DRY TAPS: ANALYZING THE EFFECTIVENESS OF DROUGHT CONSERVATION ACTIONS ENACTED BY CALIFORNIA WATER SUPPLIERS

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Abstract

Water conservation policy during a drought in California is often left to the water supplier to develop and implement with the goal of meeting a defined reduction. In December 2022, there were over 370 water suppliers in California. Most research has focused on the response of conservation actions by studying select individual suppliers. However, given California's interconnected water systems, a statewide study is warranted. This paper analyzes the cumulative actions of water suppliers using multivariable regression models and identifies what conservation actions reduced residential water use and provides reasons why each supplier should implement their own strategies to reduce the water consumption of their customer base. The analysis shows that certain actions, such as water usage restrictions and drought surcharge pricing, were effective at a statewide level in obtaining a statistically significant reduction in residential water consumption. Additional findings show responsiveness to drought policy is complex and can vary by region, supporting local research and subsequent implementation.

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1. Introduction

Water service is one of five services identified as an utility in California.[1] When turning on the tap, it is expected that potable water, also known as domestic water or drinking water, will flow and the lack thereof can render a residence uninhabitable.[2] Recent years have shone a spotlight on the water issues in California, with many reservoirs reaching historic lows resulting from increased population growth and metropolitan expansion.[3] This growth has placed a strain on reservoirs to supply the public with needed water, while the replenishment of the reservoirs has become more volatile.[4]

Drought policy making has often balanced the social, political, and environmental considerations at the time. The notices sent by a water supplier with drought use restrictions and the enactment of surcharges can seem arbitrary, leaving the customer wondering if these actions even work. Frustration can mount when customers cannot wash their car in their own driveway and are subject to higher water bills due to surcharges or fines. The policies can also become stricter over time, with no definitive end date as a season's rainfall is unpredictable. Effective and data-backed can show customers why certain drought policies are in place, offering transparency into the process and showing the results. Similar to how government spending is subject to audits, these drought conservation policies should be examined to ensure proper actions are enacted and responses obtained.

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[1] "Utilities," State of California - Department of Justice - Office of the Attorney General, accessed February 6, 2023, https://oag.ca.gov/consumers/general/utilities.
[2] "Regulation of Buildings Used for Human Habitation," 17920.3 Health and Safety Code §, accessed April 11, 2023, https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=HSC&sectionNum=17920.3.
[3] "USGS Water-Year Summary for Lake Oroville," accessed April 14, 2023, https://waterdata.usgs.gov/ca/nwis/wys_rpt/?site_no=11406800.
[4] Kai Lepley et al., "A Multi-Century Sierra Nevada Snowpack Reconstruction Modeled Using Upper-Elevation Coniferous Tree Rings (California, USA)," *The Holocene* 30, no. 9 (September 1, 2020): 1266–78, https://doi.org/10.1177/0959683620919972.

This paper utilizes the data water suppliers are required to report to the California State Water Resources Control Board to understand the effectiveness of drought conservation actions at a statewide level.[5] California is the ideal subject for a study of this kind as there have been several drought proclamations and demands for water use reduction leading to the implementation of various drought conservation actions. Additionally, given the severity of recent droughts in the state and the uncertain future of water supply stability, evaluating the methods to curb water use for this market can expose solutions with meaningful impacts.

To answer this topic, multivariable linear regression analysis and feature engineering techniques were used to evaluate the responsiveness of residential customer potable water use to the drought conservation actions implemented by their water supplier. It was found at a statewide level there are four actions that have a statistically significant reduction in water use – water usage restrictions, drought surcharge pricing, direct messaging from the supplier, and physical advertising. Additional findings show that there is considerable variation in baseline water use between regions which is explored in this paper.

The results at the regional level revealed drought conservation actions can result in different statistically significant responses from reduction in usage to an apparent increase in water consumption depending on the locality of the customer. The distinctive set of conservation actions effective for each region suggests drought conservation policy should be focused on a local level.

[5] "California Urban Water Production," Water Conservation Portal - Conservation Reporting, accessed February 20, 2023, https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/conservation_reporting.html.

2. Literature Review and Theoretical Framework

2.1 Public Policy Context

The droughts and growing metropolitan population in California have forced water suppliers throughout the state to balance rationing water supplies while still fulfilling water needs. Agriculture is a significant sector of California's water use and accounts for 77% of its water use.[6] Water in California also serves more than its face value as a commodity, with 7% of the power generated in 2021 being hydroelectric.[7] Other industries are also affected by low water levels such as recreation and tourism, highlighting the importance of maintaining adequate supplies of water.[8] Despite the largest water use sector being agriculture, conservation efforts are focused on residential and urban water users due to water rights and other political and legal reasons.[9] Conservation policy is often further complicated by politics as many water districts are managed by elected officials, who may place emphasis on re-election needs when developing policy.[10] Practical, effective, and supported policies are essential in providing for a stable water future accounting for the fluctuations in supply and demand. Currently, the most common water conservation methods are demand-side policies relying on voluntary rationing policies, command-and-control policies, or a combination of both.[11]

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[6] Ellen Hanak, ed., *Managing California's Water: From Conflict to Reconciliation* (San Francisco, CA: Public Policy Institute of California, 2011).
[7] "2021 Total System Electric Generation," California Energy Commission, accessed February 13, 2023, https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2021-total-system-electric-generation.
[8] Jake Hutchison, "Three Lake Oroville Boat Launches Close Because of Low Water Level," *The Mercury News*, September 29, 2022, https://www.mercurynews.com/2022/09/29/three-lake-oroville-boat-launches-close-because-of-low-water-level/.
[9] Sheila M. Olmstead and Robert N. Stavins, "Comparing Price and Nonprice Approaches to Urban Water Conservation," *Water Resources Research* 45, no. 4 (2009), https://doi.org/10.1029/2008WR007227.
[10] Phillip J. Ehret et al., "Systematic Review of Household Water Conservation Interventions Using the Information–Motivation–Behavioral Skills Model," *Environment and Behavior* 53, no. 5 (June 1, 2021): 485–519, https://doi.org/10.1177/0013916519896868.
[11] Olmstead and Stavins, "Comparing Price and Nonprice Approaches to Urban Water Conservation."

