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DROUGHT ADAPTATION AMONG WESTERN COLORADO WATER SYSTEMS: UNDERSTANDING INSTITUTIONAL READINESS FOR DROUGHT INFORMATION ADOPTION AND THE ROLE OF EXTREME DROUGHT EVENTS AS DRIVERS OF ADAPTATION

by

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B.A., Oberlin College, 2010

A thesis submitted to the
Faculty of the Graduate School of the
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Understanding Institutional Readiness for Drought Information Adoption and the Role of Extreme Drought Events as Drivers of Adaptation

has been approved for the Environmental Studies Program

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Lisa Dilling

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Max Boykoff

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William Travis

Date_______________

The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

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Page, Rebecca Hua (M.S., Environmental Studies)
Drought Adaptation Among Western Colorado Water Systems: Understanding Institutional Readiness for Drought Information Adoption and the Role of Extreme Drought Events as Drivers of Adaptation

Thesis directed by Associate Professor Lisa Dilling

ABSTRACT

Water is a critical and scarce resource across the western United States. Communities across the region are facing increasing risk of water shortage as demand for water resources rises and as availability of water supply is projected to decrease in the coming decades. Water managers in particular play a critical role in ensuring the sustainable management of water resources, specifically in monitoring, responding to, mitigating risks of, and ultimately building resilience to hydro-climatic variability, and to drought in particular. This thesis examines two aspects of drought adaptation among water managers, specifically a) managers' access to and adoption of *scientific knowledge and information* as a key determinant of adaptive capacity, and b) the role of *past experience with extreme drought events* as a driver of adaptation among water systems. Using a comparative case study design, the study examines five small water systems in the Western Slope region of Colorado, which comprises most of the Upper Colorado River Basin. As a snowmelt-dependent region, the Western Slope faces rising drought risk as temperatures are projected to increase with anthropogenic climate change and as the hydrologic cycle is expected to shift, making the task of improving drought preparedness ever more urgent. Regarding the use of scientific information, this study finds that water managers' willingness and ability to adopt information products is dependent on how an information product is disseminated and proven successful in other water systems and that managers of smaller-scale water systems are embedded within strong communities of practice in which information use practices are replicated and shared across professional networks. Regarding the role of past experience with extreme drought events as a driver of adaptation, this study finds that extreme events do not consistently drive adaptive change in time and space as is commonly theorized and that political motivation that arises from drought events can both serve to help and hinder drought preparedness goals. Ultimately, this paper contributes important context for state agencies, boundary organizations and other entities interested in finding windows of opportunity to support drought preparedness, including drought early warning, among local water systems.

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And lastly, thank you to my family, my ever-energetic partner, and my community of friends around the world for carrying me through a major life transition of moving to (yet another) new state and pursuing graduate studies.

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INTRODUCTION

Water is a critical and scarce resource across the largely arid western United States. Communities across the region are facing increasing risk of water shortage as demands for water resources rise and as availability of water supply is projected to decrease in the coming decades. Most of the mountain river basins across the western United States are fed by snowmelt—an estimated 1/6 of the world's population rely on snowmelt for water supply (Barnett et al., 2005). With temperatures on the rise due to anthropogenic climate change, the timing and volume of snowmelt is anticipated to change, with snowpack runoff peaking earlier in the season, more precipitation expected to fall as rain instead of snow, and increasing evapotranspiration (Lukas et al., 2014). These changes to snowmelt will likely result in overall reductions in regional water supply and increased sensitivity to dry conditions in the later summer and fall months when water uses peak each year (Mote et al., 2005). Moreover, the major drought events of the past several decades, which are commonly used by water managers as a baseline against which to plan for future water supply, occurred during a wetter-than-average period as compared to the paleo hydrologic record (Lukas et al., 2014) and may be causing managers to underestimate the likely severity of drought events in the 21st century (Milly et al., 2008). Meanwhile, demand for water supply is expected to continue to intensify throughout the western U.S., as urban populations continue to boom, new regulatory measures require more and more water to be left within rivers and streams to protect critical habitat and species, and irrigated agriculture continues to require massive diversions to support critical food production (MacDonald, 2010).

There has been mounting interest among researchers and stakeholders alike to better understand the extent to which communities across the western U.S. are prepared for increasing drought risk and what can be done to mitigate and adapt to the impacts of drought. To date, water resources related research has focused heavily on assessing and predicting the impacts of climate variability and change and other stressors to water resources (Gober, 2013). This focus on climate impacts research is mirrored by increased investments among scientists and federal agencies to produce scientific information to support decision-makers in identifying the onset of drought conditions. However, the research community has increasingly recognized the critical need for augmenting these techno-scientific approaches to building drought resilience by deepening our understanding of the social dimensions of information use specifically (Dilling & Lemos, 2011) and of adaptation in general (Burnham et al., 2016) within the water management community.

