How do we build drought resilient drinking water utilities? Learning from Californian Utilities' Drought Responses

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Abstract
California's drinking water utilities are vulnerable to drought related water quality and supply impacts. Utilities are currently managing through an extreme drought. Despite the persistence of droughts in the state, utilities have few requirements for drought planning, especially smaller ones. This study represents one of the first, statewide assessments of drought impacts and responses by the multitude of utility types that supply drinking water. This study aims to identify utility characteristics that enable drought resilience and build adaptive capacity, and inform drought management policies and strategies at multiple levels of drinking water governance.

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Introduction

Drinking water systems (utilities) throughout California are vulnerable to drought related quality and quantity impacts. The magnitude of these impacts is related both to the temporal and spatial extent of the drought as well as local vulnerability to environmental change. Additionally, water supply and demand, and climate impacts are also unequally distributed across the state, in time and over space. The intensity and frequency of droughts in California's semi-arid climate is expected to increase with global climate change (CNRA 2013). Utilities play an important role in mediating the severity of drought impacts on the communities they serve. Utilities appear differentially vulnerable, prepared for, and adapted to water supply and quality impacts due to droughts. Despite the persistence of droughts in the state's history, there are few requirements for drought hazard planning for the majority of California's utilities, in particular for responding to water quality threats. The California's Department of Water Resources' (DWR) recent climate guidance said that there are not consistent drought scenarios in place for the state, and that "drought characteristics that can be articulated for present and future conditions in an extreme scenario are an area for future development" highlighting that "requirements for planning for drought are few" (DWR 2015, p. 57) .

The vulnerability and resilience of utilities to the drought and climate impacts is related both to the temporal and spatial extent of the drought as well as the social exposure and sensitivity to environmental changes. Factors like geographic location (within California), isolation (in relation to nearby systems), type of water source (groundwater or surface water), and extent of reliance on imported versus local supplies, all influence utility vulnerability and resilience. Utility vulnerability to drought and climate change is further complicated and exacerbated by the state's drinking water crisis. There are an estimated 250,000 Californians who are water insecure (Moore et al. 2011). The Center for Community Water, an environmental justice organization based in the Central Valley, estimated that there are close to 750,000 Californians without safe drinking water: 91,000 people served by tribal or small water systems and around 660,000 served by medium and large systems (CWC 2014).

The driving research question behind the paper's model is *do certain utility characteristics, including water supply, size, and governance type lead a more or less drought resilient utility?* A drought *resilient* utility is one that has "the ability to respond to immediate water supply threats, withstand drought impacts and recover quickly. Recovery includes considering long-term conditions and planning for permanent solutions" (EPA Office of Water 2016, p.3). The authors' expectation is that due to economies of scale, capacity constraints, and lack of required planning processes, smaller utilities are less drought resilient and this is echoed in the literature (Conrad 2013; SWRCB 2015; DWR 2012). The model described in this paper seeks to measure a utility drought preparedness, and determine whether utility preparedness is a predicted by certain utility characteristics. Later phases of this study will investigate the relationship between a utility's ability to meet Safe Drinking Water Act standards (MCL violations), and type of population served i.e. disadvantaged or cumulatively burdened, and level of drought resilience.

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Utilities in California

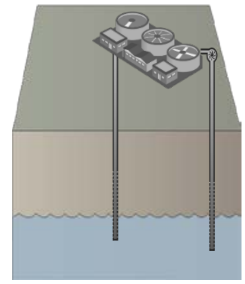

Figure 1. Groundwater reliant utility, with two supply wells.

There are more than 8,300 public water systems (PWS) that supply water to more than 98% of the California's population (SWRCB 2015). Since a PWS can be publicly owned i.e. municipal departments or county districts, or privately owned system i.e. mutual water companies, investor-owners utilities, we employ *utility* in this paper is as an all-encompassing term for PWSs responsible for serving drinking water to their customers and complying with regulations like the US Safe Drinking Water Act (1974). Of the 8300 utilities, more than 70% are both primarily reliant on groundwater and very small (25- 500 people served) (see Figures 1 and 2). Large utilities are required to submit Urban Water Management Plans; meaning that most of the state's utilities have no required drought or water shortage contingency plans. We expect utilities to appear differentially vulnerable, prepared for, and adapted to water supply and quality impacts due to droughts based on utility characteristics like size, ownership, and supply sources that are included as independent variables.