Voluntary conservation methods are easy for a utility to distribute and are typically presented in direct communication messages with the customer, either by mail or electronically. The communications can be categorized on the "information-motivation-behavioral skills model (IMB)".[12] Information communication consists of informing consumers that there is a drought, while an example of motivation communication is providing a conservation goal of a 20% reduction in use compared to the prior year.[13] Behavior skills are the actions that can be done to conserve water.[14] These three communication skills are not mutually exclusive, and messages can have any combination of the skills.[15]

The main command-and-control method is price increases, with the expectation that an increase in price will cause consumers to decrease their usage.[16] Price increases are dual-purpose for a water utility, where on one hand this financially incentivizes a reduction in water use, while on the other hand the fiscal stability of the utility is supported against the reduced water sales revenue. The way a water utility enacts the price increase falls into two categories: surcharge pricing and block pricing.[17] Surcharge pricing works by adding a fixed fee to every unit of volume sold during the period of effect. Block pricing allocates an amount of water to a household and exceeding the allotment results in greater surcharges.[18]

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[12] Ehret et al., "Systematic Review of Household Water Conservation Interventions Using the Information–Motivation–Behavioral Skills Model."
[13] Heather Hodges et al., "How Managers Can Reduce Household Water Use Through Communication: A Field Experiment," *Journal of Policy Analysis and Management* 39, no. 4 (2020): 1076–99, https://doi.org/10.1002/pam.22246.
[14] Hodges et al.
[15] Hodges et al.
[16] James E.T. Moncur, "Drought Episodes Management: The Role of Price," *JAWRA Journal of the American Water Resources Association* 25, no. 3 (1989): 499–505, https://doi.org/10.1111/j.1752-1688.1989.tb03085.x.
[17] Harrison Zeff, Gregory W. Characklis, and Walter Thurman, "How Do Price Surcharges Impact Water Utility Financial Incentives to Pursue Alternative Supplies during Drought?," *Journal of Water Resources Planning and Management* 146, no. 6 (June 1, 2020): 04020042, https://doi.org/10.1061/(ASCE)WR.1943-5452.0001228.
[18] Zeff, Characklis, and Thurman.

2.2 Effectiveness of Conservation Policies

Research has been conducted on the various types of conservation policies discussed primarily at the municipal or supplier level. The studies have shown varying degrees of success in the amount of water conserved. One study on households in Central California measured the effectiveness of messaging using the information-behavioral skills, information-motivation skills, and a combination IMB skills message.[19] On average, there was a 9.8% reduction in water use within 30 days compared to the control households which did not receive messaging, but there was not a discernible difference between the three types of messages.[20] A San Francisco Bay Area study showed policy and awareness can also be communicated through media coverage in parallel with the water supplier messaging campaigns.[21] It was found that for each increase in 20 articles relating to the drought, there was a 2% to 3.5% decrease in residential water use.[22]

A Hawaii-based study estimated that, depending on price elasticity and using only price as a conservation tool, it would take raising the price of water by 35% to 300% to obtain a 10% reduction in water consumption.[23] Another study found that, on average, in the United States a 10% price increase results in a 3% to 4% short term reduction in demand. To achieve a 20% reduction in water consumption, a price increase of approximate 50% is required.[24] Price can be an effective factor in conservation efforts, however it may take substantial price increases to obtain a reduction.

[19] Hodges et al., "How Managers Can Reduce Household Water Use Through Communication."
[20] Hodges et al.
[21] Kimberly J. Quesnel and Newsha K. Ajami, "Changes in Water Consumption Linked to Heavy News Media Coverage of Extreme Climatic Events," *Science Advances* 3, no. 10 (October 25, 2017): e1700784, https://doi.org/10.1126/sciadv.1700784.
[22] Quesnel and Ajami.
[23] Moncur, "Drought Episodes Management."
[24] Olmstead and Stavins, "Comparing Price and Nonprice Approaches to Urban Water Conservation."

2.3 Impacts of Conservation Policies

Conservation policies can have implications beyond water use reduction. Resulting adverse effects have been found to result in lower revenue for the utility, which hinders capital works projects to replace aging infrastructure.[25] In some cases it was found that water use increased, or there was an increased financial strain on low-income households.[26,27]

From a strict water conservation perspective, effective voluntary rationing is ideal. However, water utilities rely on rates to recover their costs and reduced sales during droughts can hinder their ability to repay bond debts that are used to finance long term capital projects.[28] To combat the variability in volumetric sales, utilities use fixed charges or drought surcharges to supplement revenue recovery for more than just the marginal cost of water.[29,30] An alternative approach over 50% of the utilities in California use is an implementation of a block rate structure that includes a fixed charge, allocating pricing to specific volume ranges.[31,32] However, most lacked custom ranges to allocate the amount to each house based on various factors such as lawn size, number of occupants, and building square footage.[33,34]

[25] Zeff, Characklis, and Thurman, "How Do Price Surcharges Impact Water Utility Financial Incentives to Pursue Alternative Supplies during Drought?"
[26] Benjamin Rachunok and Sarah Fletcher, "Socio-Hydrological Drought Impacts on Urban Water Affordability," *Nature Water* 1, no. 1 (January 2023): 83–94, https://doi.org/10.1038/s44221-022-00009-w.
[27] Janine M. Stone and Patrick S. Johnson, "Conserving for the Common Good: Preferences for Water Conservation Policies during a Severe Drought in Northern California," *Water Resources and Economics* 37 (January 1, 2022): 100191, https://doi.org/10.1016/j.wre.2021.100191.
[28] Zeff, Characklis, and Thurman, "How Do Price Surcharges Impact Water Utility Financial Incentives to Pursue Alternative Supplies during Drought?"
[29] Peter Mayer et al., "Water Budgets and Rate Structures: Innovative Management Tools," *Journal AWWA* 100, no. 5 (2008): 117–31, https://doi.org/10.1002/j.1551-8833.2008.tb09636.x.
[30] Zeff, Characklis, and Thurman, "How Do Price Surcharges Impact Water Utility Financial Incentives to Pursue Alternative Supplies during Drought?"
[31] Zeff, Characklis, and Thurman.
[32] Mayer et al., "Water Budgets and Rate Structures."
[33] Zeff, Characklis, and Thurman, "How Do Price Surcharges Impact Water Utility Financial Incentives to Pursue Alternative Supplies during Drought?"
[34] Mayer et al., "Water Budgets and Rate Structures."