A large literature exists on the social dimensions of adaptation. Two key dimensions include the *determinants* of adaptive capacity and the *drivers* of adaptation. The determinants of adaptive capacity, or the conditions that give rise to the capacity to adapt to the impacts of climate variability and change, have been theorized and studied by a number of scholars (Engle, 2011; Smit & Wandel, 2006; Yohe & Tol, 2002). Commonly theorized determinants of adaptive capacity include social capital, knowledge and information, human, financial and physical capital, governance and institutional arrangements, and management approaches (Lockwood et al., 2015). Access to knowledge and information, specifically scientific information, has been widely studied as a key determinant of adaptive capacity, specifically the factors that enable or constrain decision-makers to adopt information (Dilling et al., 2015; Dilling & Lemos, 2011; Kirchhoff, 2013). Understanding the decision contexts of potential users of information is essential to guide ongoing investments in information-based decision-support systems and ensure that these systems are responsive to the needs, constraints, and decision-making realities of societal decision-makers such as water managers.

Understanding the factors that turn adaptive capacity into adaptive *action,* or that *drive* adaptation, is another major area of study within the adaptation research community. While determinants of adaptive capacity describe the conditions and factors that must be present in order for a private or public decision-maker to *be able* to adapt, drivers of adaptation describe key factors identified as enabling actual *implementation* of an adaptive action. Commonly theorized drivers of adaptation are summarized by Dilling et al. 2017, and include experience with extreme events, financial incentives, the role of internal champions, access to information, community pressure, supportive institutional arrangements, and socio-cognitive factors.

This thesis seeks to contribute to the scholarship on adaptation by deepening our understanding of two specific elements within adaptation research: a) access to *knowledge and information* as a key determinant of adaptive capacity, and b) the role of *past experience with extreme events* as a driver of adaptation. While water managers' access to scientific knowledge and information has been widely studied (Kirchhoff, 2013; Lemos, 2008), few studies have systematically examined managers of rural, small-scale water systems, resulting in a body of literature that is biased to larger-scale, often municipal water systems and that may be inadvertently contributing to inequitable distribution of information across the urban-rural divide. In addition, though a number of studies have examined the relationship between drought events and adaptation within the water management sector, most studies have used drought events as an empirical context for understanding determinants of adaptive capacity (Engle, 2013) or for understanding local knowledge of drought , rather than systematically examining the causal relationship between drought events themselves and adaptive actions that emerge afterwards. This study seeks to fill these clear gaps in our understanding of water management adaptation.

Examining these two distinct aspects of adaptation within the water management sector requires looking at decisions and decision-making structures of water managers on multiple time-scales, from the seasonal to inter-seasonal use of information for drought monitoring and response to making changes to long-range water supply planning as a result of experiencing an extreme drought. Though each of these dimensions of drought adaptation are only one of a large number of factors that influence and shape adaptive capacity and adaptation to climate variability in the arid western U.S., they each represent an important piece of the daunting task of understanding how to successfully adapt to a climate in which drought events may become more severe and frequent, in a region facing development and other pressures that are in direct conflict with sustainable water resource management. In additional to nuancing and rounding out existing adaptation theory, this thesis ultimately seeks to inform those in the position of decision support providers, including boundary organizations, state and federal agencies, non-profits, and other entities with a mandate to support improved decision-making and build the capacity of water resource decision-makers. May these insights into a) the institutional readiness of water managers to use drought information products and b) the extent to which water managers have learned from and progressed as a result of past experience with drought events, help to clarify how, and under what types of conditions, decision support providers can best aid those managers with the critical responsibility of managing society's water supply.

ARTICLE 1: ADVANCING HYDRO-CLIMATIC INFORMATION USE AMONG SMALL MOUNTAIN WATER SYSTEMS

1. Introduction

Water is a critical and scarce resource across the western United States, and its sustainable and equitable management is one of the region's most important and challenging tasks of the twenty first century. Most of the mountain river basins across the western United States are fed by snowmelt, a characteristic shared by 1/6 of river basins globally (Barnett et al., 2005). Seasonal snowpack acts as a critical source of water storage throughout each year as the majority of annual precipitation occurs in the winter and spring before water demands peak in summer and fall months (Mote et al., 2005). In addition to natural inter-seasonal variability in precipitation, western river basins also exhibit high hydrologic variability from year to year (Bales et al., 2006). As temperatures are projected to increase due to anthropogenic climate change, however, seasonal runoff of snowpack is expected to shift earlier into the year, resulting in lower streamflow volumes and decreased availability of water supply for critical uses in the later summer and fall months (Mote et al., 2005). With more precipitation expected to fall as rain instead of snow (Ibid), spring snowpack levels commonly used by water managers across the western U.S. to predict seasonal water supply availability may no longer serve as a robust indicator of water supply. In addition to overall likely reductions in regional water supply, rapid population growth, new instream flow requirements for environmental protection goals, and continued irrigation demands are resulting in heightened competition for basic water resources (MacDonald, 2010).