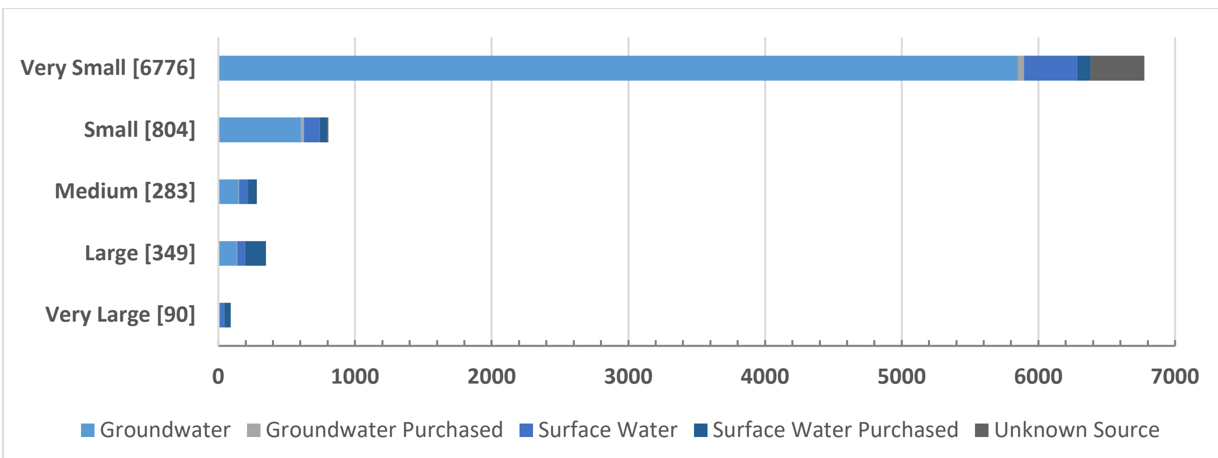

Figure 2. Dominant supply type by size class, where count of CA utilities in each class is in [ ]. Utility Data: (SWRCB 2016b)*, size classification from EPA (2017).*

Literature Review: Climate and Drought Resilience of Drinking Water Utilities

The paragraphs below explain how the literature informs our model variable selection. As explained in the methodology section in greater detail, we look at utility size, planning requirements, ownership type, and supply source type as predictors of utility resilience to water supply and quality drought impacts. The goal of comparative institutional research is to investigate the ways in which different institutions respond to the same even or crisis as a means to illuminate "the relationships between institutional features and water management outcomes" (Blomquist, Heikkila, and Schlager 2004). This model compares institutional and other features of utilities in California and how they respond to the same drought crisis event of the last several years. The aspiration is to identify utility features that lead to drought resilient outcomes.

We expect that larger systems are more likely to be prepared for the drought than smaller ones (H1). Smaller water systems have the highest rates of non-compliance with Federal Clean Drinking Water Standards (SWRCB 2015) and experience the "majority of serious water supply problems during droughts (e.g. inability to maintain fire flows, need for truck haulage of water)" (DWR 2012, p.8). Conrad (2013) articulates how "small suppliers are more likely to rely on a single source, especially groundwater, […and] are less likely to have relationships with other suppliers, thereby reducing their options for coping with severe drought". Around 440 large utilities in California are required to submit UWMPs to the state, which include a drought and water shortage contingency section.

In different drought contexts, *public* utilities appear more proactive on water conservation and more flexible in drought response than *private* water companies (Kallis & et al. 2010; Kallis et al. 2009). In their 2009 review of whether private or public ownership of water utilities differed in their approaches to water conservation Kallis et al. (2009) found that "public providers were somewhat more likely to act proactively and appeal to their users to use less water because of the [2007-2009] drought". One reason this was the case, based on interview the authors conducted was that private providers were waiting for the drought to worsen and public opinion to shift in its tolerance of water rationing programs. Whether the private-public differences persist through the current drought remains to be tested, but based on their initial findings the model tests the hypothesis that *publicly owned and managed utilities are more prepared to the drought [H_3].*

The relationship between water supply source type and drought resilience is likely linked to other characteristics like size. Larger systems tend to rely more on surface water (Figure 2). There is a wealth of research on quantifying climate and extreme event impacts on water resources. These studies frequently focus surface systems where supplies are directly impacted by climate changes in temperature and precipitation regimes e.g. rivers, lakes, reservoirs etc. (Joyce et al. 2011; Sicke, Lund, and Medellín-Azuara 2012; Vicuna et al. 2007). In California, however, the majority of drinking water systems rely on groundwater. When surface water availability diminishes, users increase their groundwater reliance: groundwater accounts for 40% of total supply in an average year but nearly 60% in dry years (DWR 2014b; DWR 2014a). *Surface Water systems are more likely to be prepared for the drought than groundwater reliant ones (H_4).* This is also partly due to the nature of surface water resources. It is much easier to physically move, exchange, sell, and transfer surface water in California's highly engineered surface water infrastructure.