Consequently, lower income households are more negatively impacted by price-based measures, and fixed charges set a floor price that no amount of conservation can offset.[35] According to a study of a city in the Central Coast of California, low-income households spent 5.2% of their income on their water bill, while high-income households only needed to spend 0.8%, which amounted to $54 and $120 respectively.[36] Another study found that 20.5% of individuals reported they would lower spending on less essential goods (e.g. education, home furnishings, personal care products, etc.) if their water bill increased by $12, while 14% percent reported they would lower spending on essential goods (e.g. utility bills, mortgage payments, medications, etc.).[37]

In certain cases, water use increased amid policies that promoted the installation of high efficiency devices, termed "the rebound effect."[38] Due to the increase of high-efficient water devices, some would be more inclined to take longer showers or run the washer more frequently without a full load due to the belief that the appliances were using less water overall.[39] These impacts show the need for equitable water conservation policies that balance the sustainability and financial implications.

2.4 Limitations and Additional Considerations

The existing research to date focuses on specific suppliers or municipalities and does not account for the interconnectedness of the water systems throughout the state. The State Water Project "is a multi-purpose water storage and delivery system that extends … two-thirds the

[35] Rachunok and Fletcher, "Socio-Hydrological Drought Impacts on Urban Water Affordability."
[36] Rachunok and Fletcher.
[37] Laura Medwid and Elizabeth A. Mack, "A Scenario-Based Approach for Understanding Changes in Consumer Spending Behavior in Response to Rising Water Bills," *International Regional Science Review* 44, no. 5 (September 1, 2021): 487–514, https://doi.org/10.1177/0160017620942812.
[38] Stone and Johnson, "Conserving for the Common Good."
[39] Stone and Johnson.

length of California" and supplies water to over 65% of Californians.[40,41] Although each supplier is responsible for monitoring the water they distribute, the consequences of not following reduction policies reach farther than just the consumers they serve. Drought response and effectiveness at the state-wide level has not been heavily studied despite the reliance of each water supplier to curtail water distribution. The research in this paper aims to provide a macro evaluation of the conservation efforts throughout the state, assessing if the measures are working as intended and if there was a consequential reduction in water use.

3. Data and Methods

3.1 Data

The analyses focus on the responsiveness of water users to conservation actions in the State of California. Potable water is regulated in California by the State Water Resources Control Board and is provided to customers by a local water supplier. This study utilized two data sets consisting of information water suppliers report to the State Water Resources Control Board. The first data set is water supplier monthly usage reports which contains 40,619 observations and ranges from June 2014 through December 2022. Three variables were used from the data set – the month of the reported information, supplier identification number, and the residential gallons per capita per day use of water.

The second data set is water supplier monthly drought actions. The data set contains 7,205 observations and ranges from October 2020 through December 2022. Drought conservation actions enacted by each supplier and the months they were in effect are provided in

[40] "State Water Project," accessed February 16, 2023, https://water.ca.gov/Programs/State-Water-Project.
[41] "U.S. Census Bureau QuickFacts: California," accessed February 16, 2023, https://www.census.gov/quickfacts/CA.

this data set. The study will focus on the drought conservation efforts of suppliers throughout California, so the monthly supplier drought action data is joined with water supplier monthly usage reports by supplier identifier and reported month creating a merged data set with 7,205 observations. There were 476 observations removed due to non-standard coding of the local drought conservation stage enacted as it is a supplier filled text field, leaving 6,729 observations for analysis.

There were 14 variables selected from the data sets for use in this analysis. The dependent variable of residential gallons per capita day (RGPCD) along with 13 independent variables. Table I contains the variables and descriptions of the variables that were used in this research.

Table I: Variables and Definitions

Variable Name	Variable Definition	Data Set
RGPCD	Number of gallons of water used per day per capita by residential customers	California State Water Resources Board – Monthly Supplier Reports
RaiseRates	Supplier raised rates as a drought conservation action (Y/N)	California State Water Resources Board – Drought Response Actions
Surcharge	Supplier enacted drought surcharges as a drought conservation action (Y/N)	California State Water Resources Board – Drought Response Actions
Rebate	Supplier provided rebates for water efficiency items (Y/N)	California State Water Resources Board – Drought Response Actions
UseRestrict	Supplier restricted water use for certain purposes (car washes, outdoor watering, etc.) (Y/N)	California State Water Resources Board – Drought Response Actions
Blocks	Supplier utilized a water block-based rate structure (Y/N)	California State Water Resources Board – Drought Response Actions
Fines	Supplier enacted the use of fines (Y/N)	California State Water Resources Board – Drought Response Actions
DirectMsg	Total number of categories used by the supplier to convey conservation actions with categories of electronic mail, paper mail, customer application, and supplier website	California State Water Resources Board – Drought Response Actions

eAds	Total number of categories used by the supplier to convey conservation actions with categories of YouTube, Facebook, Instagram, other social, radio, and news article	California State Water Resources Board – Drought Response Actions
PhysicalAds	Total number of categories used by the supplier to convey conservation actions with categories were community event, door hanger, workshop, billboard, paid advertising, and bus shelter	California State Water Resources Board – Drought Response Actions
LocalStage	Drought stages suppliers were in on a scale of 0 to 5, with 5 being the most severe	California State Water Resources Board – Drought Response Actions
Month	Year and month of the reported data	California State Water Resources Board – Drought Response Actions
ID	Unique identification number of the water supplier	California State Water Resources Board – Drought Response Actions
HydroRegion	Hydrologic region the supplier is located in	California State Water Resources Board – Drought Response Actions

