DROUGHT MANAGEMENT AND CLIMATE ADAPTATION OF SMALL, SELF-SUFFICIENT DRINKING WATER SYSTEMS IN CALIFORNIA

A Report for:

California's Fourth Climate Change Assessment

Prepared By:

Julia A. Ekstrom[1], Meghan R. Klasic[1], Amanda Fencl[1], Mark Lubell[1], Ezekiel Baker[1], Frances Einterz[1]

1 University of California Davis

DISCLAIMER

CALIFORNIA natural resources AGENCY

Edmund G. Brown, Jr., *Governor*

August 2018

CCCA4-CNRA-2018-004

ACKNOWLEDGEMENTS

This research project would not have been possible without contributions from policymakers, stakeholders, and researchers who have provided valuable input over the course of the study. We especially want to thank the many California drinking water system managers, staff, and board members, who shared their valuable time and experiences with us to help build the narrative of drinking water management, drought, and climate change adaptation.

We thank Reverend Amanda Ford of the Environmental Justice Coalition for Water (EJCW) for her skilled facilitation and leadership skills. In addition, we thank Colin Bailey (EJCW) for providing valuable insights and assistance in developing workshops. Additionally, we appreciate the advice, logistical support, and thoughtful presentations from the following for regional workshops and the policy forum: Gary Petersen (City of Salinas Public Works), Amy Little (SWRCB), Jan Sweigert (SWRCB), Heather Lukacs (EJCW), Jim Alves (City of Modesto), Paul Harris (City of Lakeport Department of Public Works), John Andrew (DWR), John Gichuki (Big Valley Rancheria), Jessi Snyder (Self Help Enterprises), Laurel Firestone (Community Water Center), Gita Kapahi (SWRCB), Jonathan London (UC Davis), Erik Ekdahl (SWRCB), Alfonso Aranda (UC Davis), Kristin Dobbin (UC Davis), Randy Reck (EJCW), Jessica Rudnick (UC Davis), Angelica Ruiz (EJCW), and Galen Treuer (University of Connecticut). We appreciate three anonymous reviewers of the earlier version of this report and helpful structural and content suggestions from Jamie Anderson (DWR).

PREFACE

California's Climate Change Assessments provide a scientific foundation for understanding climate-related vulnerability at the local scale and informing resilience actions. These Assessments contribute to the advancement of science-based policies, plans, and programs to promote effective climate leadership in California. In 2006, California released its First Climate Change Assessment, which shed light on the impacts of climate change on specific sectors in California and was instrumental in supporting the passage of the landmark legislation Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006), California's Global Warming Solutions Act. The Second Assessment concluded that adaptation is a crucial complement to reducing greenhouse gas emissions (2009), given that some changes to the climate are ongoing and inevitable, motivating and informing California's first Climate Adaptation Strategy released the same year. In 2012, California's Third Climate Change Assessment made substantial progress in projecting local impacts of climate change, investigating consequences to human and natural systems, and exploring barriers to adaptation.

Under the leadership of Governor Edmund G. Brown, Jr., a trio of state agencies jointly managed and supported California's Fourth Climate Change Assessment: California's Natural Resources Agency (CNRA), the Governor's Office of Planning and Research (OPR), and the California Energy Commission (Energy Commission). The Climate Action Team Research Working Group, through which more than 20 state agencies coordinate climate-related research, served as the steering committee, providing input for a multisector call for proposals, participating in selection of research teams, and offering technical guidance throughout the process.

California's Fourth Climate Change Assessment (Fourth Assessment) advances actionable science that serves the growing needs of state and local-level decision-makers from a variety of sectors. It includes research to develop rigorous, comprehensive climate change scenarios at a scale suitable for illuminating regional vulnerabilities and localized adaptation strategies in California; datasets and tools that improve integration of observed and projected knowledge about climate change into decision-making; and recommendations and information to directly inform vulnerability assessments and adaptation strategies for California's energy sector, water resources and management, oceans and coasts, forests, wildfires, agriculture, biodiversity and habitat, and public health.

The Fourth Assessment includes 44 technical reports to advance the scientific foundation for understanding climate-related risks and resilience options, nine regional reports plus an oceans and coast report to outline climate risks and adaptation options, reports on tribal and indigenous issues as well as climate justice, and a comprehensive statewide summary report. All research contributing to the Fourth Assessment was peer-reviewed to ensure scientific rigor and relevance to practitioners and stakeholders.

For the full suite of Fourth Assessment research products, please visit www.climateassessment.ca.gov. This report advances understanding of how small self-sufficient drinking water systems were affected and challenged by the 2012-2016 California Drought and provides insight into needs, challenges and barriers to climate adaptation to reduce risks of future extreme events.

ABSTRACT

Examining human impacts, responses, and challenges to extreme climatic events can give insight into needed directions for climate adaptation to reduce future risks. This study focuses on the 2012-2016 Drought in California, documenting how small self-sufficient drinking water systems were affected and challenged by, and responded to the extreme event. The majority of small, self-sufficient water systems in the state serve rural, low income communities, and many have low technical, managerial, and financial capacity compared to larger systems. This increases the risk that these drinking water systems will be disproportionately impacted by droughts or other disruptions. To assess the impact of drought on small water systems, we employed an iterative approach to gathering perspectives and experiences from drinking water system managers across the state. The goal of employing these iterative methods is to better understand the breadth and scope of impacts, responses, and barriers to dealing with the 2012-2016 Drought. The first stage of the data collection involved interviewing managers of drinking water systems, which were transcribed and analyzed using semi-grounded theory methods. To cross-check and advance findings from interviews in additional locations, we conducted three small regional workshops and then a larger policy forum. Multiple data collection methods allowed us to gather insights about experiences from nearly 200 water managers. This project uses local knowledge to document the social dimensions within drinking water systems during the 2012-2016 Drought and expresses the value of local knowledge in reflecting on future drinking water system needs in response to extreme events.

We found that drinking water systems, despite size or government project water reliance, experienced a similar set of drought impact, response, and barrier categories (e.g., water quantity and water quality). However, within these categories, the types of impacts, responses, and barriers differed based on both system size and water source portfolio. Common disadvantages that hinder drought resilience, and thus climate adaptation, of small self-sufficient drinking water systems include: staff capacity; financial burden of revenue loss during drought compounded with increased need for staff time for additional reporting; customer awareness and outreach challenges; and consolidation. We found that consolidation is valuable but in many case needs more state support to implement and incentivize. From a long term perspective, the absence of expressed duty and lack of concern for risks of climate change among water managers indicates a major dearth in adaptation planning among these drinking water systems. Documentation of experiences from the 2012-2016 Drought can be used to inform future planning for droughts and more broadly climate change.

Keywords: drought, climate adaptation, drinking water, small drinking water systems, disadvantaged communities, climate justice, extreme events

Please use the following citation for this paper:

Ekstrom, Julia A., Meghan R. Klasic, Amanda Fencl, Mark Lubell, Ezekiel Baker, Frances Einterz. (University of California, Davis). 2018. ***Drought Management and Climate Adaptation among Small, Self-Sufficient Water Systems in California.*** California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-004.

HIGHLIGHTS

- Many study participants agreed that existing and proposed regulatory efforts look good on paper, but contain two key flaws: 1) they target and are often developed with larger systems in mind; and, 2) they are often unfunded, potentially creating an additional burden on smaller systems. Extending sources and improving source resiliency were the top climate adaptation strategy types mentioned by both small and large drinking water system managers.
- Examples of anticipatory climate adaptation among small self-sufficient drinking water systems are largely absent; therefore, learning from drought and other extreme events is important for signaling systems' adaptation needs.
- Advancing equitable adaptation requires additional levels of assistance for local drinking water managers and systems with lower adaptive capacity.
- Small self-sufficient drinking water systems need training or other forms of support to start thinking about what climate change means for the operation, cost, and overall future of their water systems.
- Maintaining momentum created through State-supported education and outreach, partnership building, infrastructure investments, and efficiency incentives during the 2012-2016 Drought would support future drought preparedness.
- Small self-sufficient drinking water systems expressed similar overarching categories of drought impacts, responses, and barriers compared to other systems; but experienced differences within these categories, warranting continued focus on their specific needs, experiences, and perspectives.
- Three crosscutting themes arose throughout the interview and workshop-based documentation of the impacts, responses, and barriers to responding to the 2012-2016 Drought: (1) water supply resiliency and robustness; (2) funding mechanisms; and, (3) the role of communication.
- Small drinking water system managers identified common challenges resulting from the 2012-2016 Drought: conservation-driven revenue losses and related financial hardships, lack of staff capacity for meeting regulatory requirements and securing additional funding, and distrust with other nearby water users and/or their own customers.
- Barriers to managing drought impacts and advancing in climate adaptation do not exist in isolation, and small systems tend to experience a domino effect of interacting burdens related to implementation, finance, capacity, and more. Existing efforts are not robust enough to comprehensively address barriers to small drinking water systems.
- Pre-drought advantages and inherited responses demonstrate the effectiveness of actions taken in between major drought events like ongoing water conservation outreach programs, rate restructuring, infrastructure updates, and maintaining working relationships among and between systems, non-governmental organizations, and the state government.

WEB LINKS

University of California, Policy Institute for Energy, Environment, and the Economy: Climate Adaptation Program https://adaptcc.wordpress.com/

California Water Blog article posted August 6, 2017: "Small, self-sufficient water systems continue to battle a hidden drought." https://californiawaterblog.com/2017/08/06/small-self-sufficient-water-systems-continue-to-battle-a-hidden-drought/

TABLE OF CONTENTS

ACRONYMS

CIR	Climate Impact Region
CPUC	California Public Utilities Commission
CVP	Central Valley Project
CWS	Community Water System
Conservation Mandate	Emergency Regulation for Statewide Urban Water Conservation (refers to the April 2015 EO; SWRCB's regulation and subsequent update in March 2016; and self-certification process in June 2016)
DAC	Disadvantaged Community
DDW	State Water Resources Control Board's Division of Drinking Water
DWR	Department of Water Resources
EO	Executive Order
GW	Groundwater
PWS	Public Water System
non-S3 Systems	Not Small, Self-Sufficient Drinking Water Systems
S3 Systems	Small, Self-Sufficient Drinking Water Systems
SW	Surface Water
SWP	State Water Project
SWRCB	State Water Resources Control Board
The Drought	2012-2016 Drought
UWMP	Urban Water Management Plan
WSCP	Water Shortage Contingency Plan

1: Introduction

Climate change is projected to continue increasing the frequency and severity of extreme weather-related events globally, which can lead to disastrous impacts on natural resources, infrastructure, and services on which people rely. Climate change-related impacts on people will likely be disproportionately borne by marginalized and disadvantaged communities. Drinking water presents a vivid case of this disproportionate distribution of risk. Most climate adaptation research for drinking water resources has focused on large water systems or modeling surface water. While these are justified foci because a large number of people depend on these types of systems, this leaves a major gap in targeting and fulfilling small drinking water system needs for dealing with extreme events and adapting to climate change.

Approximately 86% of community water systems in California are small (serving less than 10,000 people). Most of these systems are not connected to a government water project, a trait that we describe as “self-sufficient”. Based on the best available data, we estimate that 2,075 small community water systems are self-sufficient, servicing a combined total of 1.7 million people. These small, self-sufficient systems serve a high proportion of rural areas and areas with high proportions of low income households. In California, approximately half of small systems serve disadvantaged communities, which are defined for drinking water communities as those with less than 80% of the mean household income in California (California Public Resources Code, Section 75005(g)).

In the context of drinking water, drought is defined as a period of time during which a region has insufficient water supply to meet demand. This can be due to low precipitation, excessive evaporation, overuse, or a combination of all of these factors, which tend to coincide. Historically, California and the greater Southwest Region of the United States have a long record of periodic droughts. However, over the past century, records show that most severe droughts lasted only two years. The 2012-2016 Drought, as indicated by the name, lasted approximately five years (USGS 2017). The driest period of 2012-2014 was demonstrated to be the most severe drought in the region for the past 1,200 years (Griffin & Anchukaitis 2014).

The 2012-2016 Drought (hereafter referred to as “the Drought”) was intense both in terms of its social and physical impacts on California and thus presents the opportunity to learn from an extreme event that is expected to become more frequent and severe with climate change and population growth (Diffenbaugh et al. 2015; Williams et al. 2015; Seager et al. 2015). Documentation of drinking water managers’ experiences during an extreme weather-related event is useful for both informing policy and preparing for future events at the local, regional, state, and federal levels, and for informing climate change adaptation (McNeely et al. 2016; Kates et al. 2012).

1.1 Project Goal

The overarching goal of this project was to document small, self-sufficient system managers’ perspectives, experiences, and needs for future drought resilience in the face of climate change and uncertainty. Small systems are those that serve fewer than 10,000 people, and self-sufficient system are those that do not receive any water from either of the major California water projects (State Water Project, Central Valley Project). Seeking to document managers’ experiences of small drinking water systems, four key questions guided this study:

1. How were drinking water systems impacted by the Drought?
2. How did drinking water system managers respond or seek to respond to the Drought?
3. What barriers to these responses did drinking water system managers encounter?
4. To what degree are small drinking water systems adapting to climate change?

1.2 Study Context

Situated in the Southwestern United States, California has a Mediterranean climate characterized by warm dry summers and cold wet winters with periodic dry spells. The development of agriculture and urban areas in regions that receive very little rainfall was facilitated by conveying surface water long distances, creating storage reservoirs, and tapping into aquifers, where available. Domestic use due to population growth and agriculture has grown tremendously in the state over the past century, and these two water uses have perpetuated competition over water distribution and use. Much of the agricultural water use, which on average makes up 40% of statewide water, occurs in California's Central Valley (Mount and Hanak 2016). During dry years (either legally from curtailments or physical flow decreases) agricultural users tend to decrease their reliance on surface water use and increase their reliance on groundwater (Haden et al. 2012). In addition, during these dry periods, tensions regularly mount over usage and water rights, which are escalated further by fish and wildlife requirements (for temperature, flow, etc.). All of these competing uses combined with an increased reliance on groundwater impact the availability of water in rural communities that also rely on the groundwater. Smaller drinking water systems, which serve more rural areas, were historically excluded from the power struggles and negotiations among bigger users. While the U.S. Environmental Protection Agency, California's State Water Resource Control Board, and non-governmental organizations have ongoing programs to support small water systems, the sheer quantity of water systems creates a need to document and reflect on their experiences.

Between 2012 and 2016, California experienced one of its most significant droughts, with record-high temperatures and record-low snowpack, runoff, and precipitation (DWR 2015; NIDIS 2018). The rainfall during the 2012-2014 water years (October – April) was the third lowest 3-year average, behind the droughts in 1977 and 1924 (Williams et al. 2015). The groundwater levels in long-term wells dropped to or below historically low levels in more than one-third of Sacramento Valley wells and more than half of Central Valley wells (Faunt et al. 2016). While the lower rainfall and soil moisture deficits during the Drought were within California's range of natural variability (Seager et al. 2015; Berg and Hall 2015), the long warming trend and record high temperatures intensified its impacts (Berg and Hall 2015; Diffenbaugh et al. 2015; Williams et al. 2015; Seager et al. 2015). Several studies found that anthropogenic climate change increased the risk of high winter temperatures early on in the Drought (2013-14; 2014-15), exacerbating soil moisture deficits (Herring et al. 2014; Seager et al. 2015).

California drinking water systems face challenges of continued and future droughts and other extreme events; climate change is expected to amplify these threats (DWR 2015). The likely response is increased reliance on groundwater, and subsequently overdraft and subsidence—

especially by agricultural users and more isolated rural communities with fewer supply alternatives. The Drought provides an opportunity to study and understand how drinking water systems, particularly smaller systems, could be impacted by increasingly dry and warmer years and more frequent or longer droughts.

1.2.1 Drinking Water Systems in California

Public drinking water systems (PWS) are drinking water systems that provide water for human consumption through at least 15 service connections or to at least 25 people for at least 60 days per year (EPA 2017). We focus on water systems that supply drinking water to year-round, permanent populations. Water systems are categorized by size using either population served or the total number of service connections. At the federal level, the United States Environmental Protection Agency (EPA) classifies systems by five sizes (very small through very large), where small systems serve 3,300 people or less. In certain California funding programs[1], however, the SWRCB Division of Financial Assistance defines small systems as those serving 10,000 or fewer people (EPA's medium systems size). To be inclusive of these eligible medium systems, our report defines small drinking water systems as those serving 10,000 or fewer people (approximately fewer than 3,300 service connections). In addition to serving fewer people and having fewer service connections, small water systems also have fewer intakes, wells, and interties (see Appendix A).

Classifying by size and sufficiency status, the study evaluated California drinking water systems into a classification of four groups (**Table 1**). Our main focus is set on the group of systems that are both small and self-sufficient (referring to them as *S3 systems* throughout this report). They represent the majority (87%) of California's community[2] water systems, which provide water to year-round residential populations (California Health and Safety Code, Section 116275). Our project's primary purpose is to understand the experiences of S3 systems. To do this, we compare the experiences of S3 system managers (upper left, grey quadrant of **Table 1**) with those of non-S3 systems.

Table 1: Drinking Water System Size and Sufficiency Categories
(SWP = State Water Project; CVP = Central Valley Project)

	Not connected to SWP or CVP (Self-sufficient)	Connected to SWP or CVP (Not self-sufficient)
Serving <10,001 people (Small systems)	***S3 systems***	*Non-S3 systems*
Serving >10,000 people (Larger systems)	*Non-S3 systems*	*Non-S3 systems*

1 Prop 1. DAC Technical Assistance Program

2 Community water systems are those water systems that primarily serve households. The definition according to the California State Water Board (SWRCB 2018a) is "Community Water Systems are city, county, regulated utilities, regional water systems and even small water companies and districts where people live."

