Coping with the Drought:

Water Demand Reduction in the Sonoma-Marin Saving Water Partnership Service Area

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Executive Summary

The severity of the California drought over the past decade has created an increase in water conservation efforts and a change in consumer behavior throughout the state. As a result, collaboratives such as the Sonoma-Marin Saving Water Partnership were faced with significant changes in water demand. Moving forward, now that the drought is officially over, it is important for these agencies to truly understand the factors that affect water demand in their regions.

Our team worked with the Sonoma-Marin Saving Water Partnership to evaluate trends in behavior as a result of the drought and answer the following research questions:

- What are the factors, or variables, affecting single-family residential water demand in Sonoma County? To what extent does each factor affect demand?
- How have consumer behaviors changed as a result of abnormally high media coverage of the drought?
- What might single-family residential water demand look like in the future, post-drought? Did the drought or conservation efforts cause a deviation in long-term trends?
- Have the Sonoma-Marin Saving Water Partnership's conservation efforts made a difference for single-family residential water demand?

For our analysis, we collected data from a variety of sources, including the Sonoma County Water Agency, Bureau of Labor Statistics, and the National Oceanic Atmospheric Administration to evaluate the effect of the following variables on single-family residence water demand in Sonoma and Marin Counties from 2006-2015:

- The price of water
- The intensity of the drought
- The unemployment rate
- The demographic makeup of the county
- The volume of drought-related media coverage
- Public interest in the drought, as measured by Google searches
- The amount of money the Partnership spends on conservation.

To answer the driving policy questions, our primary methodology included linear regression, GIS mapping, and qualitative analysis of our data and the Sonoma-Marin Saving Water Partnership. Due to data limitations, we ran a pooled regression model that contained our 9 retailers with the complete data that we had from 2006-2015. In addition, we ran subset regressions on smaller data sets from 2010-2015 to incorporate variables

such as pricing and household income that we had incomplete data from 2006-2015.

We found that variance in average water demand in single-family residences throughout the Sonoma County Water Agency's service region was most responsive to media coverage of the drought and the average temperature during our timeframe of interest. In addition, the effect of drought related news articles may indicate a more permanent shift in water demand behaviors in the Water Agency region as a result of the drought. We found that precipitation did not have a statistically significant effect on water demand across regressions while average temperature and the Palmer Drought Severity Index were highly significant.

Based on these findings, we recommend that the Sonoma-Marin Saving Water Partnership increase focus on engagement with the customer through public awareness and outreach programs, use targeted advertising to increase participation in conservation efforts, and improve data reporting. The Partnership should continue and expand their current rebate and educational programs to create a lasting and significant impact on single-family residential water demand. We recommend that it work closely with county boards or city councils to create new water saving goals for its retailers and that each retailer closely tracks their conservation investments and program participation. We also recommend that in future quantitative and qualitative analyses, the Partnership expands the scope of the analysis and further investigates the complications of the pricing data.

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Acknowledgements

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Introduction

The severity of the California drought over the past decade has brought increased attention to water conservation efforts and has created a significant response in consumer behavior throughout the state. As a result, the Sonoma County Water Agency and its retailers formed the Sonoma-Marin Saving Water Partnership through a MOU to influence changes in water demand and constructively respond to the effects of the drought. Now that Governor Brown has officially declared that the drought is over, it is important for the Partnership to fully understand the factors that have affected water demand in its regions, and what water demand might look like moving forward.

Our team worked with the Sonoma County Water Agency and Sonoma-Marin Saving Water Partnership to evaluate trends in behavior as a result of the drought and answer the following research questions:

- What are the factors, or variables, affecting single-family residential water demand in Sonoma County? To what extent does each factor affect demand?
- How have consumer behaviors changed as a result of abnormally high media coverage of the drought?
- What might single-family residential water demand look like in the future, post-drought? Did the drought or conservation efforts cause a deviation in long-term trends?
- Have the Sonoma-Marin Saving Water Partnership's conservation efforts made a difference for single-family residential water demand?

In order to address these questions, our team collected data from sources such as the individual retailers of the Sonoma County Water Agency, the Bureau of Labor Statistics, and the National Oceanic Atmospheric Administration. We compiled this data to create a dataset for our regression analysis that was used to inform our understanding of the factors that affect water demand.

Background

Sonoma County Water Agency

Sonoma County Water Agency provides water and services to ten cities and special districts in Sonoma and Marin Counties, which contain more than 600,000 residents. The agency is a leader in water resources management and was created in 1949 by the California Legislature for flood protection and water supply serves. Since 1995 legislation, the agency

has also dealt with the treatment and disposal of wastewater.[1] The Water Agency is unique in that most of its water comes from local sources — primarily the Russian River, Lake Sonoma, and Lake Mendocino.

The agency serves as a wholesaler of water for the following ten retailer cities/districts (Figure 1):

1. City of Cotati
2. Marin Municipal Water District (MMWD)
3. North Marin Water District
4. City of Petaluma
5. City of Rohnert Park
6. City of Santa Rosa
7. City of Sonoma
8. Valley of the Moon Water District
9. Town of Windsor
10. California American Water Company Larkfield[2]

The Water Agency is also a leader in conservation efforts, ensuring that water is saved efficiently and effectively. Throughout the most recent California drought years, the agency was proactive in conservation programs. As a result, it was able to surpass original conservation goals and recover from some of the impacts of the drought before other water agencies. Between June 2015 and May 2016, retailers reduced water demand by 26.3% overall, far greater than the agency's original conservation target of 19%.[3]

Sonoma-Marin Saving Water Partnership

The MOU creating the Sonoma-Marin Saving Water Partnership was signed in 2010, allowing for a timely response to the effects of the California drought in Sonoma County Water Agency's service region. It comprises 11 water utilities in Sonoma and Marin counties (the ten retailers and the Water Agency). Its purpose is to identify and recommend projects to maximize cost-effectiveness and efficiency of water demand in the region.[4] Since 2010, the Partnership has experienced great success through programs, education, and outreach campaigns to decrease regional water demand and increase water efficiency.

[1] Sonoma County Water Agency, 2017, "About Us," http://www.scwa.ca.gov/index.php.

[2] Due to limited data availability, we were not able to include this retailer in our analysis.

[3] Sonoma County Water Agency, 2017, http://www.scwa.ca.gov/index.php.

[4] Sonoma-Marin Saving Water Partnership, Annual Reports, http://www.savingwaterpartnership.org.

Timeline of Key Dates

Key events during our timeframe of interest include the following:

2006	Start year for our analysis.
2008	Recession begins. Local drought in Sonoma County begins.
2009	Local drought in Sonoma County ends.
2010	Sonoma-Marin Saving Water Partnership begins.
2011	Recession ends. California Drought begins.[5]
2013	Sonoma-Marin Saving Water Partnership creates a call to action for water conservation efforts.
2014	Governor Brown declares second drought state of emergency (first one to cause heavy media coverage).
2015	Governor Brown ordered mandatory water restrictions in California, which led the State Water Resources Control Board to impose a 25% restriction on water demand among California local water supply agencies for the following year.[6]
2017	Governor Brown declares that the drought is over.

Sonoma and Marin County Region

Figure 1 shows Sonoma County Water Agency's service area. The Water Agency provides water to retailers that serve more than 600,000 residents in both Sonoma and Marin Counties. The Bay Area has had a rapidly growing population in recent decades. However, in the North Bay, most of this growth occurred in the 1990s, and since then the pace of its growth has slowed compared to the South Bay and East Bay.[7]

The region has a varying range of demographics, such as median household income, education attainment, and percent Hispanic population. Marin County has the highest median age and largest percentage of non-Hispanic white population compared to the

[5] Scott, Michon and Lindsey, Rebecca, "Early years of California's drought may be linked to lingering effect of La Niña," Climate.gov. 4/20/15. https://www.climate.gov/news-features/featured-images/early-years-california's-drought-may-be-linked-lingering-effect-la.

[6] California Department of Water Resources, "Governor's Drought Declaration," 2016. http://www.water.ca.gov/waterconditions/declaration.cfm.

[7] Association of Bay Area Governments, January 2015, "A Diverse and Changing Population", http://reports.abag.ca.gov/sotr/2015/section3-changing-population.php.

other eight counties that encompass the Bay Area.[8] For those who move to the Bay Area from another location, Sonoma County is the county where most movers stay in comparison to the other counties in the region (i.e., long term relocation).[9] Between Sonoma and Marin Counties, Marin County has a higher median household income.

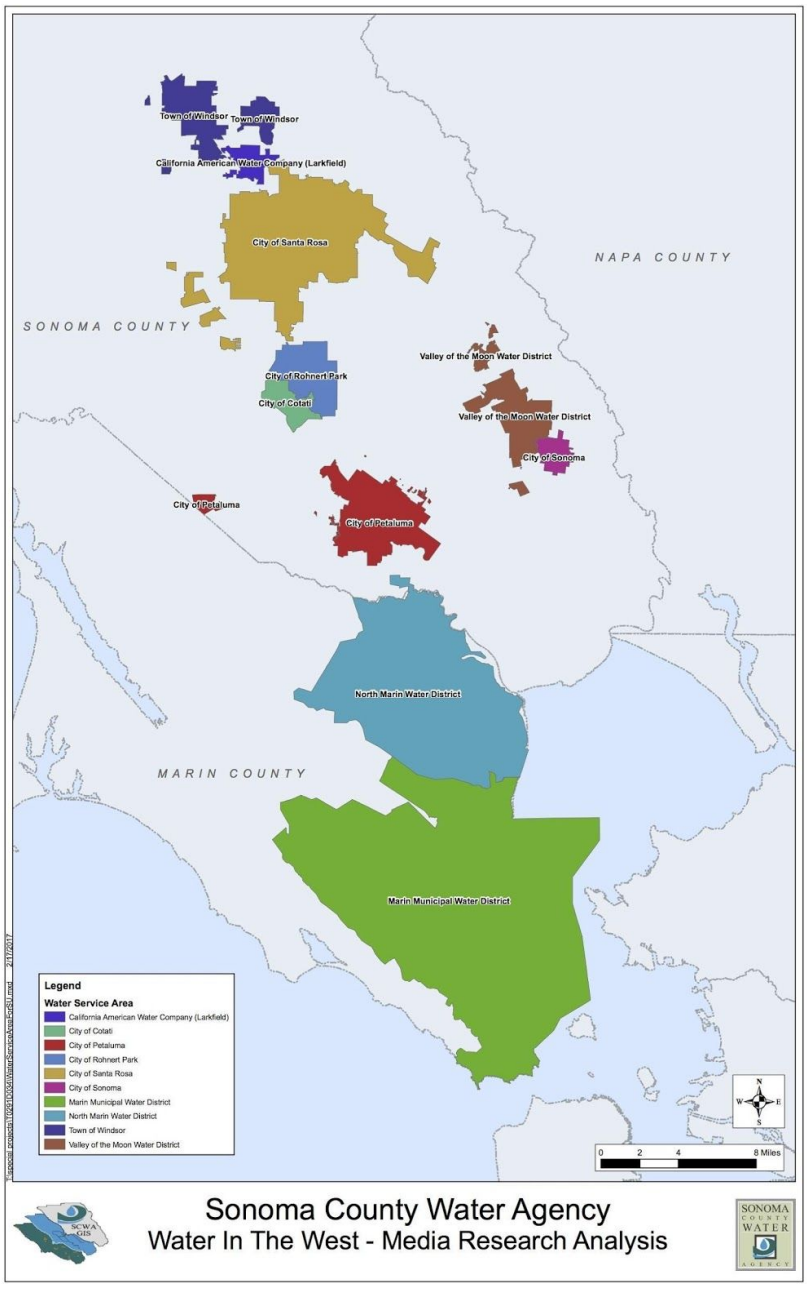

Figure 1: Sonoma County Water Agency Service Area
Source: Sonoma County Water Agency

[8] Association of Bay Area Governments, January 2015, "A Diverse and Changing Population", http://reports.abag.ca.gov/sotr/2015/section3-changing-population.php.