These regional changes in water supply and demand have prompted increased investment by scientists and federal agencies to produce drought information products to help decision-makers accurately identify the development of drought conditions, which is considered to be an essential component of drought preparedness (Luo & Wood, 2007). Notably, drought information initiatives such as the US Drought Monitor and the National Integrated Drought Information System Drought Early Warning System (NIDIS DEWS) have made targeted efforts to understand the needs of and solicit feedback from on-the-ground stakeholders in order to develop useful and usable products (McNutt, 2013), an approach commonly referred to as co-production. Social science scholars have long argued that understanding the local decision contexts for potential users (decision-makers) of climate information is critical for ensuring efficacy and impact of decision support systems (Gregory et al., 2012) and for producing usable science in general (McNie, 2007; Dilling & Lemos, 2011; Dilling et al., 2015). McNeeley et al. 2016 specifically claim that in order to improve drought monitoring products, deepening understanding of the local context of drought impacts is critical. Despite these efforts, concerns about drought risk continue to mount across the western US, and a closer, qualitative look at decision contexts of water management decision-makers can reveal new insights into the institutional readiness of community water systems (CWSs) to make meaningful use of hydro-climatic information for drought decision-making.

A robust body of literature exists that examines the various factors that shape the use of hydro-climatic information among water managers, with the goal of shrinking the gap between science and decision-making for water management—including several studies examining systems tied to mountainous snowpack-driven river basins across the western United States (Callahan et al., 1999; McNie, 2014; Pagano et al., 2001; Pulwarty & Melis, 2001; Ray & Webb, 2016; Rayner et al., 2005; Werner et al., 2013). However, most of these studies have focused on relatively large municipal or regional water systems, resulting in information adoption theory that is based on empirical studies of a particular sub-set of decision-makers. Indeed, one of the challenges commonly associated with co-production is its high transaction cost (Dilling & Lemos, 2011; Lemos et al., 2012), which requires agencies and organizations that produce and disseminate information to selectively engage with larger-scale, higher-capacity decision-making organizations (Kirchhoff, 2013).

This paper seeks to address this notable gap in the literature by contributing in-depth empirical descriptions of the information use practices, preferences, and institutional context of small scale systems. Just as large-scale systems can serve as important case studies of understanding co-production processes that require high capacity and resources (Lemos & Morehouse, 2005), small systems may serve as much needed case studies for building alternative models for advancing information use such that information is equitably distributed, accessed, and adopted. We examine three distinct aspects of the information use context of small system managers: 1. the factors that motivate or constrain managers to change the way they use information, 2. their existing knowledge networks and information sources, and 3. the aspects of information sources that influence their likelihood of adoption. Together, these questions can generate new insights into how to scale-up information uptake in a resource-constrained world and maximize the impacts of ongoing investments in drought and climate decision support systems. Using five Western Colorado water systems as comparative cases, we choose to situate this research within the snowpack-driven river basins of Colorado's Western Slope (the portion of the state west of the continental divide), given the timely concerns about reliability of snowpack-based indicators across the mountainous western U.S. and the potential need to support adoption of new hydro-climatic information products by water managers in the future.

In the following section, we summarize key literature on factors that enable or constrain information use and on alternative strategies for advancing information uptake (section 2). We then describe our research methods (section 3) and study area (section 4). Next, we present results on the factors that enable or constrain information adoption identified by interviewees, summarize interviewees' current knowledge networks, and characterize aspects of their information sources that influence adoption choices (section 5). Finally, we identify distinctions between our findings about small-scale water systems and the established literature on determinants of information adoption and consider alternative ideas for advancing and scaling information adoption in light of these findings (section 6 and 7).

2. Literature Review

We know a great deal about the factors that shape the use of hydro-climatic information (hereafter referred to as "information") among decision-makers more generally, and among water managers specifically (see Kirchhoff, 2013 for a detailed review of determinants of information use for water managers). These factors can be categorized in a variety of ways. (Dilling & Lemos, 2011) draw the distinction between "intrinsic" factors related to how the information itself is perceived versus "contextual" factors related to the institutional and social forces that shape adoption. Intrinsic factors found to be relevant to water managers specifically include perceived "fit" or relevance to decision-making needs (Bales et al., 2004; Lemos et al., 2012), alignment with spatial and temporal scale of management decisions (Cash & Borck, 2006; Cash & Moser, 2000; Dow et al., 2009; Gamble et al., 2003; Gordon et al., 2016; Jacobs et al., 2005; Jacobs & Pulwarty, 2003; Kalafatis et al., 2015; Lemos & Morehouse, 2005), perceived skill (Lemos et al., 2002; Rayner et al., 2005), salience, credibility, and legitimacy of the information (Cash et al., 2003), and accessibility and understandability/interpretability of the product (Pagano et al., 2001). Important contextual factors for water managers include managers' management values, e.g. emphasis on routine and reliability (Rayner et al., 2005) versus innovation (Lemos, 2008), the degree of risk aversion due to past experiences managing risk to systems and/or using new information products (O'Connor et al., 2005; Feldman & Ingram, 2009; Glantz, 1982; Kirchhoff et al., 2013; Lemos, 2008; Pagano et al., 2001), and whether the source of information is a trusted agency or individual with localized, sector-specific expertise (Kalafatis et al., 2015; Lackstrom et al., 2014).