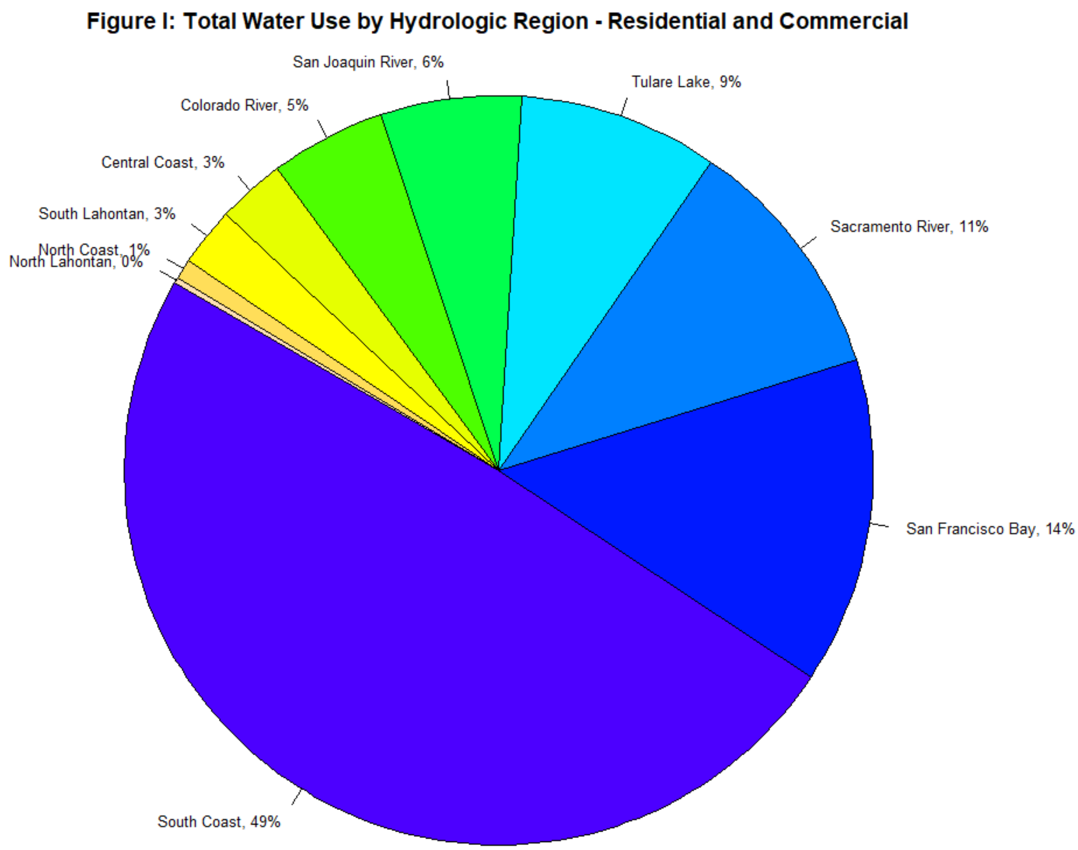


Figure I: Total Water Use by Hydrologic Region - Residential and Commercial
San Joaquin River, 6%
Tulare Lake, 9%
Colorado River, 5%
Central Coast, 3%
South Lahontan, 3%
North Coast, 1%
North Lahontan, 0%
Sacramento River, 11%
San Francisco Bay, 14%
South Coast, 49%

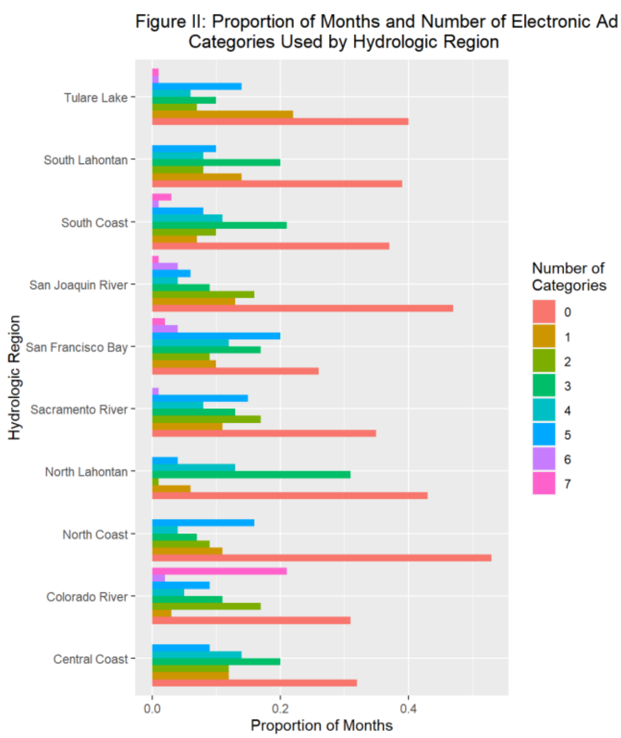


Figure II: Proportion of Months and Number of Electronic Ad Categories Used by Hydrologic Region
Tulare Lake
South Lahontan
South Coast
San Joaquin River
San Francisco Bay
Sacramento River
North Lahontan
North Coast
Colorado River
Central Coast
Hydrologic Region
0.0
0.2
0.4
Proportion of Months
Number of Categories
0
1
2
3
4
5
6
7