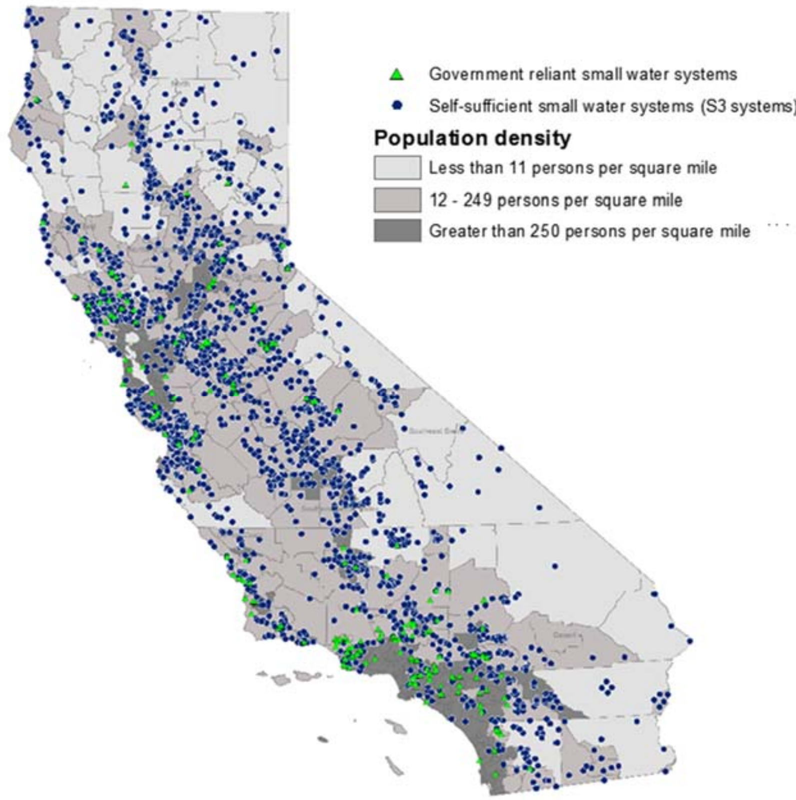

Figure 1: Map of California Small Community Water Systems. Small systems are defined as serving 10,000 or fewer people. Blue circles represent small systems that are also self-sufficient (S3 systems in this study). Green triangles represent small, government-reliant systems that purchase or otherwise receive water from either the State Water Project or Central Valley Project. The grey regions represent population density, thus indicating urban (darker grey, higher density) versus more rural areas (lighter grey, lower density). Source: Authors using data from SDWIS 2016, record of purchased or receive water in 2014 and population density from the US Census 2016.

1.2.2 Small Drinking Water Systems and Environmental Justice

Underpinning our focus on small drinking water systems is the fact that many of these systems are part of a long history of environmental and social inequity in California. Research on environmental justice and drinking water systems demonstrates that disparities develop through natural, built, and sociopolitical environments and through shared histories of marginalization and environmental injustice (Perreault et al. 2012; Balazs and Ray 2014). Such disparities are found in California in studies on water quality (Balazs et al. 2012; Balazs 2011; Balazs et al. 2011; Honeycutt et al. 2012; London et al. 2011), drinking water access (Moore et al. 2011; Christian-Smith et al. 2013; Feinstein et al. 2017; London et al. 2018) and affordability (Moore et al. 2011; Christian-Smith et al. 2013).

Adding to these environmental justice challenges, drinking water management in California is largely governed by local agencies, which are often run by boards of directors comprised of "homogenous, single interest bod[ies] of people representing the larger water users," (Hundley

2001, 534). Additionally, in California, scarcity of water and scarcity of clean, safe, affordable water is a continuing problem. The state's 2012 adoption of a *Human Right to Water* (Cal. Health and Safety Code § 116270) means that state agency decision-making must now legally consider the right to clean, safe, affordable, and accessible water.

1.2.3 Small Drinking Water Systems, Drought, and Climate Change

The Drought underscored the vulnerability of drinking water suppliers, particularly smaller and more rural systems (SWRCB 2018b). More than 181 drinking water systems in the state were in the process of applying for or receiving emergency drought funding as of March 2017 (SWRCB 2017). The Department of Water Resources' (DWR) 2010 Drought Plan (p.56) explains that the state's "small, rural water companies or districts [have] virtually no capacity to respond to drought or other emergency". It also expects that "a few hundred of the roughly 4000 smaller water companies in the state face running dry in the second or third year of a drought," (DWR 2010, p. 56). As Conrad (2013, vii) underlines, small water suppliers are also, "less likely to have relationships with other suppliers, thereby reducing their options for coping with severe drought."

As a result, drinking water systems have to find a way to manage their supplies and quality for both the immediate and long-term future. Their climate preparedness can be measured in their ability to handle impacts, respond to extreme event threats, and recover quickly and efficiently (EPA 2012). As part of this management effort, water managers must navigate a multitude of local, state, and federal policies and actions adopted before, during, and after extreme events, while continuously handling daily operations and maintenance requirements of their systems. By capturing local drinking water manager-level perspectives of the Drought, this project provides insights into preparation and adaption activities needed to address the increasing frequency and severity of extreme events under a changing climate.

2: Methods

There is a growing recognition of the need to employ a bottom-up, social science approach to adaptation like the one being employed in this project (Victor 2015). Seeking to capture the needs of these systems across California, we use an iterative mixed methods approach involving survey data, interviews (and content analysis of transcripts), regional discussion meetings/workshops, and a forum with policy-makers, government staff, and small water system representatives (Figure 2).

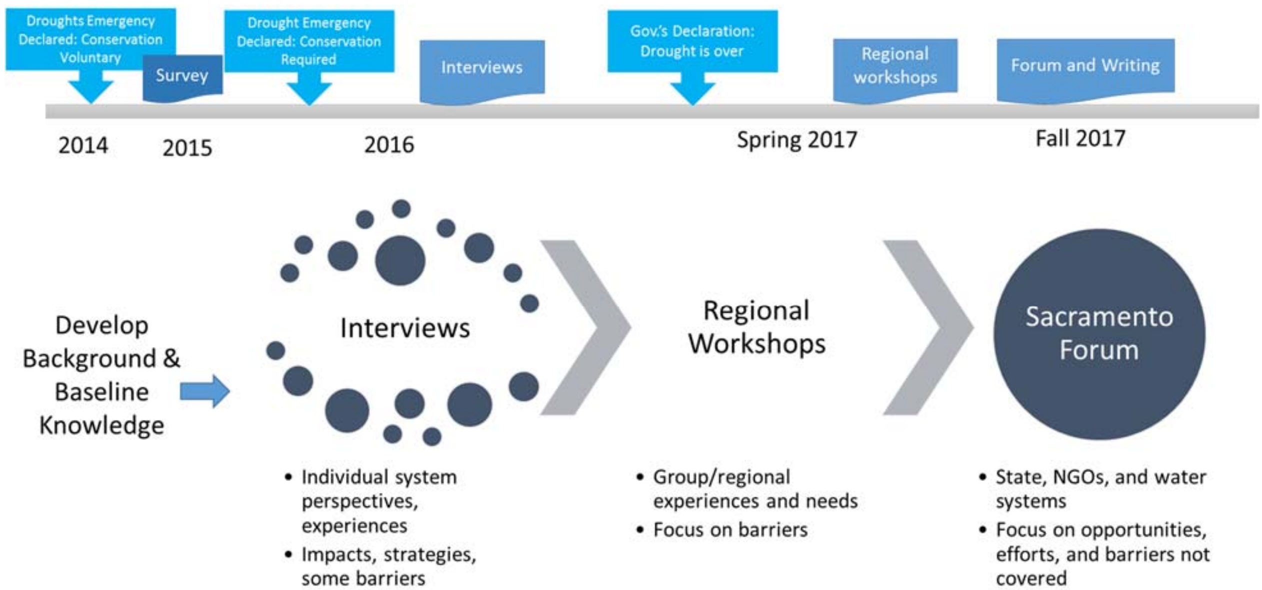

Figure 2: Timeline of study process and events, along with key state policy actions for the Drought. Source: Authors

The timeline of data collection is notable because of the climatic events shaping the experiences and perspectives of study participants. The survey was conducted between July and September 2015, shortly after the first version of the Conservation Mandate was published (June 2015). Before June 2015, system managers were encouraged to implement conservation measures voluntarily. Interviews with drinking water system managers were conducted from June through October 2016, which coincided with the revised Conservation Mandate (May 2016) that required water systems to self-certify that they had sufficient supplies for three more years. During the first half of the 2016/17 Water Year (Fall 2016 - Spring 2017), the State received higher than average precipitation, leading the Governor to declare an end to the State of Drought Emergency in April 2017, with the exception of four counties in continued need of emergency drinking water assistance (Fresno, Kings, Tulare, Tuolumne). The regional workshops were held in June and July 2017 following a wet winter, but many water systems were still feeling economic and other impacts of the Drought. The Sacramento Forum (Forum) was held at the end of Summer 2017, when the Drought experience was still fresh in people's minds. However, the previous wet winter allowed for reflection about the Drought among Forum participants rather than emergency drought management.

2.1 Framing Structure

To examine the variation across systems included in the case studies, we employed an approach and principles similar to those developed in Moser and Ekstrom (2010) to identify the climate change impacts and adaptation strategies (here "responses"), and barriers to climate change adaptation. We use this same definition of adaptation (p. 22026):

> Adaptation involves changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting non-climatic changes. Adaptation strategies and actions can range from short-term coping to longer-term, deeper transformations, aim to meet more than climate

change goals alone, and may or may not succeed in moderating harm or exploiting beneficial opportunities.

This definition was applied previously in California's Third Climate Assessment (Moser & Ekstrom 2012) and elsewhere (Archie et al. 2014). A main difference in the framework's application here is the focus on a present extreme event (the Drought), whereas Ekstrom and Moser (2014) focused data collection on a region's collective anticipation of increasing extreme events. We use the framework to organize and identify barriers to climate adaptation, but also to characterize the types of strategies undertaken (and sought but not implemented) by systems during the Drought. Applying this framework, this study assumes that, in the absence of substantial adaptation efforts, documenting impacts of a climate-related extreme event can provide valuable insights into drinking water systems' potential needs for advancing climate adaptation.

The first step involves identifying what stage an actor is at within an adaptation process (e.g., just beginning to understand what climate change could mean for the water system, or already implementing strategies to reduce the risks, etc.; see Appendix A). As observed from the 2015 survey, small water systems tended to be in earlier or non-existent stages of adaptation compared to larger systems (Ekstrom et al. 2017). The second step is identifying what barriers are impeding the process from advancing. In this case, we were interested in how managers were coping with the drought, whether or how they were planning for future droughts, and what hindered this process. The third step is examining opportunities for intervention to overcome barriers, which this study begins to address by gathering collective input from water systems and other water management stakeholders.

We use the Drought to represent an extreme event that is expected to become more common under a changing climate (Diffenbaugh et al. 2015). Previous research has shown that learning from extreme event management and damage gives valuable insight into informing what is needed for climate adaptation (Costanza et al. 2007; Dilling et al. 2017). As such, rather than focusing centrally on climate adaptation, we focus primarily on the Drought experience of water managers. We use this thorough documentation of the Drought, gathered from experiences during the peak and tail end of the drought, as a proxy for what climate change could look like for these water systems.

Time Horizon of Drought Responses

A key principle of the adaptation framework that we employ in this project recognizes climate adaptation as a process that involves actions and other efforts, the goals of which can differ by their time horizon (Moser and Ekstrom 2010). Time horizons in this context represent a continuum from short-term to long-term effort. The time horizon of an adaptation effort can help explain the extent and focus of a given effort. The goal of a particular effort can vary in its goals; some tend to be short-term or immediate actions, whereas others can be more substantial adjustments to a given system that prepare it for longer term impacts. Even more substantial shifts, or "system transformations," can be made that reconfigure the system's operations, goals, rules, and values so that it is more resilient to impacts over the long-term under a changing climate. As in Moser and Ekstrom (2010), the time horizons in our analysis are not meant to be normative in terms of the "right" time horizon for action. For example, a system seeking immediate coping responses to the Drought will face different and perhaps less challenging barriers compared to a system seeking changes that lead to system transformation (

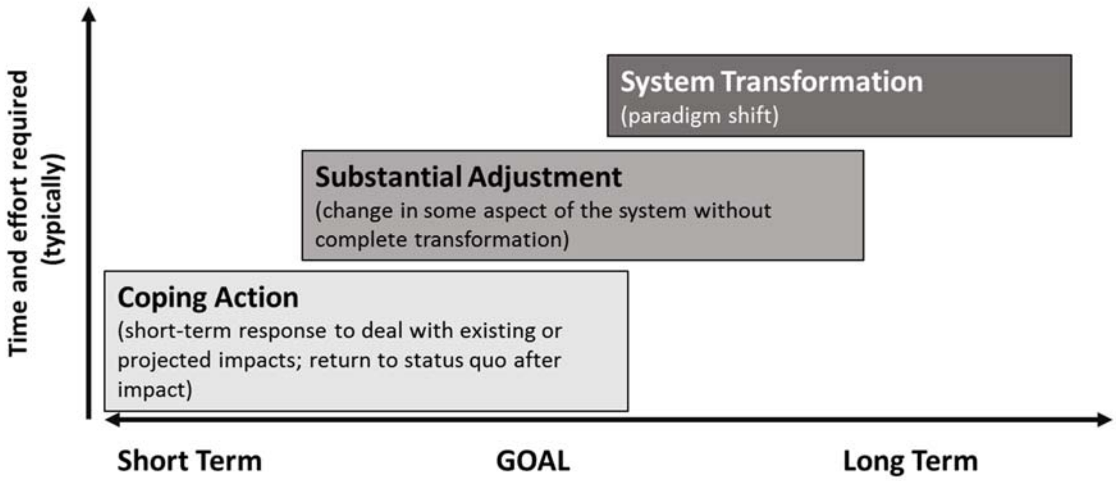

Figure 3).

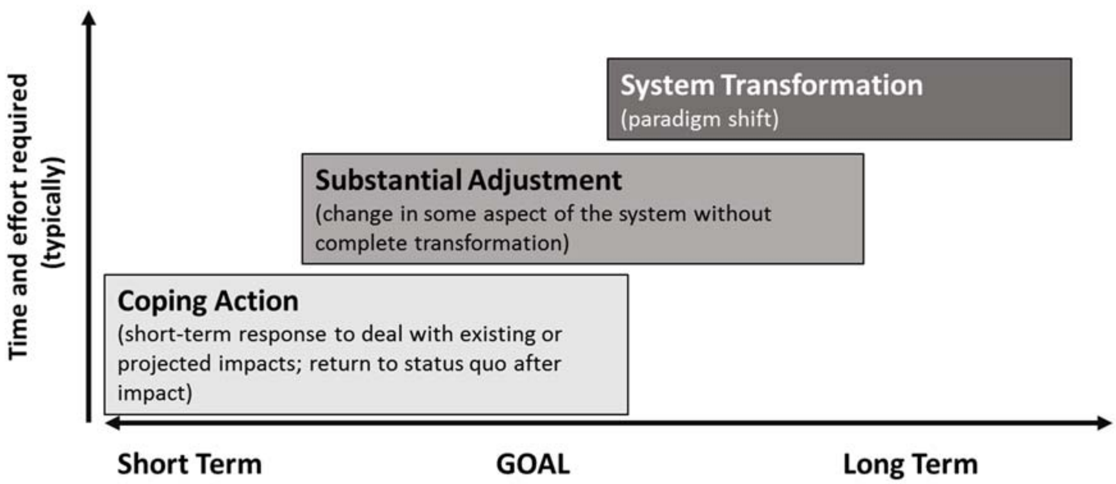

Figure 3: Scope and scale of adaptation to climate change, applied in this study to drought responses implemented by water systems between 2012 and 2016. Source: Moser and Ekstrom (2010) [redrawn].

2.2 Participatory, Iterative Methods to Capture Experiences

The vast majority of studies on drinking water system management is done by engineers, biophysical or economic modelers, and some legal scholars. Our study seeks to document experiences of managers, which involves employing methods rooted in social sciences. These methods recognize the high value of including local knowledge and, thus, systematically collecting data from people intimately involved in the daily details of managing water systems. Because our collection methods and data types differ from engineering and other modeling and legal work, we present literature in this section to confirm the history, rigor, and strengths for gathering managers' perspectives, experiences, and input as primary data.

Mechanisms for Participation

The study utilizes two methods to capture the experiences of a variety of stakeholders impacted by the Drought, focusing on managers of drinking water systems: interviews and facilitated workshops. Interviews are a common strategic method for identifying a variety of representative stakeholders. Semi-structured interviews with snowball sampling can reveal a broader social network than surveys provide (Reed 2008). Snowball sampling is a common sampling technique in social science research where study participants suggest others to recruit for the study. Interviews also effectively supplement quantitative methods by creating narratives and providing additional examples (Larson & Lach 2010). Interviews, when conducted in a structured way, are one-way dialogue and cannot provide an adequate co-learning experience for participants. In comparison, semi-structured interviews, used in this study, provide more opportunity for input from the interviewee, but still follows the bounds of the study goal (Bernard 2006).

Facilitated workshops are a participatory method that create spaces for the multiple stakeholder voices to be documented and heard; they are specifically utilized so that researchers can best consult and collaborate with participant stakeholders (Luyet et al., 2012). In addition to providing feedback and the opportunity to collaborate with researchers, workshops also facilitate knowledge sharing amongst and between other stakeholders, resulting in a co-learning experience (Patel et al., 2007). Additionally, because of the involvement of multiple stakeholders discussing in a dynamic space, workshops may showcase ongoing problems or conflicts that had not previously been obvious to decision makers (Banjade, 2005). However, Kenter et al. (2015) found that individual values about natural resource management can evolve when other people are in the same room. Workshops are successful at improving environmental decision-making and management because they provide spaces for local and scientific knowledge to converge (Patel et al., 2007; Binkley and Duncan, 2009). Group discussions in workshop settings can improve environmental resource management and policy-making and foster co-learning, deliberation, and negotiation.