[9] Association of Bay Area Governments, January 2015, "A Diverse and Changing Population", http://reports.abag.ca.gov/sotr/2015/section3-changing-population.php.

The nine retailers of Sonoma County Water Agency served over 150,000 single-family residence connections in 2015 which is an increase from the ~135,000 single-family residence connections in 2006. Over this same period of time, average annual water demand by connection in the nine retailers has decreased from over 1,300 CCFs in 2006 to just under 900 CCFs in 2015. Figure 2 demonstrates the annual percent changes in the number of single-family residence connections and average annual CCF water demand per connection from 2006-2015.[10] It is important to note that while the number of connections has not changed much during this period, water demand has changed tremendously in the Water Agency's service area. This highlights the fact that change in water demand in the region has not been driven by the population change but other factors.

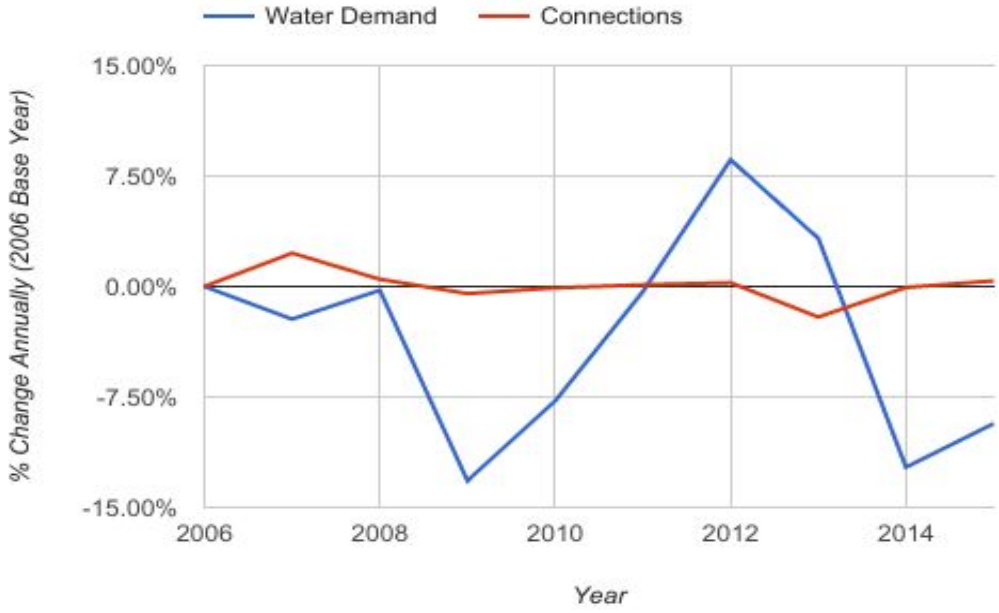

Figure 2: Percent Change Annually in Water Demand and Connections (2006 Base Year)

Climate data shows that temperature and precipitation patterns are relatively uniform across the study region, which is characterized by wet, cold winters and dry, hot summers. Average daily temperatures reach as high as 65 to 70°F in the summer months to lows of approximately 45-50°F in the winter.[11] Average annual rainfall over the study period ranges from highs of 30 inches or more in non-drought years to lows of 5-6 inches during the most severe drought years.[12] Sonoma and Marin counties experienced the drought in a similar way as the lower Bay Area, but entered into and recovered from the drought one year earlier than the rest of the state.[13]

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[10] Figure 2 only displays data from the six retailers that we have complete water demand and connections data from 2006-2015.
[11] National Oceanic and Atmospheric Administration, "Data Tools: Find a Station," https://www.ncdc.noaa.gov/cdo-web/datatools/findstation
[12] Ibid
[13] National Oceanic and Atmospheric Administration, "Divisional Data Selection," https://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp

Methodology

In order to answer our research questions, we collected data from a variety of sources and compiled into a dataset that we used for both a qualitative and a regression analysis. Through this work, it was possible to quantify and evaluate the factors that affect water demand in the Water Agency's service area.

Data

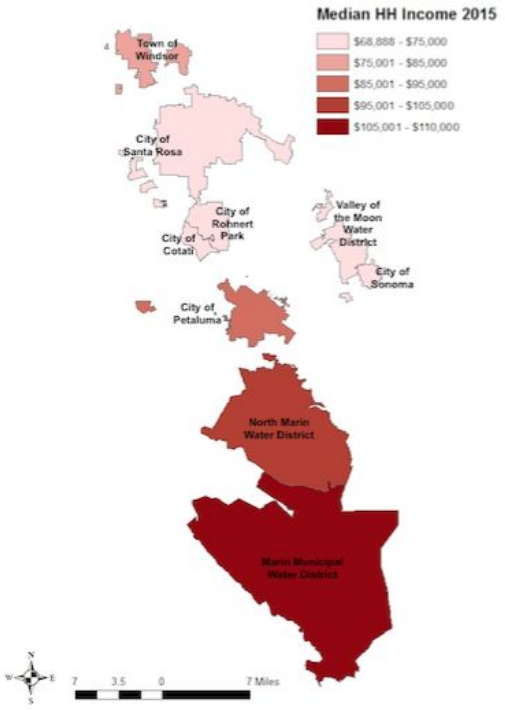
Demographic Analysis

Demographic data was collected from the Bureau of Labor Statistics and American Community Survey. The data is compiled and organized by SimplyMap, a site that gives various demographic data from the Census Bureau at the Census Tract level. We used GIS to model demographic information specific to the service areas of the retailers under Sonoma County Water Agency. Since our data was at the Census Tract level, we averaged the data for each retailer of the Water Agency to find the average demographics of interest.

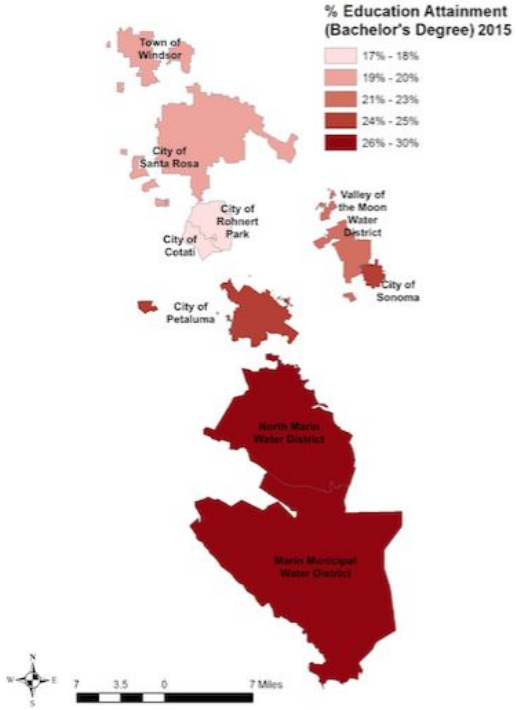
As Figures 3-5 depict, the region encompasses a diverse population. Figure 3 compares some of the variations in demographics among the water retailers in the Water Agency service region in 2015. Figure 3a shows the variation in median household income. We found that in 2015, retailers in Marin County had a higher median household income compared to the Sonoma County retailers. Santa Rosa, Rohnert Park, Cotati, Sonoma, and Valley of the Moon had the lowest compared to other retailers. This data suggests that Marin County is comparatively wealthier than Sonoma County.

Figure 3b shows similar results, that in 2015, retailers in Marin County had a higher average percentage of people with a Bachelor's Degree compared to the Sonoma County retailers. Cotati and Rohnert Park had the lowest percentage of people with Bachelor's Degree compared to the other retailers, but perhaps this is due to the fact that many people living here were enrolled in Sonoma State University.

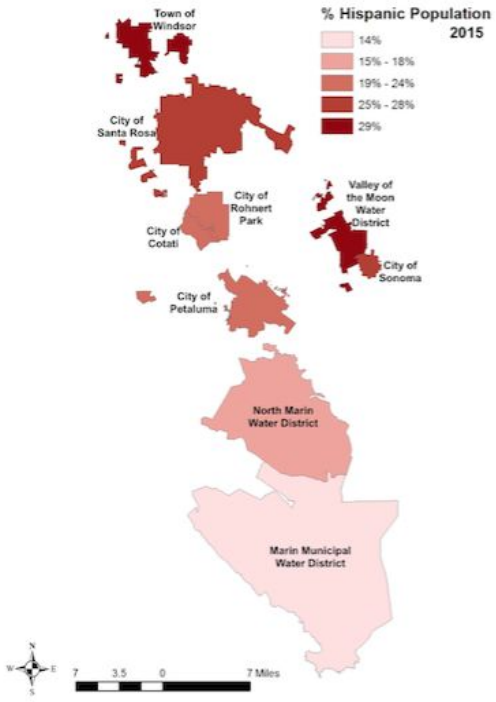
Interestingly, the opposite gradient can be seen in the percentage of Hispanic population (Figure 3c) compared to (a) and (b). It shows that in 2015, more northern retailers in the region had a higher percentage of Hispanic population compared to the more southern retailers in Marin County. In particular, Windsor and Valley of the Moon both had nearly a 30% Hispanic population.



(a): Median Household Income, 2015



(b): Educational Level, 2015



(c): Percent Hispanic Population, 2015

Figure 3: Comparison of Demographics

Figure 4 shows the variation in percent owner occupied housing among the water retailers in the Water Agency service region in 2015. We found that Windsor and North Marin had the greatest percentage of owner-occupied housing in 2015 compared to the other retailers. Santa Rosa, Rohnert Park, and Cotati had the lowest percentages, perhaps because of the proximity of Sonoma State University and Santa Rosa Junior College.

