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**Key Points:**

- Participatory surveillance is a way for governments to increase water waste monitoring capacity and achieve conservation goals
- Social and institutional aspects of community water systems correlate with water waste reporting in response to drought regulations
- Increased participatory surveillance is correlated with improved conservation outcomes

**Supporting Information:**

- Supporting Information S1

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# Public Water Waste Reporting: Contextual Correlates and Conservation Outcomes

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**Abstract** The success of water conservation restrictions depends in part on governments' capacity to monitor water use. Inviting the general public to report instances of water waste is one means of expanding government capacity to monitor and enforce water use. Why are people in some communities more frequently engaged in such "participatory surveillance" than in other communities? Does participatory surveillance help achieve conservation goals? We explore the social correlates and conservation outcomes of participatory surveillance regimes with an analysis of water conservation in the U.S. state of California. During California's historic 2014–2017 drought, the state established hotlines and websites for the public to report water waste anonymously. Californians responded by reporting more than 485,000 water waste complaints over the course of the emergency. Analysis shows that besides the water supply characteristics and drought severity, several social and institutional factors correlate strongly with complaint volume. Specifically, we find that municipal and special district utilities received more complaints than investor-owned utilities, and that complaints correlated positively with communities' level of education and partisan competition. We do not find strong evidence that communities' income, income distributions, and racial/ethnic compositions correlate with overall reporting. We further find that complaints are positively associated with conservation outcomes. Taken together, results indicate that social contexts can influence participation in participatory surveillance, and that participatory surveillance can be a potent means of enhancing water restrictions during a drought emergency.

## 1. Introduction

The success of water conservation restrictions depends in part on governments' capacity to monitor water use. Inviting the general public to report instances of water waste is a potential means of expanding capacity to monitor and enforce water use. Does the general public engage in such "participatory surveillance?" How does participation in public monitoring vary across communities? Is participatory surveillance associated with the achievement of water conservation goals?

This study explores the contextual correlates and implications of public responses to participatory surveillance as part of a regime of water restrictions adopted in response to a drought emergency. Our empirical subject is water conservation in California communities during that state's 2014–2017 drought. In response to a severe water shortage, California's governor ordered utilities to reduce potable water consumption and introduced a series of statewide measures to promote conservation. For instance, California authorities prohibited washing down driveways and sidewalks, outdoor irrigation that causes excess runoff, using a hose to wash a motor vehicle (unless the hose is fitted with a shut-off nozzle), and using potable water in a fountain or decorative water feature, unless the water is recirculated. As part of these efforts, state and local agencies established telephone hotlines and websites for the public to report water waste and violations of drought restrictions anonymously. After a complaint was made, utilities proceeded with a series of escalating enforcement steps, including informal education, formal warning, and monetary penalties. That is, the governments actively invited the public to participate in surveillance of their neighbors as a means of promoting water conservation. The people responded with gusto: over the course of the drought emergency (August 2014 to April 2017), Californians reported more than 485,000 water waste complaints. The California communities provide an extraordinary opportunity to explore participatory surveillance as a means of managing a drought emergency.

To that end, we analyze monthly water waste reporting and conservation across 408 water utilities in California during the drought emergency. To preview our results, we find that besides characteristics of water supply systems and drought severity, community education level, governance institutions, and partisan conflict correlated strongly with participatory surveillance in California communities. Water waste complaints increased as communities' share of college-educated residents increased. Municipal governments received water waste complaints significantly more frequently than did special districts, and communities served by private, investor-owned water utilities filed the fewest complaints on average. Moreover, participatory surveillance correlated positively with political competitiveness: complaints about water waste were strongest in communities where partisanship is closely divided. Communities' median incomes and income distributions did not significantly predict overall reporting, nor did their racial or ethnic compositions. Overall, social and political contexts appear to have shaped community engagement in participatory surveillance during the California drought.

Turning to outcomes, water waste complaints correlated positively with conservation, consistent with much of the previous research on public participation in public services (Nabatchi et al., 2017; V. Ostrom & Ostrom, 1977). Together these results indicate that contextual factors can shape participatory surveillance, with important implications for drought management.

We begin with a discussion of participatory surveillance as a means of public policy implementation. Discussion then turns to the ways in which social and institutional factors can affect public participation in monitoring regimes. We then introduce the 2014–2017 California drought and the governments' policy response to it. Empirical analysis of water waste complaints follows, yielding evidence that socioeconomic and institutional variables predict water waste reporting. Turning from process to outcomes, we analyze the relationship between participatory surveillance and conservation, finding that increased reporting correlates with greater conservation. We conclude with a discussion of the implications of our findings.

## 2. Water Conservation Restrictions

Policies to constrain urban water consumption can be classified into two categories: pricing and regulation (Araral & Wang, 2013; Reynaud, 2013). Sometimes characterized as "market-based approaches," prices can be used to regulate water demand with increasing-block tariffs, seasonal pricing, or rebates for efficiency (Bennear et al., 2013). Regulation, also called the prescriptive or "command-and-control" approach, principally consists of technology standards and restrictions on outdoor water use (Boyer et al., 2018; Olmstead & Stavins, 2009; Wichman et al., 2016).

Existing research on conservation focuses mainly on the effects of *adopting* conservation instruments on water consumption, leaving aside the process of implementation (e.g., Boyer et al., 2018; Kenney et al., 2004; Lee et al., 2013; Mansur, 2012). It might be reasonable to attribute the impact of pricing to its adoption, as the implementation of pricing is straightforward and involves few additional administrative costs; encouraging conservation through pricing does not require active monitoring, so long as water consumption can be measured through metering. Nevertheless, policymakers may opt for regulations over pricing for at least two reasons. First, pricing tools allocate resources by willingness to pay, which raises potential concerns for distributional inequities: conservation through pricing could disproportionately increase economic burdens on low-income households (Olmstead & Stavins, 2009). Second, conservation through pricing involves uncertainty around price elasticities; regulatory tools may provide greater certainty over the quantity of conservation with effective enforcement (Robinson & Conley, 2017).

Implementation of regulatory approaches to conservation can be more complicated and costly (Mullin & Rubado, 2017). For instance, the effectiveness of regulatory approaches relies to some degree on authorities' capacity to monitor specific instances of water use. Real-world conservation outcomes do not necessarily follow policy adoptions as night follows day; variation in implementation can affect regulatory actions significantly. For example, several communities might adopt identical water use regulations, but implement them with significantly more or less vigorous monitoring and enforcement. Analysis of nonprice conservation programs may misestimate their influence by coding them as simply binary adoption decisions rather than measuring implementation continuously (Reynaud, 2013).

Recent studies call for greater attention to the effects of conservation regulations (Robinson & Conley, 2017; Wichman et al., 2016); a focus on the implementation process and the link between regulatory implementation and water consumption will allow a deeper understanding of their effects. To our knowledge, only one study has attempted to model the effects of enforcement actions on water use. Using the case of the 2002 drought in Virginia, Halich and Stephenson (2009) found that both information and enforcement were negatively correlated with residential water use. However, their sample consisted of just 21 out of 45 localities that were "willing and able to participate," raising the specter of self-selection bias (p. 616). Moreover, Halich and Stephenson (2009) measured water restrictions with subjective perceptions of surveyed managers, not actual regulatory implementation data.

