
	.00004)	.00004)	.00004)	.00001)	.000009)	(0.00001)
me Value	0.03***	.02***	.02***	.01***	.01***	0.014***
	(0.002)	(0.002)	(0.002)	0.001)	(0.001)	(0.001)
ze	.006***	.03***	.04***	.007***	.01***	0.007***
	0.0004)	0.0004)	0.003)	.0003)	0.0003)	(0.0003)
Real Average Price	0.28***	0.37***	.33***	.57***	.57***	-0.21***
	(0.004)	(0.02)	(0.02)	0.005)	(0.005)	(0.002)
ized ET	.55***	3.1***	.01***	.27***	.28***	0.09***
	(0.005)	(0.03)	(0.03)	0.002)	(0.002)	(0.002)
ays	0.15***	1.06***	1.04***	.14***	.14***	-0.13***
	(0.007)	(0.04)	(0.04)	0.003)	(0.003)	(0.003)
				.59***		
				(1.04)		
achelor Degree		.18***		.08***		
		(0.98)		(0.01)		
raduate Degree		.54***		-0.005		
		(1.5)		(0.02)		
Pop. Of HH		-4.7*		.51***		
		(2.85)		(0.21)		

d error values are in parentheses
s indicate statistical significance at the 10%(*), 5%(**) and 1%(***) levels.

All variables in every community came back as statistically significant when Census data were excluded. The yard size variables were measured in 100 square feet, while pool size are in square feet. The square footage of the customer's yard was positive across the four communities. This fits with the expected sign, as the larger the house the more water used. Anthem has a larger change for every increase in the size of the yard. This is a bit perplexing as Anthem is the community that has HOA rules regulating the yard landscaping to that of desert or near desert.

Pool size coefficients are very close across three of the communities: Anthem, Sun City, and Sun City West. However, the change in water usage from an increase in the square footage of a pool in Paradise Valley is almost five times as large. This could be partly do to the fact that 60% of Paradise Valley customers in the dataset have pools as compared to only 5% for Sun City West, 6% for Sun City and 35% for Anthem. Encouragingly, all the variables dealing with sizes of housing characteristics came back with the expected sign, positive.

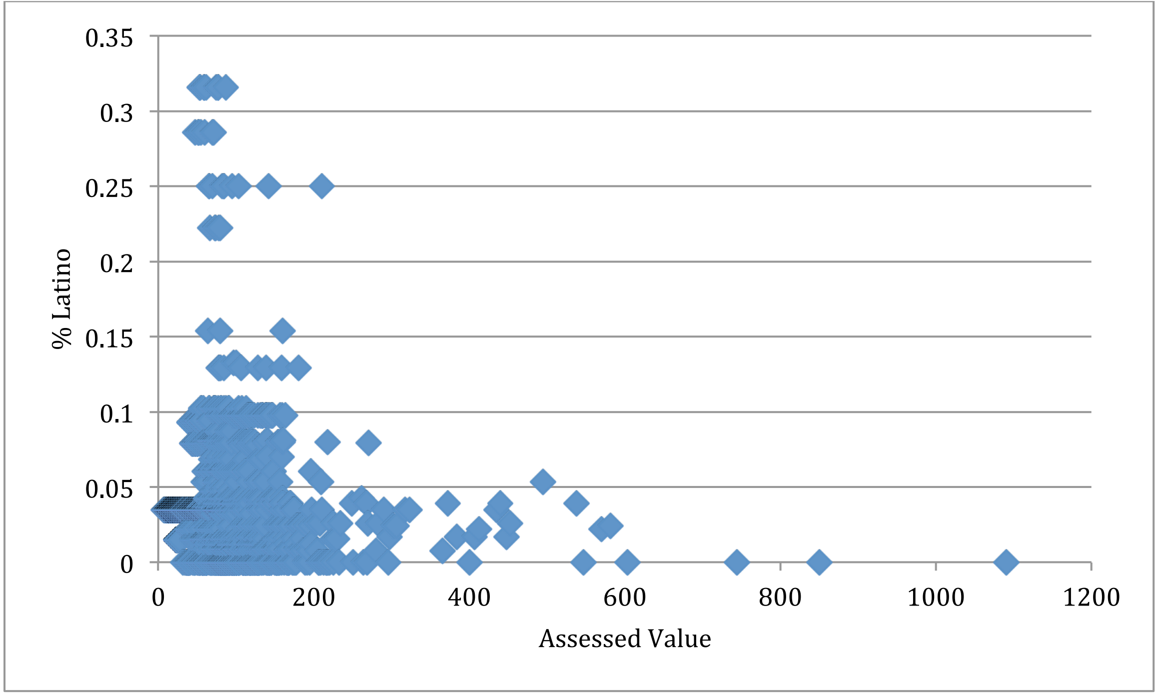
Strangely, Anthem had a negative coefficient for real home values. The expected sign was positive, as the variable was used as an approximation of income. The wealthier the household, less likely would worry about conserving water usage for the sake of keeping the bill low. The signs of the real home value coefficients were positive as expected.

The coefficients of climate data all had the expected signs across every community. Evapotranspiration was directly related to water usage, positive across all models. Once again the magnitude of the coefficient for Paradise Valley is many times that of the other communities. This once again underscores just how different the households; both in terms and income and just as importantly in terms of physical house characteristics are in terms of water usage.

All four communities saw a decrease of water usage as the number of rainy days rose. The sign of the rainy-day coefficient is as expected and the magnitude of Paradise Valley's coefficient is around 10 times greater than the other communities. This is most likely due to the sheer size difference between home lot sizes in Paradise Valley and the other areas. Even with yard size included as account for that difference, when it rains in Paradise Valley the effect is just much larger than in the other communities.

When looking at the coefficients for the Census variables, the percent of population with bachelor and graduate degree, the percent of the population that is Latin ethnicity and the average household population for Sun City and Paradise Valley there is some more confusion as the signs are not all uniform across both communities. The coefficient for the percentage Latino is negative for Sun City.

Figure 5.2: Latino vs. Assessed Value



When the Latino variable was added to the Paradise Valley model, it created instability in the model, causing the coefficient of lagged price to roughly triple. Examining the data more closely, it was found that while the percentage of the population that is Latino is highly skewed to the left, 0% Latino, where there were higher percentages the property values were much lower, hovering around $200,000(Figure 5.2).

The same left skew holds true for yard size and house size plotted against percentage Latino. What most likely happened is that the "Paradise Valley" that EPCOR services included some surrounding regions that differ demographically and economically from the more "typical" Paradise Valley residence. This instability in the model led to the decision to drop the Latino variable from the Paradise Valley model.

Education percentage results were also quite interesting. The percentage of the population with a Bachelor degree are also both positive, as was expected. The expected sign was a bit ambiguous, as it could be argued that bachelor degrees could also denote higher earnings and those with one would therefore be less likely to worry about the water bill. With this sign it seems to back up the alternate explanation, that those with Bachelors degree are more concerned or more aware of water conservation and act upon that. However, the percentage of the population with a Graduate degree was positive in Paradise Valley and negative in Sun City, but for Sun City it was not statistically significant. Because of the nature of Sun City, a planned community that has much more uniformity in the size of the houses than Paradise Valley, this may mitigate the effect that having a higher education degree would otherwise impart.

The change given in Paradise Valley with a graduate degree is larger than that of a Bachelor degree, which again backs up the hypothesis that the more education you have the more you are aware of water conservation. Another alternative explanation could be that the more education you have the better able you are to parse through a water bill. There has been some thought that the ability to better understand the water bill could lead to lower water usage. A small problem with that explanation is that if that were the reason, a dramatic redesign of water bills would be in order since it would appear that it would take a bachelors or graduate degree to understand the current one.

The sign of the lagged real average price is negative across all four communities, as expected. Simply looking at the magnitudes of the four, it seems counterintuitive that Sun City and Sun City West see smaller changes when the lagged average price increases than Anthem and Paradise Valley. It might have been expected that Paradise Valley would have had the smallest change in usage since it is the richest of the communities.