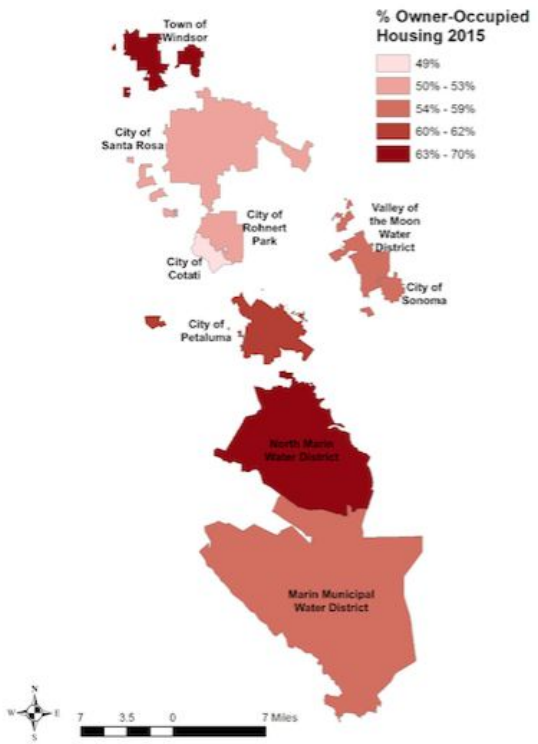


Figure 4: Percent Owner-Occupied Housing, 2015

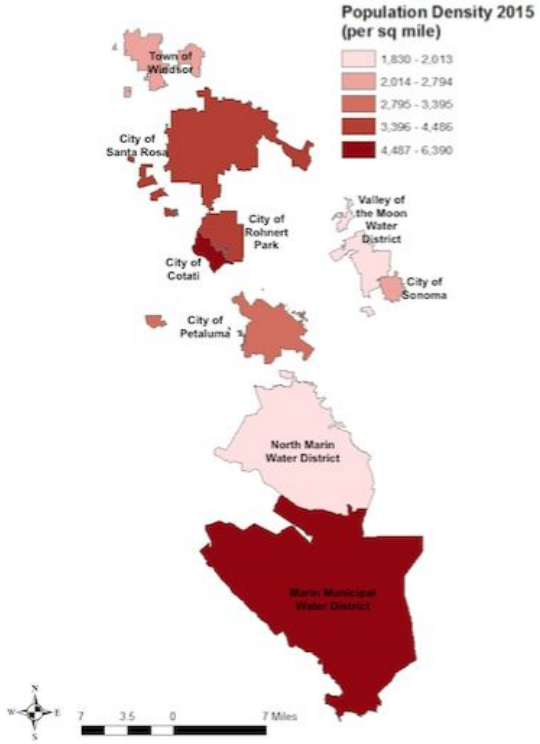


Figure 5: Population Density, 2015

Figure 5 shows the variation in population density among the retailers in the Water Agency's service area in 2015. We found that MMWD and Cotati had the highest population density in the region, indicating that the residents have smaller lot size and therefore perhaps use less water. On the other hand, North Marin and Valley of the Moon had the lowest population density, indicating that these residents can potentially have larger lots and outdoor space compared to others in the region.

Climate Data

Climate data on daily temperature, precipitation, and monthly Palmer Drought Severity Index (PDSI) ratings was collected from National Oceanic and Atmospheric Administration weather stations throughout Sonoma and Marin Counties. For PDSI, daily values were averaged over a bimonthly period to match the bimonthly data values for water rates for use in the regression (Figure 6). PDSI measures drought intensity, where increasingly negative values reflect the corresponding severity of the drought. As one can see the North

Bay experienced less severe drought conditions compared to the Central Coast, which includes the coastal region from San Francisco to San Luis Obispo area. Moreover, the North Bay got out of the drought about a year before the Central Coast.

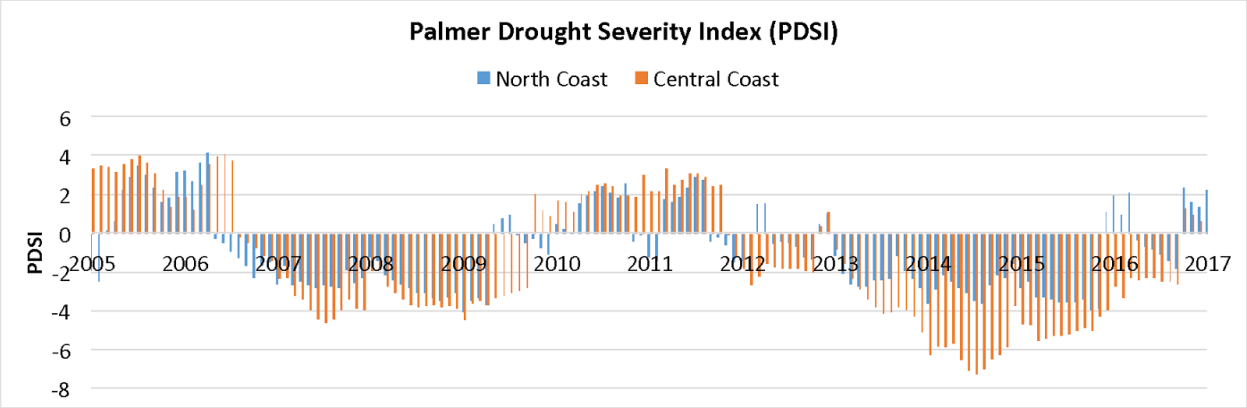


Figure 6: PDSI comparing drought intensity in Sonoma County (North Coast) and the lower Bay Area (Central Coast).

In the same way, daily values for temperature and precipitation were averaged over bimonthly periods (Figures 7 and 8). Figure 7 shows that average daily temperature by bimonthly period across climate stations was fairly uniform. In other words, the effect of temperature variation on water demand can be expected to be similar across agencies, potentially with the exception of MMWD and North Marin, which appear to have had higher average daily temperatures in winter months.

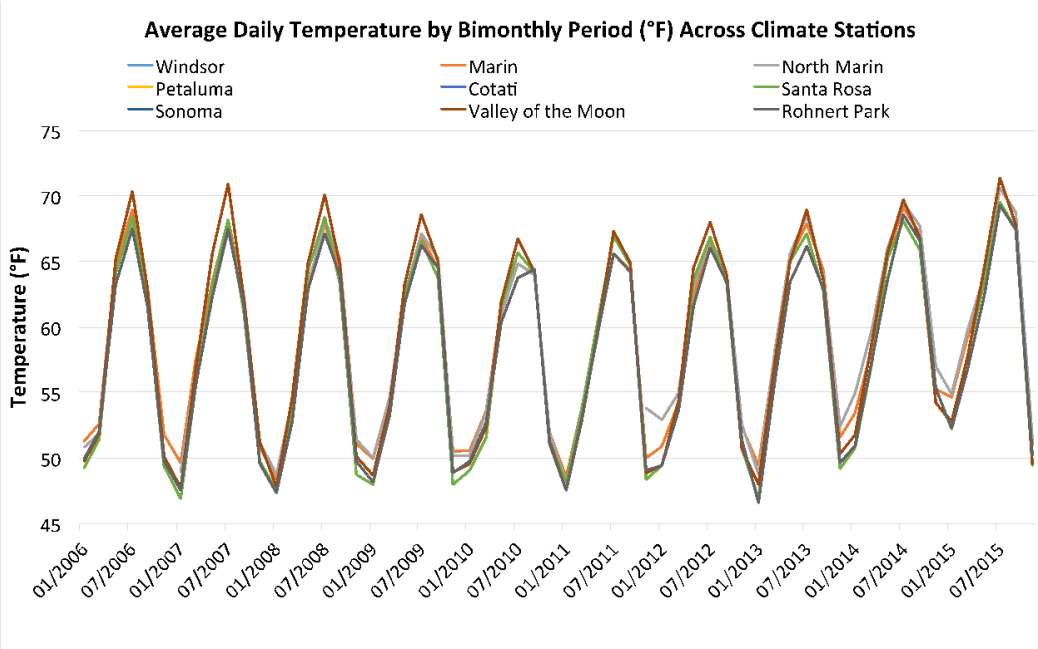


Figure 7: Average daily temperatures for each area's climate station were averaged over a bimonthly period to match the pricing data used in the regression analysis.

Figure 8 shows that precipitation levels and patterns were fairly uniform across the study area, with MMWD, North Marin, and Santa Rosa experiencing the largest amount of daily precipitation during the rainy season. Notably, Sonoma and Valley of the Moon deviated from the usual pattern between 2010 and 2012. This is likely due to the fact that during this two-year time period, many days worth of data from the Sonoma City climate station were not recorded, and therefore omitted from the monthly averages. A comparison between the months with lots of missing data in 2010, 2011, and 2012 to the same months in other years with full data suggests that many days with low or no precipitation went unrecorded, raising the average monthly precipitation. Given that this data anomaly does not vary greatly from the overall trend, and that the Sonoma City climate station otherwise has complete data, this shouldn't affect our regression results.

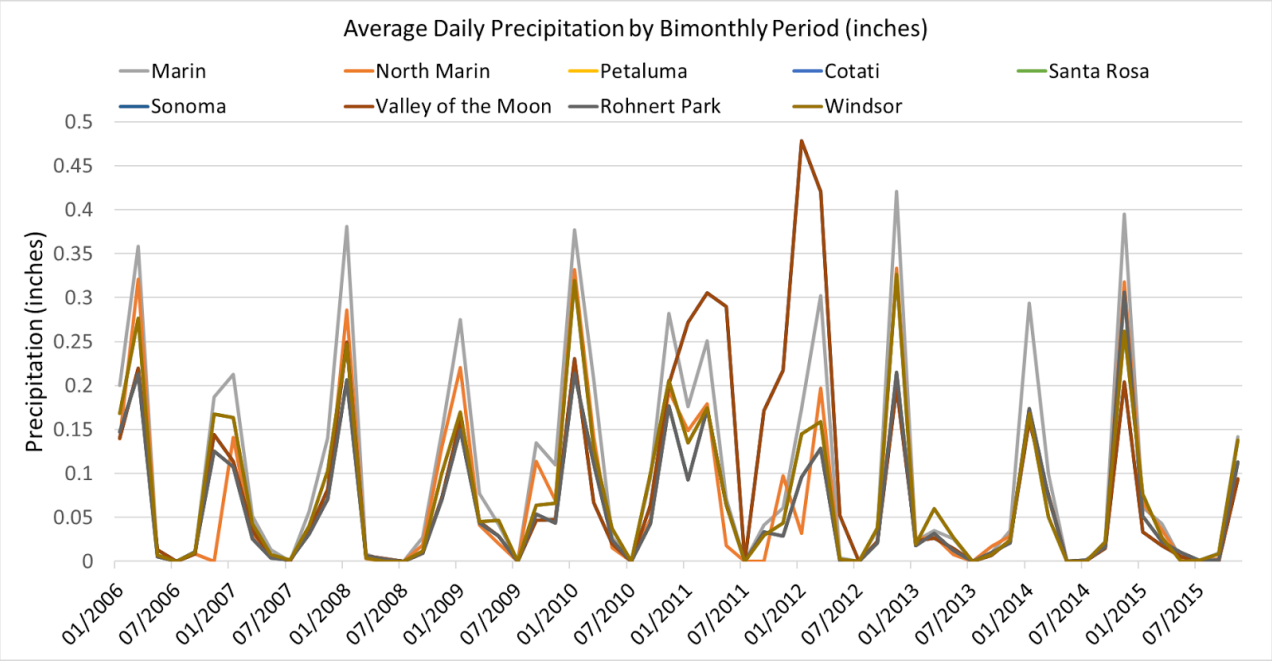


Figure 8: Daily precipitation data was sourced from each city's respective climate station and averaged over a bimonthly period to match the pricing data used in the regression analysis.