2.3 Prior Survey Data

The research design was partially informed by a 2015 online survey of water system managers (Ekstrom et al. 2017). This earlier survey found drinking water system managers varied in terms of how prepared they may be for climate change based on indicators of their climate change awareness, technical capacity to manage for climate change, and their self-reported level of adaptation action already taken. Respondents varied across regions by water system size (number of service connections and population served) and by water supply portfolio (use of groundwater, surface water, or both). Analysis of responses showed that system size and source type correlated with its degree of climate preparedness. Small systems and those reliant on groundwater more frequently measured lower degrees of climate preparedness than larger systems that relied on surface water. Further, survey responses demonstrated geographic variation in water quality impacts (Klasic et al., in review). We used response data from the survey to help develop a set of interview questions for drinking water system managers and to help identify systems to invite for interviews.

2.4 Interviews

Interviews sought to gather perspectives and experiences of drinking water system managers with the Drought. The interview schedule, approved by the UC Davis Institutional Review Board as exempt in May 2016, included the study's four key questions (Section 1.1), as well as questions about water quality and the use of climate information for a related study (Baker et al. 2018).

In Summer and Fall 2016, the field research team conducted 58 semi-structured interviews. To capture a range of water system types, we used a multi-step approach that included cluster analysis, key informant interviews, and document review. We developed a coarse typology based on source portfolio, size, and ownership type in each geographic region studied. Using this typology combined with guidance from key informants in the drinking water management sector, four research team members individually invited drinking water system managers for in-person or phone interviews between June and October 2016. We prepared an interview schedule of questions to guide the 1-2 hour interviews. We selected water systems to interview across multiple geographic regions and water system sizes, seeking to capture different perspectives, experiences, and approaches to dealing with the Drought, extreme events, and climate change.

Interviews were audio recorded and transcribed. This enabled a content analysis of 58 interviews. To tabulate patterns across the interviewed respondents, the project team manually coded transcribed interviews using an online content analysis software program, Dedoose ®. Research team members developed the coding scheme as a group to answer the research questions and make observations from conducting the interviews. Each member coded his or her own interviews generously for a broad set of thematic codes (referred to as parent codes in Appendix D). The team then divided into two sets so that only two people were responsible for applying sets of more specific codes within each theme, in order to increase coder consistency (further details refer to Appendix D).

2.5 Regional Workshops

Following the completion of interviews, in Spring and Summer 2017, we held small discussion workshops in three regions that were not well represented in the interviews. We did this to gather the collective voice of drinking water managers' experiences and perspectives and to crosscheck our findings. For assistance, we collaborated with a non-profit organization, Environmental Justice Coalition for Water (EJCW), a nonprofit specializing in working with and empowering under-served communities in California to access safe and affordable water.

The three regional workshops were held with drinking water system managers and other key decision-makers that oversee or have some other intimate experience of working with small water systems (county environmental health staff, SWRCB district drinking water engineers, concerned citizens, among others). Recruitment involved identifying key leaders in each region and inquiring whether they were interested in attending and possibly co-hosting a workshop for small water systems. We reached out to participants of the interview portion of the study in Lake County, which facilitated an invitation to introduce the project in-person. This led to the development of a workshop hosted in Lakeport. For the remaining two workshops in Modesto and Salinas, we sought to continue capturing input from areas that were not well-represented through interviews, especially those that had a high number of small self-sufficient water systems, and those that serve marginalized communities.

2.5.1 Lakeport

The first workshop was located in Lakeport, a small town in Northern California's Lake County. A summary of Lake County water systems and other regions is included in Appendix C. According to the US Census, the 2016 population estimate for Lake County is 64,116 people with a median age of 45.5 years. Nearly 90% of the population is white (US Census 2016). Lake County has a median household income (MHI) of $36,132, compared with the California MHI of $67,739. The county has 57 community water systems, all of which are small and nearly half of which are self-sufficient (27). Thirty-five of these small self-sufficient systems serve a disadvantaged community (calculated based on Census Block Groups). Water quality issues have long been a problem in Clear Lake with its frequent summer algal blooms. Residents and media reported more frequent and larger than usual blooms during the Drought, when low lake levels and warmer weather combined to create ideal growing conditions for problematic algal growth. Most residents get their water from Clear Lake or groundwater from surrounding aquifers. Additional challenges facing Lake County include wildfire and changing land use (increased viniculture and cannabis growing).

Recruitment: Part of the research team introduced our study at a water utility meeting for lake users in May 2017. Water managers expressed interest in participating a workshop with our group and they chose a date and venue for our event. We then sent out email invitations with the assistance of the regional water quality scientist, who has trusting working relationships with water managers. To provide additional context to regional issues, a concerned community member gave a personal introduction to the area to introduce two team members to local issues and the region's geography.

2.5.2 Modesto

The second workshop was held in Modesto, a medium sized city located in Stanislaus County, in the northern end of the San Joaquin Valley of California. Managers interviewed in the first stage of the study captured areas to the north and south of this region, which expressed very different impacts and experiences of dealing with the Drought. We sought collective input for understanding water issues in this part of the Central Valley, given that it received less media attention than more southern counties in the state. Stanislaus County population is 541,560 as of 2016, according to the US Census estimates. Median household income is just over $51,591 and 14.5% are living in poverty (US Census 2016). Residents are an estimated 84% white and 45.6% Hispanic or Latino. Stanislaus County has 70 community water systems, 62 of which are small drinking water systems. Of these, 57 are classified as small self-sufficient water systems according to our categorization (section 1.2.1) and 34 serve disadvantaged communities (by Census Block Groups). All of the water systems in Stanislaus County rely primarily on groundwater.

Recruitment: The research team's partner organization (EJCW) led the recruitment process for the Modesto workshop because of their prior ties with water systems in the region. They assisted in finding a local host interested in the goal of the study, and then distributed the announcement several weeks prior to the event.

2.5.3 Salinas

The third regional workshop was held in the city of Salinas, located in Monterey County. Salinas is a small/medium sized city with an estimated population of 157,218 (US Census 2016). Managers interviewed in areas to the north and south of the region, expressed different impacts and experiences of dealing with the Drought. This, combined with region's demographics, reliance on groundwater, and ongoing water quality issues, led to our inclusion of the region in this stage of the study. The region has a high proportion of disadvantaged communities and an estimated 69% of the county population speaks a language other than English at home (Census 2016). Available data show there are 161 community water systems in Monterey County, 154 of which are reliant entirely on groundwater. Additionally, 132 of the systems are classified as very small, meaning they serve fewer than 501 people. Approximately 20% (83,000) of the county's population is served by smaller (<10,000 people served) groundwater systems. The Salinas region suffers from pre-existing aquifer quality problems (Harter et al. 2012), and endured shortages during the Drought, putting smalls systems in an especially difficult position.

Recruitment: The organization partner for the research project (EJCW) was supporting small contaminated water systems in this region at the time of the workshop planning (Summer 2017), which enabled them to assist the research team with coordination, background context, logistics, and recruitment. Initial discussions with water system managers in the region indicated a need to shift the timing for the workshop so that it could occur after the Groundwater Sustainability Agency proposals were due to the State (as part of the Sustainable Groundwater Management Act process). Upon identifying a suitable time and place for the event, announcements were distributed broadly to small water system managers by EJCW and the County Environmental Health Department.

2.6 Policy Forum

As the final stage in the project, we sought to create space for a more diverse set of stakeholders, including drinking water managers, state policy makers and managers, non-governmental organizations advocating and otherwise supporting small water systems, and philanthropic organizations that help shape policy and implementation. To create such a space, we held a one-day participatory forum in Sacramento on September 20, 2017. The purpose of the Policy Forum (the Forum) was to bring together key stakeholders who play a role in directly managing or developing and implementing policies and other efforts that support small drinking water system drought resilience. It was developed in collaboration with and facilitated by the EJCW. We structured the Forum around two small group discussions on the most prevalent reported barriers to drought resilience described in the interviews and regional workshops.

To provide context to small group discussions, we began the Forum with a high-level summary of preliminary findings related to S3 system drought impacts, responses, barriers, and adaptation strategies. Workshop attendees then broke into 10 small groups where each table was asked to discuss a pre-selected barrier category, developed from the preliminary analysis (2 groups per barrier category). The top five barrier categories discussed were *physical, regulatory, awareness and education, communication, trust, and shared vision*, and *resources*. To obtain coverage from a diverse group of attendees working within each barrier category, we randomly assigned attendees to a group upon registration. During the first breakout, small groups were given a half-hour for discussion. Following this discussion, attendees could either stay in their assigned barrier category or opt to move to another table to discuss a different barrier category for an additional half hour discussion. Following the morning breakout group discussions, we held a panel conversation about small drinking water system needs and barriers. Panelists included representatives from drinking water systems, technical assistance organizations, environmental justice groups, the DWR, and academia. After the panel, attendees were again broken into 10 small groups (they selected which group to be a part of) to continue discussions around S3 barriers and needs and policy recommendations for an additional half hour.

Small group discussions were structured around four key questions related to their table's specific barrier:

- What policy (and other) efforts exist that address S3 system barriers to resilience?
- What efforts should exist to address small water system barriers to resilience?
- Are existing efforts enough to overcome the barriers facing small water systems?
- How can efforts be improved or developed and implemented in a way that makes them more effective in addressing the barriers facing small water systems?

2.6.1 Comparing Policy Efforts to Small System Barriers

Through a combination of legislative policy review, documented accounts from the Legislative Accounting Office, and EJCW's legislative tracking efforts, we developed a draft list of 83 existing and proposed but not passed, policies, programs, and other efforts to provide fodder for discussion at the Forum. Overall, these efforts fell into several categorical types: executive orders (11%, 9); regulations or administrative agency orders (18%, 15); passed legislation (37%, 31); legislation that didn't pass or was vetoed (8%, 7); local ordinances (4%, 3); ballot measures (6%, 5); nongovernmental organization (NGO) programs (5%, 4); funding programs (8%, 7); and, guidance documents (2%, 2). After identifying and compiling them, we also noted the estimated timing of each effort: long-term/permanent change; drought/emergency only; limited based on the availability of funding; and, proposed but not adopted/passed. To provoke discussions within small groups, we compared this coarse review of policy and other state efforts (efforts) to the top five barrier categories. We compiled our initial thoughts into a series of worksheets that we supplied to attendees. We also provided attendees with a preliminary draft barrier-effort gap analysis chart that compared relative emphasis placed on barriers by S3 system managers with relative emphasis of identified efforts for addressing each barrier. For more information on both of these supplementary items, see Appendix B.

Finally, a lead facilitator was assigned to each breakout group table ahead of the Forum so that we could review expectations and directions for discussions. In addition to leading discussions around their assigned barrier and policy efforts, facilitators were tasked with recording points made in conversations throughout the day. Findings from the Forum were derived from a review of these combined notes.

3: Results

The research team collected data between June 2016 and September 2017. During this time, the team conducted 58 interviews with community water system and non-system water managers, hosted three regional workshops extending the results of the interviews, and co-hosted a one-day, multi-stakeholder workshop in Sacramento (Table 2). Non-system water managers included staff from Regional Water Quality Control Board, the Division of Drinking Water, and other regional organizations. Across all data collection methods, the team gathered structured input from 185 individuals. Figure 4 shows the wide geographic coverage of input from water systems across California.

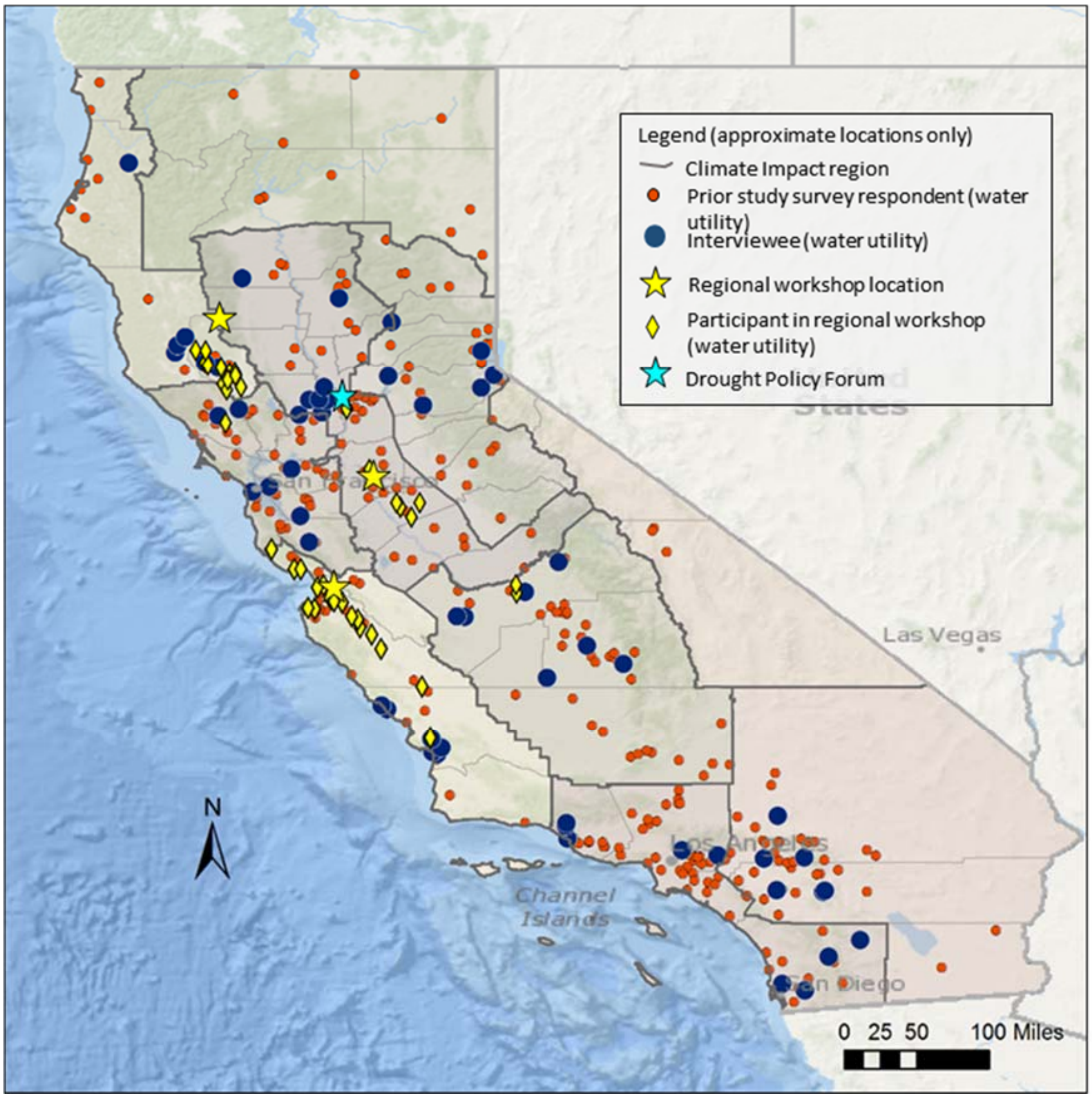

Figure 4: Approximate locations of water systems that had managers participate in interviews and regional workshops and approximate locations of regional workshops and the Policy Forum. Source: Authors.

Table 2: Summary of the number and types of participants included in each phase of the research project. The survey (in grey) was distributed prior to the beginning of this research project and is therefore not included in the *Total Number of Participants*. Source: Authors.

	Number of Participants	Target Populations
[Prior Survey]	[259]	[Water system managers]
Interviews	58	Water system managers and other non-system stakeholders
Regional Workshops	71	Water system managers and other regional water stakeholders
Policy Forum	56	Water managers including drinking water systems, state government staff, technical assistance organizations, environmental justice groups, etc.
Total	**185**	

3.1 Interview Results

A total of 58 interviews representing 49 drinking water system and 4 non-system water managers were conducted between June 2016 and October 2016. This section provides a summary of key results on Drought impacts, responses, barriers, and climate adaptation strategies mentioned during interviews by Small, Self-Sufficient Drinking Water System (S3) and non-S3 system managers, summarized in Table 3. Additional tabulated results are presented in Appendix F.

Table 3. Schematic summary of key topics documented in the study.