Important questions about the implementation of water conservation restrictions remain unanswered. How do authorities monitor water use for purposes of regulatory enforcement? To what extent does the general public engage in this monitoring? How do monitoring efforts relate to conservation outcomes?

## 3. Participatory Surveillance and Regulatory Implementation

Enforcement of any regulatory policy requires ensuring that regulated individuals or organizations comply. From forest fires to neighborhood littering, governments look to community members to help surveil conditions and report threats, and so aid in the implementation of environmental rules. Public participation is widely accepted as an important means of providing public service and implementing public policy generally because it has both instrumental and normative values, such as reducing production costs, improving service quality, fostering innovation, increasing public satisfaction, and promoting democratic practices (Brudney & England, 1983; Jakobsen et al., 2016; Linders, 2012; E. Ostrom, 1972; V. Ostrom & Ostrom, 1977). In many cases, governments actively seek community involvement in this monitoring phase of the policy process. Under this kind of participatory surveillance arrangement, governments invite the public to monitor others and report conditions or regulatory violations to the government.

### 3.1. Causes and Effects of Participatory Surveillance

As with most other forms of public participation, participatory surveillance requires individuals to bear additional costs in the form of time and other resources (Zhang et al., 2019). Research on participatory surveillance examines the effects of public reporting on preventing crimes and improving public security (R. Brewer & Grabosky, 2014; Layne, 1989; E. Ostrom et al., 1973). Research in sociology, public health, and criminal justice explores conditions that affect community willingness to report threats, crimes, and other violations to authorities (Brownstein et al., 2009; Crawford & Evans, 2012; Lyon, 2007; Reeves, 2012).

Extant research on citizen participation in public services has generally found that community-level socioeconomic factors are important determinants of public participation (Loeffler & Bovaird, 2016; Van Damme et al., 2016). Income level, education level, population density, or ethnic diversity could be significantly associated with public participation because they determine the resources, motivations, and obstacles associated with participation (Brady et al., 1995).

Political institutions and contexts might also shape public participation (Voorberg et al., 2015), as participation in the development and/or implementation of public policy is an implicit expression of support for that policy and a tacit endorsement of government involvement in an area of public policy. Engagement in participatory surveillance is especially notable in the case of water conservation, since reporting violations is costly in terms of time and resources for the individuals who report, but the gains from successful conservation are collective.

Voluminous research demonstrates that local institutions shape political processes and public participation (e.g., Hughes, 2012; Lubell et al., 2009; Mullin, 2008; Trounstine & Valdini, 2008). General purpose municipal governments (counties, cities, towns, and villages) are perhaps the most familiar to most Americans. Over the past century, however, special purpose districts have proliferated and now outnumber municipalities, especially in the western United States (Carruthers & Ulfarsson, 2003; Jimenez & Hendrick, 2010). Municipalities are in most situations more visible than special district governments, and so garner greater media attention, public participation, and voter turnout than special districts, where decision-making tends to be more professional than popular (Mullin, 2009; Teodoro, 2010) and politics tend to be "quiet"

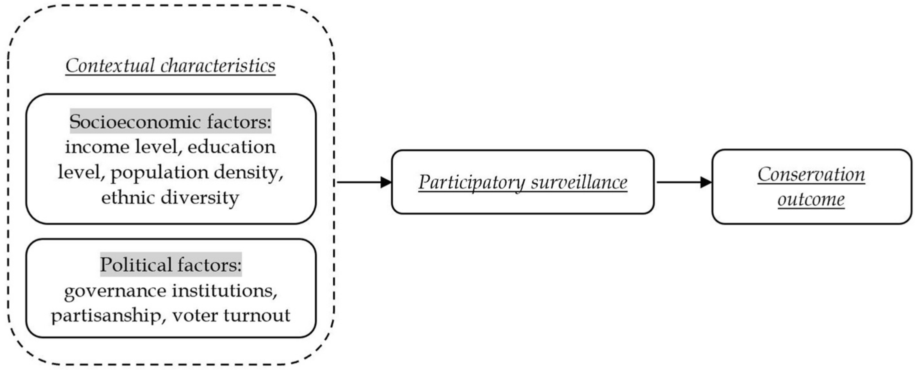



**Figure 1.** Analytical framework for participatory surveillance.

(Burns, 1994). Finally, many utilities throughout the country are investor owned and operated. These will likely garner the least public participation since private organizations are not formally responsible to voters (Hefetz & Warner, 2011; Teodoro et al., 2020).

Partisanship is an important driver of political participation (Chen, 2013; Huddy et al., 2015), and so might also be expected to influence participatory surveillance. Community members' political preferences may shape the way that they interact with each other (Abramowitz & Saunders, 2008; Jerit & Barabas, 2012; Parker-Stephen, 2013). Specifically, when partisan conflicts increase, the public may also have greater interest in civic engagement generally (Arce & Mangonnet, 2013; Patterson & Caldeira, 1983; Rainey, 2015). By the same logic, the intensity of partisan conflicts might be expected to correlate with public participation in surveillance processes.

### 3.2. Participatory Surveillance and Water Use Regulation

In exploring the antecedents and consequences of participatory surveillance as a means of managing a drought emergency, we adopt a holistic approach. That is, we expect socioeconomic and political contexts to shape public engagement in water waste reporting. Following prior research on public participation in policy implementation, we also expect increased public engagement to be associated with improved conservation outcomes insofar as the public's contribution to monitoring expands governments' implementation capacity. Figure 1 depicts our general analytical framework.

Research on participatory surveillance consists mostly of qualitative, exploratory case studies, and carries a broad normative valence that presupposes that public participation has positive effects (Nabatchi et al., 2017). Systematic, quantitative, and objective investigations of participatory surveillance remain uncommon. Beyond its objective importance and practical implications for managing water scarcity, an analysis of public participation in water waste reporting can contribute to our understanding of participatory surveillance generally.

## 4. Participatory Surveillance and the California Drought

California began experiencing long-term drought conditions in 2007, when the seasonal mountain snow that many of the state's cities rely upon for drinking water was unusually low. Although California has experienced significant overall reduction in urban water demand thanks to improved indoor efficiency, the historically severe drought nonetheless threatened the state's urban water supply (Mitchell et al., 2017). By 2013, the drought reached crisis conditions as the snowpack was just 17 percent of normal levels. In response, in January 2014 California Governor Jerry Brown issued a statewide Water Action Plan that called for sweeping reforms to water consumption and management across all levels of government (The California Water Action Plan: http://resources.ca.gov/california_water_action_plan/). The drought, however, continued to intensify; tree ring data indicate that 2012–2014 was the most severe drought in California for the past 1,200 years (Griffin & Anchukaitis, 2014). By early 2015, California's mountain snowpack was effectively gone.