Table 5.2

Lagged Average Price Coefficients

	nthem	Paradise Valley		Sun City		City West
		Census	Census	Census	Census	
Coefficient	.28***	-0.37***	.33***	.57***	.57***	0.21***
andard Error	.004)	(0.02)	0.02)	0.005)	0.005)	(0.002)

Also of interest is the change in magnitude between the Paradise Valley models when Census data was omitted. In Sun City the estimated parameter was virtually unchanged, while for Paradise Valley it increased slightly.

Because of the linear functional form of the models, to get a full picture of the effect of the lagged average price it is necessary to look at the point elasticity of the price.

$$Elasticity_{avgp} \Rightarrow \frac{\partial q}{\partial p} \cdot \frac{p}{q} = \hat{\beta}\left(\frac{p}{q}\right) \text{ (Equation 5.1)}$$

The value of elasticity varies from 0 to -∞, with 0 as perfectly inelastic, values between 0 and -1 inelastic and values less than -1 elastic. Table 5.3 shows the elasticity distribution of every lagged average price/usage combination in the data.

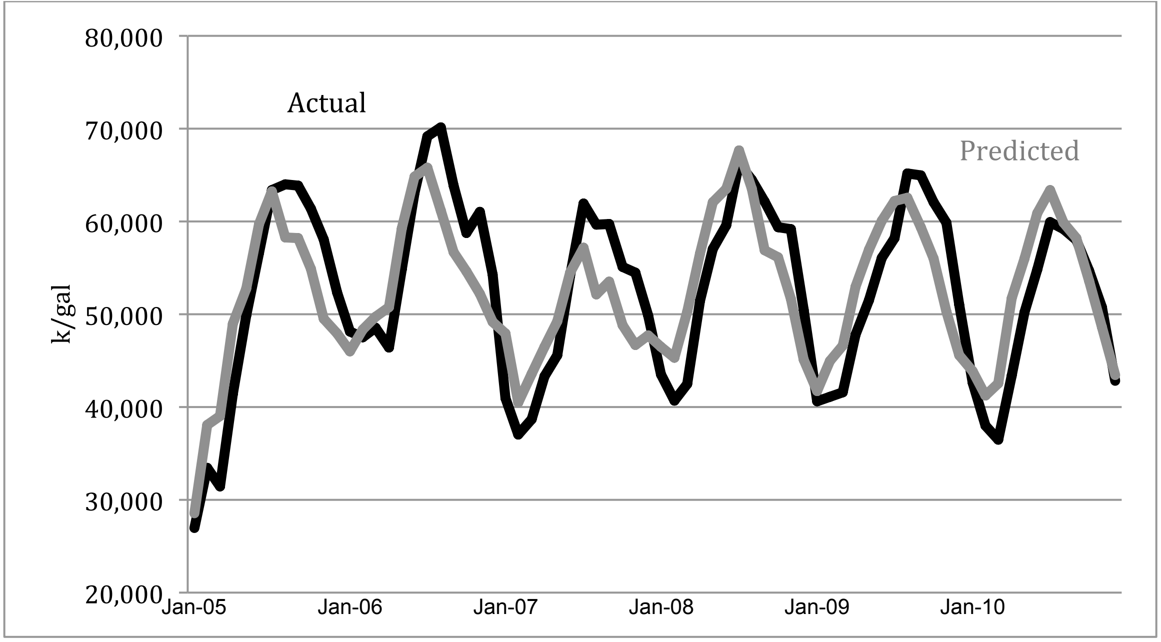
Table 5.3

Price Elasticity

	nthem	ʾaradise Valley		Sun City		ın City West
e	ɔ Dem	ɔ Dem	em	ɔ Dem	em	No Dem
	·1.09	·1.50	.36	·1.20	.19	-0.74
	·0.25	·0.22	.21	·0.32	.31	-0.21
	·0.12	·0.06	.06	·0.16	.16	-0.11
	·0.06	·0.02	.02	·0.09	.09	-0.06
	·0.02	·0.01	.01	·0.04	.04	-0.02

Price response is inelastic across all four communities. Even though the coefficient for lagged average price in Paradise Valley was not as small as those of other communities, demand is the most price inelastic. This pattern corresponds to the notion that the higher the income, the less elastic demand will be to changes in price. Anthem and Sun City West have very similar price elasticity for quantiles above 5%, while Sun City has the highest elasticity at all quantiles above 5%. It should be noted that even though Sun City has the most elastic demand, it is still considered inelastic except for about 5% of all households.

Figure 5.3: Anthem Actual VS Predicted Usage



The predicted usage from the model was then summed across all users for each month and compared to the actual total monthly usage. As can be seen, the predicted model tends to underestimate in the summer and overestimate in the winter. The difference between those values tends to be small. The average absolute percentage difference between actual total monthly usage and predicted total monthly usage of each community is only above 10% in Paradise Valley. The underestimates and overestimates in the summer and non-summer months seem to cancel each other out for the most part as can also be seen from the Table below since averaging all the differences together the percentage difference is 5% or less.

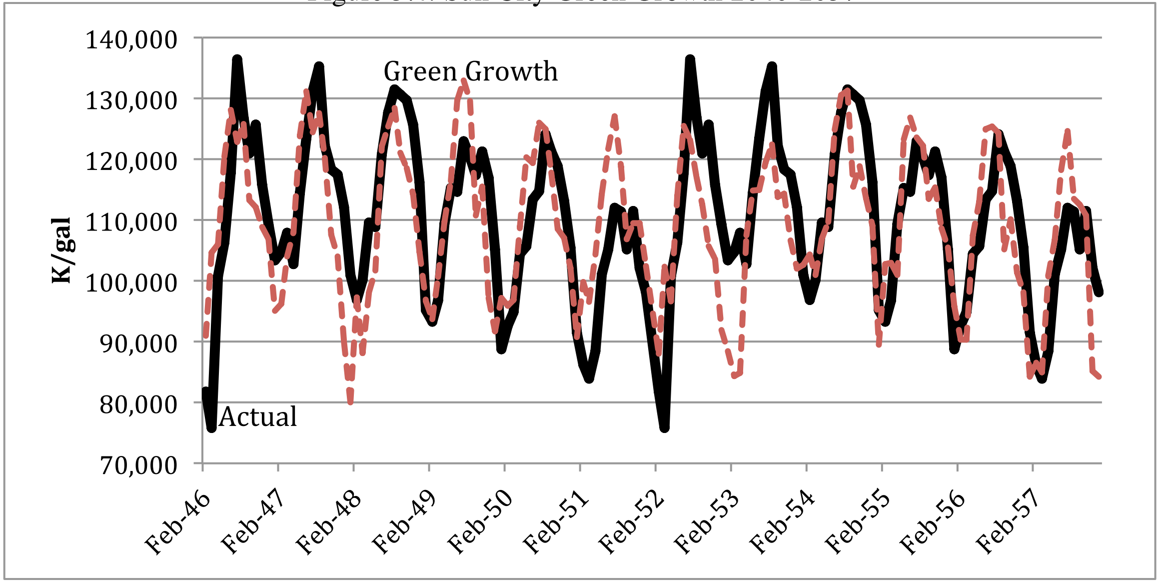
Table 5.4: Avg. Percentage Difference Between Predicted & Actual Monthly Usage

	Anthem	Paradise Valley		Sun City		un City West
	o Census	o Census	ensus	o Census	ensus	No Census
Average	1%	4%	4%	0.5%	0.5%	1%
ly Average (Abs)	9%	17%	17%	5%	5%	6%