Topic	Example Findings
Pre-Drought Advantages and Inherited Responses	• More non-S3 systems described pre-drought advantages and inherited responses • Non-S3 managers described more technologically advanced (and generally more expensive) pre-drought advantages • Many of the pre-drought advantages described by managers were changes made during or as a result of prior droughts, including many with the State's assistance or to meet its requirements: existing conservation outreach programs, water metering, having an appropriate rate structure, use of recycled water, back-up and flexible supply portfolios, sufficient storage capacity, upgraded infrastructure, and leak detection
Drought Impacts	• S3 systems faced challenges relating to their primary supplies (whereas non-S3 systems faced technical challenges)

	• Difficulty in implementing new or expanded conservation and education programs • S3 and non-S3 systems expressed observations of connections between the Drought, decreased water levels, and *water quality* changes (e.g., conservation measures linked to longer residence time in pipes which resulted in higher levels of disinfection byproducts) • Increased tracking and reporting and lack of staff capacity to meet the Conservation Mandate's requirements • An inability to make infrastructure fixes/updates, general operations and maintenance, and challenges related to growth (e.g., expansion and real estate values)
Drought Responses	• Nearly all systems discussed the use of demand management, technical strategies and financial responses to mitigate or prevent impacts • More non-S3 systems relied on their ability to switch between surface and groundwater as availability varied throughout the Drought. S3 systems with limited supply diversity, flexibility, and redundancy remain disadvantaged in this regard • Given limited supply flexibility preceding the Drought, 100% of S3 system managers interviewed pursued source extension and demand management, whereas non-S3 managers focused more on demand management • S3 managers credit the state's financial drought response with enabling technical strategies (e.g., securing emergency relief dollars to make longstanding, necessary infrastructure upgrades, or finance an emergency intertie) • Nearly all S3 and non-S3 system managers implemented coping (short term) responses, but fewer S3 system managers discussed adjusting (long-term) responses
Drought Barriers	• Most system managers discussed physical barriers (e.g., insufficient or contaminated supplies, aging and failing infrastructure, or geographical remoteness that impeded supply diversification) • S3 system managers were also especially challenged by barriers related to regulations and communication, trust, and shared vision. Many expressed concerns that the Conservation Mandate was inappropriately designed for small systems. Issues of trust and shared vision manifested within a system's leadership, between the system and its customers, and among systems on a shared water resource

Climate Change Adaptation	• Many efforts to mitigate drought impacts may increase water systems' resilience to climate change, though efforts are not necessarily done with climate change as consideration or motivation • Managers of systems with adequate capacity and concern for climate change impacts are investing in climate change assessments, planning, and other adaptation-related efforts • Managers of systems without adaptation efforts lacked technical and staff capacity as they already struggled with 'today's' needs; assumed larger water systems or the state would advise in what to do, if needed; and/or regarded climate change as beyond their responsibilities

*S3 is Small, Self-Sufficient Drinking Water Systems

3.1.1 Drought Impacts

A total of 47 of 49 drinking water system managers (24 S3 systems, 23 non-S3 systems) mentioned some type of drought impact. Through an inductive process, we organized all of the mentioned drought impacts into nine categories, as shown in Figure 5. This section presents a brief overview of impacts discussed, followed by a focus on water quality impacts and impacts to groundwater-reliant systems specifically.

All of the S3 system managers interviewed described at least one *drought impact* to their system. Illustrating the hardships experienced, one S3 manager explained,

> "It [the Drought] screwed us up so bad...When the drought mandates came down from the governor, it didn't affect the golf courses or the farms, it was just the people. And they're screaming- why are you getting 25% of the savings from 10% of the problem? You need to go after the others...We set-up a conservation program. We didn't have money for rebates, but we did some ordinances, so we could impose penalties, but the board was very reluctant about imposing penalties on people for that very reason-- when they're watching the golf course across the street overwatering onto the street and they're not supposed to water anymore. It was very difficult for us." (S3 system manager)

Similar proportions of S3 and non-S3 system managers (across all water supply types) mentioned the same top drought impact categories (Figure 6). Impacts most frequently expressed across all systems were: *water quantity* (70%, 33), *managerial* (68%, 32), *water quality* (66%, 31), *regulatory* (62%, 29), and *social reaction/shift* (55%, 26). These top five are described below. Economic impacts are also described because it was within the top five impacts among S3 systems. Although the most frequently noted impact categories were similar across system types, the specific impacts within the groupings discussed varied between S3 and non-S3 system managers. Notably, 58% (14) of S3 and 74% (17) of non-S3 system managers mentioned impacts to their system's drinking water quality. While S3 system managers described challenges relating to the quality of their primary supplies (deeper wells showing increased arsenic and manganese), non-S3 system managers discussed State Water Project (SWP) or Central Valley Project (CVP) curtailments that forced a shift in reliance from their primary source (e.g., Colorado River) to a backup source that, in some cases, made mixing sources to reach water quality standards (e.g., salinity) difficult. Different types of *managerial* impacts were also discussed by S3 system managers (71%, 17) than non-S3 system managers (57%, 13). S3 system managers frequently mentioned implementing new or expanded conservation and education programs. In one system, the manager hired a water auditor to educate consumers on which parts of their landscape to replace with drought-tolerant plants. In comparison, non-S3 system managers described more technical managerial impacts, such as needing to upgrade to an advanced water quality treatment system.

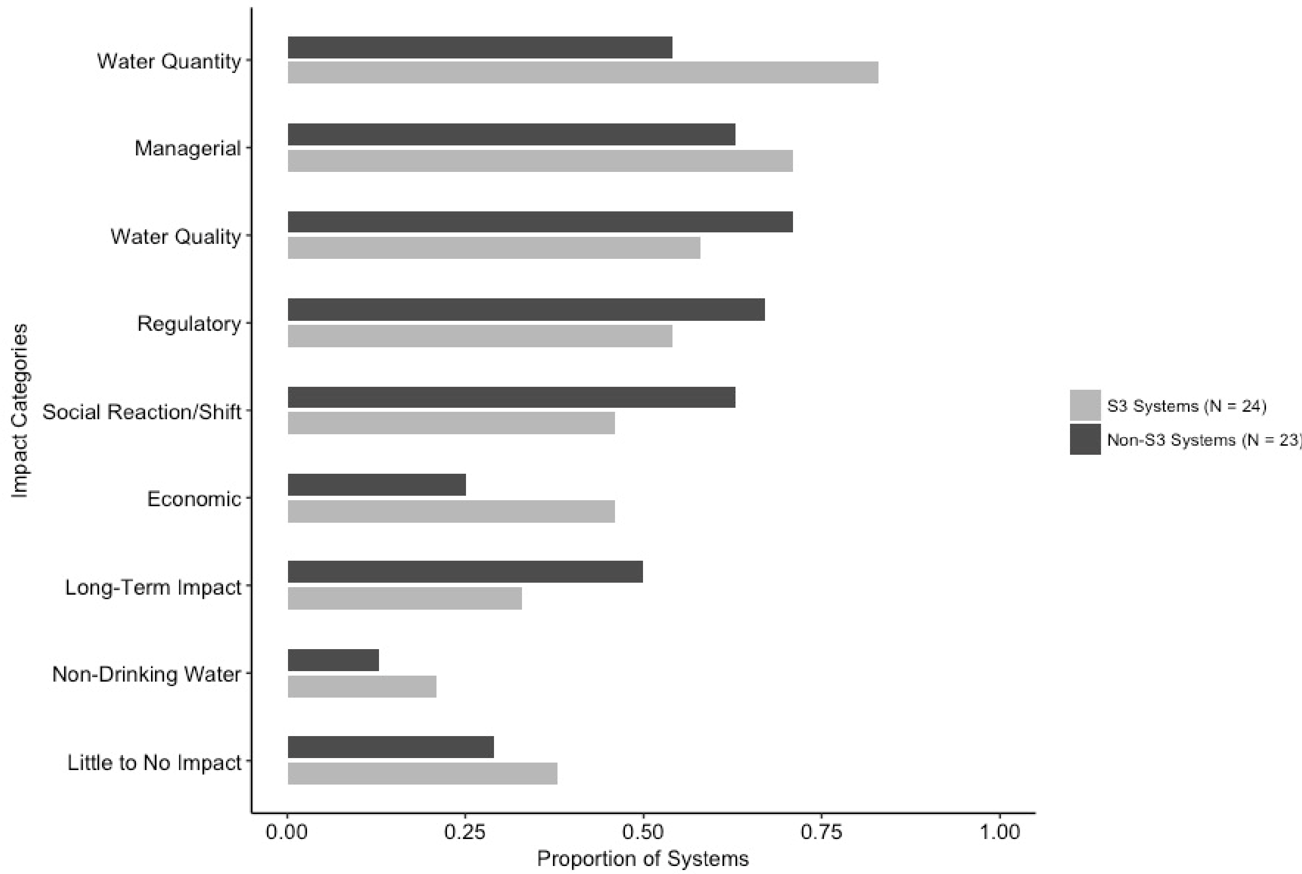

Figure 5: Drought Impact Categories by System Type. Organized in descending order according to proportion of Small, Self-Sufficient Drinking Water System (S3) managers. Refer to Appendix F for category definitions and more information. Source: Authors

Water Quantity Impacts

Water quantity impacts focused on the amount of water available to consumers and other water users during the drought. Twenty of the 24 S3 system managers discussed some type of *water quantity* impact (the top ranked impact among S3 systems). Specific impacts ranged from reduced streamflow to dry lakes to decreasing well levels. The level of impact also varied across S3 systems, with some managers explaining they faced no impact to water delivery, while others discussed having to haul water or apply for emergency drought funding to meet demands through drilling deeper wells (for example). One manager noted difficulties with their local sources (creeks) running dry and the impact it had on farmer livelihood. Another manager described how the drought and reduced water levels would potentially impact economic growth in their community. Several of the managers interviewed also drew connections between decreases in water quantity and increases in *water quality* impacts (discussed below).

Managerial Impacts

Managerial impacts discussed by all systems, including groundwater-only systems, covered shifting staff responsibilities to include policing and enforcement or education and outreach, re-calibrating models and tools used to run the system, and changing water management techniques. Several system managers discussed the increased strain on staff time to ensure consumers were following Conservation Mandates. Managers also frequently reported the paradox of drinking water managers trying to get their consumers to use less water. One system manager stated, "It's like what I was just explaining to someone today, it's my job to get the water out of the ground into the tap. It's her [conservation staffer] job to stop the people from using the tap." In another system, a manager noted that the Drought forced them to re-calibrate their water availability model. This process led their system to conclude that there was not enough water to meet the potential demand of a proposed a 1,000-home expansion in their community. In a different interview case, the manager talked about a change in how their whole system was being managed; they now work with other local government staff to try to reduce energy costs associated with groundwater pumping so they can limit cost increases levied on consumers.

The Conservation Mandate was discussed extensively in interviews as causing managerial impacts like increased tracking and reporting and lack of staff capacity to meet the Mandate's requirements. Related to this last point, shifting (and new) staff responsibilities and priorities were also a big impact to S3 system managers during the Drought.

Water Quality

S3 system managers often drew connections between the Drought, decreased water levels, and water quality impacts. For example, some managers noted increased levels of arsenic and manganese as well levels dropped, while others noted increased levels of nutrients and algal blooms in surface water sources. In one interview, a manager described how the proliferation of algal blooms disrupted their water distribution process because they had to take apart the filter every 4-5 hours to remove buildup. Other contaminants like turbidity, acidity, and saltwater intrusion were described as increasing due in at least in part to the Drought. Managers in several cases noted that, while their water quality never worsened enough to impact distribution to consumers, it did result in consumer taste and odor complaints. In another case, a manager discussed difficulties relating to managing a groundwater plume (not caused by the Drought) that was exacerbated by lowered groundwater levels. Several managers also discussed the challenges of balancing conservation with water quality. For example, conservation would result in water 'sitting in the pipes' which in turn, resulted in a buildup of disinfection byproducts (DBP). These DBP challenges were often attributed by S3 managers to regulatory impacts, specifically, the Conservation Mandate.

Regulatory Impacts

In terms of regulatory impacts, the Conservation Mandate was discussed extensively by managers representing all system sizes and water source types. The Mandate had specific implications for S3 systems and drought management. The common complaints that S3 system managers made were that 1) a "one size fits all" approach does not work, 2) the time allowed for implementation/compliance was unrealistic for smaller systems, and 3) they often lacked the resources necessary (water meters, staff capacity) to provide detailed water use information. In comparison, non-S3 system manager primary complaints related to the amount of required tracking and reporting, and the externally imposed limitations on water use (in cases where a manager explained that they had ample supply of water to meet existing demands).

Regulatory impacts described by surface water managers included water allocation curtailments, increased paperwork and reporting burden, and the Conservation Mandate. The Conservation Mandate was the most frequently reported regulatory drought impact to surface water systems. In one case, a drinking water manager noted that their system had enough water quantity to supply consumers with 100% allocation, but the *regulatory* impacts required them to refuse paying customers. In other cases, surface water managers noted that the Drought was a "regulatory drought"; the lack of water was not a challenge for their system, but the regulatory burden and requirements under the Conservation Mandate impacted them the most. On the other hand, a few managers did talk about how the Conservation Mandate was good for their system because it enabled them to have additional weight and to shift consumer attitudes and behaviors. Similarly, another system manager noted that the Conservation Mandate helped their system build cooperation and agreement around a new financial incentive in their tiered rate structure.

Drought Impacts to Groundwater Only Systems

Fourteen of the 47 managers who reported some type of Drought impact represented systems that rely solely on groundwater. As noted in the methods section, N values were too small to further breakdown water sources by system types, but the majority of systems using only groundwater (referred to as 'GW-only') are S3 systems. More than 50% of managers of GW-only systems discussed managerial, water quantity, regulatory, social reaction/shift, and economic impacts.

Water quantity impacts are one of the top impact categories discussed in GW-only system manager interviews. Decreased groundwater levels were, in many cases, also linked to water quality and managerial drought impacts. For example, lowered groundwater levels in several cases was linked to increases in arsenic and hardness (water quality impacts) and in another case, well pumps failed, driving the manager's decision to haul water supplies until the pump was fixed and put back online. A few system managers mentioned problematic interactions over nearby shared groundwater because of simultaneous agricultural and residential use. Interviewees pointed to agricultural 'over-usage' of water as a cause of severely decreased groundwater levels, and described examples of private landowners stockpiling pumped groundwater in surface ponds.

Social reaction/shift Drought impacts were also discussed by GW-only system managers. The most frequently mentioned type of social reaction/shift impact related to consumer attitudes and behaviors around conservation efforts. In one case, a manager discussed consumer animosity brought on by other water users in the community with seemingly limitless water availability and no conservation requirements. In this particular case, community members were angry with golf course and agricultural stakeholders. In another case, a manager described the difficulty of being part of a lower income community surrounded by a larger, wealthier community. The neighboring community refused to follow Conservation Mandates on a shared groundwater basin and, while the larger system did pay fines, the penalty was less than the loss of revenue that would have resulted from conserving water. Therefore, the interviewee described the frustration of the neighboring community and refused to reduce consumption, which in turn put more pressure on the shared supply. Other social reaction impacts to GW-only systems included more positive impacts, such as consumer self-policing of neighbors, a longer-term shift in consumer attitude towards conservation during drought and non-drought times, and increases in collaborative partnerships working towards immediate and longer-term water management.

Economic Impacts

Many interviewees reflected on the economic impact of the Drought. The majority of economic impacts discussed by managers included an inability to make infrastructure fixes/updates, general operations and maintenance, and challenges related to growth including expansion and real estate values. For example, in one case, a drinking water manager noted that one extreme consumer reaction (social reaction/shift) to conservation efforts was to allow trees and landscaping to completely die. This negatively impacted real estate values in a location that was already challenged by low home values. In another case, a system manager discussed challenges with meeting conservation targets, which sparked them to start lawn buy-back and other incentive programs. The manager noted that the programs had limited success; while they did decrease water use, it was not enough to meet targets and siphoned more funding away from their already limited budget for infrastructure repairs.

Pre-Drought Advantages

In addition to discussing impacts from the Drought, S3 and non-S3 system managers also described a number of *pre-drought advantages* or plans and actions they credit with helping them to avoid larger impacts to their systems. Fewer S3 system managers (42%, 10) than non-S3 system managers (79%, 18) mentioned some type of pre-drought advantage and overall, S3 managers described less technologically advanced (and generally less expensive) advantages. In contrast, non-S3 managers discussed more technically advanced and costly advantages like recycled water programs, advanced treatment technologies, and finance planning prepared for droughts. Overall, regardless of size or sufficiency status, having sufficient back-up supplies was a pre-drought advantage for all systems. Water meters also were reported as an advantage among a diverse set of system managers. Proactive education and outreach programs were also noted by managers of both S3 and non-S3 systems. Managers discussed how these activities garnered community support easily and allowed the managers to more readily meet conservation goals and targets.

Systems with Little Perceived Drought Impact

While nearly all of the drinking water system managers described at least one Drought impact to their system, several interviewees commented that their systems felt little or no impact from the Drought (N = 16, 9 of which were S3 system interviews). All but one of these also mentioned impacts from the Drought in another part of their interview. The perceived lack of drought impact can be a physical reality in some cases and/or a social response that could put a system at higher risk due to potential inaction. This perspective was expressed in interviews with managers in Northern California regions, all of which also had supply portfolios with both groundwater and surface water. California's northern regions tend to be characterized by higher levels of precipitation and snowpack storage.

3.1.2 Drought Responses

All 49 drinking water system managers (24 S3 systems, 25 non-S3 systems) mentioned some type of Drought response in interviews. Through an inductive process, we organized Drought responses into 10 categories, and coded for both *inherited responses* (actions prior to the drought), and *aspirational responses* (actions imagined for future droughts). More than half of all system managers reported at least one inherited response, but of these, more represented non-S3 (56%) than S3 (46%) systems (Figure 6). The most frequently reported Drought response category was technical strategies (92%), followed by demand management (90%), and then financial responses (61%), source extension or diversification (59%), institutional or organizational (57%) and partnerships, cooperation and coordination (57%). However, as found in the impact analysis above, within categories of responses, the specific types of responses S3 and non-S3 system managers discussed varied. For example, 83% (20) of S3 and 40% (10) of non-S3 system managers mentioned relying on financial responses. With respect to developing source flexibility, a type of technical response, only 46% of S3 system managers mentioned this, compared to 80% of non-S3 system managers. One of the most common technical strategies described by S3 system managers was improvements to existing infrastructure.

Below, the drought response strategy mentioned by the most respondents is discussed (with demonstrative quotes). We also discuss the financial responses and the discrepancy between emphasis among S3 and non-S3 systems.