### 4.1. Policy Response

The State Water Resources Control Board (SWRCB) holds legal authority over all local retail, wholesale, and agriculture water resources in California. In June 2014, the SWRCB issued a series of orders to curtail water use in urban areas, including mandatory conservation rules for 408 of the state's retail water utilities. In May 2015, the SWRCB adopted an emergency regulation to implement a mandatory 25% statewide reduction in potable urban water use between June 2015 and February 2016 (SWRCB RESOLUTION NO. 2015-0032 https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2015/rs2015_0013.pdf). To achieve the reduction, the emergency regulation assigned each urban water supplier to one of nine tiers of conservation targets based on their relative historical demand patterns (we discuss these conservation targets further, below).

Much of California's residential water demand is driven by discretionary outdoor use (e.g., lawn watering and car washing), rather than by essential indoor use (e.g., drinking, cooking, and flushing toilets). Accordingly, in July 2014, the SWRCB approved a statewide emergency regulation that mandated fines of up to $500 a day for residents who waste water on such activities. For example, the SWRCB regulation prohibited washing down driveways and sidewalks, watering of outdoor landscapes that cause excess runoff, using a hose to wash a motor vehicle (unless the hose is fitted with a shut-off nozzle), and using potable water in a fountain or decorative water feature, unless the water is recirculated.

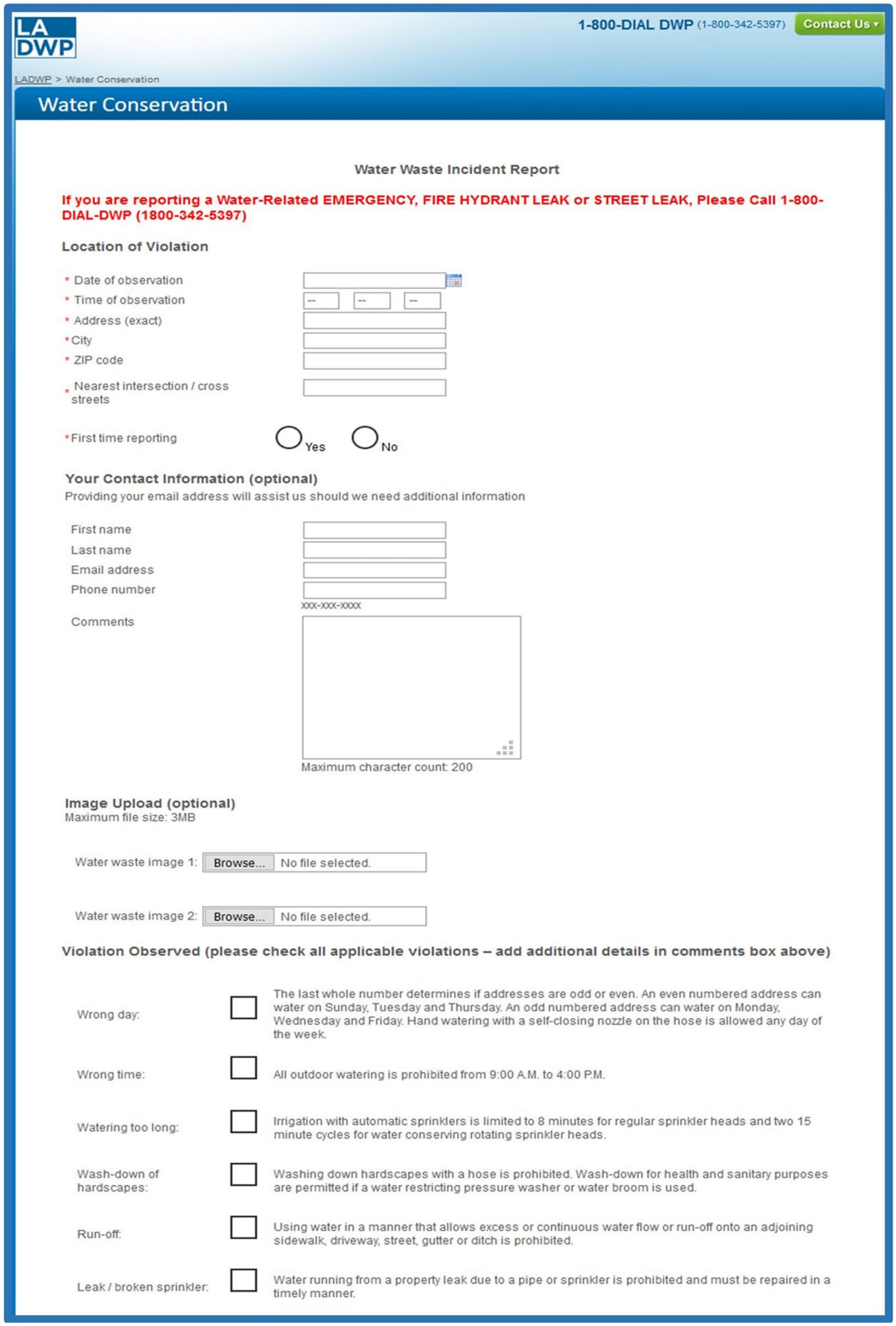
### 4.2. Anonymous Public Reporting

The state also established an online portal and telephone hotline to allow anonymous reporting of water waste violations. The state website invited participants to identify specific locations of water waste and submit photographs documenting the violation. In effect, California established a high-profile regulatory regime for water conservation, with participatory surveillance as an explicit element of its implementation.

Although the state issued the emergency regulation, the utilities were responsible for enforcing it, and so in this instance participatory surveillance mainly involved the public working with local utilities. In addition to the state's efforts, utilities established their own online portals and telephone hotlines to allow anonymous reporting of water waste. These online portals and telephone hotlines invited participants to identify locations of water waste and submit photographs documenting the violation. For example, Figure 2 shows the Los Angeles Department of Water and Power's water waste reporting website.

To track progress, the SWRCB required water utilities to report a variety of water use data, including the number of water waste complaints received online or through telephone calls. Additionally, utilities patrolled their service areas directly by sending staff to residential communities in search of water waste. After receiving complaints or observing violations, utilities proceeded with a series of escalating enforcement steps. The first enforcement step was a “follow-up action,” an informal intervention that typically involved investigating a reported violation and then sharing information with the violator with a goal of inducing compliance through education. The second step of enforcement was the issuance of a formal warning, where the utility documented the violation and informs the violator of the SWRCB regulations and its threat of $500 daily penalties. The final step was the issuance of a formal penalty and fine.