Water Demand Data

Using the water deliveries and connections data received from Sonoma County Water Agency, we were able to compile the average bi-monthly CCF per single-family residence connection water demand across the nine retailers. In order to compare the data across the retailers, we standardized the water demand into the same unit (CCF). Since some of the retailers only submitted bi-monthly data, we made all of the retailers deliveries data bi-monthly in order to accurately compare them. The bi-monthly data was then divided by the number of single-family residence connections during a certain year. This data was essential to our analysis to help us quantify the extent our variables such as climate, media

coverage and demographics have on individual household's water consumption habits.

Our analysis of the data allowed us to see trends in water consumption throughout the nine separate retailers. Water consumption in the Water Agency's service area is highly seasonal, but examining yearly trends showed that water demand has generally decreased since 2006. Figure 9 depicts water demand annually in CCF per connection from 2006-2015 in the nine different Sonoma County Water Agency retailers. This figure was useful in analyzing water demand trends over our time period as it demonstrated how the retailers in general were affected similarly by the Great Recession (2008-2010) and the drought (2011-2017). An interesting observation was the increase in water demand from 2010-2013 that correlated with the economy improving, but then water demand fell in a clear negative trend line from 2013-2015, which demonstrates the probable effects of media and conservation efforts on water demand. This was essential for our project because we were trying to figure out the extent to which media and conservation expenditures account for this decrease.

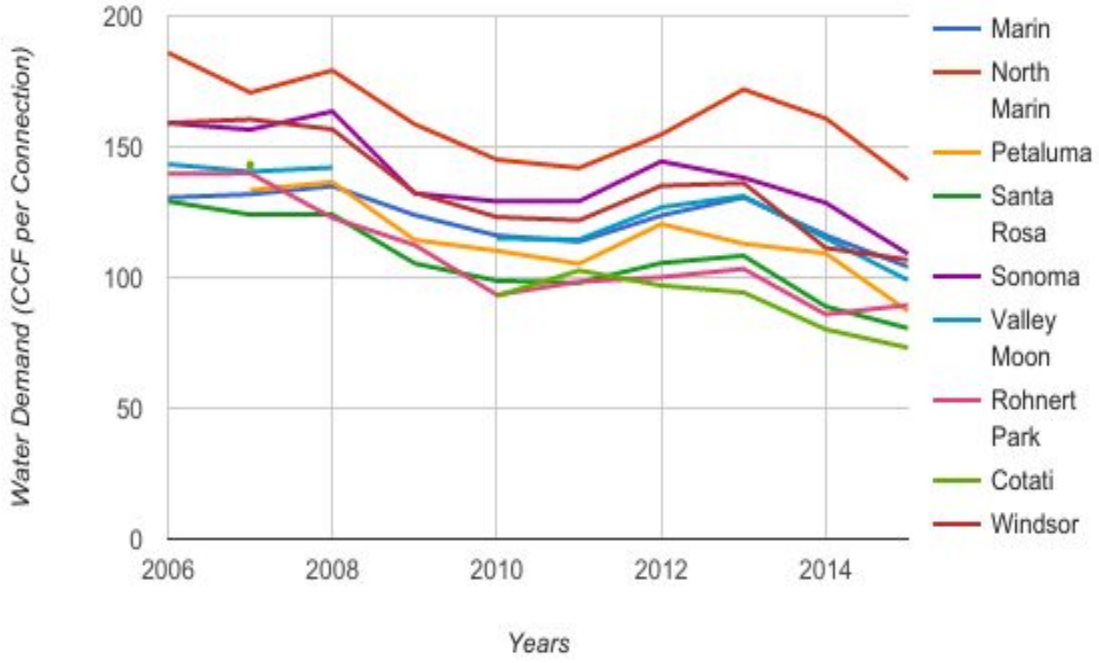


Figure 9: Annual Water Demand in Sonoma County Water Agency's service area from 2006-2015

Figure 10 shows the water demand bi-monthly in CCF per connection from 2006-2015 among the six agencies for which we had complete data. This figure demonstrates the wide fluctuation in water demand as a result of seasonality and the overall negative trend-line in water demand from 2006-2015.

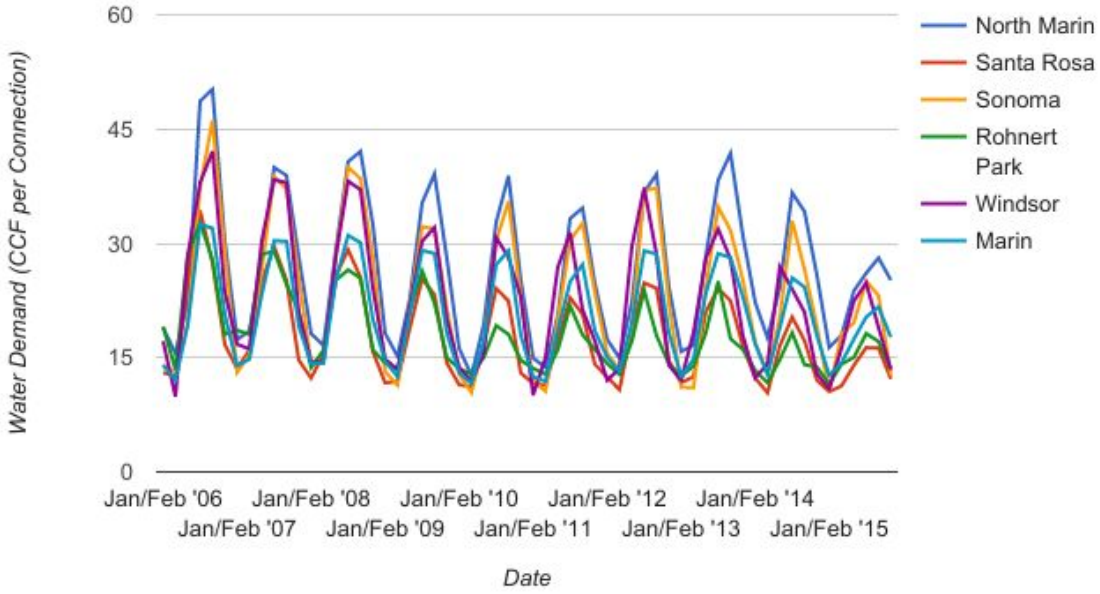


Figure 10: Bi-Monthly Water Demand in Sonoma County Water Agency's service area from 2006-2015

Pricing

Price is an important factor that can affect consumer use and can be an important factor in modeling water demand. Using the pricing structures received from 5 of the retailers, we were able to find the average price paid per CCF by single-family residences of each retailer during a bi-monthly period. Each of the 5 retailers had slightly different pricing structures, but in general the structure included a service charge (either monthly or bi-monthly) along with a price for water at either a single tier price for all use or at a multi-tier price where prices increased as a residence used more water. The average price per CCF was calculated by using the standardized water deliveries per connection for a monthly period and calculating how much the average household would pay for that month. The bi-monthly periods were then combined in order to find the average price paid over the two-month period. The average price paid by single-family residences was then adjusted to 2015 dollars based on the CPI from 2006-2015.

There were some slight differences in the pricing structures that made it difficult to perfectly compare how changes price relates to changes in water demand. For Rohnert Park, we only received data from 2011-2015 versus 2006-2015 for the other four retailers. MMWD's multi-tier system includes different tier quantities depending on whether it is a summer or winter month which is different than the other retailers that keep the tier quantities the same all year long. These differences in pricing structures created some difficulties in the regression that will be touched upon later in the report.

Unemployment

We collected unemployment data primarily from the Bureau of Labor Statistics (BLS), which provided bi-monthly unemployment rates for the entire study period (2006-2015) for Marin and Sonoma Counties, as well as for cities with populations over 25,000 people in the Sonoma-Marin Saving Water Partnership service area. More unemployment data from the California Employment Development Department (CEDD) was used to supplement the BLS data, but CEDD only provided data from 2010-2015.

We found that Marin County overall has had lower overall unemployment rates compared to Sonoma County. For example, in 2015 Marin County had a 3.6% unemployment rate, compared to a 4.9% rate in Sonoma County that same year.[14] Figure 11 shows these differences in the unemployment rates between Sonoma and Marin Counties from 2006 to 2015.

For municipalities without BLS data, we used county-level unemployment rate data in the regression, but ran an additional regression for the 2010-2015 period using the CEDD data to confirm that the coefficients did not differ greatly when more accurate data was used. Given that the North Marin and Marin Municipal retailers serve many different small population centers, county-level data was used for their regressions.

Figure 11: Unemployment Rate, 2006-2015

[14] Bureau of Labor Statistics, "Unemployment in the San Francisco Bay Area by County," 2017. https://www.bls.gov/regions/west/news-release/unemployment_bayarea.htm.

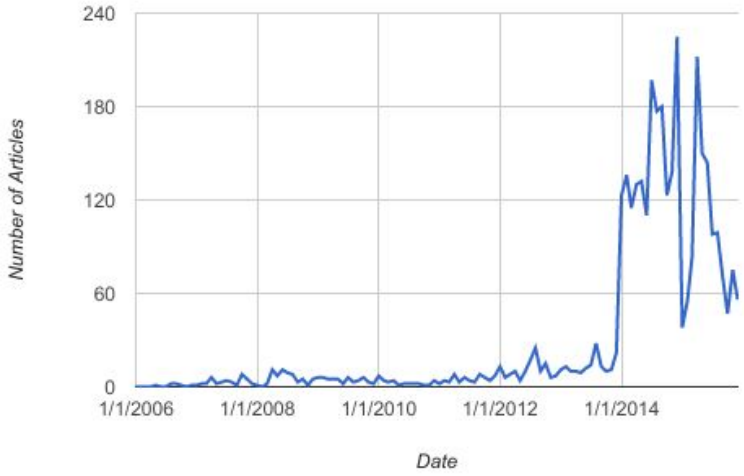
Media

We used the software package *Articulate* to find how many times phrases related to "California drought" appeared in national, statewide, and local news sources. The eight sources we searched were *SFGate, The LA Times, The New York Times, The Orange County Register, The Sacramento Bee, The San Diego Union-Tribune, The Wall Street Journal,* and *USA Today*. Due to limited media coverage during our years of interest, we did not include the local news sources of *The Press Democrat* or *Marin Independent Journal*. Using the sum of our range of news sources, we found that once Governor Brown declared a State of Emergency for the drought in January 2014, there was a spike in media coverage related to the drought. We also found that this heightened media coverage continued through 2015 as well. This spike is shown in Figure 12a.