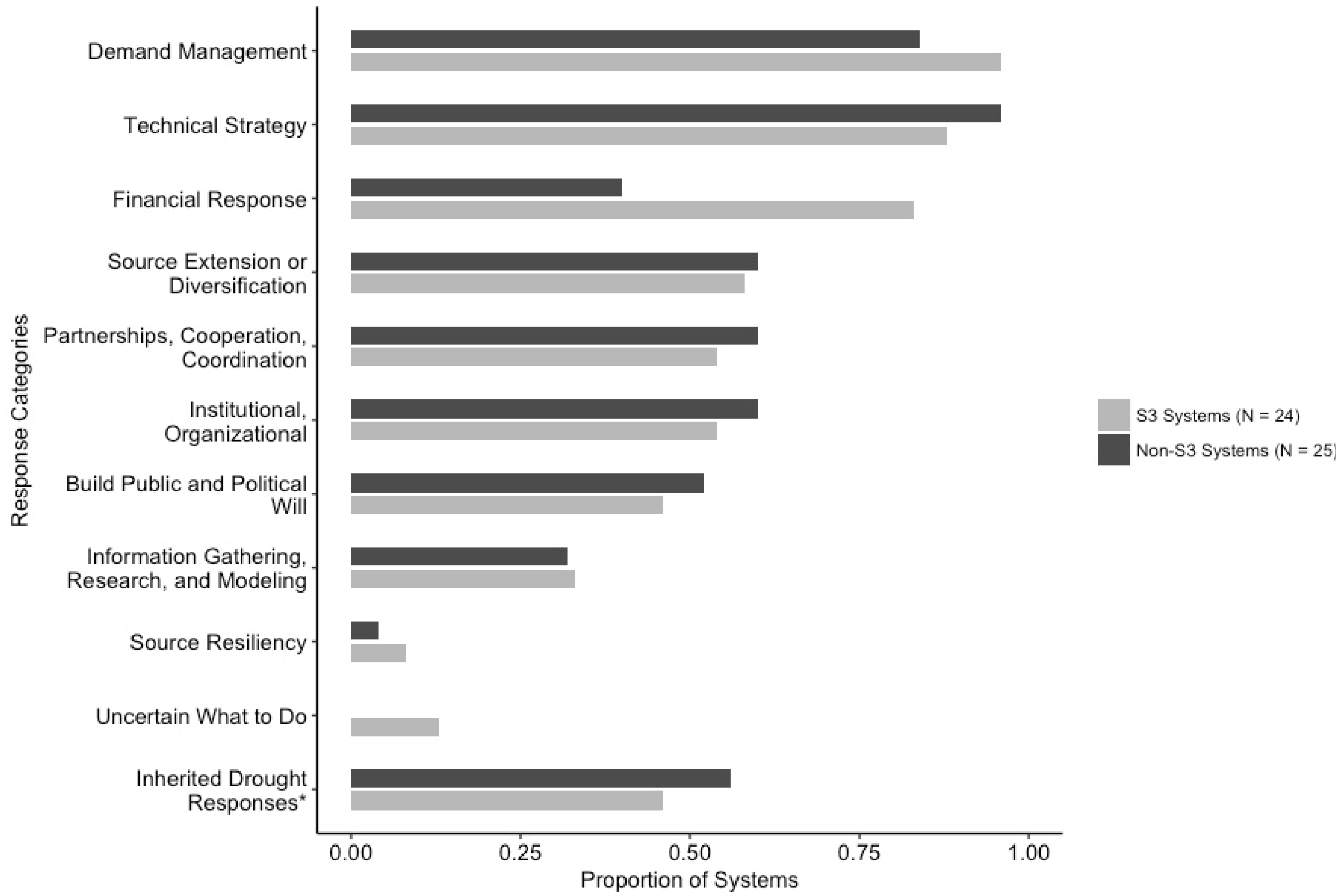

Figure 6: Drought Response Categories by System Type. Organized in descending order according to proportion of Small, Self-Sufficient Drinking Water System (S3) managers. Inherited drought responses were analyzed separately from the rest of the drought categories. Source: Authors

Three S3 system managers mentioned a general uncertainty around what to do for long-term drought preparedness, or if the Drought worsened significantly. One manager explained, "I think the plan is honestly, well the plan is no plan, but the plan is to truck water or drill another well." Another operator explained, "I mean there's not much they can do. They have to have water and they only have one way to get it, so if it got below the screens, it would be uninhabitable." Despite this expressed uncertainty over what to do for worsening of the current drought and the future, these systems still implemented various other drought responses.

Demand Management in S3 Systems

All but one S3 system manager (96%) discussed the use of some type of demand management response. S3 demand management drought responses entail a mix of residential conservation focused policies and programs (83% of systems), both voluntary and mandatory, as well as a suite of outreach and messaging to customers about conservation (46% of systems), and responses to the state's Conservation Mandate (62%). Among outreach efforts, managers mentioned directly communicating to their customers through newsletter columns and city meetings regarding the severity of local drought impacts to their water supplies and the necessity for conservation. A commonly reported challenge with local messaging efforts was that nearby water systems may have slightly different goals and messages:

> "[the nearby larger system] has their own written protocol and they're large enough that they didn't have to follow what the state mandated because they are a large enough system and they have their own, you know, tiered out conservation plan that was state board approved. So they had a different system than what we had. Ours was way stricter, way stricter, way more strict. So that's I think, that's a huge challenge, was the public's view on water conservation and which rules they had to follow and why they had to follow them." (S3 system manager)

In response to this particular example, three nearby system managers worked together to develop joint messaging and outreach for their communities. This served the dual purpose of relaying a consistent message and building a larger resource pool (staff and financial). Other S3 systems managers who reported communication and outreach-related demand management responses described increased transparency and detail in customer billing materials, development of workshops on rainwater harvesting, and promoting greywater use and drought tolerant landscaping.

With regards to the Conservation Mandate, S3 system managers discussed responses relating to communicating its requirements; using varying levels of enforcement and calculating new Gallons Per Capita per Day targets. In other instances, the Conservation Mandate changed the way the system typically managed demand, catalyzing development of conservation measures into the small water district:

> "This is the first year that our water district has spent money ourselves on conservation. [...] The setup has always been that the little people like us don't do conservation. We give money [to wholesaler] and then they hire staff and do that work because they're a larger organization, and then all of our customers are eligible for the conservation programs under them.[...] It'd be a nightmare if we all tried to run stuff like that." (S3 system manager)

A handful of managers also reported that they begrudgingly complied with the Conservation Mandate. In one interview, an S3 manager explained:

> "And then we have the State Water Boards trying to impose regulations, water conservation regulations, most of which have not been very carefully thought through...to put it very very gently.... it just doesn't work like that... [...]. We as a water district, [use] less than 2% of the water gets pumped here so what we do or don't do has no effect on resources so you require everyone to water their outdoor, their 3 outdoor plants two days a week? Nothing will survive two days a week in this climate. [...] I'm being pressured [by his board, vocal community members] to make regulations that don't make any sense. " (-S3 system manager)

Other S3 system managers described their lack of internal capacity to enforce the Conservation Mandate, suggesting that "bigger systems seem to have [an] easier time responding to quick regulatory changes" given that they have staff devoted to conservation efforts, whether or not there is a drought. Staff at smaller systems already have many responsibilities and priorities, limiting their ability easily to add on conservation outreach and enforcement activities.

Financial Responses

Financial responses were adopted by 83% of S3 system managers. They included pursuing rate-related changes (adjustments and conservation/drought surcharges) and external financial assistance to implement technical or source extension/diversification strategies. Among S3 system manager responses, some reported undergoing a Prop 218 rate adjustment process to raise rates and incentivize conservation. In a few instances, rate adjustments processes were successful because of the Drought. One S3 system interviewee credited the severity of the Drought with enabling them to adopt a tiered rate structure with without customer pushback:

> "... before the drought, when we tried to implement a tiered rate system to promote conservation, it was actually challenged through the legal process. [...] our bylaws said you're only allowed this much per day [above which you incur a penalty]. So, with that penalty, it was 1500 [gallons]. With the drought, we moved it down to 1200 [gallons], and now we're in the process of taking that possibly even to 900 [gallons] through a bylaw change to be something more reasonable with what we see as today's environment in this type of climate etc." (S3 system manager)

S3 system managers also mentioned that introducing conservation or drought surcharges enabled them to both penalize overuse and ensure that their system reached state-mandated conservation targets. Managers also noted that the rate adjustment was a response to a longer-term need for a more appropriate rate structure to meet infrastructure needs and distribution requirements. For example, one S3 manager explained that prior to the Drought (and his joining the staff) in 2011,

> "the district was in severe financial distress to the point where we actually went through a [Prop] 218 process immediately and raised the rates 100% over the next 5 years just to keep the doors open- just to keep delivering water to people. We've just gone through another 218, they just closed earlier this month [summer 2016], where the rates will be raised another 100% over the next 5 years to accommodate the infrastructure that we need on an interim basis to maintain water quality [...] we have to essentially pass all of our costs through to our ratepayers if they want to maintain water coming out of their faucets." (S3 system manager)

For other systems, the Drought also aggravated longer standing affordability issues. One S3 manager noted that Prop 218 processes failed due to resident pushback and tensions that preceded the Drought. Prior to the Drought, the wholesale was delivering raw source water that surpassed the ability of the S3 systems aging treatment plant's capacity. Prior to the Drought, the S3 system made several attempts to increase rates to upgrade the treatment facility. Ongoing SDWA water quality violations made raising rates for disadvantaged households untenable. When the cost of water from the wholesaler tripled during the Drought, there was another failed Prop 218 process. Consumer pushback escalated, and they were at risk of losing access to the water entirely. Eventually, the system was able to access emergency drought assistance from the SWRCB to offset the higher water costs from the wholesaler.

S3 system managers also mentioned accessing local, state and federal grants and loans. A commonly cited funding source was DWR's Prop 84 Integrated Resource Water Management (IRWM) Drought Grants. These grants made funding available to S3 (and other) system managers through the system's IRWM group. In a few interviews, managers pointed to funding provided by their wholesaler: "[...] they're like our big brother. They are very open to supplying seed money for these grants which is nice." When relationships were strong, like this one, S3 managers also described turning to wholesalers for advice and technical assistance.

Despite the availability of multiple types of Drought-related funding, S3 system managers often mentioned that the application processes were onerous. Even when time and/or staff were made available to apply, it didn't guarantee funding. As one S3 system manager described the process,

> "[the Prop 84/IRWM grant process was] a lot of work for us. We're a really small agency and it's just, I had to do the grant stuff... but it was [a] really hectic, busy time. Even after the project was built I was still scrambling on a lot of the grant."

As an added layer of challenge, S3 system managers of private water systems noted that their ownership type made them a low priority compared to public water systems, "In terms of eligibility for grants, we're the last man on the totem pole as a private entity. People think 'for profit' can afford to finance their own efforts" and went on to explain the rules by which they struggle to pay for certain assets they can't include in the rate base. In a small number of interviews, managers also voiced their frustration with the state's determination that their water quality issues were not "drought-induced", and therefore, were ineligible for emergency funding.

Supply Type Affects Responses

There is a notable difference in financial responses pursued by groundwater (87% of systems) and surface water (54%) systems that is likely driven by the fact that groundwater systems are mostly smaller and were therefore in need of funding and were eligible for special funds. In comparing by source type, more than half of the GW-only systems mentioned relying on partnerships, cooperation and coordination. Demand management and technical strategies remain highly adopted strategies in systems only using surface water (referred to as 'SW-only') and systems with both supply sources.

Time Horizon of Drought Responses

In terms of the time horizon of the Drought response goals, we were able to code the majority of excerpts describing Drought responses (462/591) by this classification: coping, substantial adjustment, and system transformation. Time horizons of responses were similar between S3 and non-S3 systems: 96% (23, 24 respectively) of each type mentioned coping efforts, and 20% of each system type mention system transformation (Figure 7). One difference lies in the count of systems that mention substantial adjustments: 96% of non-S3 and 79% of S3 systems discussed at least one Drought response in this time horizon.

In addition to comparing counts of systems by category, we also looked at Drought responses themselves by time horizon. More than half (56%) of S3 drought responses were coded as coping. Of these, the majority were demand management actions, such as temporary residential conservation measures that could be lifted once the Drought emergency ended. Other less common coping strategies include technical approaches like switching between existing supplies and using interties or hauling water. For the portion of S3 drought responses that were coded as substantial adjustments (44%), most were financial responses (26%), followed by technical strategies and source extensions (18% each), and information gathering (13%).

Notably, close to two-thirds of non-S3 systems drought responses were also coded as coping (64%) compared to 36% of their responses coded as adjusting or transforming.

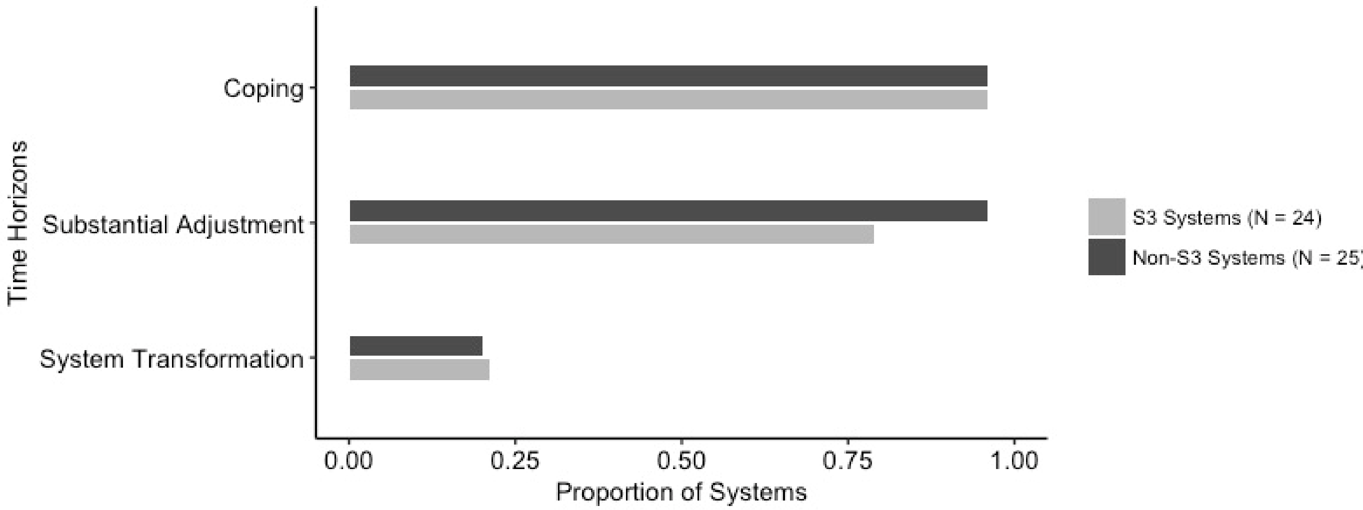

Figure 7: Time Horizons of Drought Responses, by System Type. Organized in descending order according to proportion of Small, Self-Sufficient Drinking Water System (S3) manager. Source: Authors

Lastly, there were only six drought responses mentioned by S3 systems that were coded as transformational. Half of these were technical strategies that facilitated supply portfolio diversification, such as managed aquifer recharge, installing a reverse osmosis system to mitigate chloride, and building an emergency potable reuse facility that would later become a permanent, long-term alternative supply. For some S3 systems, partnerships were only drought coping efforts, temporary means to manage drought impacts. In more instances, the formation of new relationships with nearby systems and with users of the same source represented a substantial adjustment in the way the water system had been managing droughts previously. It is possible that partnerships and cooperation fostered by the recent drought, if retained, can be leveraged in the future. Similarly, while building public and political will were not commonly adopted responses to the drought, they were more commonly considered to be long-term changes, compared to temporary shifts. As with partnerships, the shift in local will to conserve water or value water differently, if retained, could position the water system well during the next drought.

Aspirational Responses

Aspirational drought responses are actions, plans, or other response types that system managers mentioned wanting to do to better prepare for current and future droughts. Aspirational drought responses were not implemented during the Drought for various reasons, but managers could still be in the process of planning for or implementing them. More than half of the system managers in the study mentioned some sort of aspirational response (Figure 8). Also, a higher proportion of S3 system managers (79%) than non-S3 system managers (60%) identified aspirational drought responses. Overall, 69% of system managers described at least one type of aspirational drought response.

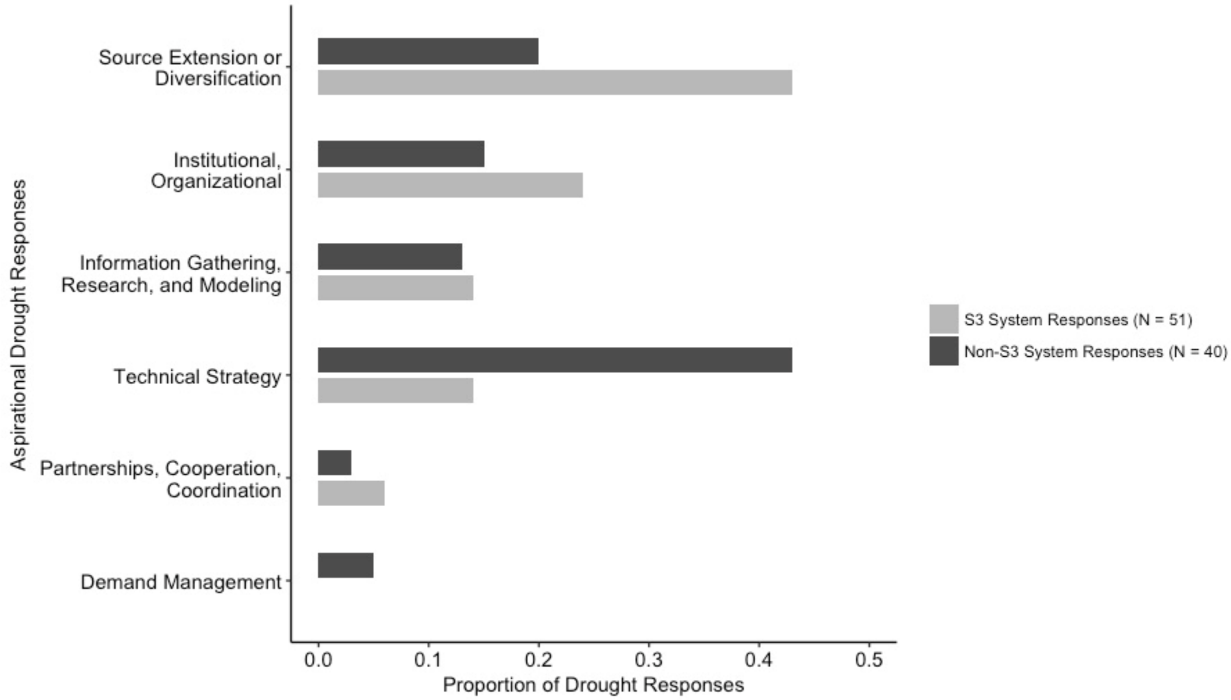

Figure 8: Proportion of Aspirational Drought Responses by System Type. Organized in descending order according to proportion of Small, Self-Sufficient Drinking Water System (S3) manager.