California's size and diversity provide an excellent opportunity to explore participatory surveillance and water conservation in socioeconomic and political context, as outlined in Figure 1. The utilities that were subject to the state conservation mandate varied considerably in water use, drought conditions, service population, community demographics, and other economic indicators. The 408 California utilities also varied in their institutional arrangements: 202 are agencies of municipal or county governments, 144 are special districts, and 62 are private, investor-owned firms. Partisanship also varied significantly across the drought-stricken California



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Water Conservation

Water Waste Incident Report

If you are reporting a Water-Related EMERGENCY, FIRE HYDRANT LEAK or STREET LEAK, Please Call 1-800-DIAL-DWP (1800-342-5397)

Location of Violation

* Date of observation
* Time of observation
* Address (exact)
* City
* ZIP code
* Nearest intersection / cross streets
* First time reporting Yes No

Your Contact Information (optional)
Providing your email address will assist us should we need additional information

First name
Last name
Email address
Phone number xxx-xxx-xxxx
Comments
Maximum character count: 200

Image Upload (optional)
Maximum file size: 3MB

Water waste image 1: Browse... No file selected.
Water waste image 2: Browse... No file selected.

Violation Observed (please check all applicable violations – add additional details in comments box above)

| | | |
|---|---|---|
| Wrong day: | ☐ | The last whole number determines if addresses are odd or even. An even numbered address can water on Sunday, Tuesday and Thursday. An odd numbered address can water on Monday, Wednesday and Friday. Hand watering with a self-closing nozzle on the hose is allowed any day of the week. |
| Wrong time: | ☐ | All outdoor watering is prohibited from 9:00 A.M. to 4:00 P.M. |
| Watering too long: | ☐ | Irrigation with automatic sprinklers is limited to 8 minutes for regular sprinkler heads and two 15 minute cycles for water conserving rotating sprinkler heads. |
| Wash-down of hardscapes: | ☐ | Washing down hardscapes with a hose is prohibited. Wash-down for health and sanitary purposes are permitted if a water restricting pressure washer or water broom is used. |
| Run-off: | ☐ | Using water in a manner that allows excess or continuous water flow or run-off onto an adjoining sidewalk, driveway, street, gutter or ditch is prohibited. |
| Leak / broken sprinkler: | ☐ | Water running from a property leak due to a pipe or sprinkler is prohibited and must be repaired in a timely manner. |

**Figure 2.** Los Angeles Department of Water and Power (https://www.ladwp.com) water waste reporting website.

communities. The share of registered Democratic Party members in total registered partisans in 2016 ranges from 24% to 93% among the utilities analyzed here, offering a wide range of local partisan competitiveness.

## 5. Data and Methodology

Our analysis uses pooled time series data from the SWRCB's Monthly Reporting Archive and its monthly observations of 408 water utilities in California during the state's drought emergency period: August 2014 through April 2017 (California State Water Board's Monthly Reporting Archive http://www.waterboards.ca.gov/water_issues/programs/conservation_portal/conservation_reporting.shtml). These utilities provide urban water supplies, and so our analysis does not include agricultural water regulations or demands. We merge these data with system information from the Environmental Protection Agency's Safe Drinking Water Information System (SDWIS) in 2014 and community information from the U.S. Census' 2015 American Community Survey's five-year estimates (ACS), and 2016 voter registration data from the California Statewide Database.

### 5.1. Estimating Participatory Surveillance

We measure participatory surveillance as the number of complaints received per thousand population served by each utility in each month. Utilities received an average of 0.38 drought complaints per month per thousand people, although the rate of reporting varied considerably across communities and over time. Our unit of analysis is the utility-month. Therefore, our analysis is of aggregated complaints within a utility service area, rather than individual complaints. We use ordinary least squares regression to estimate participation, with standard errors clustered by utility.

### 5.2. Socioeconomic Variables

We estimate water waste complaints with several socioeconomic contextual covariates. First, we include the mean-to-median ratio of residents' income in the models to examine the potential effect of income inequality (Corcoran & Evans, 2010; Dagum, 1980). Although the Gini coefficient is a more common and precise metric of inequality, local-level Gini data are not available for California in ways that can be aggregated to utility service areas. The mean-to-median income ratio is a useful proxy in absence of finer metrics (Birdsall & Meyer, 2015), and generally reflects public perceptions of income distribution (Bredemeier, 2014; Meltzer & Richard, 1983; Perotti, 1992). More densely concentrated populations might increase the likelihood that incidents of water waste are observed at random; meanwhile, there might be less outdoor water use and water waste for people to observe when population density is high. Therefore, there might be a ∩-shaped relationship between population density and complaints. To capture this nonlinearity, we include population density (1,000 population per square mile) and its squared term in our estimates.

Racial/ethnic diversity is calculated using $1-\sum_{i=1}^{n} p_i^2$ (i.e., the Gibbs-Martin or Blau index), where $p_i$ represents a share of an ethnicity $i$ in a population. Separately, we also include the percentages of Black, Hispanic, and Asian population, the percentage of adults with a bachelor's degree, as well as the percentage of the population with incomes below the poverty level, in the communities served by the utilities. Lower overall rates of political participation among poor and nonwhite populations suggest that participatory surveillance might also be lower among these same populations. Similarly, we expect median household income to correlate positively with violations of water restrictions because more affluent homes tend to feature larger irrigated areas and swimming pools.

### 5.3. Political Variables

To evaluate the relationship between governance institutions and participatory surveillance, we fit models with binary indicators: *municipal government* equals 1 if the water utility is operated by a general purpose municipal government (zero otherwise), and *special district* is coded 1 if the water utility is operated by a special district (zero otherwise) (Two of the utilities in our data set are operated by county governments. These are coded as *municipal* utilities because they are generalpurpose local governments led by elected legislative councils). Private, investor-owned utilities serve as a reference category.

To examine partisan competitiveness, the level of party competition in each service area is measured as one minus the difference between registered Democrats and Republicans divided by total registered Democrats and Republicans. Mathematically, this measure is:

$$1 - \left| \frac{\text{Registered Democrats} - \text{Registered Republicans}}{\text{Total Registered in a Major Party}} \right|$$

A higher value indicates more intense party competition. For instance, if a service area were entirely dominated by one party (i.e., a single party enjoys 100% of major party registrations), then the value of the party competition index would be zero. If a service area were exactly evenly divided between Democratic- and Republican-registered voters (50% Democrats and 50% Republicans), the value of this party competition index would be one. Partisanship was measured for each utility by aggregating precinct-level party registration data. We drew data on party registration from the California Statewide Database, which contains information on voting and registration for statewide elections in California since 1992 (University of California. 2018. California Statewide Database. http://statewidedatabase.org/index.html). We aggregated the number of individuals registered as Republicans and Democrats in the 2016 general election for each voting precinct overlapping utilities' service areas to develop a measure of major party registration share for each utility. Utility boundary data were drawn from the California Environmental Health Tracking Program, which contains current service areas for all the utilities in our data set (California Environmental Health Tracking Program. 2018. Water System Service Areas. https://trackingcalifornia.org/water-systems/water-systems-landing).

Importantly, party competition as measured by registrations positively and significantly correlates with voter turnout in the present sample. Figure 3 shows the relationship between 2016 general election turnout across the 408 California communities served by the utilities analyzed here across the range of party competitiveness (The positive relationship between party competition and voter turnout holds in fully specified regression models reported in Table S1 inthe supporting information). This positive correlation suggests a generally heightened level of general civic participation in communities where party competition is stronger (Lipsitz, 2009), which could also presage greater engagement in participatory surveillance for water conservation.