Methodology

The section introduces the online survey used to elicit utility manager's experiences with water-quality issues and perception of threats to water quality due to extreme climate and weather events like droughts, floods etc. Survey responses, coupled with publicly available data about California utilities, serve as the data for the model developed in this study. An ordered Logit model is used to for the observed ordinal, dependent variable, of drought resilience. The aim is to move beyond binary outcomes of resilient or not, and to have a range of drought resilience "score" from 0 to 5, for both water quality and supply. The section closes with describing the independent and hypotheses tested by the model and how the dependent variable of drought resilience scores was estimated.

Online Survey

The *California Water Quality and Extreme Events Survey* was an online survey distributed in August 2015 to 756 contacts that represent 925 utilities that met certain criteria. The purpose of the study was to gather information from water resource managers on considerations of past and future risks of extreme events on drinking water quality management and to identify the type of information they need to manage those risks. Using APPOR disposition codes, the overall survey Response Rate 2 is 34.3% (n=259) and Cooperation Rate 2 is 84.6%. More information about the survey design and its disposition report is available in the supplemental materials from Ekstrom et al. (2016).

Model Description

The model seeks to answer the research questions of whether certain utility characteristics, including water supply, size, and governance type lead a more or less drought resilient utility. The model developed and analyzed in this paper is an initial look at the ways in which utilities differ in their resilience to the current drought. There are two institutional variables-utility ownership type, and planning requirement i.e. existence of an Urban Water Management Plan (UWMP). The model currently assumes the same level of exposure and sensitivity to drought impacts, by holding this constant, the model compares utility characteristics that contribute to a utility's placement on drought resilience scale. There are additional variables that are still missing from this analysis given time and data collection constraints and will be included in later versions of this paper.

Independent Variables and Hypotheses: Utility Characteristics

Independent variables are based on data publicly available from the SWRCB Drinking Water Repository (SWRCB 2016b), and on data compiled by the author as received from SWRCB and the Department of Water Resources list of utilities with UWMPs. Four hypotheses are tested, based on four independent variables summarized in Table 1, model variables are listed in [ ] at the end of each hypothesis statement:

- **H_1: Utility Size—** Larger systems are more resilient than smaller systems due to more capacity/resources. [β_{size}]
- **H_2: Planning Requirement**—Utilities that have an Urban Water Management Plan (UWMP) are more resilient because they are required to plan for droughts. *[Have a UWMP = 1 | no plan = 0; β_{UWMP}]*
- **H_3: Utility Ownership Type—** Publicly owned and managed utilities are more resilient to the drought than privately owned systems, due to greater customer accountability. *[Privately owned yes = 1| no = 0; $\beta_{private}$]*
- **H_4: Utility Supply Source--** Utilities reliant on any groundwater (GW) are less resilient than utilities relying on any surface water (SW) or any purchased water

(PW). GW is often less regulated and monitored, indirect drought impacts aren't always planned for, and supplies may be less flexible *[GW, SW, PW; β_{XW}]*

Table 1. Overview: Independent Variables

Independent Variables		Explanation	Data Source
(β_{size}) Utility Size, Classified by Population Served (% of survey respondents also shown)		(5) Very Large (100,001+) (8.9%) (4) Large (10,001-100,000) (32.4%) (3) Medium (3,301-10,000) (15.6%) (2) Small (501-3,300) (28.1%) (1) Very Small (25-500) (12.4%)	(SWRCB 2016c)
(β_{UWMP}) Planning Requirement		1= have UWMP | 0 = no UWMP	(Vail, B. 2015, personal comm.)
($\beta_{private}$) Ownership		1= private | 0 = not private *[based on initial categorizations of 1= federal, 2= local, 3= mixed, 4 = private]*	(SWRCB 2016c)
Supply Source	(β_{GW}) Any Groundwater (β_{SW}) Any Surface Water (β_{PW}) Any Purchased Water	Volume of water by supply type: groundwater, surface water or purchased water, was reported in a utility's 2014 Annual Report, submitted to the SWRCB. These three binary variables are calculated based on whether each supply is > 0.	(SWRCB 2016a)

Dependent Variables: Drought Resilience Score

Two dependent variables are used to evaluate utility drought resilience for impacts on 1) water quality (WQ) and 2) water supply (WS). Each dependent variable is a calculated resilience score, based on survey responses to different questions (see Table 2). An ordered logit model is run for each dependent variable. A utility's possible Drought Resilience Score range from 0 (no plan) to 5 (have an implemented/sufficient plan). Given skipped questions and missing information, 23 observations were removed resulting in a final *n* of 236.