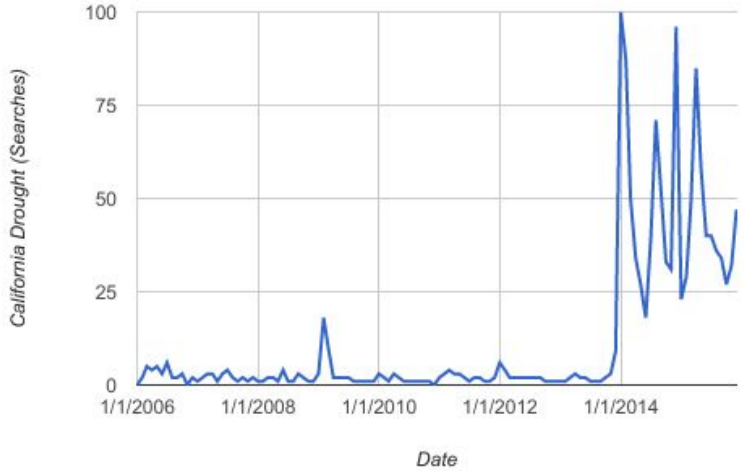
We also used Google trends to examine search queries related to the drought and water conservation from 2006-2015.[15] Our goal from this was to gauge public interest in the drought and conservation efforts. We were able to restrict the search queries to the Bay Area in order to see what people in and near the Water Agency's service region have been searching on Google. The results showed a large increase in queries related to the drought since January 2014, consistent with the increase of media coverage as a result of Governor Brown's declaration in 2014. This can be seen in Figure 12b. Water conservation search queries have been fairly constant since 2006 with the highest number of searches happening in April 2015, shown in Figure 12c. This recent uptick coincides with the mandatory statewide water demand restrictions, which began in April 2015.[16] It also may demonstrate increased citizen awareness of and interest in California's water challenges and water conservation.

[15] Google Trends, "California Drought," San Francisco Bay Area, 01/01/2006-12/31/2015. https://trends.google.com/trends/explore?date=2006-01-01%202015-12-31&geo=US-CA-807&q=California%20drought.

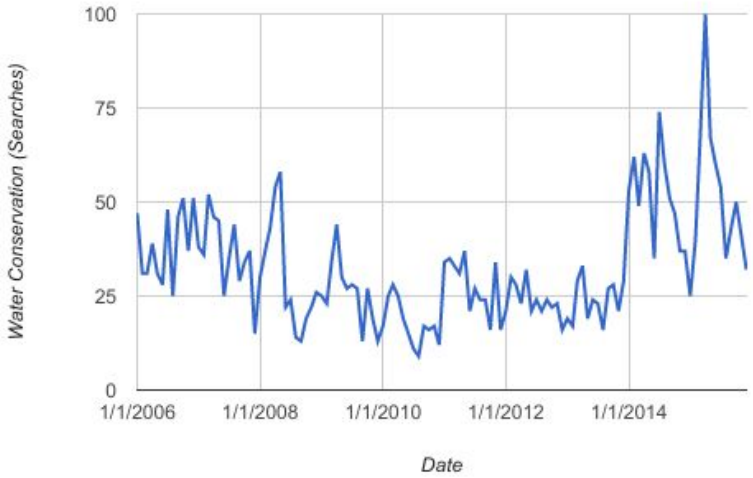
[16] Megerian, Chris, Stevens, Matt, and Boxall, Bettina. "Brown orders California's first mandatory water restrictions: 'It's a different world.'" LA Times. 4/1/15. http://www.latimes.com/local/lanow/la-me-ln-snowpack-20150331-story.html.



(a): Articles related to "California Drought," Articulate



(b): Google Trends timeline of searches of "California Drought"



(c): Google Trends timeline of searches of "Water Conservation"

Figure 12: Media Searches, 2006-2015

Conservation Budget

In order to determine if the Sonoma-Marin Saving Water Partnership's efforts had an influence on water demand, we compiled the Partnership's conservation budget from 2010-2015. We collected this data using the Partnership's annual reports, found on their website. Figure 13 below demonstrates the cumulative amount of money that the Partnership has spent since it's inception in 2010 which is over $35,000,000. The cumulative amount of spending is important as certain conservation education and investments into water conserving equipment such as toilets or washers carry over year after year. However, for our regression, the annual totals were used each year and divided into six bi-monthly periods for each year to match the water demand data.

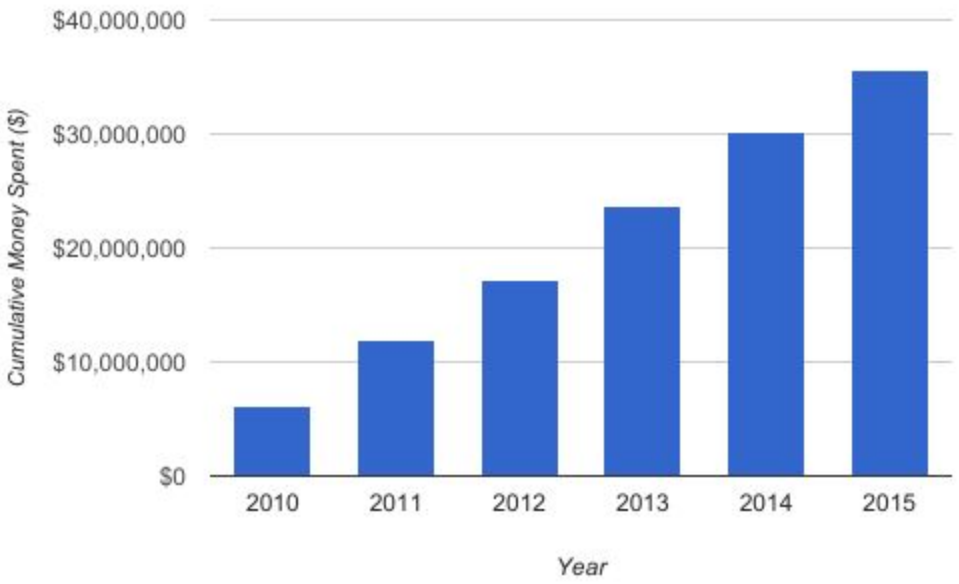


Figure 13: Cumulative Partnership Expenditures 2010-2015

Qualitative Analysis

In our research, we included both qualitative and quantitative analysis. Our data was compiled with the goal of putting it in a regression to quantify the effects of various factors on water demand. However, we first performed qualitative analysis to compare specific variables against water demand, find the correlation between variables, and consider some other impacts on our results. This qualitative analysis is important so that we can study certain factors in isolation to further understand their effects. Additionally, it aided our ultimate recommendations to the Sonoma County Water Agency and Sonoma-Marin Saving Water Partnership.

Quantitative Analysis: Regression

After collecting and qualitatively analyzing our data, we proceeded with our analysis using econometric modeling. We used the data analysis software Stata to perform ordinary least squares (OLS) linear regression, an approach that shows correlations between explanatory variables (like temperature and water price) and one dependent variable (in our case, how much water single family residences use). This approach can tell us, to name one example, if and to what extent a *rise* in temperature is associated with *more* water consumption.

We collected bimonthly data for 9 retailers from 2006 to 2016. The maximum number of observations in our dataset was thus 540, or 9 retailers observed 60 times each. However, we were missing water demand data from three retailers for a total of five years: Petaluma (2006), Valley of the Moon (2009), and Cotati (2006, 2007, and 2009). Each missing year of data excludes six bi-monthly periods, which means our new maximum number of observations in our dataset was 510. We did not have a full 510 observations for each variable, however, which is why we developed three regressions (see Table 2 below):

- Regression 1: *Base Case* (includes all retailers, 2006-2015)
- Regression 2: *Adding Budget Variable* (includes all retailers, 2006-2015)
- Regression 3: *Adding Income & Price Variables* (includes 4 retailers, 2010-2015)

Regression 1 includes all relevant variables for which we had 510 observations. The resultant model is as follows:

$$\ln(\text{Water Demand})_{it} = f(\text{Articles}_t, \text{Unemployment Rate}_{it}, \text{Precipitation}_{it}, \text{Temperature}_{it}, \text{PDSI}_{it}, \text{Whether Retailer is "High Income"}_i)$$

This equation explains water demand as a function of the variables on the right hand side. These variables are specific to time and place. The subscript "t" means that a variable changes over time. The subscript "i" means that a variable changes across retailers. We log-transform our dependent variable in order to reduce variability in our water demand data. The log-transform also allows us to interpret our results in terms of *percent-change* in water demand. This log-linear approach to water demand modeling is often used for these reasons.

Our "high income" variable assigns retailers into two groups according to their populations' median household incomes. MMWD, North Marin, Petaluma, and Windsor are assigned to the high income group. This allows us to infer the relationship between median household income and water demand even though we did not have a full 510 observations of median household income data.

For our temperature variable, we believe that temperature influences water demand in

part by affecting public perception of the drought's severity (where people are more conscious of their water demand when the weather is hot and less so when the weather is cool). We therefore speculated that maximum or minimum daily temperature might capture that perception better than average daily temperature, and ran our main regression using average, maximum, and minimum daily temperature for robustness. All three temperature variable coefficients varied little in magnitude. As a result, we decided to only use the average daily temperature in our regressions.

Regression 2 adds a conservation budget variable which accounts for conservation expenditures by the Sonoma-Marin Saving Water Partnership that began in 2010. We use regression 1 as our base model and then add the conservation budget variable to the regression in order to compare the two. This allowed us to examine the effect that money spent by the Sonoma-Marin Saving Water Partnership had on water demand. This regression was run on our entire dataset, with the variable for budget being a 0 from 2006-2009 as the Partnership did not exist in those years. While there was conservation money spent during this time period, the 0 is used to allow us to measure the impact of formalizing the relationship amongst the partners through the creation of the Partnership.

Regression 3 adds the variables median household income and average water price to a new base case regression. We have the least amount of data for this regression as we only have pricing data from four retailers, and only have household income from 2010-2015. This regression includes retailers MMWD, North Marin, Santa Rosa, and Windsor — the four retailers for which we had price information — and begins in 2010 — the start date of our median household income variable. This regression is run on 144 observations versus 324 observations in regression 2 and 510 observations in the base case (Regression 1). Despite the small number of observations, we were interested to see potential correlation between price and household income on water demand.

Table 1 shows the breakdown of which variables are included in each regression. The table is followed by our units of measurements for the eight variables in our regressions.