Additionally, we include the percent of voter turnout in 2016 presidential election, aggregating precinct-level turnout data the same way we aggregated party registrations. We use the monthly Google Trends' search volume index on the topic "Drought" in California to measure public attention to the drought (Kam et al., 2019; Quensel & Ajami, 2017), which we expect to positively predict water waste complaints.

### 5.4. Utility and Supply Variables

Our estimates include several variables to control for utility characteristics. First, we control for each utility's conservation potential by including the utility-level conservation target set by the SWRCB in 2015 in the models. As noted earlier, assigned each urban water supplier to one of nine tiers based on their residential gallons per capita per day (R-GPCD) for the months of July to September 2014. Each tier of utilities was then assigned a conservation standard that ranged between 4% and 36%, with higher historical R-GPCD utilities receiving higher conservation standards. In setting varying standards, the SWRCB recognized that water systems varied considerably in predrought water use patterns: communities that were already relatively conservative in water demand have relatively little room for additional conservation, while high-demand communities have much greater potential for conservation (Teodoro et al., 2020). A higher conservation target mandated by the state indicates more conservation potential.

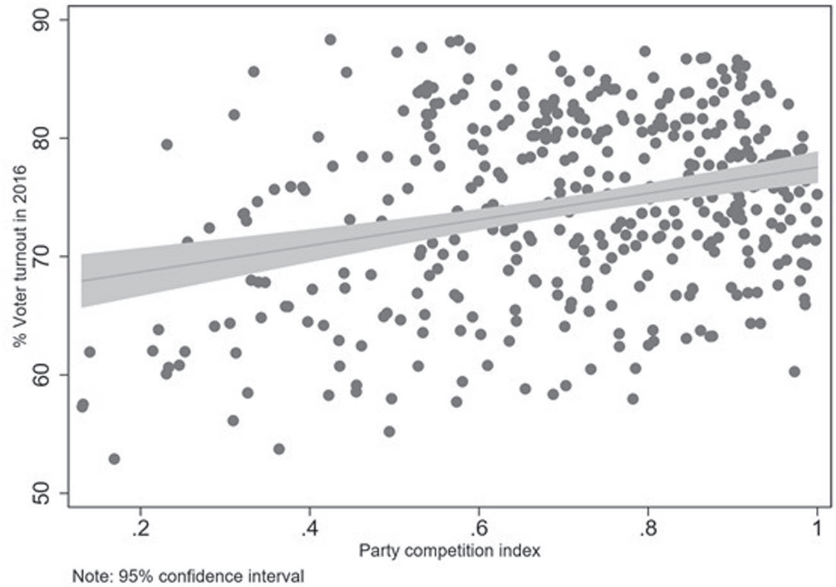


**Figure 3.** 2016 California voter turnout by party competition.

Communities also varied in the degree to which they regulated water use, and so we control for the strength of local water restrictions, measured as outdoor irrigation days allowed per week. To account for differences in customer base in each community, we control for the percentage of water demand from residential (as opposed to commercial or industrial) customers. We account for the water source of a utility by setting two variables: a dummy equal to one if a utility relies on groundwater and zero otherwise; a dummy equal to one if a utility purchases water from a wholesale supplier, and zero otherwise.

California covers a large and varied geographic area, with considerable variation in moisture and drought conditions across the state. Since local drought conditions might affect participatory surveillance, we control for drought severity with data from the National Drought Mitigation Center at the University of Nebraska-Lincoln. Their weekly drought score measures drought conditions on a 6-point scale ranging from normal conditions to exceptional drought. Using GIS, we calculated the percentage of each utility's service area experiencing each level of drought condition each week. We then created a weekly average drought condition that calculated the overall drought condition weighted on the percentage of the service area at each level of severity. We then aggregated the weekly measure into an average monthly measure. For the weeks that overlapped months, we weight them according to the number of days in each month.

Table 1 provides a descriptive summary of all variables used in the analysis that follows. Our estimates include fixed effects for each month. Since the distribution of participatory surveillance is highly skewed, all models exclude the top 1% outliers (when waste reports were greater than 5.0 per 1,000 population) to bolster the robustness of the estimated relationships.

## 6. Results

Table 2 presents estimates of participatory surveillance with three OLS regressions: the first (Model A) includes only the utility characteristics; the second (Model B) adds the social variables, including mean-median income ratio, population density, population density squared, ethnic diversity, poverty rate, median household income in thousands of dollars, the percentage of adults with bachelor's degrees, and the percentages of Hispanic, Black, and Asian population. Inclusion of these socioeconomic and demographic variables improves overall model fit and efficiency ($\Delta R^2$ 0.01, $\Delta$ AIC −172.63, $\Delta$ BIC −97.72), consistent with the general idea of social context influencing citizen participation. For more on using AIC and BIC in evaluating model specification, see Burnham and Anderson (2004)). A likelihood-ratio test of whether the inclusion of the socioeconomic variables in Model B improved on Model A rejected the null of no improved fit ($\chi^2 = 192.63$, $p < 0.001$).

Model C adds the political variables, including governance institutions (municipal or special district), party competition, percent voter turnout, and Monthly Google trend. Inclusion of these variables further improves overall model fit and efficiency ($\Delta R^2$ 0.01, Δ AIC −233.41, Δ BIC −203.44). Once again, a likelihood ratio test indicates improved fit over Model B ($\chi^2 = 241.41$, $p < 0.001$).

To illustrate and compare the relationships of the explanatory variables with water waste complaints, we plot standardized coefficients in Figure 4. This plot shows the relationship between a one standard deviation change in each variable and the number of monthly water waste complaints per 1,000 population.

### 6.1. Correlates of Water Waste Reporting

Our results provide notable evidence regarding the relationship between community of socioeconomic and political variables and the volume of water waste complaints lodged with utilities. Models B and C indicate that there is a statistically significant ∩-shaped relationship between population density and complaints, with an inflection point at about 191,000 population per square mile. Figure 5 displays this relationship, showing how complaints vary across levels of population density. This finding supports our expectation that when population density increases, the likelihood of observing water waste increases, but that at very high densities there might be less outdoor water use and water waste for people to observe. Communities with more people with a bachelor's degree are significantly more likely to file complaints. Substantively, Models B and C indicate that a one standard deviation increase in percent with a bachelor's degree is associated with 0.08 complaints per thousand population in a month (or +21.3% relative to the mean). We do not find strong evidence that other socioeconomic and demographic variables correlate with water waste reporting.

As Model C shows, all else equal, the public reported more complaints to special district utilities than to investor-owned utilities (the reference category), and even more complaints to municipal utilities. In substantive terms, these differences indicate that, all else equal, special districts received 0.07 more and municipal utilities 0.18 more drought violation reports per thousand persons relative to investor-owned utilities. A Wald test shows that the +0.12 difference between municipal utilities and special districts is statistically significant ($F = 11.36$, $p = 0.00$).