The most common type of aspirational response for S3 systems involved source extension or diversification, strategies that many small systems struggle to self-finance compared to non-S3 systems. Study participants expressed that investing in these types of responses would be beneficial to mitigating future drought impacts.

3.1.3 Drought Barriers

A total of 47 of 49 drinking water system managers (22 S3 systems, 25 non-S3 systems) mentioned some type of impediment to dealing with the Drought, referred to here as *drought barriers.* Excerpts from two systems did not definitively describe a drought barrier and were excluded from analysis. Through an inductive process, we coded all of the mentioned drought barriers into twelve categories. More than half of all system managers described *physical* (87%, 41), *regulatory* (81%, 38), *communication, trust, and shared vision* (70%, 33), *resource* (68%, 32), and *awareness and education* (53%, 25) barriers. In addition, both S3 and non-S3 managers mentioned similar top drought barrier categories (Figure 9). However, within categories, the specific types of barriers S3 and non-S3 system managers discussed varied. For example, 86% (19) of S3 system managers described regulatory barriers (the highest proportion of S3 system managers), compared with 76% (19) of non-S3 system managers (the second highest proportion of non-S3 system managers). In both instances, managers described the Conservation Mandate as a regulatory barrier, however some S3 system managers noted that it was a barrier because it failed to consider the needs of smaller systems (reflecting the policy at the time of interviews), while some non-S3 system managers noted that it prevented them from supplying water to their consumers.

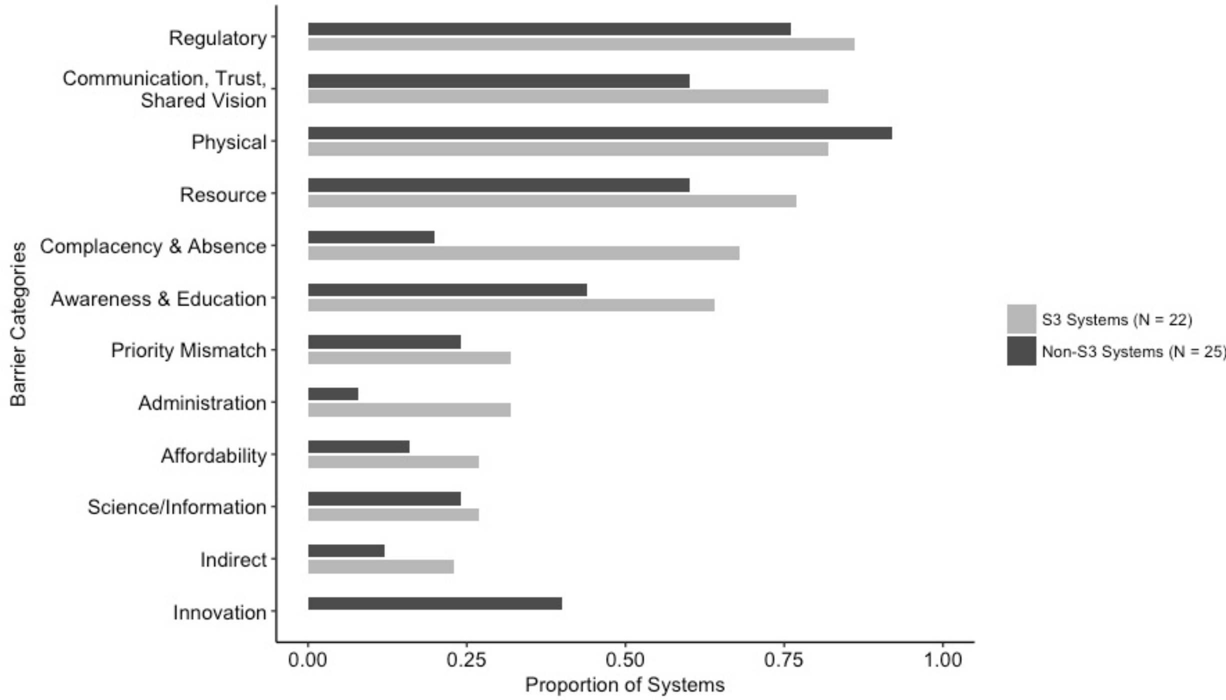

Figure 9: Drought Barrier Categories by System Type. Organized in descending order according to proportion of Small, Self-Sufficient Drinking Water System (S3) manager.

The barrier category of innovation showed a striking difference between S3 and non-S3 systems. It was mentioned in interviews with 40% (10) of non-S3 system managers and 0% (0) of S3 managers. Non-S3 system managers described innovation barriers as obstacles that existed because a management action had never taken place before. Some non-S3 system managers identified planning and operating drinking water systems for both drought and floods as particularly cutting-edge and difficult. The complete absence of barriers associated with innovation among S3 systems may indicate a lack of pursuit for innovations among those interviewed. This could be explained by their limited staff and other planning capacity to seek out innovations in the midst of the Drought.

Among the S3 managers interviewed, we found that within the *regulatory* barrier category, S3 system managers often mentioned the Conservation Mandate and its failure to consider smaller system challenges and needs. One manager discussed how smaller systems felt as though the state only talked to larger systems prior to passing the policy. Other S3 managers described regulatory barriers related to the official state definition of 'disadvantaged community' or what constituted 'drought impact' with respect to funding eligibility. In some cases, the state eligibility requirements for emergency funding also precluded certain system ownership types, creating a regulatory and resource barrier. Finally, some S3 system managers noted challenges related to historic rate structures that didn't consider drought and its potential financial impacts.

Physical barriers (the second highest proportion of S3 system managers) related primarily to water quantity (insufficient supplies) and water quality (contaminated supplies). S3 system managers discussed their shift in reliance from surface water whose availability depends on wet weather, to groundwater sources of varying water quality. This shift in sources and potential future dependency on groundwater concerned some managers who highlighted water quantity and quality as barriers to long-term resilience. Another physical barrier discussed was geographic remoteness preventing physical consolidation. One board member noted that their previous board spent a great deal of money running tests and calculating potential costs of consolidation. Ultimately, consolidation was ruled out, however, because the required pipeline would cost them millions of dollars. Infrastructure barriers facing S3 system managers included subsidence-induced well failures, leaky storage tanks, slow pumps, and decentralized distribution systems that are designed so that if one portion fails, the repair would be too costly to replace with current resources.

Another top barrier was communication, trust, and shared vision, reported by 82% of S3 system managers. Many of the S3 system managers noted challenges related to local politics. For example, S3 managers discussed frustrations with board members that failed to acknowledge climate change and the importance of longer term planning. Other local politics challenges, external to the system, also fell into the communication barrier category. These included things like climate belief (or not) and multiple watershed stakeholders with different management priorities. A common theme in the communication barrier category revolved around consolidation. In one system, managers reported that two of three local small systems wanted to consolidate, but the third did not, so none of the systems consolidated. In another S3 system, a manager noted that the consumers weighed heavily on the decision not to consolidate because they generally don't trust 'outsiders'.

3.1.4 Climate Change Adaptation Strategies

Across all interviews, there were 147 excerpts coded for at least one climate change adaptation strategy. Coding was applied liberally, meaning that if there was a clear indication the strategy could reduce the system's risk to climate change, the excerpt was coded as climate adaptation. Only 34 of the 53 interviews, (14-S3 systems and 20-non-S3 systems) discussed at least one adaptation strategy. We found these strategies naturally grouped into seven non-exclusive categories and were largely related to improving resiliency to drought long-term (Figure 10). These closely followed the categories observed in the Drought responses, though some were not considered adaptation given their short-term focus (e.g., demand management). Other categories such as partnerships, cooperation, coordination, and financial response were not discussed in regards to adapting to climate change specifically, despite these potentially being valuable types of strategies for increasing water systems' resiliency under a changing climate. The seven categories documented were: source extension or diversification; source resiliency; technical strategies; institutional or organizational-focused; building public and political will; learning how to use or otherwise incorporate new information; and "other". Source extension was mentioned by the highest proportion of system managers (74%, 25), followed closely by source resiliency strategies (68%, 23). The order of adaptation strategies among S3 system managers showed a similar pattern among system types for adaptation strategies relating to source extension and diversification, source resiliency, and technical strategies. However, there was a noticeable difference in the proportion of respondents that talked about institutional organizational-related adaptation strategies, building political will, and learning how to use new information. For example, nearly 40% of S3 system managers mentioned source extension, compared to 64% of non-S3 system managers. Every adaptation strategy was more commonly mentioned by non-S3 system managers than S3 system managers.

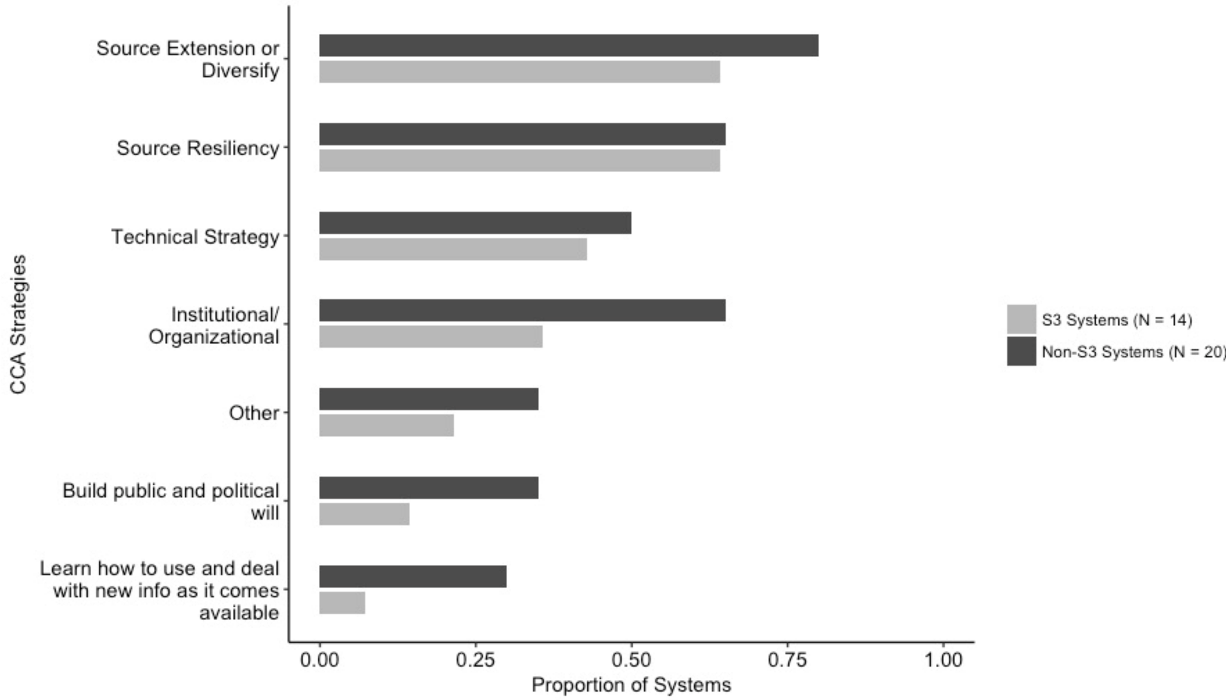

Figure 10: Climate Change Adaptation Strategies by System Type. Organized in descending order according to proportion of Small, Self-Sufficient Drinking Water System (S3) managers that described the strategy type.

The top climate adaptation strategy types raised by both S3 and non-S3 system managers were source extension and source resiliency, which aligns with the emphasis on aspirational drought responses. Source extension was also a common approach implemented in response to the Drought (and in line with current drought planning). Efforts to improve source resiliency were not prevalent in drought responses described in interviews, but are an important part of long-term planning for water resource management in California. Eighty percent of non-S3 system managers described efforts to extend or diversify sources, compared to 64% of S3 system managers. The largest difference in climate adaptation strategies between S3 and non-S3 system managers was the emphasis that non-S3 system managers tended to place on institutional or organizational-related approaches to adaptation. This form of adaptation indicates a deeper and long-lasting change in an organization, which is critical to support adaptation processes over the long-term (Næss et al. 2005; Measham et al. 2011). Given that only very few managers of S3 systems discussed organizational-related approaches indicates less of an emphasis on long-lasting change that is needed for adaptation processes.

When viewing specific adaptation strategies described by count (counts within each category), we see an even higher difference between S3 and non-S3 systems in the prevalence of institutional-related adaptation strategies. Across the 13 non-S3 system managers noting an institutional type of adaptation strategy, a total of 35 specific institutional-related strategies were described showing an average of nearly 3 per interviewee. However, of the five S3 systems noting this same type of adaptation strategy, each only described one institutional-related adaptation strategy. Using the analysis on counts of strategies amplified the pattern seen in most of the adaptation strategy types, including learning how to use new information and building political will, both critical in very early stages of adaptation processes.

The analysis of adaptation strategies was coarse compared to the more in-depth analysis presented on Drought-specific experiences. This is a reflection of the amount of time spent on the topics in interviews. Interview questions related to climate adaptation often were "dead-end" questions in that the interviewee appeared uncomfortable, unconcerned about climate change risks to the water system, or had an answer related to reducing greenhouse gases. A small set of mostly larger (non-S3) water systems demonstrated advanced knowledge and forethought about climate change science, projections for their water system, and thinking about the future. Smaller systems that had not yet invested in climate adaptation responded to interview questions about climate impacts with inquiries about what climate impacts are projected for their region, indicating an interest when engaged in the topic. The lack of knowledge and acknowledgement signifies the need for support in training or otherwise helping S3 systems start thinking about what climate change means for their operations, costs, and overall future of the water system.

3.2 Regional Workshops

Upon completion of the initial interview analysis, which was based on individuals' perspectives, we sought to share, verify, and build on findings from small water systems through a more collective venue, given the benefits suggested by Luyet et al. (2012), Banjade (2005), and Cornwall (2008). In June and July 2017, we hosted three workshops, each attracting a total of 16-35 people interested in the impact of the Drought and the needs of small water systems in the region. Workshops were structured around the research questions and thus were similar to the interview questions. We employed initial findings from interviews as material to facilitate discussions, gather feedback, and verify of findings from the interviews. Unlike the interviews that included all sizes of water systems, the regional workshops were specifically focused on the issues of small self-sufficient systems to allow for collective input on the study's focus.

Climatically, ecologically, and socially, the regions are very different, representing a sample of the diverse biogeography of California. Impacts emphasized across the three workshops were similar to those expressed in interviews – physical quantity and quality, followed by regulatory (Table 4). They also expressed responses that were consistent with interview findings, like discussing the consumer outreach and incentive programs to decrease demand and increased (or new) compliance. One clear difference in the findings from the workshops compared to the interviews was that financial barriers came up more prominently in the workshops. This could be because of the nature of the collective discussions or the timing of having endured the Drought for a longer period (or both). Several workshop participants emphasized their experiences restructuring their water rates, as well as the additional treatment implemented or sought. Each group noted innovations that came about at least in part because of the severe Drought. These included building partnerships, collaborations, and relationships among water systems and other stakeholders in the region as a way to figure out how to combat impacts over the long term. Barriers encountered also included many similarities: financial hardships with the revenue decrease as demand decreased, staff capacity for keeping up with the regulatory requirements and seeking/applying for additional funding, and difficulties of distrust with other water users and customers. Full summaries of the workshop report-out notes are provided in Appendix C.