5.2 Counter-factual Results

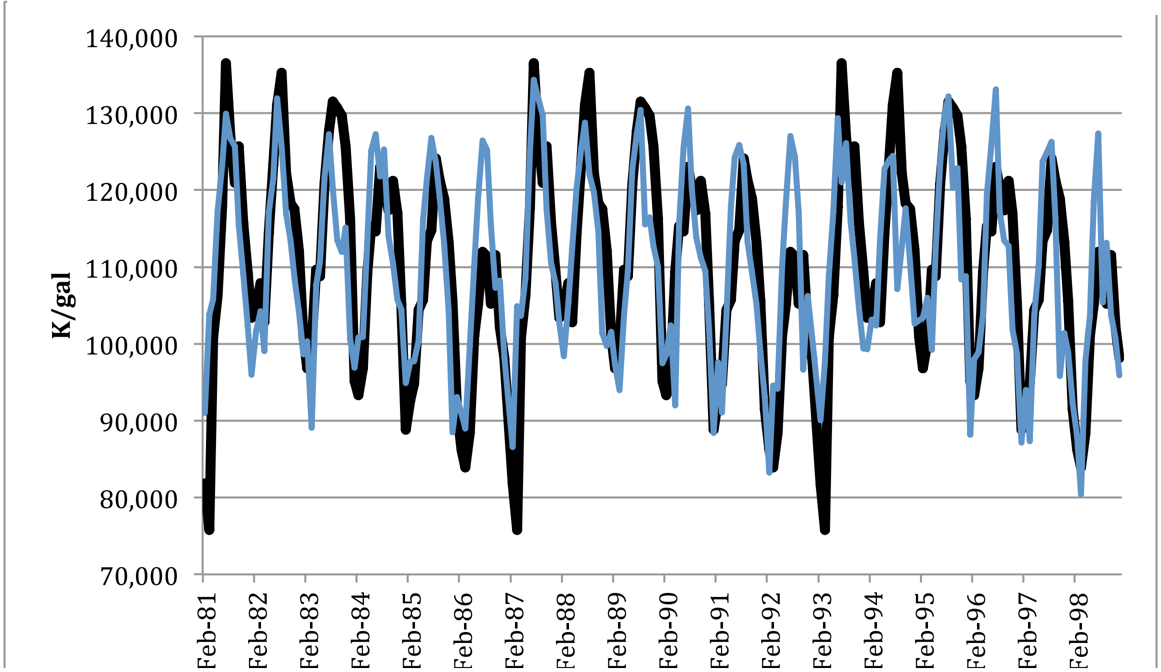
After regressing the usage for the current period the next step was to calculate "counter-factual" scenarios where current evapotranspiration and precipitation were replaced by IPCC projected values. Only two scenarios of the Max Planck model had the predicted datasets necessary for the use of this paper, the Slow Growth model and the Balanced/Green Growth model. Projected monthly ET and daily rain values were taken for the years 2046-2065 and 2081-2100. For the graphs below charting the total monthly usage, the actual usage has been graphed alongside the counter-factual values. After the initial 6 years, the actual usage numbers are plotted again so that comparisons can be made across the entire time period rather than in 6-year increments

Figure 5.4: Sun City Green Growth 2046-2057



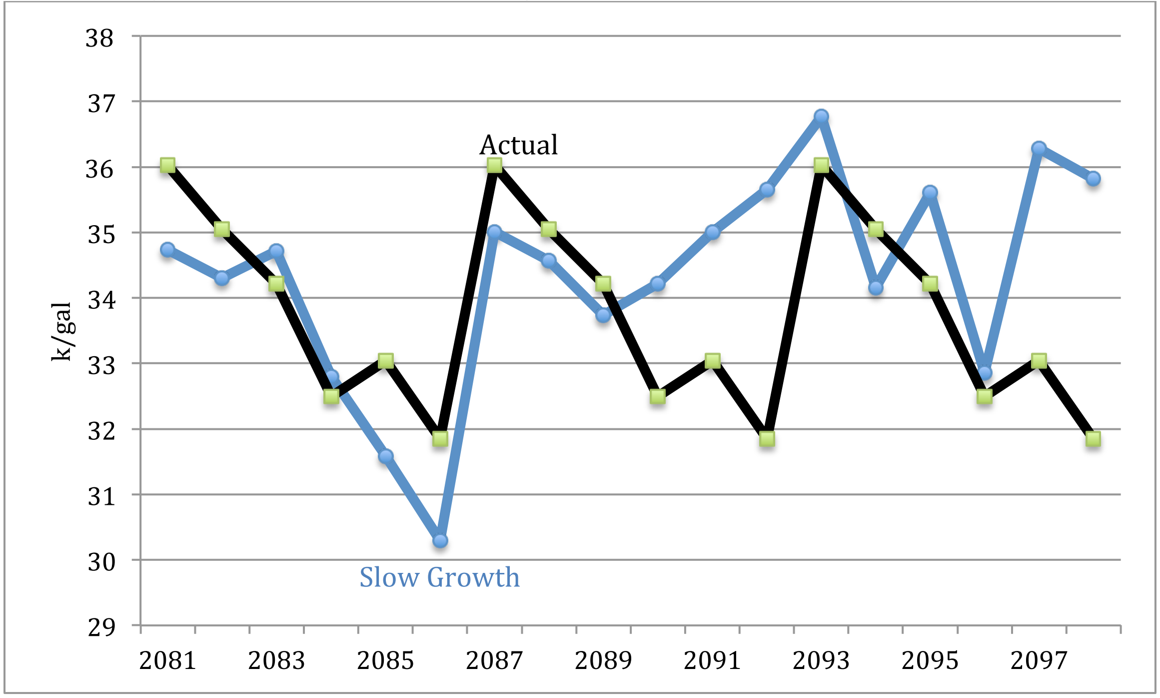
The results are not what were expected. Over the course of the coming century, when any six-year period of any community's total usage is compared with the actual usage the predicted usage was generally less is summer months. There also is not as clear a story as to how the usage changes. When looking across all communities, the greatest change is in the winter months. Even then, because of the gradual nature of the upward trend in ET (~20% growth over 150 years) the change only really becomes clear when looking at

Figure 5.5: Sun City Slow Growth 2081-2098



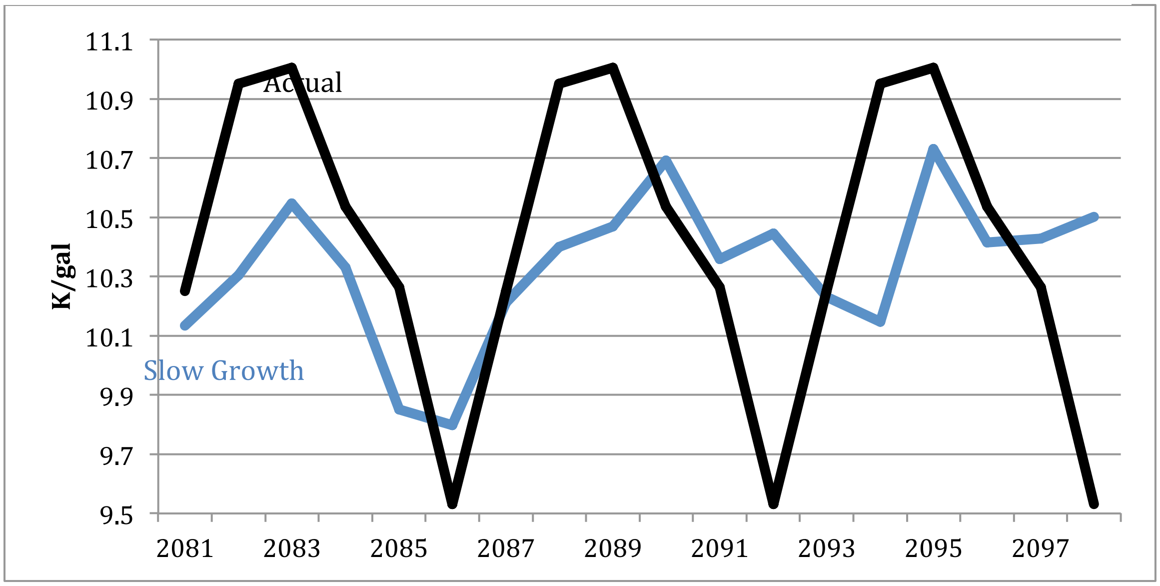
the counter-factual scenarios starting in the year 2081. Across all four communities, while there are periods that projected water usage outstrips actual water usage there is not a single community that has water usage exceeding actual usage across all time periods.