We also know that, among these factors, organizational scale (i.e. human capacity and resources) and technical capacity is of particular importance in influencing climate information adoption (Bolson & Broad, 2013; Callahan et al., 1999; Glantz, 1982; Lemos, 2008; Lemos et al., 2014; Pagano et al., 2001). Capacity matters in multiple ways. First, studies have shown that managers must possess a certain degree of technical capacity to be able to accurately understand and apply information, due to the inherently subjective nature of interpreting a product in the context of other types of information and determining its implications for management decisions (Bolson & Broad, 2013; Callahan et al., 1999). Moreover, human capacity is needed to be able to engage in co-production processes due to the demand on staff time and resources that iterative interaction with scientists requires (Dilling & Lemos, 2011; Lemos et al., 2012). Private information tailoring services typically require financial resources that only larger-scale water management organizations can afford (Jacobs & Pulwarty, 2003). A diversity of staff skills, trainings, and backgrounds among stakeholder organizations may also support successful co-production (Morisette et al., 2017). Many of these insights have come out of studies that quantitatively examine the explanatory power of capacity as one of multiple independent variables potentially related to information uptake (Callahan et al., 1999; Kirchhoff, 2013), or that examine cases of co-production processes involving larger-scale management organizations

(Bolson & Broad, 2013; Lemos, 2008; Pagano et al., 2001). Selectively examining the information use contexts of managers at small-scale water management organizations can help nuance our understanding of how exactly capacity matters for information adoption and under what circumstances it matters.

Finally, knowing that capacity is a key barrier, the science translation community has begun to investigate alternative strategies for promoting information usability. One widely established approach to bridging the gap between the production and use of scientific knowledge focuses on the boundary organization, which serves as an intermediary at the boundary of science and decision-making and facilitates translation of information, interaction and exchange, and mutual understanding between producers and users of scientific knowledge (Kirchhoff et al., 2015). Though engagement of boundary organizations has been shown to improve information usability and uptake, the traditional boundary organization model, which is centered around a single organization, is resource-intensive (Dilling & Lemos, 2011) and difficult to scale (Lemos et al., 2012). One work-around that has emerged in recent years is the idea of leveraging and bolstering existing knowledge networks as a means of scaling information adoption (Bidwell et al., 2013), such that climate information can be diffused across a broader community of decision-makers without needing to intensify the role of any single boundary organization or duplicate efforts (Dilling et al., 2015). This can take different forms – one specific model is the boundary chain model, which involves linking two or more boundary organizations together to leverage the assets, skillsets, stakeholder relationships, and social capital that different boundary organizations possess to disseminate usable climate information in more resource-efficient manner (Kirchhoff et al., 2015; Lemos et al., 2014). Another model is the idea of linking regional knowledge networks populated by boundary organizations and objects with more specialized, sector-specific networks of practitioners, or communities of practice (Kalafatis et al., 2015). By linking together these networks, the credibility and legitimacy of the regional knowledge networks, combined with the sector and decision-specific expertise possessed by the community of practice, leads to improved tailoring, interpretation, and usability of information. Traditional boundary organization arrangements and leaner, more resource-efficient models such as boundary chains (Lemos et al., 2014) and linked knowledge networks (Kalafatis et al., 2015), are fundamentally concerned with improving the connection between information producers and users in order to improve translation of information.

The diffusion of innovation concept is yet another framework through which to examine advancing the use of information across a broad spectrum of decision-makers. Diffusion of innovation theory focuses less on translational issues between the producer and adopter and more on the roles that different members of group of potential adopters play in facilitating the diffusion of a social, technological, or scientific innovation (in this case: hydro-climatic information products) across existing networks (Rogers, 1995). How and from whom a prospective adopter learns about an innovation, matters. An innovation tends to first diffuse within a social system, which is made up of individuals or organizations that are interested in achieving some common goal. Norms and relational structures within a social system can facilitate or hinder diffusion of innovation within the social system. While an innovation is introduced to a social system by an innovator, who must be willing to absorb the risk and uncertainty of trying something new, early adopters play a critical role in normalizing the innovation and providing advice and information to others about the innovation (Ibid).