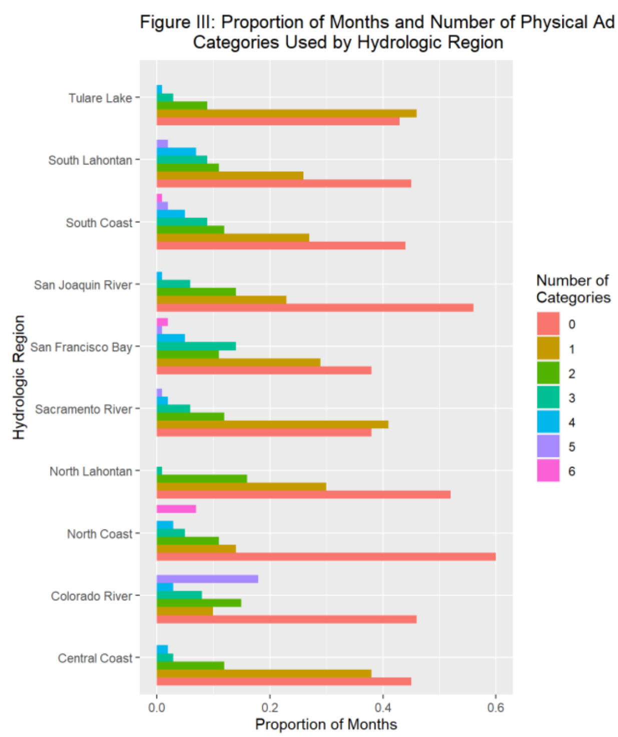


Figure III: Proportion of Months and Number of Physical Ad Categories Used by Hydrologic Region
Tulare Lake
South Lahontan
South Coast
San Joaquin River
San Francisco Bay
Sacramento River
North Lahontan
North Coast
Colorado River
Central Coast
Hydrologic Region
0.0
0.2
0.4
0.6
Proportion of Months
Number of Categories
0
1
2
3
4
5
6

3.2 Methods

Traditional conservation action variables were selected from the data set for analysis. Supplier was a control variable across all models to account for local factors such as rainfall, prices, population density, and socio-economic measures among others. The conservation data set provides some conservation actions as “Y” to indicate the action was enacted, otherwise, the field is left empty. This was recoded to “1” to indicate the action was enacted, else it was “0”. In the case of advertising and outreach, the 17 fields were consolidated into three primary categories, electronic advertising, physical advertising, or direct messaging to create efficient feature engineered independent variables. The original mode of communication and the subsequent consolidated category definitions are defined in Table I.

The analyses utilized both log-linear and linear-linear ordinary least squares multivariable regression models with various control variables. Log-linear multivariable regression was chosen to study the impact of conservation action independent variables by percentage change providing a meaningful unit to measure the change. Linear-linear multivariable regression was chosen to observe the baseline differences between regions and provide a quantitative volume unit for reference.

All models have residential gallons per capita per day as the dependent variable and contain the traditional conservation variables. The traditional conservation actions can be grouped into three types, financially incentivized, command-and-control, and outreach. The financially incentivized conservation actions were done by raising rates, utilizing drought surcharges, offering rebates, use of block pricing, and the implementation of fines. The command-and-control action studied was the use restrictions. Outreach was studied using the number of methods for direct messaging, number of categories of electronic advertising used, and number of physical advertising categories used.

4. Results

4.1 Significant Predictors Result in Overall Lower Consumption

Two multivariable analyses were done to evaluate the effects of conservation actions on residential gallons per capita per day (RGPCD) with the results presented in Table II. Both models utilize the supplier as a control variable. The first model identified the statistically significant conservation variables as drought surcharges, raising rates, use restrictions, fines, and electronic and physical advertising. The use of drought surcharges reduced water consumption by 6.6% and the implementation of use restrictions reduced consumption by 2.9%. Counterintuitively, the institution of fines raised water consumption by 8% and higher rates increased consumption by 4%, while electronic advertising or physical advertising used for promoting water conservation increased water consumption by 0.9% and 1.4% respectively. This meant that if a supplier advertised on social media, television, and radio, there was a predicted increase in water use of 2.7%. The adjusted R^2 for the first model is 0.689, meaning that 68.9% of the variation in the data can be accounted for by this model. The increase in water use by traditional conservation variables in this model indicates the model may suffer from omitted variable bias.

The second model utilized the calendar month as a control variable to account for the seasonality of water and any latent variables that may be attributed to the change in water use throughout the year. Drought surcharges, use restrictions, direct messaging from the supplier, and physical advertising were the most effective statistically significant conservation actions reducing residential water use resulting in 5.6%, 3.2%, 1.3% and 1.5% respectively. There were no significant traditional conservation actions identified that caused an increase in water use and 86.6% of the variance in the data can be accounted for in this model, a 17.7% increase from model one.

Table II: Statewide Responsiveness to Conservation Actions

	Dependent Variable:	
	Log Transformed RGPCD	
	(1)	(2)
RaiseRates	0.040^{*} (0.019)	0.022 (0.014)
Surcharge	-0.066^{***} (0.019)	-0.056^{***} (0.013)
Rebate	0.019 (0.015)	-0.005 (0.010)
UseRestrict	-0.029^{*} (0.012)	-0.032^{***} (0.008)
Blocks	-0.024 (0.078)	0.093 (0.053)
Fines	0.080^{***} (0.021)	0.016 (0.013)
DirectMsg	0.001 (0.005)	-0.013^{***} (0.003)
eAds	0.009^{*} (0.004)	0.005 (0.003)
PhysicalAds	0.014^{**} (0.005)	-0.015^{***} (0.003)
Constant	4.216^{***} (0.046)	4.059^{***} (0.025)
Month Control	No	Yes
Supplier Control	Yes	Yes
Observations	6,729	6,729
R^2	0.708	0.874
Adjusted R^2	0.689	0.866
Residual Std. Error	0.256	0.169
F Statistic	37.618^{***}	104.628^{***}

Note: $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$
Standard errors are robust standard errors
RGPCD is water use measured as residential gallons per capita per day
Data Source: California State Water Resources Control Board

4.2 Regression Results with Hydrologic Regions

California comprises ten hydrologic regions – Central Coast, Colorado River, North Coast, North Lahontan, Sacramento River, San Francisco Bay, San Joaquin River, South Coast, South Lahontan, and Tulare Lake. The Appendix contains a map, Figure V, with the boundaries of each hydrologic region. Every water supplier in the state belongs to one of the hydrologic regions and the regions are mutually exclusive. An analysis was done to include an independent variable for the hydrologic region with the results presented in Table III. There was a negligible increase in the adjusted R^2 value for Model 3 which may be attributed to the supplier geographical area being a subset of the hydrologic region resulting in no significant improvement in the model. All four significant conservation variables found in model two were also found in models three and four.