Figure 5.6: Annual Paradise Valley Counter-Factual & Actual Avg. Usage 2081-2098



In order to get a slightly clearer picture, with the monthly variability taken out it is helpful to look at the total annual or average annual usage for each community. In figure 5.6, the counter-factual average annual usage for the Slow Growth A2 scenario graphed against the actual usage, here duplicated 3 times in order to provide a comparison across all 18 years. The graph from Paradise Valley looks very different in comparison to the graphs generated from the other 3 communities, a not surprising results considering how different Paradise Valley is. The graph in Figure 5.7 of Anthem looks very similar to those for Sun City and Sun City West but the pattern is not similar to what was seen in Paradise Valley. For these three communities, the usage is almost always less even when using evapotranspiration and rainy day values projected out almost a century from today.

Figure 5.7 Annual Anthem Counter-Factual & Annual Avg. Usage 2081-2098



6 Conclusions

The purpose of this research was twofold. The first part was to model water demand in order to better understand what explains consumer behavior. The importance of this, especially in desert cities such as the Phoenix metro region, is obvious. The second part was to use the water demand model to examine possible alternative scenarios that could give water managers better ideas of how demand would change if climates change. The model of current water demand produced results consistent with theory and previous studies.

The expected sign of the coefficient on lagged average price was negative, indicating that particular price variable works well in modeling water demand. Further, the use of the lag rather than the current period average price used in many other studies minimizes the simultaneity bias inherent in a block rate structure where price and quantity are determined simultaneously. The inelasticity of price response also accords with previous studies and theory.

The use of evapotranspiration(ET) values rather than temperature is a relatively new addition to the water demand literature. Most previous studies focused on weather variables such as temperature and monthly precipitation. Using ET has the advantage of focusing on what drives water usage for landscaping, since ET is itself a measure of how much water is lost from the ground and plant ground cover. Also, using the number of rainy day events likely gives a better picture of how rain affects water use than simply total rain since one inch of rain for ten days would affect households' water use differently then ten inches on a single day. The signs of the coefficients for both ET and rainy days were as expected: ET has a positive effect on monthly water demand while number of rainy days diminishes demand.

When predicted ET was used to generate counter-factual monthly water scenarios, the outcome was somewhat different than what was expected. This counter-intuitive outcome makes more sense when put into the context of the relationship between the actual evapotranspiration values taken from Arizona Meteorological Network(AZMET) and those taken from the Intergovernmental Panel on Climate Change(IPCC) projections. The ET numbers taken from the IPCC Max Planck models are statistically downscaled from global to extremely local (community) values. Statistical downscaling is a process of establishing a relationship by modeling actual large scale ET numbers on actual local ET numbers to establish the relationship between the two and then using that relationship to downscale the IPCC projected values. It might therefore be important to examine the relationship between the AZMET and IPCC values more closely.

The fact that even with the IPCC ET trending up, the projected ET does not always exceed observed ET is cause for further study. When the Max Planck ET numbers for the observed period (2005-2010) were regressed using a simple linear regression on actual ET, the estimated intercept was always close to 1 and the coefficient was very close to 1 as well. This indicates that even the statistically downscaled ET nearly always has lower values than AZMET ET series. An adjusted IPCC ET value might be one way to match predicted and actual values. Once adjusted, downscaled ET could then be substituted into the econometric model to make counter-factual predictions.

The Global Climate Models(GCM) models all generally agree about the rising temperatures but do not agree on whether precipitation will increase or decrease. This lack of agreement could mean predicted daily rain data is not the appropriate variable to use. The number of daily rainfall events could be replaced either by a monthly precipitation or perhaps by taking the standard deviation both above and below the number of rain events and adding that to the observed period data.

The counter-factual usage projections indicate rising winter usage. While this may not be as much of a problem as rising overall usage, increased winter usage merits attention. Lower surface water flows during the winter months, when snowpack has yet to melt, could be an issue in the coming decades. Rising winter demand could pose strains on supply dependent on Colorado River and Arizona surface water flows that depend on winter snow melt.

Further research into this vital topic is continuing and should avail itself to new data sources that may have been previously unavailable. Chief among these would be a "green index" variable, which uses satellite imaging to measure landscaping differences across yards of individual customers or even community-wide users. Type of landscaping is likely the greatest determinant of discretionary outdoor water use with presence of a pool. In this study the effect of the yard size was based simply on size in each community, but variability from household to household landscaping, especially in Paradise Valley, could have large impacts on water demand. Interacting yard size, pool size, and the green index variables with ET and rainy days might produce interesting results as well.

Not only would adding satellite imaging to new research lead to more accurate results, it could also lead to important policy implications for municipal regions grappling with ensuring future water security. The results could be used to argue for or against citywide rules regarding yard use, similar to those already used by the home owners association in Anthem to mandate desert or near desert landscaping.

Interacting yard and pool size with weather variables was attempted unsuccessfully in this research. Being able to successfully add these interactions would also be a very good next step. Since weather most likely affects only or at least mostly outdoor water use these variables would also be able to more closely mirror how the weather affects water use rather than just the dimensions of the property that need water.

Secondly, finding a way to incorporate the use of public service announcements and water conservation programs on the community would also be very helpful. The problem of how to quantify such an announcement at the household level may be difficult but the variable could perhaps be constant across all areas where the same campaign took place. Finally, it must be noted that the observation period is over the same period that the “Great Recession” hit American homes. The gradual decrease in water usage over the observed period could be in part due to the impacts of the recession. Conversely, if there were not a recession, households might have spent even more money on upgrading fixtures and switching to more efficient landscaping watering tools. Looking at an extended observation period, say the entire decade starting in 2000, could help in pinpointing what, if any, the effect of the downturn in the economy had on people’s water usage.

Being able to accurately model and predict water use is of vital importance. While not perfect this study attempts to add to the surprisingly slim literature that analyzes at how possible climate change, whether natural or manmade, could affect water usage and by extension water security.