The diffusion of innovation concept aligns with the concept of a community of practice, which can generally be conceptualized as networks of actors fundamentally defined by a shared social identity (Wenger, 2000). Pelling et al., 2008 draw an additional distinction between networks, which are fundamentally defined by connections and relationships "that cross boundaries of identity", and communities, which are "associations found in shared identity, where shared values and practices are reinforced" (p. 870). In the context of a professional industry such as water management, conceiving of professional networks as communities of practice can illuminate strategies for advancing information adoption. For example, earlier studies of adoption of seasonal climate forecasts (SCFs) by water managers conclude that piloting SCFs in actual water management systems through demonstration projects, and documenting project successes, is a potential strategy for encouraging widespread adoption of SCFs among water managers (Callahan et al., 1999; Pagano et al., 2001). The concept of communities of practice is also exploited in the linked knowledge network model proposed by (Kalafatis et al., 2015), but in their context is focused on capitalizing on the trust established within professional networks in terms of interpreting and translating information products, rather than demonstration.

Efforts to-date to generate, test, and empirically evaluate new strategies for information diffusion represent exciting advancements for promoting equitable access to increasingly sophisticated hydro-climatic information. While these strategies have been built upon a robust body of knowledge about the various factors that influence climate adoption, it behooves the research and usable science community to round out this knowledge by continuing to examine new empirical contexts, particularly the institutional contexts of the small-scale systems that these strategies purport to serve.

3. Methods

We used a comparative case study design (Yin, 2014) to characterize decision contexts for information use among five Western Slope water systems. A comparative study allowed us to identify themes that emerge across multiple units of analysis (water system organizations) and for a broader understanding of decision contexts for information use, beyond what a single case study design could offer (Ibid). We selected cases that reflect the large variation in water systems found across the Western Slope region (see next section for description of cases selected). Our goal is to build theoretical knowledge about advancing drought information use in resource-constrained systems tied to mountainous, snowmelt-driven river basins, rather than to draw conclusions generalizable to other empirical contexts. Therefore, we did not randomize the selection process but rather strategically selected systems that represent the heterogeneity of systems across the region.

The data used in this study were collected through a combination of in-person, semi-structured interviews (Schensul et al., 1999) (n=14; 2-4 interviewees per organization) with key staff in the winter and spring of 2017 and an in-depth document review which allows for triangulation of self-reported information from interviewees. Our criterion for selecting participants was that the individuals had to play some role in operational decision-making related to water supply and drought management. Snowball sampling (Bernard, 2000) was used to identify additional interviewees at each organization, based on recommendations by the original contacts made at each entity. We interviewed every individual recommended by our initial contacts at each organization. Though we only interviewed 14 managers in total across these five systems, due to the small nature of these organizations, those 14 individuals included nearly every key personnel responsible for decision-making related to water supply. Our relatively small sample of interviewees therefore captured the views of the central decision-makers at each organization.

Interview questions focused on the following themes: key concerns in managing water supply, characterizing annual decision making processes, information used to make decisions, and preferences and barriers related to information use. The interview protocol was pre-tested with two water systems outside of our study area, and we made revisions to interview prompts based on tester feedback.

We also requested key internal documents from interviewees of each of the five systems; among the 30 documents shared by the study participants, we selectively reviewed 24 of the documents that described internal decision structures related to water supply management, drought monitoring, drought response, or information use as a way of triangulating and/or supplementing descriptions of decision structures provided by interviewees (a detailed description of water managers' decision structures related to drought can be found in section 4). These included internal water supply planning memos, drought response plans, forecast reports, and reservoir operations plans.

Interviews were manually transcribed, and interview transcripts and entity documents were coded using the qualitative coding software *NVivo* (Bazeley & Jackson, 2013). Codes were developed based on emergent themes from the interview and document data as well as from relevant literature on information use and usability. By basing the initial development of codes on key literature reviewed, we were able to quickly focus in on relevant a priori coding categories that were directly tied to our research questions. Emergent coding categories allowed us to systematically capture themes unanticipated from the literature.