Table 1: Regression Scenarios

	Regression 1: *Base Case*	**Regression 2:** *Adding Budget*	**Regression 3:** *Income & Price*
Retailers Included	9	9	4
Bimonthly Observations	60 (01/2006 - 01/2016)	60 (01/2006 - 01/2016)	36 (01/2010 - 01/2016)
Total Observations *(Retailers * Observations) - missing data*[17]	510	510	144
$Unemployment_{it}$	X	X	X
$PDSI_{it}$	X	X	X
$Temperature_{it}$	X	X	X
$Precipitation_{it}$	X	X	X
$News\ Articles_{t}$	X	X	X
$High\ Income_{it}$	X	X	
$Conservation\ Budget_{it}$		X	
$Median\ Income_{it}$			X
$Price_{it}$			X

Our units of measurement are as follows:

- **Water Demand:** Average bimonthly CCF/connection
- **Articles:** The number of drought-related articles published in a bimonthly period
- **Unemployment rate:** Percentage of the working population that is unemployed
- **Precipitation:** Inches of daily rainfall, averaged over bimonthly periods
- **Temperature:** Average daily degrees Fahrenheit, averaged over bimonthly periods
- **PDSI:** Unitless PDSI scale that ranges from -10 (dryest) to +10 (wettest)
- **Water Price**
    - **Avg. Price:** Average price paid per CCF by single-family residences of each

[17] For regression 1 and 2, we are missing data from Petaluma (2006), Cotati (2006, 2008 & 2009), and Valley of the Moon (2009). In regression 3, we are only using Marin, North Marin, Windsor, and Santa Rosa due to missing price data from the other five retailers.

retailer during a bi-monthly period. (2015$)

- **Income:** Median household income within a retailer's jurisdiction (2015$)
- **Budget:** Dollars spent by the Partnership annually.

Results

Qualitative Analysis

The analysis below offers correlations between various variables and water demand. While these qualitative results are correlative and should not be taken as causal conclusions, they informed our quantitative regression analysis results and interpretations, and provide guidance on areas for future analysis.

Water Demand vs. Population Density

Figure 14 demonstrates the relationship between population density and single-family residential water demand in 2015 in the nine retailers. Each point is a separate retailer that is plotted as a result of their single family residence water demand versus their average population density in 2015. As we suspected, with greater population density comes lower water demand in CCF per connection. This is perhaps due to the fact that higher population density generally correlates with smaller lot sizes and outdoor spaces of properties, where people use less water compared to those in lower population density areas with larger lots and outdoor spaces.[18]

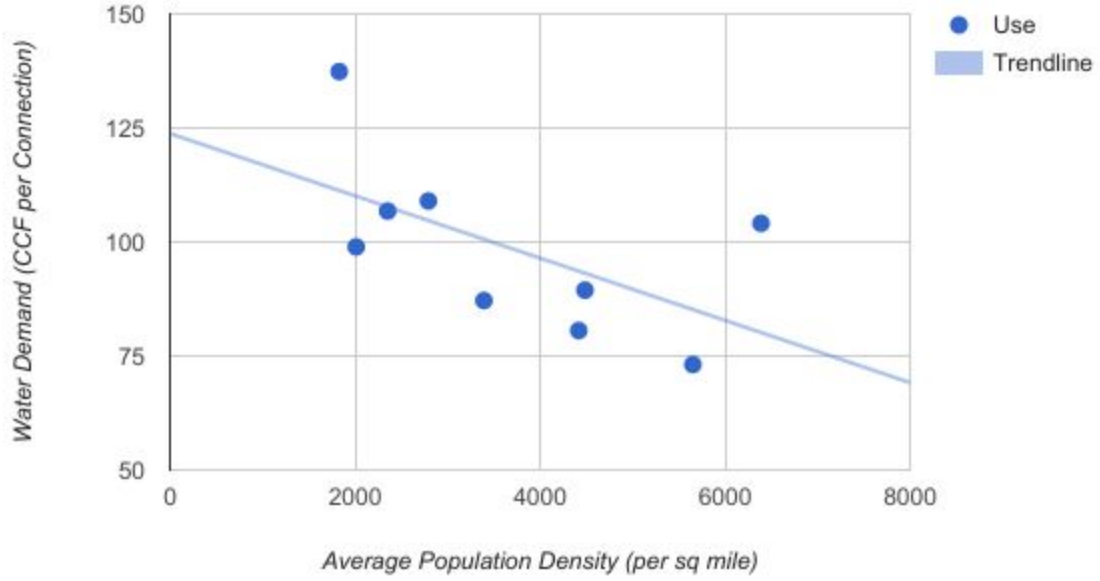


Figure 14: Total Annual Water Demand by Retailer in 2015 vs Population Density

[18] Kopits, Elizabeth, McConnell, Virginia, and Miles, Daniel, "Lot Size, Zoning, and Household Preferences: Impediments to Smart Growth?," Resources for the Future. April 2009. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-09-15.pdf.

Water Demand vs. Median Household Income

Figure 15 depicts the relationship between household income and single-family residential water demand. Each point is a separate retailer that is plotted as a result of their single family residence water demand versus their average household income in both 2010 and 2015. As much of the literature on water demand suggests, household income is a strong indicator of the amount of water a connection or household will use. Additional income for a household is typically associated with demanding more water which may come as a result of having larger homes or being less affected by the amount of money spent on water. An interesting aspect of Figure 15 is that the slope of the trend lines of 2010 and 2015 have not changed much despite the changes in income and water demand during that time period. As one can see, the water use in 2015 is lower than the water use in 2010, and this makes sense because the real household income decreased in all retailers from 2010-2015.

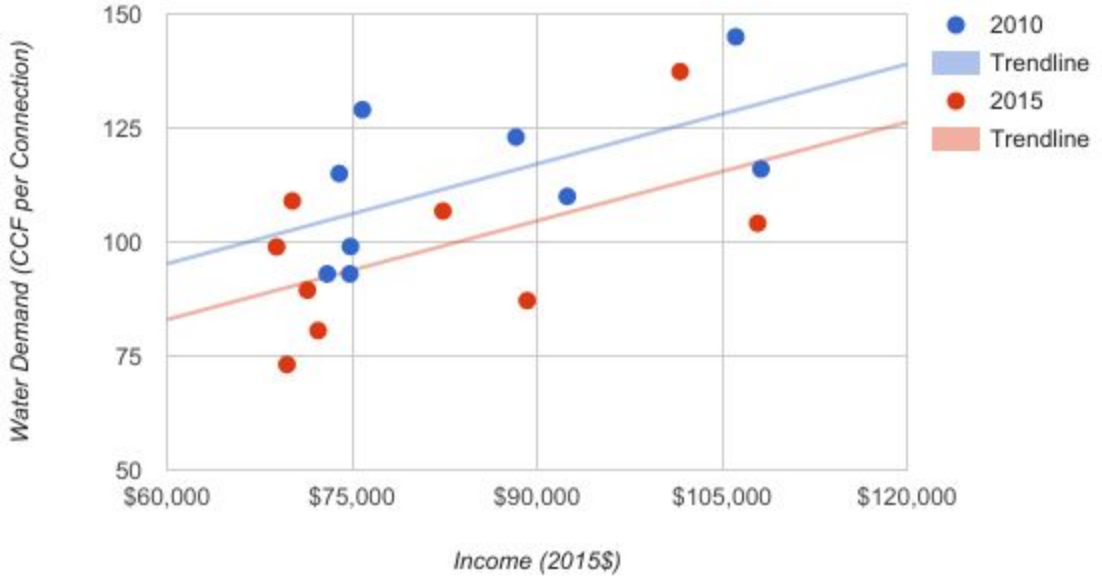


Figure 15: Total Annual Water Demand by Retailer in 2010 & 2015 vs Household Income

Water Demand vs. Educational Level

Education level is often used as a variable to explain variance in water demand. Figure 16 indicates the relationship between having higher educational levels and single-family residential connections demanding more water. While educational level is related with water demand, it is also similar to other variables for water demand such as household income level, lot size and unemployment rate. As a result, it is important to remember that while education level correlates with water demand, there are other factors that may account for this relationship.

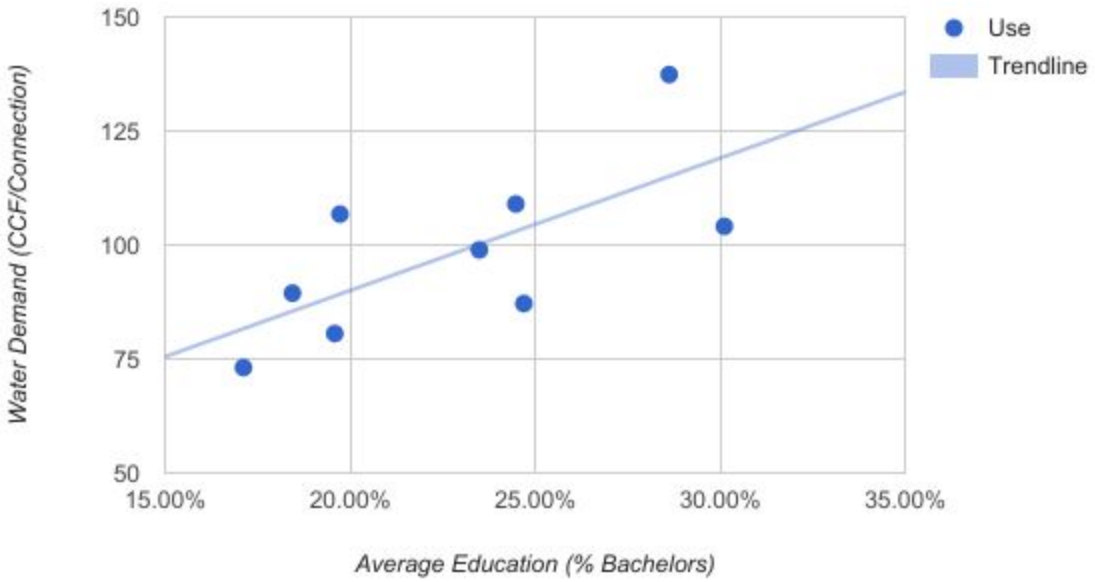


Figure 16: Total Annual Water Demand by Retailer in 2015 vs Educational Level

Water Demand vs. Percent Hispanic Population

Demographics, such as racial composition of regions, can be drivers of water demand. Certain cultures may have different attitudes towards water use, and the racial makeup of a retailer can help inform decisions for the retailer moving forward in terms of outreach and education. Figure 17 demonstrates the relationship between single-family residential water demand and percent Hispanic population in 2015 throughout the retailers. It is interesting to note that most of the retailers have large Hispanic populations with MMWD and North Marin being slightly behind. This data shows that all of the Sonoma County retailers have on average about a 25% Hispanic population. We were unable to compare Hispanic water demand to other ethnicities so this figure is primarily an illustrative example of the potential statistical relevance of racial composition.