Appendix

Figure 7.1: Anthem Counter-Factual Water Usage 2046-2057

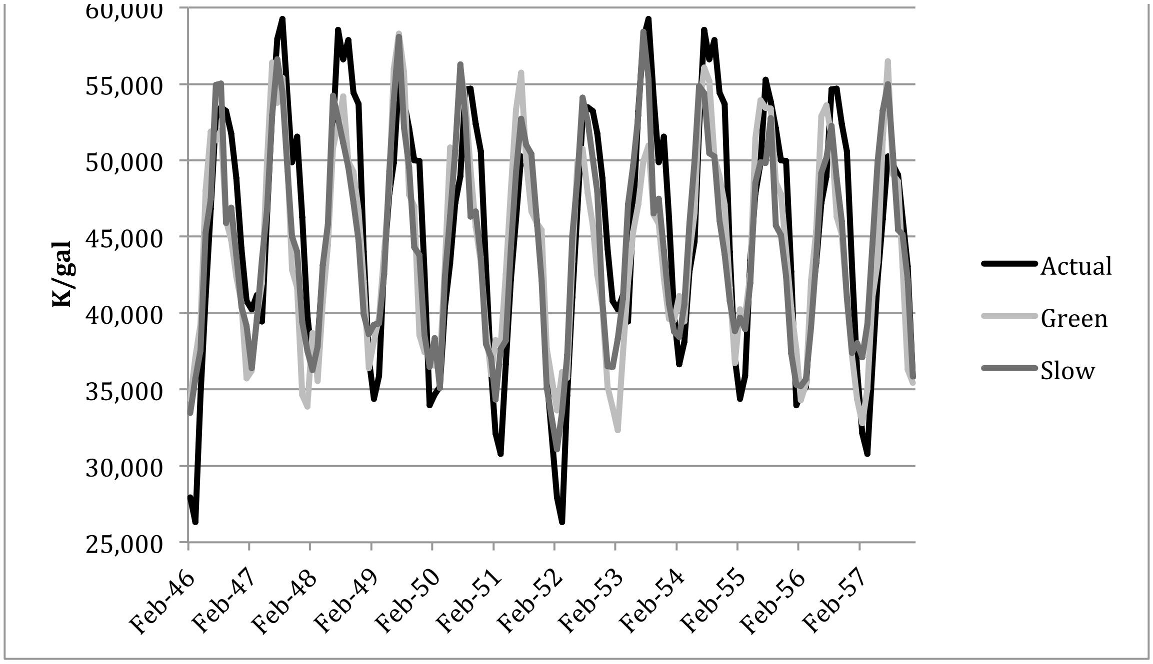


Figure 7.2: Anthem Counter-Factual Water Usage 2081-2098

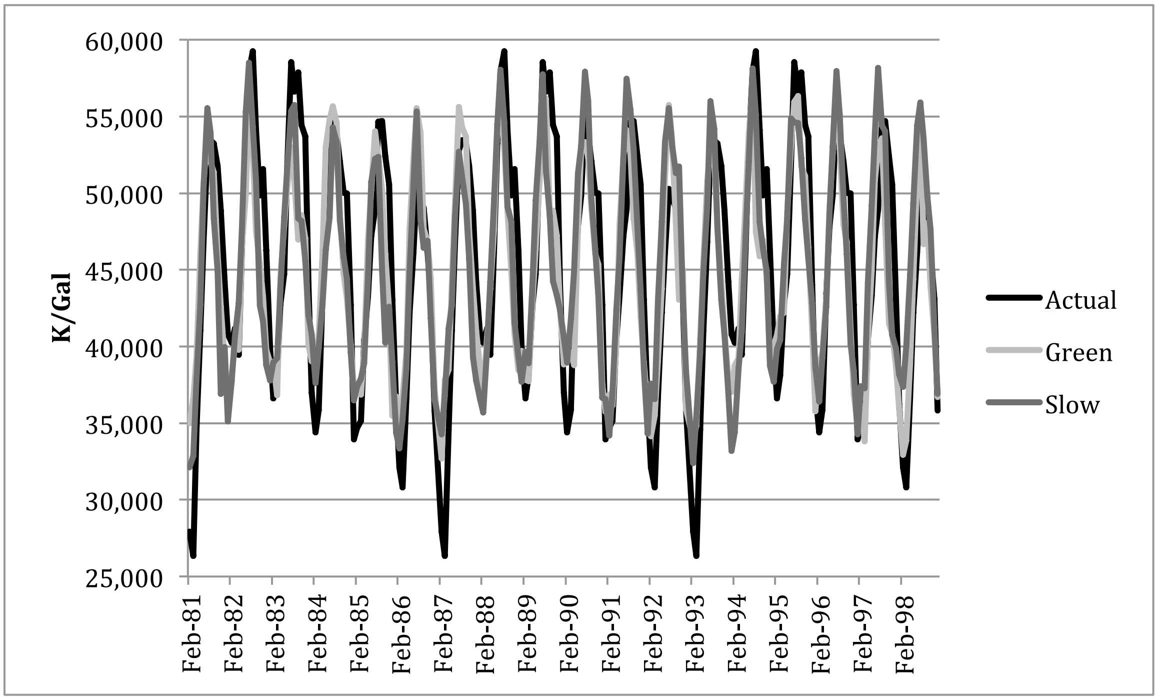


Figure 7.3: Paradise Valley Counter-Factual Usage 2046-2057

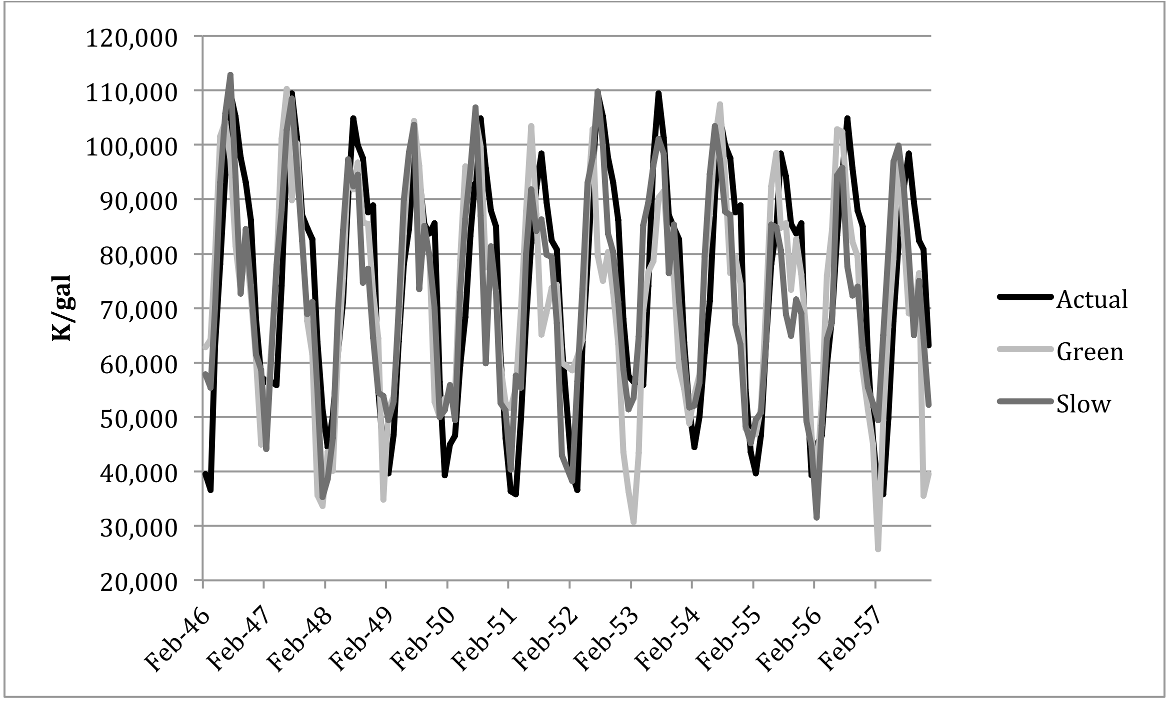