The analysis presents differences in baseline usage between the hydrologic regions. Models one, two, and three are log-linear ordinary least squares (OLS) models focusing on identifying the percentage change of independent variables to measure the impacts of the conservation actions. Model 4 is a linear-linear OLS model with the same control and independent variables as model three to obtain the baseline usage in gallons. It was found that the average residential user in the Sacramento River region has an 88 gallon per day increase in water use above the baseline Central Coast region, while the average increase for the residential users in the San Francisco Bay region was only 24 gallons. The significant differences in baseline usage demonstrate the variation in water use between the regions and the ability to be responsive to conservation actions.

Table III: Responsiveness to Conservation Actions with Hydrologic Region

	Dependent Variable:	
	Log Transformed RGCPD	RGPCD
	(3)	(4)
RaiseRates	0.022 (0.014)	3.083 (2.150)
Surcharge	-0.056*** (0.013)	-5.430*** (1.528)
Rebate	-0.005 (0.010)	-1.124 (1.612)
UseRestrict	-0.032*** (0.008)	-3.053** (1.173)
Blocks	0.093 (0.053)	11.204 (5.912)
Fines	0.016 (0.013)	2.854 (1.863)
DirectMsg	-0.013*** (0.003)	-1.513*** (0.448)
eAds	0.005 (0.003)	0.441 (0.369)
PhysicalAds	-0.015*** (0.003)	-1.638** (0.510)
HydroRegionColorado River	0.284*** (0.034)	13.421** (5.031)
HydroRegionNorth Coast	0.175*** (0.031)	10.219** (3.552)
HydroRegionNorth Lahontan	0.669*** (0.076)	54.527*** (8.321)
HydroRegionSacramento River	0.949*** (0.065)	88.331*** (9.161)
HydroRegionSan Francisco Bay	0.364*** (0.028)	23.940*** (4.293)
HydroRegionSan Joaquin River	0.327*** (0.054)	19.585*** (4.971)
HydroRegionSouth Coast	0.764*** (0.046)	59.144*** (5.830)
HydroRegionSouth Lahontan	0.900*** (0.043)	79.713*** (6.790)
HydroRegionTulare Lake	0.864*** (0.042)	76.420*** (5.954)
Constant	3.695*** (0.020)	28.129*** (3.258)
Month Control	Yes	Yes
Supplier Control	Yes	Yes
Observations	6,729	6,729
R^2	0.874	0.820
Adjusted R^2	0.866	0.808
Residual Std. Error	0.169	23.776
F Statistic	104.628***	68.651***

Note: *p<0.05; **p<0.01; ***p<0.001
Standard errors are robust standard errors
RGPCD is water use measured as residential gallons per capita per day
Data Source: California State Water Resources Control Board

4.3 Individual Hydrologic Region Regression Models

Utilizing the insights from Table III, analyses were conducted for each hydrologic region due to the significant variation in baseline usage between regions. The results are presented in Table IV and Table V. The five highest water use hydrologic regions are the South Coast, San Francisco Bay, San Joaquin River, Sacramento River, and Tulare Lake with the regression results displayed in Table IV. The five lower water use hydrologic regions are the Central Coast, Colorado River, North Coast, North Lahontan, and South Lahontan regions and the results are displayed in Table V.

Table IV: Highest Use Hydrologic Regions Responsiveness to Conservation Actions

	Dependent Variable:				
	Log Transformed RGPCD				
	South Coast	San Francisco Bay	San Joaquin River	Sacramento River	Tulare Lake
	(5)	(6)	(7)	(8)	(9)
RaiseRates	0.040* (0.018)	-0.025 (0.036)	-0.009 (0.043)	-0.020 (0.042)	-0.010 (0.036)
Surcharge	-0.035 (0.021)	-0.043 (0.026)		-0.036 (0.047)	0.012 (0.081)
Rebate	-0.027 (0.014)	-0.023 (0.020)	0.016 (0.022)	-0.021 (0.028)	0.067 (0.041)
UseRestrict	-0.044*** (0.011)	-0.007 (0.018)	-0.067* (0.030)	-0.042 (0.027)	0.097* (0.041)
Blocks	0.133*** (0.035)				
Fines	-0.005 (0.022)	0.010 (0.030)	0.013 (0.026)	0.022 (0.030)	-0.057 (0.040)
DirectMsg	-0.011** (0.004)	-0.020** (0.007)	-0.009 (0.008)	-0.016 (0.009)	-0.014 (0.009)
eAds	0.006 (0.004)	-0.001 (0.007)	0.010 (0.007)	-0.004 (0.008)	-0.009 (0.010)
PhysicalAds	-0.009* (0.004)	-0.004 (0.007)	-0.024* (0.011)	-0.001 (0.010)	-0.014 (0.018)
Constant	4.039*** (0.044)	4.116*** (0.042)	4.067*** (0.054)	4.465*** (0.054)	4.225*** (0.050)
Month Control	Yes	Yes	Yes	Yes	Yes
Supplier Control	Yes	Yes	Yes	Yes	Yes
Observations	2,732	828	508	697	591
R^2	0.889	0.856	0.884	0.899	0.845
Adjusted R^2	0.881	0.844	0.872	0.889	0.831
Residual Std. Error	0.134	0.154	0.133	0.158	0.192
F Statistic	108.698***	69.929***	76.293***	94.198***	60.251***

Note: *p<0.05; **p<0.01; ***p<0.001
Standard errors are robust standard errors
RGPCD is water use measured as residential gallons per capita per day
Data Source: California State Water Resources Control Board

It was found that every hydrologic region in Table IV except for the Sacramento River region contained a statistically significant conservation action. However, the Sacramento River region's model still accounted for 88.9% of the variation in the data indicating static usage during the period of study and users were not responsive to conservation actions. The Tulare Lake region only had one significant conservation action, use restriction, which indicated when use restrictions were active there was a 9.7% increase in water consumption. The Tulare Lake model accounted for 83.1% of the variation in the data, the lowest of the five models. The use of block-based water allocations and fines in the South Coast region were found to increase water use by 13.3% and 4% respectively, while the remainder of the statistically significant conservation actions in Table IV reduced water consumption.