Table 2. Dependent Variable: Drought Resilience,

Water Quality Resilience Score	***Water Supply Resilience Score***
31. Do you have a written drought plan?	31. Do you have a written drought plan?
32. Does plan include water quality impacts?	33. Have you implemented it?
34. Is plan sufficient for WQ Impacts?	35. Is plan sufficient for water supply Impacts?
Possible answers to survey questions 32-35 include yes, no, and somewhat	

This ordered logit estimates the cumulative probability of being in one score category of drought resilience versus all lower or higher categories, while the distances between adjacent levels are unknown.

Results

A utility's possible Drought Resilience Score range from 0 (no plan) to 5 (have an implemented/sufficient plan); see Table 3 and Figure 3 for a distribution of Resilience scores for each dependent variable, WQ and WS. The output of the first ordered logit (water quality preparedness) is summarized in Table 4 and the second ordered logit (water supply preparedness) is summarized in Table 5. Utility size was the only significant explanatory variable for both models with a small, but positive relationship on the dependent variables. In contrast, both ownership and groundwater reliance have negative and significant relationship on water supply preparedness. Population class and UWMP are the only variables with positive coefficients, suggesting a slight increase (given their magnitude) in the chances that utility will be observed with a higher drought preparedness score. In contrast, ownership and supply sources all have negative co-efficient of varying magnitudes which a higher chance that a utility will be observed with a lower drought preparedness score.

Table 3 Frequency Table of Resilience Scores, n= 236

Score	*WQ*	*WS*
0	52	52
1	20	44
2	36	15
3	68	20
4	12	18
5	48	87

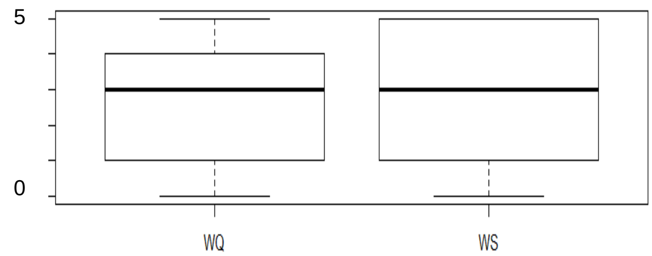

Figure 3. Distribution of Resilience Scores for Water Quality (WQ) and Water Supply (WS)

Holding all other variables constant, the odds of a utility with a one unit change in size (population class) being in the next highest score of drought preparedness is 1.328 times (for Water Quality) and 1.468 times (for Water Supply) the odds of a utility in one size class smaller. Similarly the odds of a utility being in the next highest score of drought preparedness when they have an UWMP (x = 1) is 1.321 times and 1.687 times the odds of a utility without an UWMP for Water Quality and Water Supply, respectively. However, all of the 95% confidence intervals cross 1 suggesting no real difference despite the odds ratios suggesting otherwise (see Table 4 and Table 5).

Table 4. Water Quality Drought Preparedness

Independent Variables	**ß**	**95% CI**	**Std. Error**	**t Value**	**Odds Ratio**	**95% CI**
(β_{size}) Population Class	**0.284***	(-0.014 - 0.582)	0.152	1.867	1.328	(0.985-1.792)
(β_{UWMP}) UWMP (1= have plan)	0.278	(-0.415 - 0.972)	0.354	0.786	1.321	(0.661-2.653)
($\beta_{private}$) Ownership (1= private)	-0.441	(-1.060 - 0.178)	0.316	-1.397	0.643	(0.345-1.194)
(β_{GW}) Any Groundwater Reliance	-0.416	(-1.014 - 0.194)	0.308	-1.332	0.664	(0.361-1.212)
(β_{SW}) Any Surface Water Reliance	-0.006	(-0.590 - 0.577)	0.298	-0.021	0.994	(0.554-1.785)
(β_{PW}) Any Purchased Water Reliance	-0.235	(-0.792 - 0.322)	0.284	-0.826	0.791	(0.452-1.379)
Observations, n = 236	*Note:*	**p<0.1; **p<0.05; ***p<0.01*				