Figure 7.4: Paradise Valley Counter-Factual Water Usage 2081-2098

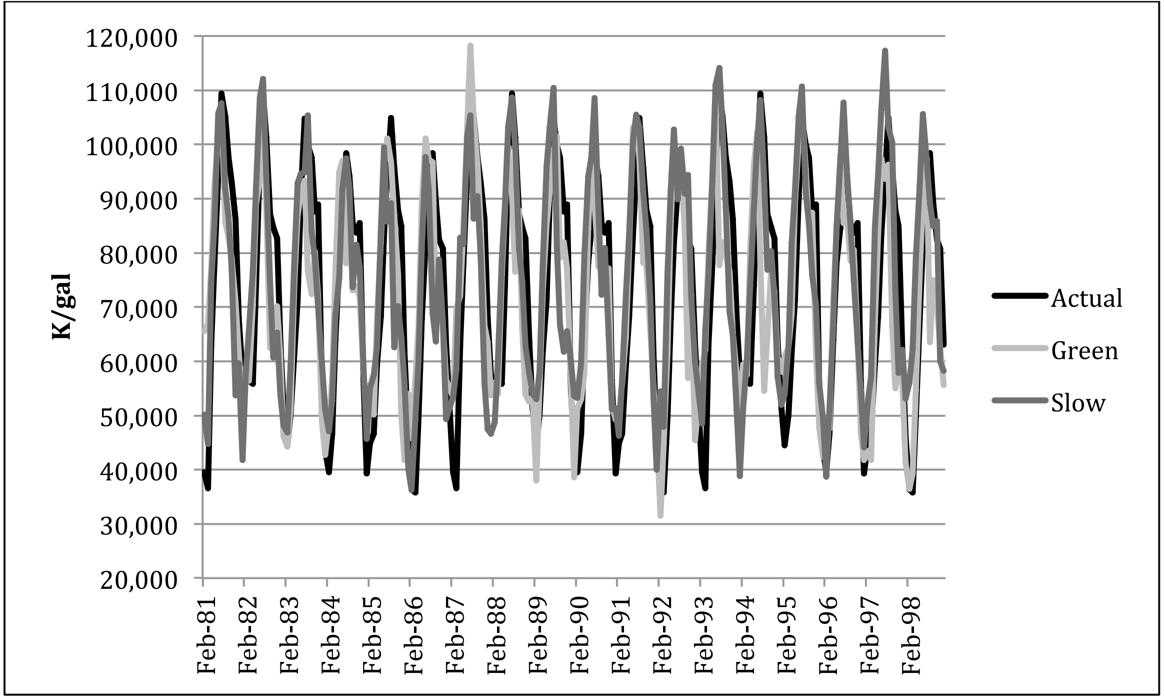


Figure 7.5: Paradise Valley Census Counter-Factual Water Usage 2046-2057

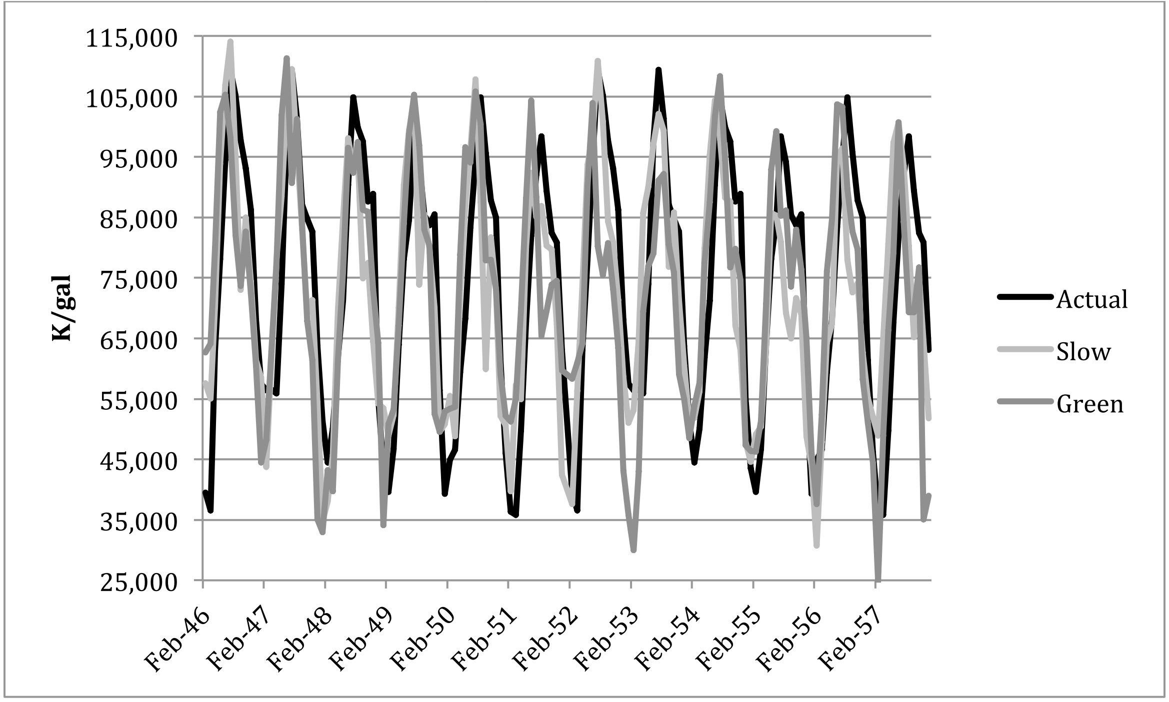


Figure 7.6: Paradise Valley Census Counter-Factual Usage 2081-2098

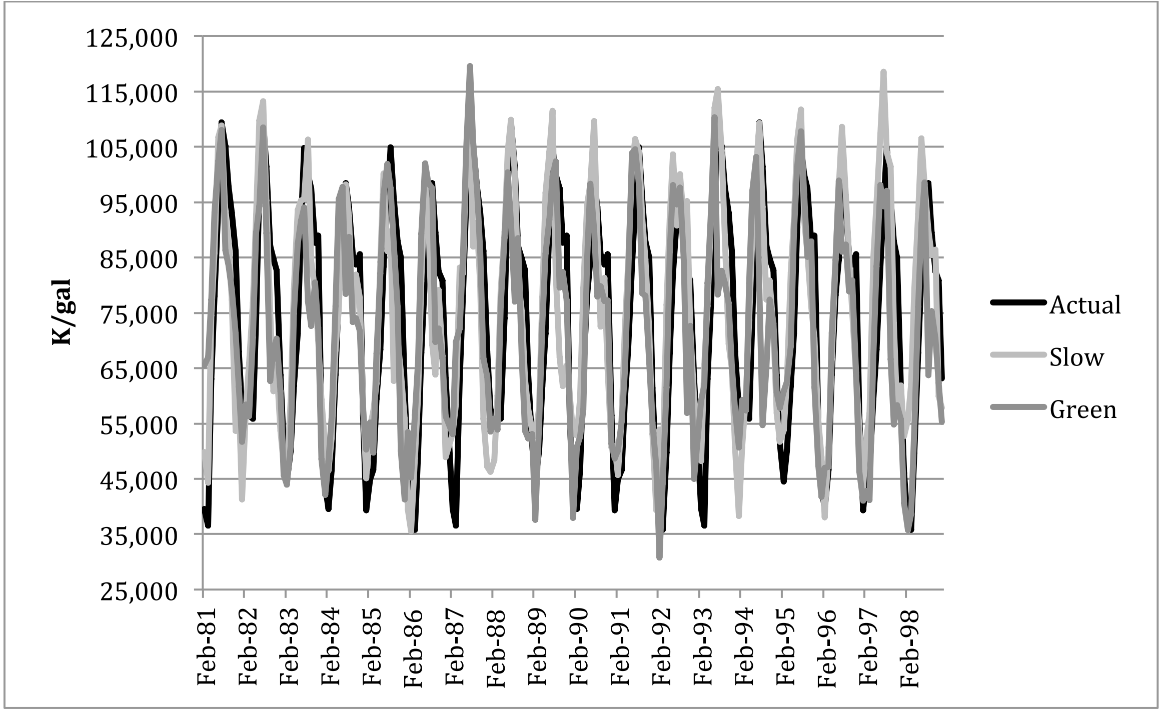