Table V: Lower Use Hydrologic Regions Responsiveness to Conservation Actions

	Dependent Variable:				
	Log Transformed RGPCD				
	Central Coast	Colorado River	North Coast	North Lahontan	South Lahontan
	(10)	(11)	(12)	(13)	(14)
RaiseRates	0.055 (0.030)	0.032 (0.032)	0.114 (0.080)		0.049 (0.056)
Surcharge	-0.115^{*} (0.046)	0.027 (0.047)	-0.028 (0.051)		-0.046 (0.034)
Rebate	0.0001 (0.023)	0.035 (0.027)	0.041 (0.047)		0.019 (0.038)
UseRestrict	-0.033 (0.019)	-0.069 (0.051)	-0.093 (0.056)	-0.047 (0.077)	-0.030 (0.039)
Blocks					0.012 (0.054)
Fines	-0.085^{***} (0.020)	0.042^{*} (0.019)	0.033 (0.090)		0.053 (0.037)
DirectMsg	-0.003 (0.007)	-0.048^{***} (0.012)	-0.007 (0.017)	-0.061 (0.060)	0.025 (0.014)
eAds	-0.004 (0.005)	0.018^{*} (0.009)	0.006 (0.016)	0.006 (0.039)	-0.015 (0.015)
PhysicalAds	-0.024 (0.011)	-0.003 (0.011)	-0.001 (0.023)	0.006 (0.099)	-0.027^{*} (0.013)
Constant	4.405^{***} (0.034)	4.611^{***} (0.049)	3.686^{***} (0.049)	3.670^{***} (0.121)	4.698^{***} (0.081)
Month Control	Yes	Yes	Yes	Yes	Yes
Supplier Control	Yes	Yes	Yes	Yes	Yes
Observations	549	231	255	67	271
R^2	0.924	0.950	0.648	0.912	0.889
Adjusted R^2	0.917	0.942	0.595	0.876	0.871
Residual Std. Error	0.116	0.106	0.185	0.203	0.143
F Statistic	124.520^{***}	118.015^{***}	12.331^{***}	25.486^{***}	51.822^{***}

Note: *p<0.05; **p<0.01; ***p<0.001
Standard errors are robust standard errors
RGPCD is water use measured as residential gallons per capita per day
Data Source: California State Water Resources Control Board

In Table V it was observed that the North Lahontan region suppliers implemented the fewest drought conservation actions, even while 22 of the 29 months of the observed time were declared drought state of emergencies with counties part of the North Lahontan region being some of the declared counties.[42] Additionally, as seen in Figure II and Figure III, the North Lahontan region utilized no electronic advertisements for over 40% of the period of study, and no physical advertisements for over 50% of the period of study. The North Coast and North Lahontan regions had no statistically significant conservation actions, and the model for the North Coast had only 59.5% of the variation in the data accounted for by the model. The Colorado River region model contained two traditional conservation actions found to increase water use, fines increased water use by 4.2% and electronic advertising increased use by 1.8% for each electronic advertising category used. The models in Table V have less total number of statistically significant conservation variables compared to models in Table IV, and the models have less observations as there are fewer water suppliers in the regions along with lower populations.

4.4 Utilization of Specific Conservation Actions Leads to Lower Water Use

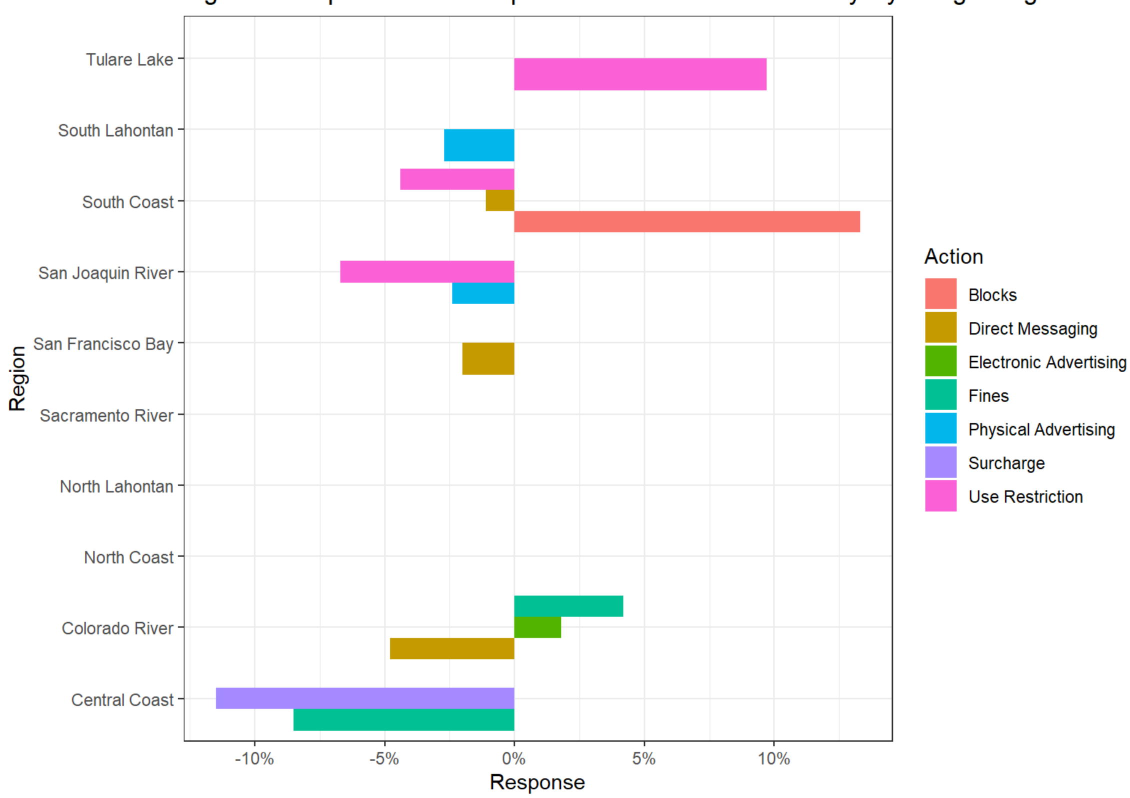
It was found that specific conservation actions resulted in an overall reduction in residential water consumption at a statewide level. In the model containing hydrologic regions, Model 3, the same conservation factors are found in the model without including hydrologic regions. However, in Model 3 it was also found that different regions have different baseline usages which could impact how residents can respond to the conservation actions. Targeted actions for each region may result in more effective reductions as water consumption and needs can vary significantly between regions. For the South Coast region, Model 5, the highest reduction in water use was the implementation of use restrictions resulting in a 4.4% reduction, while each form of direct communications from the water supplier resulted in a 1.1% reduction.