Table 5. Water Supply Drought Preparedness

Independent Variables	ß	95% CI	Std. Error	t value	Odds Ratio	95% CI
(β_{size}) Population Class	**0.384****	(0.083 - 0.684)	0.153	2.505	1.468	(1.087-1.987)
(β_{UWMP}) UWMP (1= have plan)	0.523	(-0.180 - 1.226)	0.356	1.459	1.687	(0.837-3.423)
($\beta_{private}$) Ownership (1= private)	**-0.574***	(-1.188 - 0.040)	0.313	-1.832	0.563	(0.304-1.040)
(β_{GW}) Any Groundwater Reliance	**-0.566***	(-1.182 - 0.049)	0.314	-1.802	0.568	(0.304-1.045)
(β_{SW}) Any Surface Water Reliance	-0.278	(-0.863 - 0.306)	0.298	-0.934	0.757	(0.421-1.359)
(β_{PW}) Any Purchased Water Reliance	-0.324	(-0.889 - 0.240)	0.288	-1.127	0.723	(0.409-1.268)
Observations, n = 236	*Note:*	**p<0.1; **p<0.05; ***p<0.01*				

In general, while some of the model coefficients are significant they are all small suggesting the strength of the independent variables on the dependent variable in the model is weak. Despite, this somewhat weak relationship larger systems appear to score higher (H1) for both measurements of drought preparedness and non-private utilities seem to be less likely to score low suggesting that publicly owned and managed utilities are more likely to be more prepared to the drought (H3). [H1] Larger systems are more prepared for drought impacts on WS and WQ; as small systems are not required to have an UWMP [H2], the size coefficient is statistically significant but the odds ratios are for size and UWMP are similar. Privately owned systems [H3] are .643 and .563 less likely to be prepared for both WQ and WS, respectively.

Implications

Summary survey results suggest that current plans do not sufficiently accounted for water quality, and supply-focused plans could prove inadequate in the face of future drought. Of the survey respondents who reported having a written plans, nearly 34% of respondents said that their plan was insufficient for managing drought impacts to water quality and 24% felt their plan was insufficient for managing impacts to water supply. Additionally, irrespective of plans, close to 40% of respondents reported that the drought impacted water quality (97/245).

Conclusion

The DWR identified gaps in planning for utilities after reviewing historical drought experiences, including the “improvement of drought preparedness” for small systems (DWR 2015, p. 75). The State is, and should continue, to focus on the drought resilience of privately owned, small, groundwater reliant utilities. For larger systems, unless planning requirements change, we would expect that current drought contingency plans will remain insufficient for mitigating impacts from future droughts. Especially because climate projections show that droughts are likely to increase; all utilities would benefit from a specific focus on drought-related water quality planning, and small ones would benefit from drought planning in general.

Governor Brown’s May 2016 drought related Executive Order (EO, B-37-16) includes three directives aimed at helping utilities “manage and prepare for dry periods” (Brown 2016). The state hopes to build local and regional drought resilience by updating current planning requirements to include longer and more severe droughts, and establishing a process for small water suppliers and rural communities not currently covered by UWMPs. To be successful in this endeavor, state agencies tasked with implementing the EO benefit from research like this study that captures utilities’ experiences and local knowledge of successful drought responses, barriers, and opportunities where state intervention and support is welcomed. Additionally, identifying which system characteristics enable a utility to respond and adapt to droughts can be used to encourage drought resilience among other utilities, both within California and the region water management structures.

Next Steps

In 2016, the research team completed 57 utility level interviews across 9 of California’s climate impact regions. Of these 57, 35% were groundwater reliant, 56% were surface water reliant (including purchased water), and faction rely on both groundwater and surface water (5%). As a group, interviewed utilities collectively serve water to about 8.1 million Californians, close to 20% of the State’s utility customers. This does not include populations served by wholesale-only utilities interviewed like Metropolitan Water District of Southern California, Mojave Water Agency, and San Diego Water Authority who deliver water to an additional 18.7 million Californians. Interviews highlight that the diversity of drought impacts and responses are driven by a utility’s geographic isolation, regional policy process participation, and reliance on imported versus local water sources. The next phase of research will be to compare and contrast findings between the survey, model and interview analysis.

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