Turning to party competition, we find that a one standard deviation increase in party competition is associated with a 0.03 (or +8.3% relative to the mean) increase in drought violation reports per thousand population. After accounting for party competition, there is effectively zero correlation between voter turnout and the water waste complaints. Somewhat surprisingly, the popular salience of the drought measured by monthly Google trend negatively correlates with complaints. One potential explanation for the negative correlation between Monthly Google trend and waste complaints is that when the drought became more salient, utilities and the public generally conserved more water and there might be fewer drought violations to be reported. Alternatively, there might be a substitutive relationship between searching for drought issues from the Internet and filing complaints given people's limited time and attention on the drought.

Utility and supply variables yield some notable results too. As expected, conservation potential and outdoor watering restrictions (i.e., the reverse of water days allowed per week) are significantly associated with complaints. However, we find a negative relationship between percentage of residential usage and complaints, which suggests that complaints were more frequent in places with more commercial and industrial water use. This finding suggests that it might be socially easier and more psychologically satisfying for people to report water waste by commercial and industrial water users than by their residential neighbors. This participatory surveillance pattern might also apply to other policy areas (e.g., environmental pollution) since commercial and industrial organizations tend to generate more salient

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**Table 1**
*Summary Statistics (August 2014 to April 2017)*

| Variable | Obs | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|
| Complaints per 1,000 population | 13,393 | 0.38 | 1.19 | 0.00 | 47.29 |
| % Monthly potable water conservation compared to 2013 | 13,393 | 19.41 | 13.32 | −108.42 | 79.23 |
| Municipality | 13,393 | 0.49 | 0.50 | 0.00 | 1.00 |
| Special district | 13,393 | 0.35 | 0.48 | 0.00 | 1.00 |
| Party competition | 13,393 | 0.71 | 0.20 | 0.13 | 1.00 |
| Percent turnout | 13,393 | 74.31 | 7.68 | 52.90 | 88.32 |
| Monthly Google trend | 13,393 | 41.51 | 19.48 | 20.00 | 100.00 |
| Mean-median income ratio | 13,393 | 1.29 | 0.11 | 1.05 | 2.08 |
| Population density | 13,393 | 6.80 | 23.59 | 0.00 | 423.47 |
| Ethnic diversity | 13,393 | 0.53 | 0.14 | 0.05 | 0.78 |
| % Hispanic | 13,393 | 41.35 | 23.54 | 4.55 | 97.49 |
| % Black | 13,393 | 4.15 | 5.19 | 0.00 | 43.59 |
| % Asian | 13,393 | 11.61 | 12.74 | 0.10 | 67.13 |
| % Bachelor degree | 13,393 | 29.21 | 16.16 | 1.86 | 79.90 |
| % Income below poverty | 13,393 | 15.08 | 7.51 | 2.40 | 41.30 |
| Median household income ($1,000) | 13,393 | 67.17 | 24.27 | 23.06 | 229.10 |
| % State conservation standard | 13,393 | 24.54 | 8.51 | 4.00 | 36.00 |
| Water days allowed per week | 13,393 | 3.91 | 2.26 | 0.00 | 7.00 |
| % Residential use | 13,393 | 69.87 | 15.39 | 0.05 | 100.00 |
| Groundwater | 13,393 | 0.34 | 0.47 | 0.00 | 1.00 |
| Purchased water | 13,393 | 0.43 | 0.50 | 0.00 | 1.00 |
| Drought score | 13,393 | 3.92 | 1.47 | 0.00 | 5.00 |

and negative consequences than residents. Utilities with purchased water received fewer complaints than utilities with utilities provide their own source water. Drought severity correlates slightly positively with complaints received.

### 6.2. Conservation Outcomes

To examine the relationship between participatory surveillance and outcomes in the case of the California drought, we analyzed the correlation between water waste complaints and utilities' overall water conservation. The dependent variable in this second analysis is the monthly percentage water conservation compared to the same month in 2013. This measure of conservation for utility $i$ in month $m$ of year $y$ is calculated as:

$$\text{Water conservation}_{i,y,m} = \frac{\text{Production}_{i,m,2013} - \text{Production}_{i,m,y}}{\text{Production}_{i,m,2013}}$$

Notably, this is the official conservation metric that the SWRCB adopted at the onset of drought emergency order.

Given the dynamic nature of the dependent and independent variables, we employ the Arellano-Bond dynamic estimation procedure to use current and past information to estimate utility water conservation. This generalized method of moments (GMM) approach uses first differencing to remove the unobserved panel-level effects and use instruments (e.g., the lagged dependent variable and endogenous variables) to create moment conditions (Arellano & Bond, 1991). A test for the serial correlation structure rejects no autocor-

**Table 2**
*Estimated Complaints per 1,000 Population, August 2014 to April 2017*

| | Model A | | Model B | | Model C | |
|---|---|---|---|---|---|---|
| OLS regression | Coefficient (Robust SE) | *p* | Coefficient (Robust SE) | *p* | Coefficient (Robust SE) | *p* |
| Municipality | | | | | 0.180 (0.03) | 0.000 |
| Special district | | | | | 0.070 (0.04) | 0.050 |
| Party competition | | | | | 0.160 (0.08) | 0.037 |
| Percent turnout | | | | | 0.000 (0.00) | 0.995 |
| Monthly Google trend | | | | | −0.005 (0.00) | 0.000 |
| Mean-median income ratio | | | 0.108 (0.16) | 0.513 | −0.008 (0.17) | 0.963 |
| Population density | | | 0.006 (0.00) | 0.000 | 0.005 (0.00) | 0.000 |
| Population density squared | | | −0.000 (0.00) | 0.000 | −0.000 (0.00) | 0.000 |
| Ethnic diversity | | | 0.005 (0.11) | 0.962 | −0.073 (0.11) | 0.516 |
| % Hispanic | | | 0.000 (0.00) | 0.662 | 0.000 (0.00) | 0.771 |
| % Black | | | −0.003 (0.00) | 0.116 | −0.001 (0.00) | 0.644 |
| % Asian | | | −0.000 (0.00) | 0.860 | 0.000 (0.00) | 0.767 |
| % Bachelor degree | | | 0.005 (0.00) | 0.007 | 0.005 (0.00) | 0.005 |
| % Income below poverty | | | 0.001 (0.00) | 0.737 | 0.002 (0.00) | 0.569 |
| Median household income ($1,000s) | | | −0.002 (0.00) | 0.167 | −0.001 (0.00) | 0.272 |
| % State conservation standard | 0.014 (0.00) | 0.000 | 0.015 (0.00) | 0.000 | 0.014 (0.00) | 0.000 |
| Water days allowed per week | −0.027 (0.01) | 0.000 | −0.026 (0.01) | 0.000 | −0.026 (0.01) | 0.000 |
| % Residential use | −0.002 (0.00) | 0.009 | −0.002 (0.00) | 0.005 | −0.002 (0.00) | 0.034 |
| Groundwater | −0.040 (0.04) | 0.331 | −0.028 (0.04) | 0.505 | −0.035 (0.04) | 0.395 |
| Purchased water | −0.072 (0.04) | 0.067 | −0.074 (0.04) | 0.066 | −0.087 (0.04) | 0.028 |
| Drought score | 0.042 (0.01) | 0.000 | 0.039 (0.01) | 0.000 | 0.039 (0.01) | 0.000 |
| Constant | −0.140 (0.10) | 0.166 | −0.363 (0.30) | 0.231 | −0.120 (0.34) | 0.723 |
| $R^2$ | 0.216 | | 0.228 | | 0.242 | |
| AIC | 21118.158 | | 20945.525 | | 20712.120 | |
| BIC | 21410.327 | | 21312.610 | | 21109.171 | |