Table 4: Summary of Participant Report-Out from Regional Workshops on Small Water Systems' Experiences with the Drought

	Lakeport	Modesto	Salinas
Location Description	• Situated in Lake County • Between coastal mountain range and Sacramento (Central) Valley • City located on Clear Lake • Clear Lake is shallow and has long history of algal blooms • Many residents depend on Clear Lake as drinking water source	• Northern-edge of San Joaquin Valley • High reliance on groundwater • Economy dominated by agriculture	• Central Coast valley • High reliance on groundwater • Prone to saltwater intrusion • Prone to high nitrates from historical agricultural use
Impacts	Physical: • Worsened lake quality • Low groundwater levels • Low lake levels exposed intakes Regulatory: • Demand reduction approaches led to water (hydrant) theft • Increased tension with agricultural stakeholders	Physical: • Decreased water quality • Groundwater over-pumping • Fiscal uncertainty tied to reduced demand Regulatory: • Financial and staff resource burden • "Fear of the unknown" of future state activities and the length of drought	Physical: • Decreases in groundwater and surface water levels • Increased nitrates • Saltwater intrusion • Turbidity events

	Lakeport	Modesto	Salinas
Responses	• Outreach and incentive programs to reduce consumer demand • Compliance monitoring • Tiered Water Rates • Increased treatment to deal with worsening water quality • Applied for some funding but lacked staff capacity to take full advantage	• Applied for loans to reduce revenue loss • Partnering with local retailers to offer rebates to consumers • Upgraded treatment system to deal with worsening water quality	• Collaborative effort to assist neighbor systems • Efforts to increase and improve water storage and capture of wastewater • Public education and awareness campaign • Increased rates in non-low-income areas
Barriers	• Financial and paperwork burdens • Lack of staff capacity to apply for grants • Difficulty reducing demand • Infrastructure updates needed • Low political will to fix water quality challenges • Post-fire population and demand decrease resulting	• Distrust among stakeholders • Insufficient financial resources • Reliance on a single source of water • Costly infrastructure upgrades • Lack of staff capacity to seek out additional funding	• Difficulty applying for funding • Consumer resistance to conservation due to transient nature of community population and inconsistent media messaging • Shortcomings of “one size fits all” policies

in revenue loss and creating larger financial burden

	Lakeport	Modesto	Salinas
Strategies to Overcome Barriers, Needs, Opportunities	• Collaboration between stakeholders • Consolidation • Obtaining State and Federal financial and technical support • Work with other smaller systems to plan for extreme events • Develop scenarios for future regulations that better account for varying utility needs	• Continue drought-related meetings across stakeholders • Need to improve trust and work collaboratively with system managers, policymakers, agriculture, industry, and with consumers to develop long-term strategies • Need State financial support to increase staff capacity for small systems • Need unified messaging (templates) to save staff time and resources and create a consistent message • Need to diversify water portfolio	• Develop financial resources (local savings account) • Increase technical asset management assistance for small systems • Stakeholder collaboration • Strategic release of water regulations (e.g. reduce water use at same time as regulation allowing systems to enforce customers compliance) • Agreements between larger and smaller systems to create more equitable distribution of financial and technical assistance

3.3 Policy Forum

In the third iteration of data collection, we sought to build on the previous stages by verifying our findings to date with a more diverse set of stakeholders. Water management in California is governed across multiple interconnected levels. State and federal drinking water regulations and policies create the boundaries within which a water system must operate. Other major players forming and affected by water policy go beyond government stakeholders and include non-profit organizations, philanthropic foundations, and organizations representing and assisting water systems. Holding a forum, in continued partnership with EJCW, created a space for this diverse set of stakeholders to converge and share insights.

The *Forum on Drought Resilience for Small Water Systems* (Forum) was held on September 20, 2017, in Sacramento, CA. In total, 56 state policymakers, drinking water system managers, nonprofit and philanthropic organizations, and academic researchers participated the Forum. Small group conversations focused on discussing and identifying existing and potential efforts that may help small water system managers meet existing needs and overcome barriers to drought resilience. One of the key messages emerging for the Forum was that barriers do not exist in isolation; they are often intertwined (e.g., failing infrastructure may fall under *physical* and *resource* barrier categories). The inherent overlapping of barriers further complicates an already difficult process of identifying effective policy responses. Even when efforts may address overlapping barriers, Forum attendees noted that they are not robust enough to address all barriers facing small systems.

Forum attendees also described the role of *collaboration* as an essential component of any effort aimed at reducing small system barriers. Tribal representatives and those policymakers involved in tribal water management also placed additional emphasis on collaboration as a key to integrating the unique needs of tribal water organizations. In many of the conversations on the role of collaboration, Forum attendees shared their enthusiasm for and confidence in the potential capabilities of the Sustainable Groundwater Management Act (SGMA). Specifically, attendees described how SGMA has the potential to address several small system barriers, such as *physical* and *communication, trust, and shared vision.*

While attendees generally agreed that existing and proposed regulatory efforts look good on paper, they identified two flaws: 1) they target and are often developed with larger systems in mind and 2) they are often unfunded, potentially creating an additional burden on smaller systems. Discussants also generally agreed that, in their experience, small systems find it difficult to meet new regulations in part due to a lack of implementation grace period. Relating back to an earlier point on barriers as overlapping challenges, when regulations outline an expectation that all systems meet requirements on the same timeline, small systems tend to experience a domino effect of burden; not only do they fail to meet the implementation deadline, but they may also face staff capacity challenges, supply availability concerns, financial hardships, and more. This is consistent with findings from Moser et al. (2018) on barriers to funding adaptation among local governments. They found that governments need to overcome bundles of barriers simultaneously in order to advance adaptation.

On the topic of *solutions for overcoming small system barriers,* Forum attendees spent much of the small group breakout time discussing potential models of small system drought assistance. For example, participants discussed the East Porterville project, a multi-year effort which funneled millions of dollars into an unincorporated community that was considered to be “ground zero” for the Drought; hundreds of homes had lost access to clean, running drinking water (DWR 2017). This effort pulled together a multitude of stakeholders to first provide bottled water to dry households and ultimately to facilitate consolidation and drinking water connections between homes and a centralized system. Despite its eventual success, however, Forum attendees noted that this is not a feasible solution to apply statewide because of the high financial and time investment. Although not a small system example, the East Porterville case serves as a useful demonstration of the importance of trust and the state's flexibility, as well as the financial resources it takes to build the necessary trust when it does not already exist.

In summary, attendees agreed that policy efforts and campaigns should consider incorporating performance measures to ascertain each effort's effectiveness in helping small system managers overcome barriers to drought and climate resilience. Perhaps most importantly, Forum attendees agreed that the conversation around drought, drinking water, and small systems needs to be continued despite Governor Brown declaring the Drought over for the majority of California in early 2017.

4: Discussion

4.1 The Drought and Connections to Climate Change Adaptation

We set out to inventory the Drought experiences of small, self-sufficient water systems with the intention of providing some insights into ongoing efforts and needs for climate adaptation. We found that, based on the systems studied in this project, small, self-sufficient water systems have different drought experiences and needs than larger systems. As with other complex natural resource management issues, "the devil is in the detail." Three crosscutting themes arose throughout the interview and workshop-based documentation of the impacts, responses, and barriers to responding to the Drought: (1) water supply resiliency and robustness; (2) funding mechanisms; and, (3) the role of communication. Below, we review each theme, noting differences observed in interviews between the S3 and the non-S3 systems.

4.1.1 Water Supply Resiliency and Robustness

The first theme discussed frequently in interviews and workshops was the critical role of a resilient and/or robust supply portfolio. Making a system's supplies more drought prepared can involve expanding storage capacity, upgrading distribution system components and water treatment facilities, replacing wellheads, and drilling wells deeper. All of these technical strategies are pursued to add source redundancy and diversify supply portfolios. With these advantages, many of the non-S3 systems were more physically prepared for the Drought. Many non-S3 systems have to file Urban Water Management Plans (UWMPs) with the State, part of which requires them to develop a Water Shortage Contingency Plan. For these systems, the existence of such plans combined with the ability to enact the plan as needed was an inherited response that many S3 systems lacked. In general, large non-S3 systems tend to have the technical, managerial and financial capacity to invest in strategies that positively influence long-term drought preparedness. Comparatively, small systems (both S3 and non-S3) are not required to file an UWMP and often have lower capacity to extend sources or diversify portfolios. Supply diversification and source redundancy were articulated by S3 systems as aspirational drought responses, motivated by water quality and quantity challenges. Therefore, for these systems, preparing for major drought often relies on access to external funding sources to make such changes.

Supporting and facilitating system consolidation is a state policy that could potentially support source resiliency and alleviate water quantity and quality barriers facing S3 systems. One example of successful managerial consolidation described in an interview was the decision to voluntarily purchase and subsume nearby smaller rural systems. Under the umbrella of a single administration, they were able to combine their rate structure and collectively prepare the system for drought even though the source waters of the two systems were not physically connected. In cases where geographical isolation (as opposed to local politics) prevents physical or cost-effective consolidations, external funding and technical expertise could be leveraged to assist with potential managerial consolidations to aggregate management capacity and rate bases. In some extreme cases, consolidation is not an option and some alternative is necessary.

4.1.2. Funding Mechanisms for Small Systems

Financial resources and constraints were key components of impacts, responses, and barriers expressed by managers. Funding and financing were described as necessary for improving supply portfolios and supporting other challenges faced during the Drought. A prevalent challenge raised by small system managers was both consumer affordability and the need for systems to restructure rates. In several cases, rates had remained stagnant for years and even decades. The system's ability to generate revenue therefore did not keep pace with operation and maintenance needs. This in turn created an aged and failing system infrastructure that ultimately impacted water reliability and distribution. Updating rate structures can be an expensive, lengthy, and politically contentious process that ultimately requires a two-thirds public approval (via Proposition 218 of the California Constitution, 1996). This legal financing challenge also makes it more difficult to update rate structures in a way that would help systems dynamically prepare for drought in the long-term and as climate adaptation.

In an effort to assist drinking water systems (particularly smaller systems serving disadvantaged communities), the state made a number of funding packages and other processes available during the Drought to both provide emergency assistance and help facilitate restructuring of rate systems. These included things like the emergency drought funding made available specifically for water systems from Prop 84 (Safe Drinking Water Bond Act of 2006), AB 92 (Committee on Budget. Water, 2015), and AB 93 (Budget Act of 2015) and created the Office of Sustainable Water Solutions to promote permanent and sustainable drinking water solutions. While this money was crucial to minimizing many drinking water system challenges during the Drought, several S3 system managers discussed the onerous process of applying for funding, which discouraged them from applying in some cases. The state addressed similar complaints by introducing flexibility like making verbal agreements on funding projects. A few system managers mentioned the speed with which their emergency funding application were processed and executed.

Further, many of the S3 system managers we interviewed were frustrated over the existing definition of 'disadvantaged community'. In statute, 'disadvantaged communities' (DACs) are defined as, "...the entire area of a water system or community where the median household income [MHI] is less than 80 percent of the statewide average" (California Health and Safety Code, Section 116275aa). Managers in our study noted that the definition is outdated and inappropriate for the water sector. Further, being able to prove DAC status through independent surveying is an additional burden facing many small systems. According to interviews and regional workshop discussions, this is especially the case in rural areas of California, where Census data tends to overestimate household income. An easier process by which a system can prove the MHI of their customers could enable systems to be eligible to apply for a wider range of funding opportunities that are otherwise unavailable to them. As interviewees and workshop participants expressed, eligibility is just one of many barriers preventing small systems from pursuing their aspirational drought responses. Many barriers and responses lie outside the manager's immediate decision-making space and may require regional and state-level engagement for long-term solutions.

4.1.3 The Role of Communication

The third crosscutting theme that arose throughout the study was the importance of communication, including communication between water system managers and consumers, between multiple water systems, between the State and water systems, and between water systems and other water users (agricultural uses, recreational, conservation, or other). Communication is a critical tool for managers to reduce demand and encourage conservation behaviors among consumers. The State's communication to the public was an important complement to local efforts. S3 system managers relayed how helpful it was to be able to point to a consistent Save Our Water campaign message when working to change their customers' water usage or in communicating the Drought's severity locally. Communication among systems and between systems and other water users proved important for building trust, sharing information and advice, developing water sharing agreements, and in some instances, effectively coordinating county-level drought responses.

The majority of S3 system managers discussed outreach and communication efforts with their consumers in at least one portion of their interview (impacts, responses, barriers, adaptation strategies). This underscores the critical role that communication plays in drought management, particularly because it is a relatively 'low cost' activity compared with infrastructure upgrades or other technical responses. Driven primarily by decreasing water availability and/or quality and the Conservation Mandate, consumer communication was described both positively and negatively by S3 managers. For example, some S3 system managers discussed using the Conservation Mandate as a means for placing the blame on the State related to water curtailment and outdoor watering limits. In these cases, consumers tended to commiserate with system managers. In other regions, S3 system managers mentioned that multiple system managers collaborated to develop a consistent consumer message.

In other cases, managers discussed being "forced" to develop outreach campaigns to meet the Conservation Mandate. To do so, many expressed diverting funding that could have otherwise targeted infrastructure upgrades. When water system managers did launch campaigns, their messaging aimed to reduce water use, but as some managers described in their interviews, the messaging became problematic when it was inconsistent between neighboring systems with customers exposed to multiple campaigns. For example, a system with adequate financial resources might choose to ignore a state requirement to curb water even if a fine is levied, because in comparison, the fine was less than the potential revenue loss of cutting service. When a larger, often wealthier, system was located next to a smaller, often less wealthy, system that was limiting outdoor watering to two days a week, consumers became upset. Despite this conflict, outreach and conservation remained important strategies- mentioned by 46% of S3 systems compared to 28% of non-S3 systems.

The majority of communication barriers facing S3 system managers related to local politics and multiple stakeholders with multiple and often opposing priorities. These challenges all related to building and maintaining trust. It would be beneficial to compile positive trust-building case examples to illustrate approaches that are useful for building trust between water use and management stakeholders. For example, balancing the high pressure and quantity required by firefighters with the slower distribution and lower pressure of drinking water supply. Tensions between agricultural and drinking water stakeholders were also raised by a large number of managers. A common attitude expressed was that agriculture uses the majority of the water, so why wouldn't agricultural use be held to the same (or stricter) conservation requirements as community drinking water systems? Additionally, views on climate change by both managers and among consumers and other water users in the community came up as specific examples of communication barriers. These views and perceptions of climate change and their relation to water use and conservation is closely linked with communication efforts related to awareness and education. Outreach campaigns can bring drinking water system managers and consumers together by educating community members on the value of water and the process of getting water from the source to the tap.

The State has attempted to improve drinking water manager communication through efforts like the, Save Our Water Campaign, and Making Conservation a Way of Life (EO-B37-16). California dedicated over $1 million annually in communication efforts through the Save Our Water campaign towards the 25% conservation goal during the Drought. While more research is needed to understand what motivates consumers to conserve water, our study shows that there appears to be a continued demand for better outreach to and education of consumers about the value of water, the importance of conservation, and the potential repercussions of not conserving. Seeing as both S3 and non-S3 system managers reported physical barriers as their top concern, messaging and communication barriers are closely tied and therefore, must be addressed to prevent even larger barriers from forming. While the Save Our Water Campaign aimed to help with messaging during the Drought, it was not crafted to work towards building trust. One potential solution may be the Human Right to Water (AB 685), passed in 2012, which establishes the state's goal to ensure access to safe water by recognizing "every human being has the right to safe, clean, affordable, and accessible water" (California Water Code, Section 106.3). As of now, however, AB 685 remains unfunded, so as Forum participants expressed, if it is going to assist S3 system managers in building trust and communication with other managers, the state should consider (at least partially) funding it.

4.1.4 Looking Towards the Future

Looking towards the future, we can garner insights from using the Drought to study the impacts and management of an extreme event projected to increase under a changing climate. From this study we found that for future droughts there were clear findings, which also apply to supporting climate adaptation (Table 5).

Table 5. Key messages from the study as they pertain to drought and climate adaptation

Key Messages Learned from Study Participants	Drought-Preparedness Audience	Climate Adaptation-Relevance
Conservation mandates should not be one size fits all statewide; reporting requirements can create greater burden for smaller systems, and having drought plans in place prior to droughts is beneficial	State	Yes, organizational learning is an attribute for adaptive management
Existing and proposed regulatory efforts look good on paper, but there are two flaws: 1) they target and are often developed with larger systems in mind and 2) they are often unfunded, potentially creating an additional burden on smaller systems	State	Yes, if metrics are developed to track effectiveness that include small system-focused indicators
Small systems tend to experience a domino effect of burden; not only do they fail to meet a policy implementation deadline (e.g. Conservation Mandate), but they may also face staff capacity challenges, supply availability concerns, and financial hardships	State, Local water districts,	Yes, multiple simultaneous challenges are common in adaptation processes; thus, recognizing and addressing these clusters of burdens together can also help advance adaptation
Small water systems need assistance with climate adaptation and this likely requires different approaches than what is provided to larger systems	State government; supportive non-governmental organizations; philanthropic foundations	Yes, directly
Need better income surveys in rural areas to more accurately capture demographics of water system customers	Federal, state governments	Yes, multiple long term benefits to improving Census surveys that supports adaptation efforts
Defining disadvantaged communities should be specific for drinking water sector	State, Groundwater Sustainability Agencies	Yes, may help to increase small systems' access to needed funds for upgrades and capacity-building

Need continued and improved outreach to and education of consumers about the value of water, the importance of conservation, and the potential repercussions of not conserving	State, Federal, local districts, regional organizations, educational organizations	Yes, can help improve public and political support for conservation and increase efficient, careful use of water

First, small systems in general need different approaches compared to large systems to help them through droughts. They also need assistance with climate adaptation, and this likely requires different approaches than what is provided to larger systems. Second, conservation mandates should not be one size fits all. This message was clearly heard in 2015 and 2016, leading the state to revise the mandate, but it is important to carry this lesson into future droughts with a new administration. Third, study participants expressed the need for a more reliable way to define disadvantaged communities (DACs) for water systems. Many rural areas do not have sufficient Census data to have DAC status documented and thus, need to organize and fund individual surveys to become eligible for state drought assistance grants. Along these lines, defining DACs should be specific for drinking water sector, but would benefit from incorporating lessons learned from the CalEnviroScreen cumulative pollutant exposure index developed by the California Office of Emergency Health Hazard Assessment (OEHHA). Lastly, but certainly not least, small self-sufficient systems need assistance to strengthen their participation in regional planning processes. Participants expressed that "on paper" SGMA appears to assist in the supporting smaller systems' participation in local groundwater planning, but already there are indications that these systems will remain left out of management planning.