Figure 7.7: Sun City Counter-Factual Water Usage 2046-2057

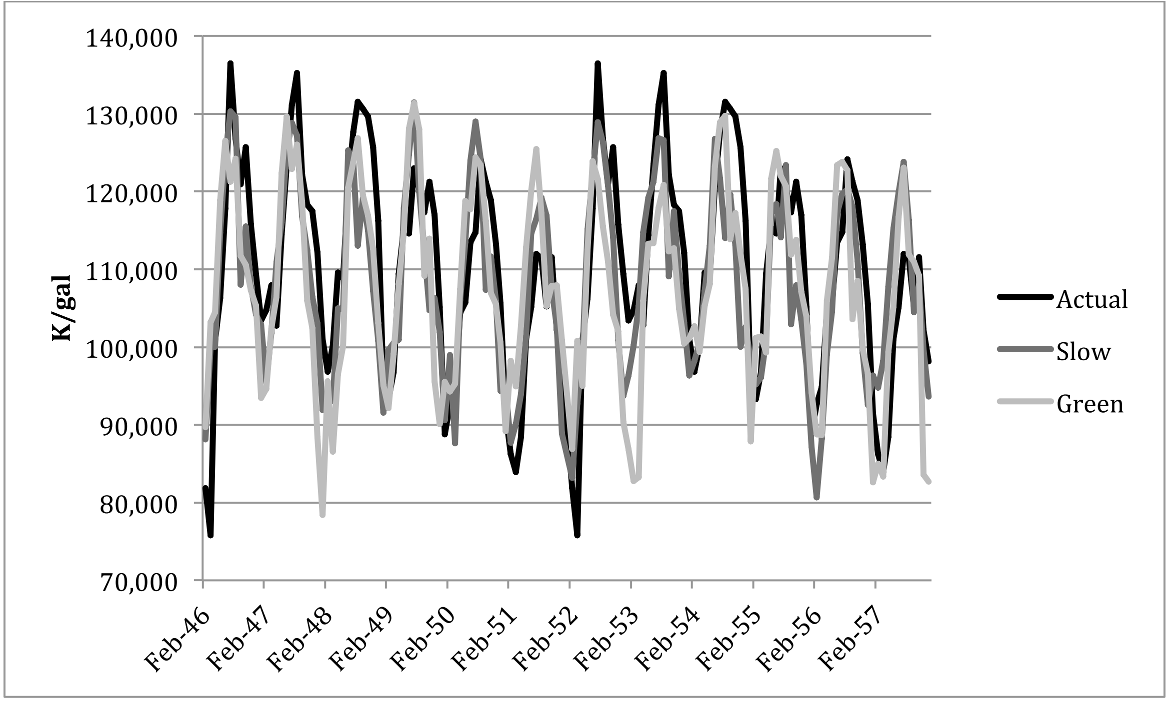


Figure 7.8: Sun City Counter-Factual Water Usage 2081-2098

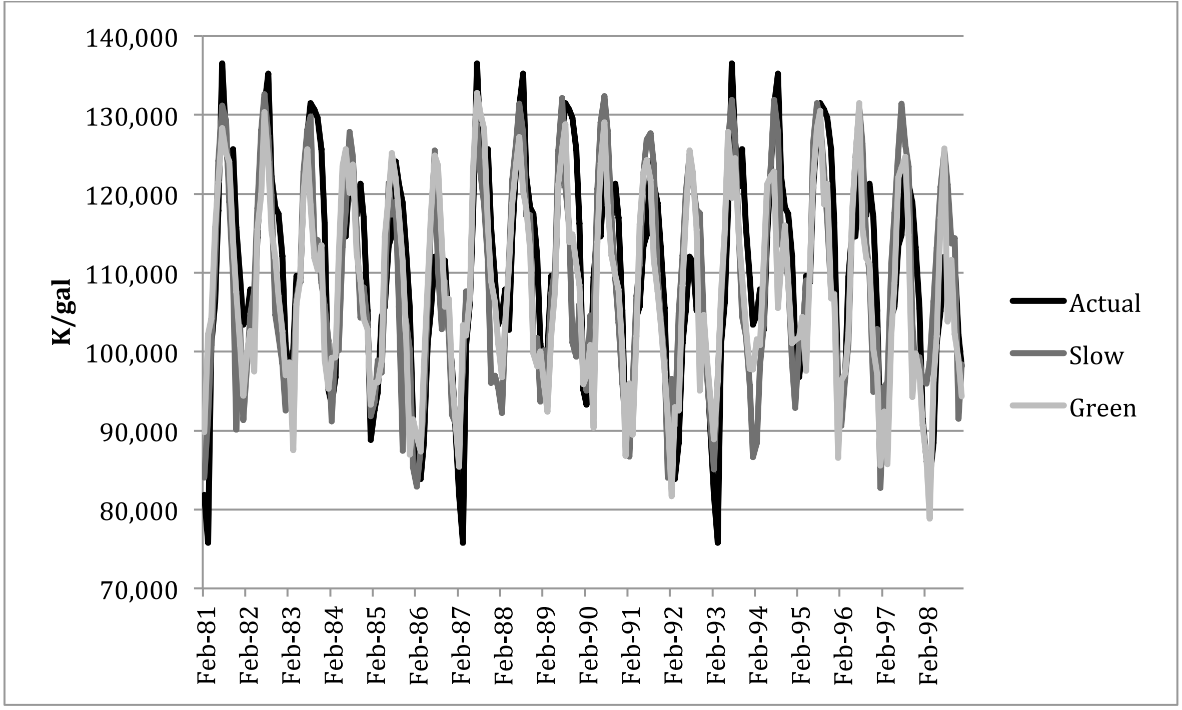


Figure 7.9: Sun City Census Counter-Factual Water Usage 2046-2057

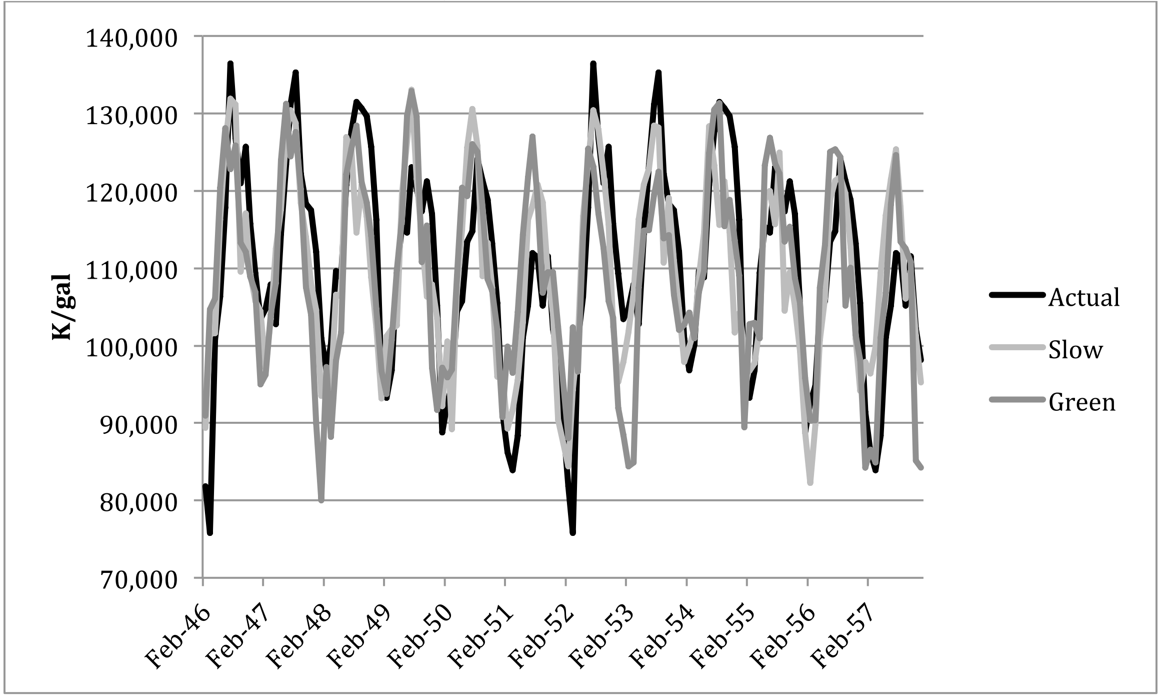


Figure 7.10: Sun City Census Counter-Factual Water Usage 2081-2098