[42] Gavin Newsom, "Proclamation of a State of Emergency" (Executive Department - State of California, April 21, 2021), https://www.gov.ca.gov/wp-content/uploads/2021/05/5.10.2021-Drought-Proclamation.pdf.

In contrast, use restrictions were not found to be a significant conservation action for the San Francisco Bay region, but each form of direct communications from the supplier resulted in a 2.0% reduction in consumption. The analyses identified various conservation actions that are effective at a statewide level, as well as for each hydrologic region.

As seen in Figure I, the hydrologic regions in Table IV account for 89% of the potable water use in the state with the South Coast region making up 49% of it. There were no two regions that had the exact same statistically significant conservation actions further demonstrating the variation in use and response to the different drought conservation actions. Due to certain regions and suppliers accounting for larger percentages of total water use, increased focus on research in conservation methods to target residents of high-volume suppliers can have more impact on the statewide conservation efforts.

Figure IV: Top Three Most Impactful Conservation Actions by Hydrologic Region



Note: Some regions had less than three significant conservation actions
Negative percentages indicate conservation, positive indicate additional use
Data source: California State Water Resources Control Board

5. Conclusion

Certain drought conservation actions are effective at a statewide magnitude in reducing residential water use. However, the reduction in water use varies depending on which action was implemented, along with where the water user is located. Nearly 50% of water use in the state is attributed to a single hydrologic region, the South Coast region, with the second most at 15%. Due to this distribution, actions found to be significant in the South Coast region may bias the actions deemed successful at the state level since the hydrologic regions in the state can have varying water needs.

Evaluation at the hydrologic region level revealed the statistically significant conservation actions for each region. Some regions proved to have no impactful conservation actions at all, which was attributed to either a lack of implementation or lack of user response. In Figure II and Figure III, the differences between the suppliers in the hydrologic regions and how frequently and aggressively they utilized physical and electronic advertising was visualized. The differences in implementation of conservation actions between the suppliers may have impacted the reception of such actions.

The findings show there is reason to allow and encourage water suppliers to study effective conservation policies to implement during a drought. In this study, it was found that each hydrologic region contained a unique set of conservation actions that resulted in a statistically significant response, albeit not always a decrease in use. Limitations in this paper include the omission of weather data, lack of quantitative values for percentages increases in pricing for drought surcharges or fines, and the dependence on self-reported information for each water supplier.

Future studies can focus further on actions specific to hydrologic regions, regional wholesaler areas, or individual suppliers with higher frequency and more descriptive data. Additionally, those studies could identify supplier characteristics including percentage of customers in single family homes, number of lawns, and other attributes to enable prediction of reduction for suppliers founded on studied suppliers and the composition of their customer base. Sourcing data from a multitude of reporting entities will enable more accurate analysis of conservation actions and the potential responses as the importance of this topic grows.

State policy makers can use the generalized research at a statewide, regional level or a similarly identified supplier to mandate certain conservation actions when water suppliers fail to self-implement, such as those in the North Lahontan region in this study. Water suppliers in select areas may not have ample motivation to study or implement conservation actions as the supplies nearby are plentiful. However, given that California water can travel throughout the state in aqueducts and pipes to drought-stricken regions, rationing by all would prolong the existing supply until the next replenishment of reservoirs.

Potable water is a resource essential to life and effectively managing it in areas with scarce supply is necessary. Locating more water sources is one option to increase the supply to meet demand, but finding ways to encourage reduction for a sustainable future is a longer-term solution. The research in this paper and future further research on this topic can enable policy makers to create effective data backed decisions when choosing to implement conservation strategies that affect their constituents.

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7. Appendix

Figure V: California Hydrologic Regions

California State Geoportal. "Hydrologic Regions." Accessed April 2, 2023. https://gis.data.ca.gov/datasets/2a572a181e094020bdaeb5203162de15_0/about.

8. Curriculum Vitae

Galen Cheung is a Californian who was raised in the San Francisco Bay Area. He attended Mission College in Santa Clara and obtained associate degrees in mathematics, physics, and biology. He then transferred to San Francisco State University where he completed his Bachelor of Science in Statistics.

Galen currently works as a data analyst in the Water Resources and Civil Infrastructure Group at Stanford University. He is also a certified Water Distribution Operator – Grade D2 in California. He will complete his Master of Science in Data Analytics & Policy at The Johns Hopkins University in August 2023, after which he intends to continue using data analytics as the foundation for decision making, empowering data driven decisions.