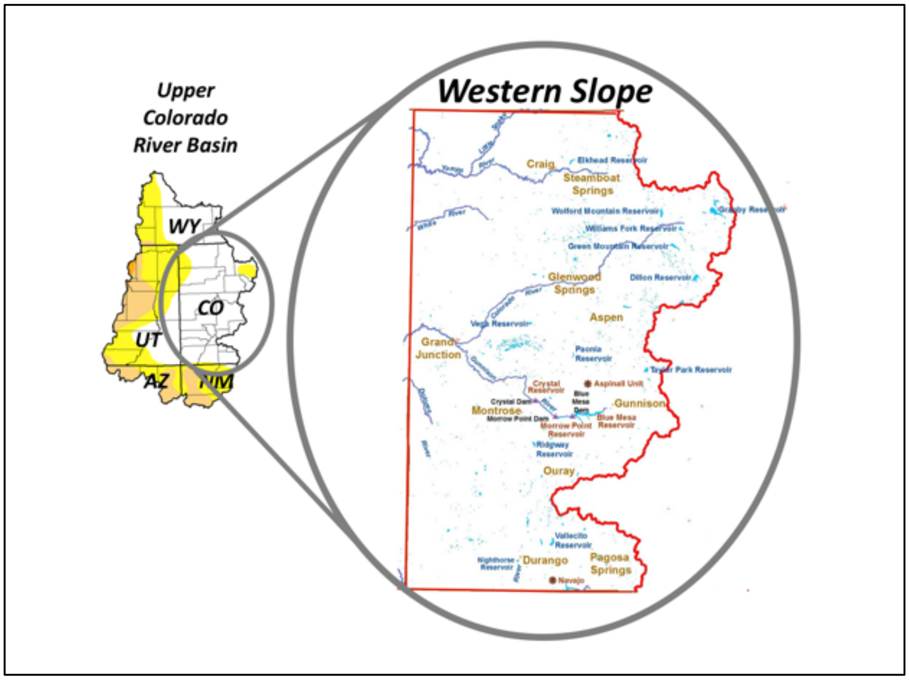
4. Case Description

a. Colorado Western Slope

This study focuses on Colorado's Western Slope region, which encompasses much of the Upper Colorado River Basin (UCRB). The UCRB originates in the headwaters region (Livneh et al., 2015) where the hydrology can be categorized as snowmelt dominated, with complex topography (Livneh et al., 2014). Other snowmelt-dominated systems in the western U.S. include the Columbia, Missouri, and California/Sierra-Nevada systems, and a wide-range of systems exist internationally – an estimated 1/6 of the world's population rely on snowmelt for water supply (Barnett et al., 2005). The overarching issue faced by these systems is that snow storage often exceeds that of man-made reservoirs (Mote, 2006), making information about changing snowpack critical to water resource management. The principal economic sectors across the Western Slope include ranching, irrigated agriculture, natural resource development, recreation, tourism, and mining. As stated in the Colorado Climate Change Vulnerability Study (Gordon & Ojima, 2015), "virtually every aspect of Colorado's economy is tied to water." This is especially true for the economy and culture of the Western Slope. Water on the Western Slope is needed for a wide variety of uses, including municipal, industrial, recreation (e.g., rafting, fishing), irrigated agriculture, and ecological flow needs, e.g., for endangered species.

The Western Slope, like the rest of the state of Colorado, is governed by the prior appropriation system, a legal system that gives senior water rights priority over more junior water rights; seniority is determined by the time when the water rights were purchased (Getches, 1990). Water rights are decreed for a specific 'beneficial use', which in the state of Colorado includes domestic, municipal, agricultural, industrial, and recreation use (Getches, 1990). Instream flows, or water intentionally kept in a stream for the purpose of preserving or improving the natural environment and protecting species of that stream, were later established as a legal type of beneficial use in the 1970s (Ibid). Much of the water originating from the Western Slope is allocated for use elsewhere, either via the Colorado River to meet water demands of other states downstream, or routed through trans-mountain diversions that bring water to the more populous and agriculturally intensive areas of eastern Colorado. Future water demand is expected to triple across the Western Slope, with the majority of that demand coming from the municipal and industrial sectors (Gordon & Ojima, 2015). Simultaneously, climate change is expected to cause earlier snowmelt and peak runoff (Ibid.). Reduced flows not only affect irrigation and municipal users, but also affect tourism and recreation, such as rafting and fishing.

Figure 1. Map of Western Slope Region of Colorado



b. Cases: Five water systems

We selected five water systems across Colorado's Western Slope region to examine in this comparative case study. The five systems generally represent the range of systems found throughout the Western Slope region, which supports a large agricultural sector, industry, power production, recreation, as well as a growing population of small cities and towns. Local water systems across the Western Slope include municipal utilities, regional retail water suppliers, wholesale water suppliers (such as water conservancy districts), and ditch companies. The amount of storage available to these entities is also varied, with some entities managing and benefiting from large federal reservoirs, and some entities depending solely on snowpack as their form of storage. Water systems found throughout the Western Slope are generally smaller (in terms of number of people served and/or GDP of agricultural activity supported through supplying irrigation water) and lower capacity (in terms of the number of staff) than the large municipalities and irrigation districts found throughout the more densely populated east slope of Colorado. For example, the largest domestic water provider in the Western Slope region serves 80,000 people and delivers 10,000 acre-feet of water annually, as compared to the largest provider in the front range area serving over 1 million people and nearly 300,000 acre-feet of water annually (Lowrey et al., 2009).