Additionally, future questions arose that could be examined to continue building on this study. To complement our findings, it would be valuable to document what happens post-drought. Does the memory of the Drought influence how the water system is managed and more broadly how systems participate in regional activities? Monitoring the post-drought efforts of the state and water systems could help address ongoing questions. Are conduits supporting social relationships built during the Drought maintained? To what extent does planning return to business-as-usual? Were there state policies or behavior or institutional changes made during the drought that continue in the post-disaster period? For those that maintain these efforts, why and how? And do these efforts make them likely to be more prepared and able to deal with the next severe drought period?

Answering multiple additional questions surrounding small water systems could help guide the development of best practices for how to reduce risk and vulnerability to climate change impacts. These could vary from developing indicators of what puts one small system at higher risk than another, to completing more quantitative exercises to assess the attitudes and needs around improving awareness about climate change (e.g., is there a way to train board members about the projected impacts and would this be helpful or does the knowledge just need to be within the system's staff?).

4.2 Reflections on Process as a Way to Collectively and Iteratively Gather Data

Process

This project employed three methods to gather empirical data: semi-structured interviews, regional-focused workshops with small water system managers, and a broader forum to collect perspectives and experiences from water system managers. Together these methods allowed us to gather information from a diverse set of water system managers and other stakeholders involved in water resource management, and also allowed us to cross-check and build on findings as the study progressed. As with any research project, there were strengths and limitations encountered, which are described below.

Strengths

Overall, the strengths of the multi-pronged structured study of iterating through three stages of data collection served the project goals well. It led to a substantial amount of data collected, achieving the overarching project objective to better understand and document the experiences of the Drought on small, self-sufficient water systems. This study demonstrates i) how to document experiences using qualitative, in-depth collection, ii) how to translate those experiences through content analysis into quantitative information, and iii) how to use that information to facilitate communication of quantitative results in conjunction with qualitative descriptions. In addition to the wealth of information gathered, this approach gave us high geographical coverage and qualitative input from a large number of people. Lastly, we found this iterative method especially beneficial for cross-checking findings across individuals and group responses and across stakeholder types. Thus, triangulating findings and sharing and verifying them with different drinking water managers increased the transparency and reliability of results.

Limitations

In reflection of the limitations of the iterative method employed in this study, the most notable drawback was the demand for time to both set up each stage of the process and to switch between methods. The research team spent several weeks meeting once or even several times per week to develop the interview schedule, train ourselves to become consistent across interviews, and consistently apply codes to transcripts. It also took time to set up interviews and travel long distances, as any fieldwork of this nature requires. Subsequently, with our multi-pronged approach to conduct workshops, our team's methodological training and study design development had to shift gears considerably in early winter 2017, as transcribing interviews was coming to a close. We sought to initiate early discussions with stakeholders across different regions to test the waters as a way to determine workshop locations. Due to the timeline, we did this reconnaissance stage simultaneous to the stage of coding and beginning transcript analysis. The development of workshops was an entirely different skillset, and we recognized the need for external assistance with additional skills. This included a professional facilitator and a masters student skilled in participatory research. These additions were key, yet we still had not accurately anticipated what a time-consuming process the regional workshops would be. Upon realizing the time and capacity deficiencies, we collaborated with EJCW for additional assistance to conduct workshops, and assist with the Forum. Our EJCW partnership was essential for recruiting water managers to participate in our day-long regional workshops in Modesto and Salinas, especially. This partnership was instrumental in the success of the workshops and the Forum, though in retrospect we would allocate a larger portion of the timeline and budget for such activities and partners. This would be necessary for a more two-way partnership, to dedicate time from both the university and the NGO partner to co-develop goals and reflect on findings as analysis was done.

5: Conclusion

There is no resource more vital to a society's health than drinking water. California is an already semi-arid climate with a highly diverse and complex suite of water system governance. Building on the state's current progress in supporting the water sector in adaptation efforts, this report provides insight into the need to assist small, self-sufficient systems to prepare for climate change and future droughts. Options that transform and better define the roles, accountability, and responsibilities related to adapt could make the changes necessary to prepare small drinking water systems and their customers for climate change.

6: References

Archie, K.M. et al., 2014. Unpacking the "information barrier": Comparing perspectives on information as a barrier to climate change adaptation in the interior mountain West. *Journal of Environmental Management*, 133, pp.397–410.

Balazs, C., 2011. *Just Water? Social Disparities and Drinking Water Quality in California's San Joaquin Valley*. UC Berkeley. Available at: http://escholarship.orhttp//escholarship.org/uc/item/8z17v6gtg/uc/item/8z17v6gt.

Balazs, C. et al., 2011. Social disparities in nitrate-contaminated drinking water in California's San Joaquin Valley. *Environmental Health Perspectives*, 119(9), pp.1272–1278.

Balazs, C. et al., 2012. Environmental justice implications of arsenic contamination in California's San Joaquin Valley: a cross-sectional, cluster-design examining exposure and compliance in community drinking water systems. *Environmental Health: A Global Access Science Source*, 11(1), p.84.

Balazs, C.L. & Ray, I., 2014. The drinking water disparities framework: on the origins and persistence of inequities in exposure. *American Journal of Public Health*, 104(4), pp.603–611.

Baker, E., Ekstrom, J., and Bedsworth, L. (2018) Climate information? Embedding climate futures within social temporalities of California water management. *Environmental Sociology*. Available at: https://doi.org/10.1080/23251042.2018.1455123

Banjade, M.R., Ojha, H., 2005. Facilitating deliberative governance: innovations from Nepal's community forestry program e a case study in Karmapunya. 81: 403. http://pubs.cif-ifc.org/doi/pdf/10.5558/tfc81403-3

Berg, N. & Hall, A., 2015. Increased interannual precipitation extremes over California under climate change. *Journal of Climate*, 28(16), pp.6324–6334.

Bernard, H.R., 2006. *Research Methods in Anthropology: Qualitative and Quantitative Approaches*, Rowman Altamira.

Binkley and Duncan 2009. The past and future of Colorado's forests: Connecting people and ecology. *Ecology and Society* 14(2). Available at: http://www.jstor.org/stable/26268297

CalNRA, CDFA & CalEPA, 2014. *California Water Action Plan*. Available at: http://resources.ca.gov/california_water_action_plan/

Christian-Smith, J. et al., 2013. *Assessing Water Affordability: A Pilot Study in Two Regions in California*, Okland, CA: Pacific Institute. Available at: http://tularelakebasin.com/alliance/index.cfm/project-documents/pacific-institute/assessing-water-affordability/.

Cornwall, A. 2008. Unpacking 'Participation': models, meanings and practices. *Community Development Journal* 43(3):269-283.

Conrad, E. 2013. *Preparing for New Risks: Addressing Climate Change in California's Urban Water Management Plans*. Prepared for the California Department of Water Resources. University of California Berkeley, June 2013.

Costanza, R., Graumlick, L. Steffen, W. et al. 2007. Sustainability or collapse: what can we learn from integrating the history of humans and the rest of nature? *AMBIO: A Journal of the Human Environment* 36:522-527.

Diffenbaugh, N.S., Swain, D.L. & Touma, D., 2015. Anthropogenic warming has increased drought risk in California. *Proceedings of the National Academy of Sciences of the United States of America*, 112(13), pp.3931–3936. Available at: http://dx.doi.org/10.1073/pnas.1422385112.

Dilling, L. et al., 2017. Drivers of adaptation: Responses to weather- and climate-related hazards in 60 local governments in the Intermountain Western U.S. *Environment and Planning A*, p.0308518X1668868.

DWR, 2010. *California Drought Contingency Plan*, Sacramento, CA: California Department of Water Resources.Available at: https://www.water.ca.gov/LegacyFiles/waterplan/docs/cwpu2013/Final/vol4/drought/01California_Drought_Contigency_Plan.pdf (Accessed: January 2018).

DWR, 2015. *California's Most Significant Droughts: Comparing Historical and Recent Conditions*, Sacramento, CA: California Department of Water Resources. Available at: http://www.water.ca.gov/waterconditions/docs/California_Signficant_Droughts_2015_small.pdf.

DWR, 2017. DWR - Water Conditions: City of Porterville Water System. Available at: http://www.water.ca.gov/waterconditions/porterville.cfm [Accessed: 12 December 2017].

Ekstrom, J.A., Bedsworth, L. & Fencl, A., 2017. Gauging climate preparedness to inform adaptation needs: local level adaptation in drinking water quality in CA, USA. *Climatic Change*, 140(3–4), pp.467–481. Available at: http://link.springer.com/10.1007/s10584-016-1870-3.

Ekstrom, J.A. & Moser, S.C., 2014. Identifying and overcoming barriers in urban climate adaptation: Case study findings from the San Francisco Bay Area, California, USA. *Urban Climate*, 9:54–74.

EPA 2012. Adaptive Response Framework for Drinking Water and Wastewater Utilities. A Report of the Climate Ready Water Utilities EPA 817-F-12-009, Available at: https://www.epa.gov/sites/production/files/2015-04/documents/adaptive_response_framework_for_drinking_water_and_wastewater_utilities.pdf

EPA 2017. Drinking Water Requirements for States and Public Water Systems. Webpage; Available at: https://www.epa.gov/dwreginfo/information-about-public-water-systems (Accessed: April 2018).

Exec. Order No. B-40-17. https://www.gov.ca.gov/docs/4.7.17_Exec_Order_B-40-17.pdf Note: This order declared by Governor Jerry Brown terminates the drought state of emergency declaration from January 17, 2014 for all counties except Fresno, Kings, Tulare, and Tuolumne.

Faunt, C.C. et al., 2016. Water availability and land subsidence in the Central Valley, California, USA. *Hydrogeology Journal*, 24(3), pp.675–684. Available at: http://dx.doi.org/10.1007/s10040-015-1339-x.

Feinstein, L. et al., 2017. *Drought and Equity in Calfornia*, Okland, CA: Pacific Institute, The Environmental Justice Coalition for Water. Available at: http://pacinst.org/app/uploads/2017/01/PI_DroughtAndEquityInCA_Jan_2017.pdf.

Griffin, D. & Anchukaitis, K.J., 2014. How unusual is the 2012-2014 California drought? *Geophysical Research Letters*, 41(24), pp.9017–9023. Available at: http://doi.wiley.com/10.1002/2014GL062433.

Haden, V.R., Niles, M., Lubell, M., Perlman, M., & Jackson, L. 2012. Global and Local Concerns: What Attitudes and Beliefs Motivate Farmers to Mitigate and Adapt to Climate Change? *PLoS* Available at: https://doi.org/10.1371/journal.pone.0052882

Harter, T. & Lund, J.R., 2012. Addressing Nitrate in California's Drinking Water: With a Focus on Tulare Lake Basin and Salinas Valley Groundwater: Report for the State Water Resources Control Board, Davis, CA: Center for Watershed Sciences, UC Davis.

Herring, S.C. et al., 2014. Explaining extreme events of 2013 from a climate perspective. *Bulletin of the American Meteorological Society*, 95(9), pp.S1–S104.

Honeycutt, K. et al., 2012. *Technical Report 7: Alternative Water Supply Options for Nitrate Contamination*, Davis, CA: Center for Watershed Sciences, UC Davis.

Hundley, N., Jr., 2001. *The Great Thirst: Californians and Water-A History, Revised Edition*, University of California Press.

Kates, R.W., Travis, W.R., Wilbanks, T.J. 2012. Transformational adaptation when incremental adaptations to climate change are insufficient. *Proc. Natl. Acad. Sci.* U. S. A. 109:7156–61; doi:10.1073/pnas.1115521109.

Kenter, J., O'Brien, L., Hockley, N. et al. 2015. What are shared and social values of ecosystems? *Ecological Economics* 111:86-99; https://doi.org/10.1016/j.ecolecon.2015.01.006.

Larson, K.L. & Lach, D., 2010. Equity in Urban Water Governance Through Participatory, Place-Based Approaches. *Natural Resources Journal*, 50(2), pp.407–430.

Liang, Y., Hendersen, L. and Ken, K. 2017. Running Out of Water! Developing a Message Typology and Evaluating Message Effects on Attitude toward Water Conservation. *Environmental Communications*, 12(4):541-557.

London, J., Huang, G. & Zagofsky, T., 2011. *Land of Risk, Land of Opportunity: Cumulative Environmental Vulnerabilities in California's San Joaquin Valley*, Davis: UC Davis Center for Regional Change.

London, J., Fencl, A., Watterson, S., et al. 2018. The Struggle for Water Justice in California's San Joaquin Valley: A Focus on Disadvantaged Unincorporated Communities. A Report of the UC Davis Center for Regional Change. Available at: https://regionalchange.ucdavis.edu

Luyet, V. et al., 2012. A framework to implement stakeholder participation in environmental projects. *Journal of Environmental Management*, 111: 213–219. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301479712003416.

McNeeley, S.M., Beeton, T.A., Ojima, D.S., McNeeley, S.M., Beeton, T.A., Ojima, D.S. 2016. Drought tisk and sdaptation in the Interior United States: Understanding the importance of local context for resource management in times of drought*. *Weather. Clim. Soc.* 8:147–161; doi:10.1175/WCAS-D-15-0042.1.

Measham, T.G. et al., 2011. Adapting to climate change through local municipal planning: barriers and challenges. *Mitigation and Adaptation Strategies for Global Change*, 16(8), pp.889–909.

Moore, E. et al., 2011. *The Human Costs of Nitrate-Contaminated Drinking Water in the San Joaquin Valley*, Available at: http://www.pacinst.org/reports/nitrate_contamination/\nhttp://www.centralvalleybusinesstimes.com/links/nitrates report.pdf.

Moser, S.C. & Ekstrom, J.A. 2010. A framework to diagnose barriers to climate change adaptation. *Proceeding of the National Academy of Sciences (PNAS).* 107(51):22026-22031.

Moser, S.C. & Ekstrom, J.A., 2012. *Identifying and Overcoming Barriers to Climate Change Adaptation in San Francisco Bay: Results from Case Studies*, Publication number: CEC-500-2012-034, Sacramento, CA: California Energy Commission.

Moser, Susanne C., J.A. Ekstrom, J. Kim, S. Heitsch. (Susanne Moser Research & Consulting, Department of Water Resources, Local Government Commission and ICF). 2018. ***Adaptation Finance Challenges: Characteristic Patterns Facing California Local Governments and Ways to Overcome Them***. California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-007.

Mount, J. and Hanak, E. 2016 Water Use In California. Report by the Public Policy Institute of California, Available at: http://www.ppic.org/publication/water-use-in-california/

Næss, L.O. et al., 2005. Institutional adaptation to climate change: Flood responses at the municipal level in Norway . *Global Environmental Change*, 15(2), pp.125–138.

Nalau J, Preston BL, Maloney MC, Maloney M. 2015. Is adaptation a local responsibility? *Environ. Sci. Policy* 48:89–98; doi:10.1016/j.envsci.2014.12.011.

NIDIS (National Integrated Drought Information System). 2018. California Drought: 2011-2017. U.S. Drought Portal (website, accessed June 27, 2018). Available at: https://www.drought.gov/drought/california-no-stranger-dry-conditions-drought-2011-2017-was-exceptional

Patel, M., Kok, K. & Rothman, D.S., 2007. Participatory scenario construction in land use analysis: An insight into the experiences created by stakeholder involvement in the Northern Mediterranean. *Land Use Policy*, 24(3), pp.546–561.

Perreault et al., 2012. Environmental injustice in the onondaga lake waterscape, New York State, USA. *Water Alternatives*, 5(2), pp.485–506.

Quesnel, K. and Ajami, N. 2017. Changes in water consumption linked to heavy news media coverage of extreme climatic events. *Science Advances*, 3(10): e1700784; doi:10.1126/sciadv.1700784.

Reed, M.S., 2008. Stakeholder participation for environmental management : A literature review. *Biological Conservation*, 141(10):2417-2431.

SDWIS. 2016. Drinking Water- Safe Drinking Water Information System – SDWIS. Webpage Data Portal; Available at: https://data.ca.gov/dataset/drinking-water-%E2%80%93-safe-drinking-water-information-system-%E2%80%93-sdwis (Accessed April 2018).

Seager, R. et al., 2015. Causes of the 2011-14 California drought. *Journal of Climate*, 28(18), pp.6997–7024.

Shi, L., Chu, E., Anguelovski, I., Aylett, A., Debats, J., Goh, K., et al. 2016. Roadmap towards justice in urban climate adaptation research. *Nat. Clim. Chang*. 6:131–137; doi:10.1038/nclimate2841.

SWRCB. 2017. California State Water Resources Control Board Drinking Water Drought Funding: March 23, 2017. Available at: https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/drought/funding_map.pdf

SWRCB. 2018a. What is a Public Water System? (Webpage, accessed June 27, 2018). Available at: https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/waterpartnerships/what_is_a_public_water_sys.pdf

SWRCB. 2018b. Drought Impact on Public Drinking Water Systems (Webpage). Available at: https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/DroughtImpact_PublicDrinkingWaterSystems.html

Thornton, T. and Manasfi, N. 2010. Adaptation--Genuine and Spurious: Demystifying Adaptation Processes in Relation to Climate Change. *Environment and Society: Advances in Research* 1: 132–155; doi:10.3167/ares.2010.010107.

US Census. 2016. *QuickFacts United States Website* (Searchable by County or City): Population Estimates (July 1, 2016); Available at: https://www.census.gov/quickfacts (Accessed: October 2017).

USGS 2018. 2012-2016 California Drought: Historical Perspective. Webpage. Available at: https://ca.water.usgs.gov/california-drought/california-drought-comparisons.html (Accessed April 2018).

Victor, D. 2015. Embed the social sciences in climate policy, *Nature* 520:27-29.

Williams, A.P. et al., 2015. Contribution of anthropogenic warming to California drought during 2012–2014. *Geophysical Research Letters*, p.2015GL064924.