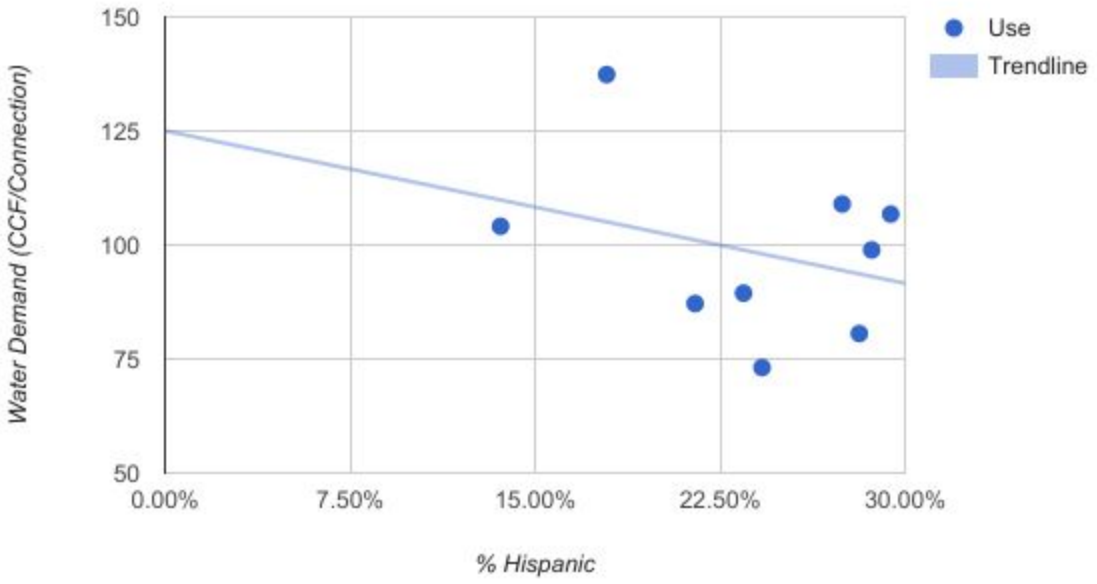


Figure 17: Total Annual Water Demand by Retailer in 2015 vs % Hispanic Population

Water Demand vs. Unemployment Rates

Unemployment rate, similar to household income, can be strongly correlated with water demand. As unemployment rates increase, it is expected that water demand decreases and vice versa. Figures 18 and 19, which show the unemployment rates for Sonoma and Marin counties versus CCF per connection single-family residential water demand in those counties, demonstrate the correlation between these two variables from 2006-2015. Figure 18 shows the aggregated annual water demand of the retailers in Sonoma County versus the annual unemployment rate in Sonoma County. Figure 19 shows the aggregated annual water demand of the retailers in Marin County versus the annual unemployment rate in Marin County.

An interesting takeaway from these figures is that unemployment and water demand are inversely correlated from 2006-2013, as one would expect, but in 2013-2015 they become correlated and trend in the same direction. Similar to the household income analysis, this demonstrates how the traditional methods of modeling water demand may have changed due to public knowledge of the drought and changed consumer behaviors and attitude toward water demand.

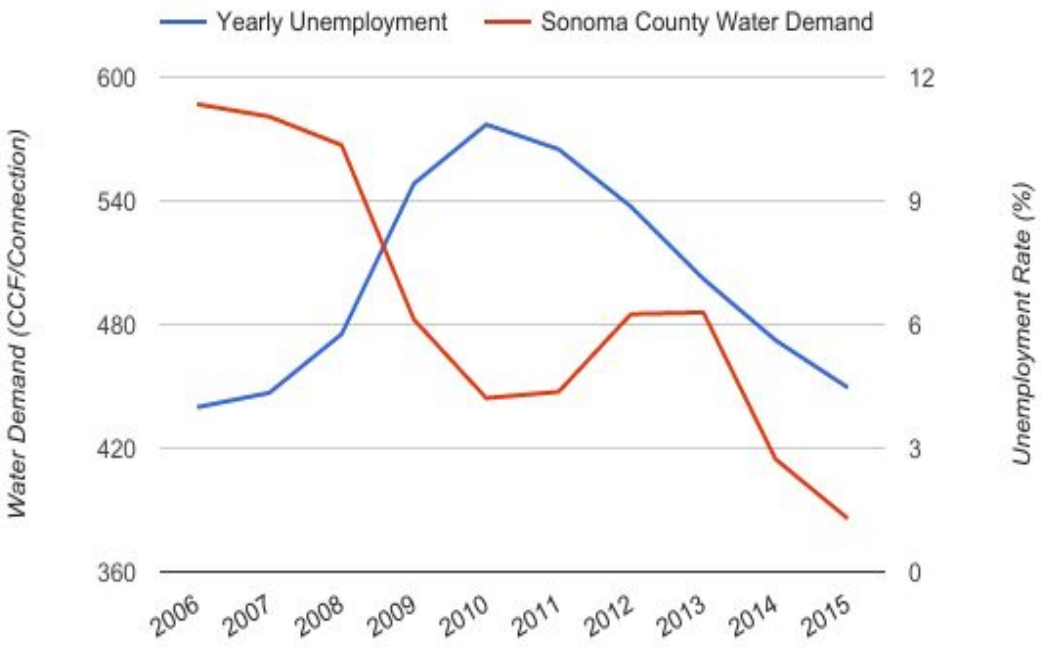


Figure 18: Aggregated Water Demand vs Unemployment Level in Sonoma County (2006-2015)

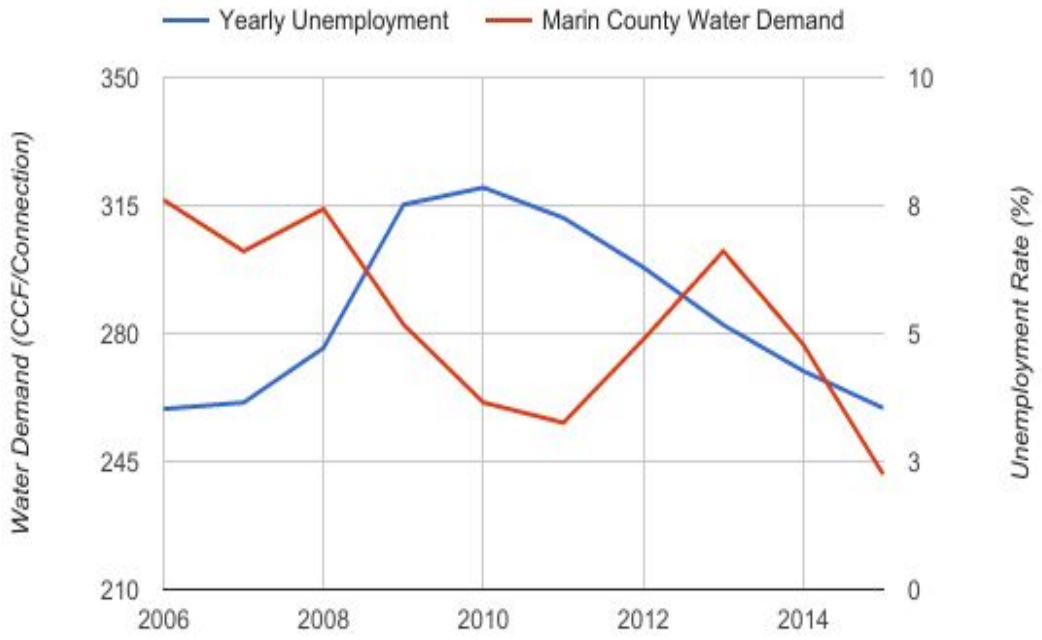


Figure 19: Aggregated Water Demand vs Unemployment Level in Marin County (2006-2015)

Quantitative Analysis: Regression Results

Regression 1: Base Case

Recall that our base case regression includes all relevant variables for which we had at least

510 observations. (This means we had to exclude price and income variables.) Table 2 shows the model outputs with base case variables (column 1), their coefficients (column 2), and their variance inflation factors, or VIFs (column 3, in parentheses). The VIF metric tells us whether the variables we included in our model are highly correlated, or *collinear*, which would be a problem for our regression. VIF values lower than 5 are considered permissible. Finally, a system of stars ranks the statistical significance of each coefficient, where three stars is the most statistically significant (p<0.001).

Table 2: Regression 1 Results

All Retailers, 2006-2015

	Base Model	
Articles	-0.00130***	(1.38)
Unemployment Rate	-0.0213***	(1.61)
Precipitation	0.0993	(1.94)
Temperature	0.0376***	(1.82)
PDSI	-0.0172*	(1.77)
High Income Retailer	0.114***	(1.14)
Constant	0.912***	
r2_a	0.543	
N	510	

vif in parentheses
* p<0.05, ** p<0.01, *** p<0.001

All variables in this model are significant at the 5-percent level (p<0.05), except for precipitation. This result is consistent with the econometric literature, which finds temperature as more explanatory of water demand than rainfall.[19]

With respect to our variable of interest, *volume of drought-related articles*, we find a coefficient of -0.00130. This means that an increase of 10 drought-related articles during a bimonthly period is associated with a reduction in single-family residential water consumption on the order of 1.3 percent, or 100 drought-related articles is associated with a 13% decrease in water use. We cannot conclude here that news articles themselves *cause* a reduction in water demand. Rather, this variable is a way to quantify the intensity of the public and political interest in the drought. For example, we see a big spike in the articles variable after Governor Brown declared a drought state of emergency in 2014. In the two years before the announcement, each bimonthly period averaged 25 drought-related news

[19] M. M. Haque, P. Egodawatta, A. Rahman, A. Goonetilleke, Assessing the significance of climate and community factors on urban water demand. Int. J. Sustain. Built Environ. (2015), doi:http://dx.doi.org/10.1016/j.ijsbe.2015.11.001.
M. S. Babel, N. Maporn, V. R. Shinde, Incorporating Future Climatic and Socioeconomic Variables in Water Demand Forecasting: A Case Study in Bangkok. Water Resour. Manag. 28, 2049–2062 (2014).

articles. In the two years after, each bimonthly period averaged 243 drought-related news articles. The Water Agency's service area residents accordingly reduced their water consumption after the announcement. However, during this time California's drought situation actually improved. Thus, even though the drought situation improved (PDSI went up), water demand continued on its downward trend, presumably because of increased public awareness due to political action, as quantified by the articles variable. This narrative fits with our negative coefficient on PDSI. Public perception of the drought at this time had possibly more of an effect on water consumption than did the less-salient PDSI value, which is a measure of soil moisture.

The rest of our coefficients seem sensible as well. We find that higher unemployment is associated with *less* water use and that higher average temperatures are associated with *more* water use. Additionally, we find that the high income retailers (MMWD, North Marin, Petaluma, and Windsor) experience 11-percent higher water demand on average than the other retailers.

Regression 2: Adding Budget

In order to add the budget variable, we keep our base model the same as in regression 1 from 2006-2015. We then ran a separate regression where we include our budget variable in order to see how this affects our base model. Table 3 below demonstrates the regression results.