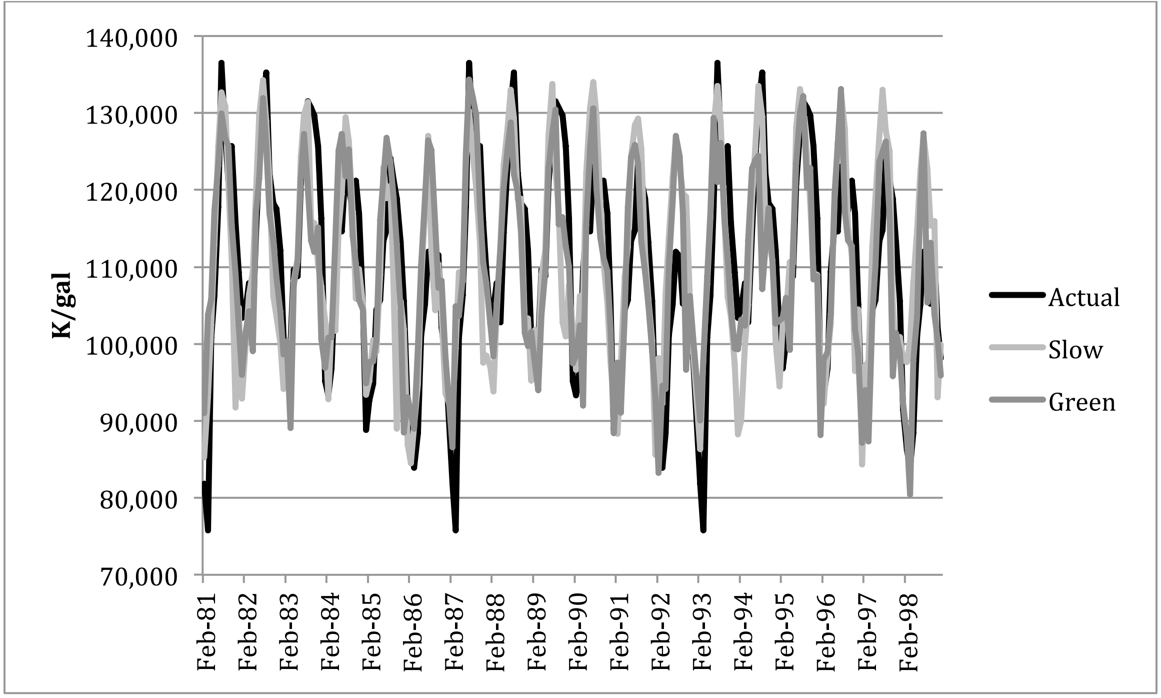


Figure 7.11: Sun City West Counter-Factual Water Usage 2046-2057

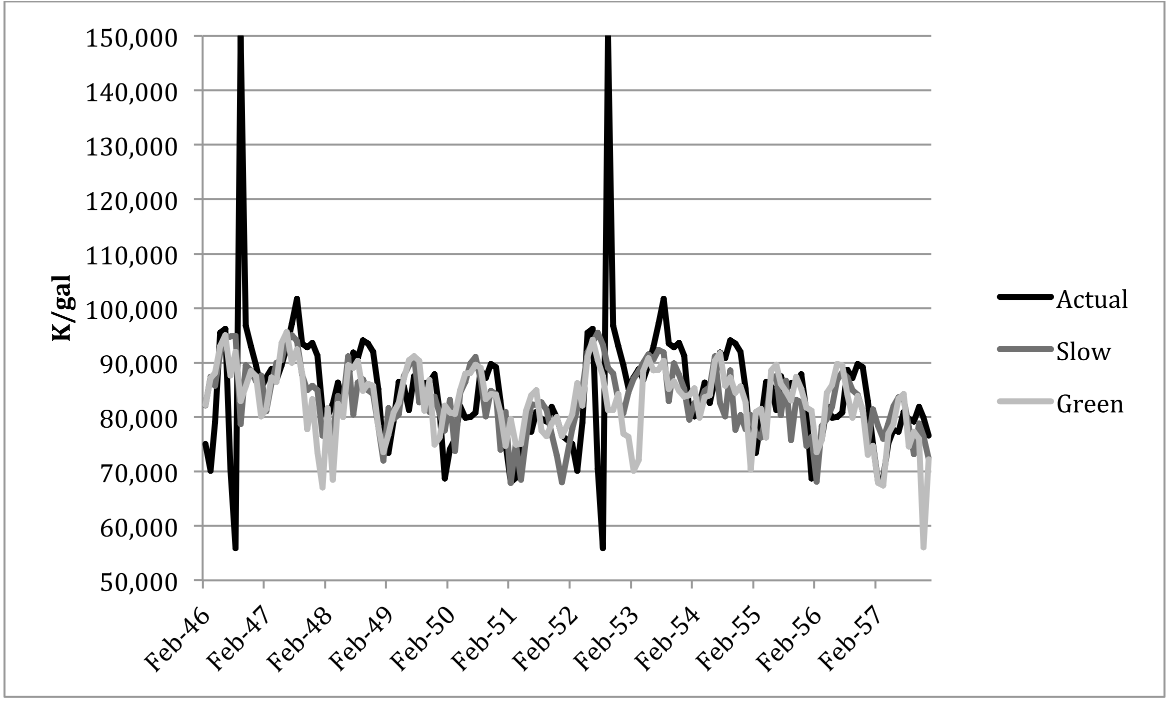
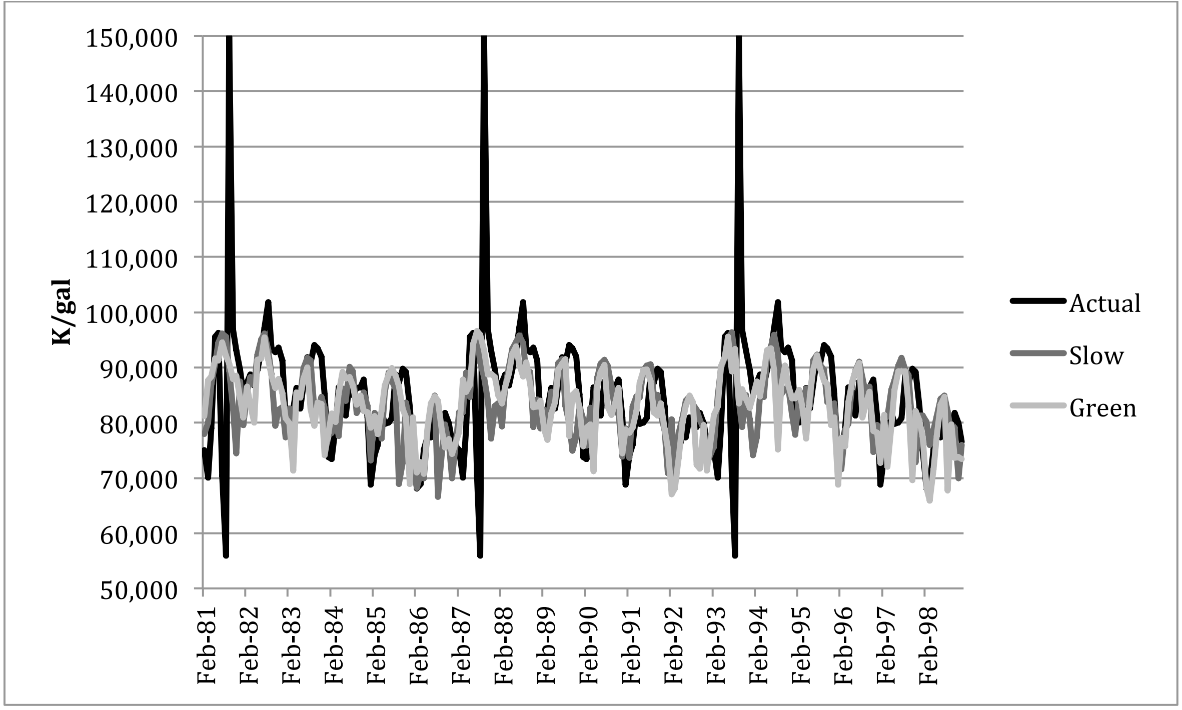


Figure 7.12: Sun City West Counter-Factual Water Usage 2081-2098



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