*Note*. Observations = 13,247. Dependent variable is complaints per 1,000 population received by each utility each month. Standard errors clustered by utilities. Models also include month dummies and exclude the top 1% outliers (waste reports >5.0 per 1,000 population). Two-tailed *p*-values reported.

relation of order 1 ($z = -11.28$) and cannot reject no autocorrelation of order 2 ($z = -0.41$). Accordingly, there is evidence that the Arellano-Bond model assumptions are satisfied. The time-invariant variables are automatically dropped from the model, and the analysis yields estimates of within-unit variation over time.

Table 3 reports the resulting estimates of conservation and Figure 6 plots the standardized coefficients. As in Figure 4, the standardized coefficients in Figure 6 show the relationship between a one standard deviation change in each variable and percent water conservation. As Model D shows, complaints significantly and positively correlate with water conservation. Substantively, one more complaint per thousand persons is associated with a 0.56 percent increase in monthly water conservation. Although this effect is small in percentage terms, it translates into a significant volume of water. Summed across the utilities analyzed here, one more complaint per thousand persons per month would have resulted in 32 billion gallons (121 billion liters) of additional water saved over the period of analysis: enough to supply the City of San Francisco for roughly 16 months.

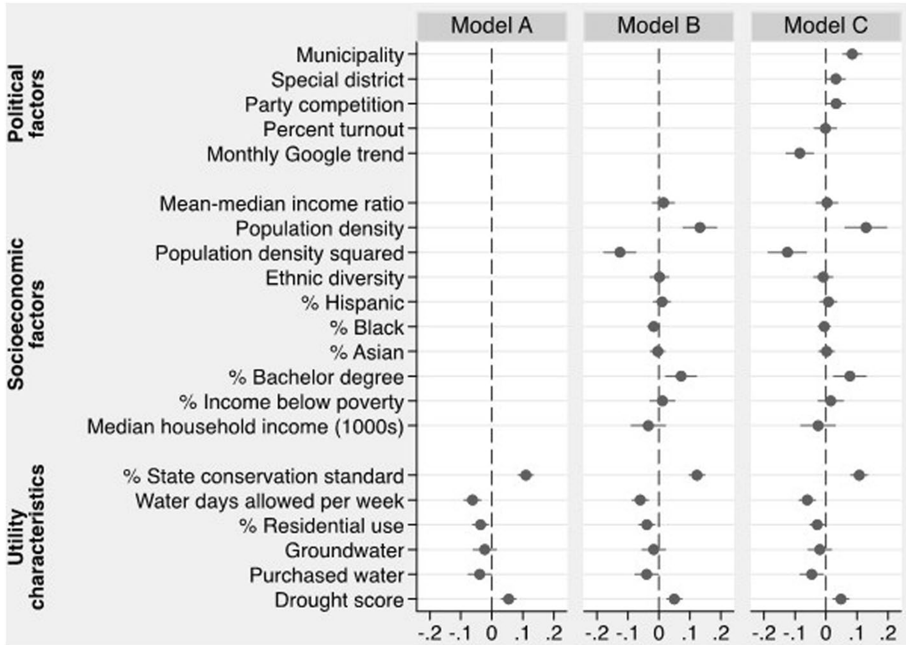


**Figure 4.** Standardized coefficients (95% confidence interval). Note: Dependent variable is the number of complaints per 1,000 population received by each utility each month. Plot shows the relationship between a one standard deviation change in each variable and the number of water waste complaints per 1,000 population.

It would be inappropriate to infer from this analysis alone that Californians' participatory surveillance *caused* the observed conservation outcomes. However, participatory surveillance seems likely to contribute to the conservation outcomes through at least two mechanisms. First, participatory surveillance can directly increase the social and/or economic costs of outdoor water waste. Second, participatory surveillance may change residents' beliefs about the possibility of being observed and the importance of water conservation, which might influence their behavior. Moreover, our results are consistent with expectations about expand-

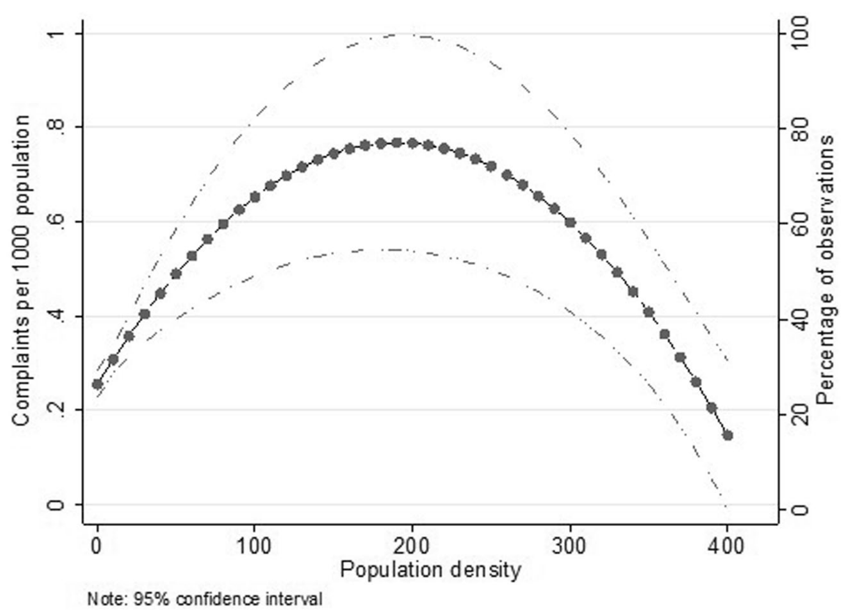


**Figure 5.** Population density and complaints.

**Table 3**
*Does Participatory Surveillance Correlate With Conservation?*

| GMM model | Model D Coefficient (Robust SE) | $p$ |
|---|---|---|
| Complaints per 1,000 population | 0.555 (0.25) | 0.026 |
| Water days allowed per week | −1.868 (0.10) | 0.000 |
| % Residential use | 0.073 (0.03) | 0.032 |
| Monthly Google trend | 0.089 (0.01) | 0.000 |
| Drought score | −0.974 (0.09) | 0.000 |
| Lagged % Monthly water conservation compared with 2013 | 0.338 (0.02) | 0.000 |
| Constant | 15.152 (2.52) | 0.000 |
| Chi-squared | 1998.118 | |

*Note*. Observations = 13,329. Dependent variable is each utility's monthly percentage water conservation compared to the same month in 2013. Robust standard errors clustered by utilities in parentheses. Two-tailed $p$-values reported.

ed monitoring capacity and align with previous findings that public participation has a positive impact on policy outcomes (Nabatchi et al., 2017).