Figure 1. Summary of selected cases by attribute

Organization type	Business type	Customer use	Storage	Total water/people served
Water conservancy district	Wholesale	Irrigation Augmentation	Total reservoir storage 44,000 AF	26,000 AF in annual contracts
Water conservancy district	Retail	Domestic use	Total reservoir storage 11,960 AF	33,000 accounts 80,000 people 10,000 AF per year
Water conservancy district	Wholesale	Irrigation Augmentation	Total reservoir storage 108,087 AF	1857 AF in augmentation 106,230 AF available for irrigation (amount used varies year to year)
Municipality	Retail	Domestic use Irrigation	No storage	3500 accounts 2000 AF per year
Municipality	Retail	Domestic use Irrigation	No storage	10,000 people 3377 AF per year

c. Temporal dimensions of drought information use: decision calendars

Decision calendars are useful for understanding decision context for information use because they allow for a temporal analysis of when critical decisions are made and when information enters or could potentially enter the decision-making process (Ray & Webb, 2016). Though each of the entities have unique operational characteristics that result in information use practices and differing response options, the five entities exhibit similar decision making timelines throughout each water year, with key operational decision points and hydro-climatic monitoring activities occurring in roughly the same seasons during the year. The seasonality of drought monitoring and response is described below:

Figure 2. Generic decision calendar for Western Slope water managers

Season	Decisions / Information Used
Ramp down / observation (Oct-Dec)	● Systems with reservoirs adjust releases to achieve target end-of-season elevation ● Entities begin monitoring the local hydrology and getting a sense of the water supply as early as October, depending on when snow first starts to fall in their drainage. ● Too early to take any action
Anticipation / early warning (Jan-Mar)	● All entities begin to increase snowpack monitoring frequency in the case of drier-than-average hydrology. ● Each entity has some sort of 'mid-winter' signal or indicator that triggers some preliminary action, even if that action is simply to pay closer attention ● Some entities at this time take preliminary actions in anticipation of drought conditions
Planning / response (Apr-Jun)	● Entities begin to make more critical and real-time decisions about drought management for the upcoming use season, regardless of the type of information (observational vs forecast) entities use as their main indicator of drought. ● Each entity has some type of second indicator or trigger that results in some operational response and effort to mitigate drought impacts. ● The triggers vary both in terms of the degree to which they are quantified and formalized ('75% reservoir levels' versus 'assessment of streamflow, weather predictions, and

	temperature) and in terms of the type of information taken into account.
Ongoing Drought Management (Jul-Sep)	● Systems' available water supply for the use season are for the most part understood and communicated. ● Some entities communicate or coordinate with neighboring water users to do make releases or reduce use to avoid administration in their basin ● Some follow-up actions are available to step up use restrictions or revise release schedule based on changing conditions

5. Results

Here we first present findings on factors that managers identify as motivating or constraining their adoption of information, drawing on (Dilling & Lemos, 2011) categorization of "intrinsic" versus "contextual" factors. We then describe the ways in which interviewees' find out about or acquire new information and the factors related to information-seeking that influence their adoption.

a. Determinants of information use

Intrinsic factors: scale, skill, and understandability

Scale was the most widely mentioned criteria for prioritizing and adopting information products. As one manager put it, every *"little pocket of the mountain"* has distinct *"nuances"* that aren't captured by regional information, making *"localized data"* essential for decision making (case 5). There is a clear need for data that *"best represents the direct source of inflow"* for any given system (case 1); local information *"is actually much more relevant to [their] problems"* (case 4); especially because it can capture institutional factors that affect water availability, e.g. *"the subtleties of how the river gets administered"* (case 5). One manager mentioned *"local"* as making the difference between using a product to directly influence a decision versus using it for general background and context:

> The more localized, the more likely I would use it. And that's why most of these tools that are qualitative, we just say they're qualitative. Because they aren't local enough to necessarily be meaningful. (case 5)

For managers who depend on inflow forecasts to manage reservoirs (case 1, 3), **skill** is also of critical importance. Concern about predictive skill of CBRFC forecasts drove one group of managers (case 2) to develop their own SWE-based forecast model (case 2), while another manager at a different system (case 3) values the skill of CBRFC forecasts as their indicator for decision-making so much that they support additional snowpack data collection needed to improve the accuracy of inflow forecasts.

Understandability in terms of the scientific inputs and assumptions going into a new information product was also mentioned by one manager as a key factor in determining whether he would adopt it in his decision-making. According to this interviewee, lack of transparency creates a transaction cost for managers to figure out the embedded parameters of a product which in turn leads to *"inertia"* and reliance on existing tools (case 5).

Contextual factors: capacity, experience with drought, generational turnover

The most widely identified determinant of information adoption among the interviewees was **organizational capacity**, including both staff resources and technical expertise. Several managers mentioned that, as part of small organizations, they and their colleagues face "*manpower constraints"* (case 1) and generally lack *"the ability to fund staff that monitors all of this"* (case 4) as well as the *"time or energy to be able to…do a full review of what people are…looking at"* (case 1). In addition to simply having the staff resources to monitor for new products, some managers specifically mentioned a lack of technical expertise to *"have a new* *statistical model built up"* from new products and data (case 1) or conduct their own forecasting (case 3). Managers at one system use consultants to make up for the lack of in-house expertise, but one manager expressed that it "can be a hindrance sometimes" (case 5).