Table 3: Regression 2 Results

All Retailers, 2006-2015

	Base Case		Add Budget	
Articles	-0.00130***	(1.380)	-0.000957***	(2.253)
Unemployment Rate	-0.0213***	(1.605)	-0.00925	(2.221)
Temperature	0.0376***	(1.820)	0.0371***	(1.829)
Precipitation	0.0993	(1.937)	0.0459	(1.955)
PDSI	-0.0172*	(1.770)	-0.0134	(1.809)
High Income Retailer	0.114***	(1.142)	0.129***	(1.181)
Budget			-0.000109**	(1.940)
Constant	0.912***		0.910***	
r2_a	0.543		0.552	
N	510		510	

vif in parentheses
* p<0.05, ** p<0.01, *** p<0.001

The resultant regression finds that budget is significant and results in a decrease in water

demand as the budget increases. This demonstrates the importance that money spent on the Partnership has had on decreasing water demand in the various retailers. In addition, we find that articles, temperature, and our control for being a high income retailer are still significant. The combination of the budget and article signifies the importance that public awareness of the drought has had on reducing water demand. These are important results as the Sonoma County Water Agency and the Partnership have control over their conservation budget while they do not have control over variables such as temperature.

Regression 3: Adding Income & Price

Our final regression includes four retailers (MMWD, North Marin, Santa Rosa, Windsor) from 2010 to 2015. As shown in Table 4, we present our typical base model in the "Base Model" column, then we added the variables median household income and average water price in successive columns.

Table 4: Regression 3 Results

Subgroup Retailers, 2010–2015

	Base Case	Add Price	Add Income	Add Both
Articles	-0.000978**	-0.00100**	-0.000762*	-0.000796*
	(2.175)	(2.181)	(2.334)	(2.352)
Unemployment Rate	-0.0571***	-0.0558***	-0.0200	-0.0215
	(2.140)	(2.146)	(3.993)	(4.007)
Temperature	0.0384***	0.0392***	0.0376***	0.0384***
	(1.969)	(1.993)	(1.975)	(2.003)
Precipitation	-0.146	-0.118	-0.268	-0.238
	(1.976)	(1.981)	(2.014)	(2.025)
PDSI	0.0346	0.0361	0.0111	0.0138
	(2.532)	(2.537)	(3.044)	(3.075)
Avg. Price		0.0295		0.0231
		(1.044)		(1.066)
Median Income			0.00000642**	0.00000598*
			(1.917)	(1.957)
Constant	1.241***	1.054**	0.420	0.330
r2_a	0.496	0.502	0.518	0.520
N	144	144	144	144

vif in parentheses
* p<0.05, ** p<0.01, *** p<0.001

We find that the average price coefficient is not significant in any specification in our model to predict water demand. For this reason, we cannot make any conclusions about the real effect of average price. This is perhaps due to water customers not being sensitive to water price, limited changes in average price over time or just due to our limited number of observations. We find that the income coefficient, on the other hand, to be significant in both models that it is present. A retailer's water demand is positively correlated with its median household income. This finding is widely supported by the literature, and it is unfortunate that we were unable to use this variable in regression 1 due to data limitations.

In addition, temperature and articles are found to be significant in the four models above. These two variables were significant in all of our different regressions which demonstrates the powerful effect that seasonality and public awareness have on water demand.

Omitted Variables

In any regression analysis, there is the potential for omitted variable bias. Omitted variable bias occurs when a variable that does in fact influence the dependent variable (water demand) is not included in the regression. When this happens, the effect of that omitted variable is instead distributed across the other included variables. Public awareness media spending by the State (in addition to the spending by the Agency), likely had a real impact on water demand in Sonoma and Marin counties, but was not included as a variable in the regression due to time constraints and data availability. Given that State spending would likely have decreased water demand, we assume that the regression coefficients of the other variables instead captured that effect and are therefore slightly smaller than they would have been had State spending been included. Another potential omitted variable is the effect of social media coverage, which is currently not included in our model. While it is an interesting topic, we believe the number of articles by itself is a good proxy of public awareness. A third potential omitted variable is the individual retailer rebate programs, which may have an effect on water demand. The magnitude of the effects of omitted variables in this analysis is likely small (most of the influential variables related to water demand were included), but should be taken into consideration if the results are being used for specific numerical projections.

Recommendations

From our analysis, we found that the variance in average water demand in single-family residences throughout Sonoma County Water Agency's service region was most responsive to media coverage of the drought in addition to the average temperature during our timeframe of interest. The increase of political and public awareness of the drought and water resource challenges, facilitated by news articles and media coverage, may indicate a more permanent shift in water demand behaviors in the Water Agency's region. While

traditionally unemployment rate and median household income are measures of water demand, we found that an increased public awareness of the California drought has shifted water demand trends, as seen in our qualitative and quantitative analysis. We offer several recommendations to further the effectiveness of the Sonoma County Water Agency and Sonoma-Marin Saving Water Partnership's efforts and encourage future analyses.

Recommendations for the Agency and Partnership

1. Focus on engagement with the customer through public awareness and outreach programs

Our results show that the anomalously high media coverage of the California drought, as represented by the number of articles written about it, is a clear and statistically significant driver of water demand. From our analysis, we believe that there has been a deviation in long-term single-family residential water demand trends, particularly due to the heightened public awareness of the drought with an increase in media coverage and outreach programs. Therefore, we recommend that in future drought management plans Sonoma-Marin Saving Water Partnership puts public awareness and outreach programs at the forefront of methods to decrease water demand among consumers.

In particular, we recommend that the Partnership continue programs such as their K-12 educational program, presentations at events such as the Sonoma County Fair, and teachers' workshops. These efforts contribute to heightened public awareness of water conservation efforts, programs, and rebates. Maintaining these efforts over time will help to increase the profile of water, making it a more frequent part of household conversation. In addition, the Partnership should engage more actively with local and regional media outlets to receive additional earned media.

As we saw in our Google Trends analysis, there was heightened public interest in the California drought and water conservation after media coverage of political statements or measures related to the drought. For example, there was a significant spike in searches related to the drought in January 2014 when Governor Brown declared the second drought state of emergency. Additionally, we saw in April 2015 a spike in searches about water conservation after the State board imposed a 25% restriction on water demand among California local water supply agencies. We recommend that the Partnership works closely with local government to further influence consumer behavior and conservation efforts. For example, the Partnership can work with county boards or city councils to create specific goals for water conservation, implementing plans following the effectiveness of SBx7-7's 20 x 2020 for the Water Agency's service area.

2. Use targeted advertising to increase participation in water conservation efforts

As we found in our qualitative analysis, many of the retailers have approximately a 25%

Hispanic population. Additionally, we found that in areas with a higher level of educational attainment, there is an increase in single-family residential water demand. This increase is perhaps due to a greater income from this greater educational attainment. We recommend that the Partnership works to create plans designed for each retailer's specific population of residents, and uses targeted advertising to create more effective shifts in water demand or consumer behavior. The Partnership can implement more Spanish language campaigns to those retailers which have a higher Hispanic population, or can target outreach towards those with Bachelor's degrees or higher income since they typically have a higher water demand. Retailers also can use gadgets, behavior platforms, or apps to further engage specific groups by informing them about their water use and how they compare to their neighbors or peers.

The Partnership may also consider focusing pricing changes or incentive structures on higher income areas in Marin and Sonoma Counties during drought periods. The data suggests that during times of water shortage, high-income areas may be important targets for water demand reduction opportunities. The Partnership can target ad campaigns or specific rebate, toilet, or washer programs to high income retailers in order to create a greater overall reduction in water demand. In 2015, the Partnership achieved over 3,000 water smart home evaluations, installed around 5,000 more efficient toilets, and gave around 1,000 high-efficiency washer rebates.[20] We recommend that they continue these types of programming, with a particular focus on high-income areas.

Additionally, we found that lower population density is correlated with higher single-family residential water demand. This is perhaps due to the fact that with a lower population density, people may have larger lot sizes and outdoor spaces, meaning people might use more water. In 2015 the Partnership removed over 1 million square feet of lawn and gave over 1,000 rebates for Cash for Grass/Mulch Madness.[21] We recommend that the Partnership targets these types of rebate programs to low population density district retailers.

Moreover, another key factor for determining single-family residential water demand was seasonality, with higher water demand per connection during the warmer months of the year. Therefore, we recommend that the Partnership increases conservation budget spending particularly in the summer months, through similar rebate and education programs. The Partnership can also promote the use of less water-intensive native plants for landscaping. We believe that this focus on water conservation education and programming in the summer months would result in a more efficient use of the conservation budget.

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[20] Sonoma-Marin Saving Water Partnership, 2015-2016 Annual Report. http://www.savingwaterpartnership.org/wp-content/uploads/15-16-SMSWP-Annual-Report-v8web.pdf.

[21] Ibid.

3. Improve data reporting

Though our conservation budget variable was not significant in our regression, we think that this is perhaps due to data limitations (low sample size and omitted variables). Therefore, we still are confident that the Partnership has been beneficial for the Water Agency's service area. This is especially because it is a great way to unify the retailers and create a mutual goal among retailers to reduce water demand throughout the region.

Future analyses could benefit from more detailed data on retailer-specific and partnership-wide conservation budget spending, programs, and participation level. In the same way, Sonoma County Water Agency standardizing and/or centralizing pricing data from its retailers could greatly facilitate future analyses.

Additionally, we recommend that there be a database that standardizes water demand units and pricing structures across the Water Agency's retailers. Currently, various retailers use different metrics for water demand, such as CCF, acre feet or thousand gallons. In our analysis, we chose to standardize all the water demand data we used to CCF, but standardizing to any metric would greatly increase the ease of analysis and comparison across retailers in future analyses. Also, creating a database will ensure that all data is available for future analysis as currently there is missing water demand or pricing structures from various retailers.

Recommendations for Future Analyses

1. Expand scope of analysis

Our analysis only covered single-family residences, but it would be interesting to examine the differences in behavior changes in multi-family residences, commercial buildings, or other deliveries. Perhaps the magnitude of the effects of the variables we studied in this analysis would change when considering other water consumers in the region. Additionally, the Sonoma-Marin Saving Water Partnership may learn how to better target its efforts and outreach campaigns with a more comprehensive image of water demand patterns and behavior across all connections, rather than just looking at the single-family residential water demand.

We also recommend that future analyses further investigate demographic variables such as race/ethnicity, languages spoken, more comprehensive educational attainment metrics, and age in both qualitative and quantitative analyses. Through this in-depth study of demographics, the Partnership may learn how to more effectively use targeted advertising and programming to its diverse population of consumers.

2. Further investigate complications of pricing data

Pricing posed a large challenge to our group when trying to incorporate it into our regression. This was primarily due to the circularity of the average price paid per CCF of water in conjunction with water demand. Since many water retailers use tiered pricing, consumers pay the most for their water when their water demand is the highest. For example, in the summer months a consumer will likely pay more on average for water than in the winter months because they will often reach the second tier of pricing. When the average price paid per CCF is the highest, the consumer also chooses to demand the most water which is not intuitive to how consumers normally respond to price. We attempted to overcome this challenge by creating a dummy variable for warm months to account for this seasonality, but we had to get remove of it due to its high correlation with temperature.

Price as a determining factor for water use also faces the challenge that water demand isn't directly sensitive to price in the same way that other goods are, both because of the delay consumers experience in receiving their bill and the difficulty the general public has in estimating their daily water use. Changes in water pricing, therefore, might not be the most effective mechanism for encouraging changes in water use going forward.

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