The estimated coefficients of the time-varying control variables yield other interesting findings, as well. As expected, when there are more water days allowed per week (i.e., weaker outdoor watering restrictions), utilities tend to conserve less water. The percentage of residential use is positively associated with water conservation, which suggests that the residential communities are more responsive to the state conservation policy than the commercial or industrial communities. The salience of the drought measured by monthly Google trend positively is significantly associated with water conservation, consistent with other studies of media salience and water conservation (Bolorinos et al., 2020; Quensel & Ajami, 2017). Finally, the severity of drought conditions is negatively associated with water conservation, which is counter-intuitive and deserves deeper examination with more information.

## 7. Discussion

Restrictions on outdoor water use have been and are likely to remain important instruments for policymakers seeking to drive conservation in California and elsewhere. Although the agricultural sector is the single largest water user in California, legal and political constraints make it difficult for policymakers to reallocate water from agricultural to urban areas (J. Brewer et al., 2007). Policymakers thus choose policy tools that may help reduce water consumption during droughts given their limited ability to increase supply (Olmstead & Stavins, 2009). Discretionary urban outdoor water use is an obvious target for conservation efforts in California, since Californians in urban areas use 50% or more of their water consumption outdoors for nonessential purposes like sidewalk cleaning, car washing, and nonagricultural irrigation (State Water Board Adopts 25 Percent Mandatory Water Conservation Regulation: https://www.waterboards.ca.gov/press_room/press_releases/2015/pr050515_water_conservation.pdf). Beyond California, water systems use participatory surveillance through anonymous online reporting as part of their water use restrictions in the U.S. states of Colorado (https://www.denverwater.org/residential/rebates-and-conservation-tips/summer-watering-rules/report-water-waste), Florida (https://www.swfwmd.state.fl.us/form/water-restrictions-violation), Nevada (https://www.lvvwd.com/conservation/water-waste/report-water-waste/), and Texas (https://www.

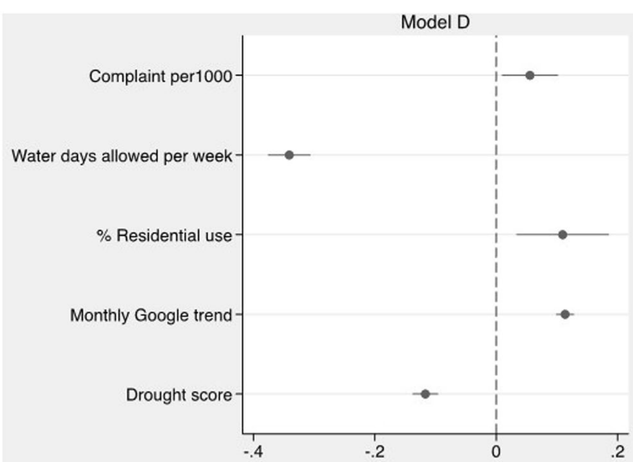


**Figure 6.** Standardized coefficients (95% confidence interval). Note: Dependent variable is each utility's monthly percentage water conservation compared to the same month in 2013. Plot shows the relationship between a one standard deviation change in each variable and the percentage of water conserved.

saws.org/conservation/water-waste/report-water-waste-form/), among others. Similarly, participatory surveillance systems accompany water use restrictions in Australia (https://www.sydneywater.com.au/SW/water-the-environment/what-we-re-doing/water-restrictions/report-about-water-restrictions/) and Canada (https://vancouver.ca/home-property-development/alert-us-of-water-waste.aspx).

In theory, inviting the public to serve as conduits of information about water waste expands authorities' capacity to monitor conditions and can make restrictions more effective. However, employing participatory surveillance means that demographic, socioeconomic, and political contexts are likely to condition the enforcement of water conservation regulations. California utilities' experience with participatory surveillance in the implementation of water regulations during a drought emergency revealed that water waste reporting indeed varied considerably by social context. We found that, other things being equal, communities with higher mean education were likely to file complaints. Comparing municipal, special district, and investor-owned utilities, we found that the public reported violations most frequently under municipal governments, less frequently under special districts, and least under investor-owned systems. We also found that water waste complaints increase as party competition in a community increases. Further analysis shows that participatory surveillance correlates with water conservation, consistent with most prior research on public participation in public services.

Notably, the empirical inferences in this work are limited by their reliance on aggregated utility-level data. Verifying the specific direct and indirect mechanisms that link social contexts to water waste reporting requires data on individual attitudes and behavior. Does water waste reporting vary systematically by race, ethnicity, gender, income, education, or partisanship? Do environmentalism or other ideologies predict reporting? Do community members know the institutional differences between service providers? How do water systems' the visibility and organizational capacity affect a community member's choices to report water waste? Do social and/or political conflicts increase participatory surveillance by inducing more "tattling?" Ideally, researchers would take advantage of exogenous shocks or instrumental variables to identify definitively the effects of social and political factors on participatory surveillance. However, randomized, controlled experiments on participatory surveillance are in most instances impracticable due to legal and ethical considerations. Nevertheless, observational analyses provide a useful basis for inferring relationships between social factors and water waste reporting. Future research with fine-grained data should further examine the determinants of direct and indirect individual-level reactions regarding participatory surveillance.

Practically, this study demonstrates that calls for participatory surveillance may strengthen water conservation regulations during a drought emergency. California's government asked the public to monitor and report on each other's environmental behavior, and Californians responded with nearly a half-million reports of water waste over the course of the drought, with apparently positive results for conservation. At the same time, our findings underscore the fundamentally social nature of participatory surveillance as a means of implementing water restrictions. Authorities seeking to follow California's model should bear in mind that demographic, socioeconomic, institutional, and political contexts are likely to condition the effects of participatory surveillance approaches, and plan accordingly. In particular, policymakers ought to take into account the ways that education levels, population densities, governance institutions, and political competition can shape drought reporting. Participatory surveillance efforts in communities served by investor-owned water utilities, with lower levels of education, little political conflict, and/or low population densities may require additional public outreach to be effective.

## Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

## Data Availability Statement

Original water conservation data are available from the California State Water Resources Control Board: www.waterboards.ca.gov/water_issues/programs/conservation_portal/conservation_reporting.html. Original elections data are available from the University of California's California Statewide Database:

10.1029/2020WR027805

http://statewidedatabase.org/index.html. Original water utility boundary data are available from the California Environmental Health Tracking Program: https://trackingcalifornia.org/water-systems/water-systems-landing. Original demographic and socioeconomic data are available from the U.S. Census: https://data.census.gov. The compiled data set and replication code for this study are available at Data sets and replication files are available at http://mannyteodoro.com and at Harvard Dataverse (https://doi.org/10.7910/DVN/OZ2IYK).

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