Some managers actively compare themselves to the larger organizations in the region that are seen as possessing an ideal level of capacity and technical expertise to keep up with emerging products:

> Denver Water, for example, has a much more concentrated ability to dial into this stuff on a daily basis. They're sophisticated, they've got managers and forecasters that we simply can't afford. (case 3)

> If you look at the Front Range, you get that intensity, those large organizations that are very, very well staffed, very well skilled, and so forth. And you look on the Western Slope, there's no one organization that can come even close. (case 5)

Another common contextual factor that played a role in determining adoption of new information products was the **type of experience managers had in the past with product adoption.** For one system (case 1), managers had relied on CBRFC forecasts for several years to manage their reservoir, but over time found it to be insufficient in terms of its accuracy and impacts to reservoir management decision-making. These same managers were ultimately motivated by a **recent experience with an extreme event** to change the way they were using information to drive decision-making, an action they had wanted to take but had not yet gotten around to. Shortly after the drought of 2012, managers at the system shifted off of an external forecast product provided by the Colorado River Basin Forecast Center (CBRFC) and developed their own probabilistic forecast model based entirely on SWE inputs. As explained in an internal memo about the adoption of the new tool:

> The proposed system is more conservative than relying upon early season forecasts, but it almost guarantees that demands will be met even in the event of a busted official forecast. (case 1)

For another system (case 2), the 2002 drought had significant negative impacts within their sub-basin, but due to their own drought risk mitigation investments prior to the drought, their system was not impacted and they did not impose any use restrictions among their customers. However, the managers at that system were still driven to change their information use practices and begin *"participating a heck of a lot more"* in regional water supply condition discussions such as the Colorado Climate Center's NIDIS Drought Early Warning System, not because of their own sense of vulnerability but because they were *"getting a lot of heat"* from local and regional stakeholders that they had not done enough to support drought recovery for the region.

The last contextual factor that was raised among the interviewees was **staff turnover** among water management staff. A manager at one system (case 1) attributed the development of a new reservoir management operational tool to staff turnover in the mid-2000s. After starting as the new district engineer, he had "*a different expectation of the science that could be used"* to manage the reservoir and avoid *"being wrong half of the time",* which is how the previous manager had approached managing the reservoir. A manager at another system (case 4) attributed being better prepared for drought now than in the past due to having *"newer employees"* that *"have a bunch of different contacts"* and *"are well versed with looking at forecasts and using technology".* Staff turnover can also pose challenges to maintaining continuity and institutional knowledge about how to best use information in the context of a system's particular operations: managers at case 5 expressed concern over the imminent retirement of a senior staff member, who played a key role for many years in interpreting hydro-climatic information for decision-making.

b. Information dissemination: knowledge networks and influence of information sources

Current knowledge networks

Managers primarily accessed information products directly from agency websites and portals, such as NRCS for snowpack data, USGS for streamflow data, and NOAA for temperature and precipitation forecasts. Only one manager regularly participated in university-based boundary activities such as the Western Water Assessment Climate Dashboard and the Colorado Climate Center Drought Early Warning System webinar; the other thirteen interviewees were either vaguely familiar with the platforms but never participated or had never heard of them.

When asked about their typical channels for information outside of their main sources, interviewees mentioned a number of regional or national professional organizations, such as American Water Works Association (case 2), Colorado Water Congress (case 2), the Bureau of Reclamation (case 1), and the Colorado River District (case 4, 5). A few managers mentioned *"keeping in touch with peers and other communities"* (case 4) and checking in with *"other utilities in the valley"* (case 5).

Rather than looking to these organizations and peers specifically for learning about new information products, managers instead rely on these industry peers for their interpretation of emerging drought conditions based on those peers' own preferred information products. For example, one manager relied on one particular individual at the Colorado River District to interpret drought conditions on an annual basis, in lieu of looking directly at drought information products such as the CBRFC streamflow forecasts:

> [Staff member at Colorado River District], in the spring time period, he's in daily communication with the River Forecast Center on what they're expecting. And he gives us the big picture of what's happening everywhere, on the West Slope…I don't know

> how he does it. Basically you get him on the line, you just say, what's happening this year, do you see anything that's out of the ordinary. (case 5)

Another manager explained that, though the Bureau of Reclamation's drought predictions are not directly relevant to his own water system, he still thinks "*they do an amazing job in terms of tracking things*" based on "*the information available to them"* and finds value in paying attention to them in terms of getting *"a general sense of how we're looking compared to the rest of the state"* (case 1).

Influence of information sources

Some managers (case 1, 2, 3) mentioned the importance of how an information product is disseminated to them. One manager was more likely to use a new information product if he heard about it from *"an agency I'm familiar with"* (case 3), i.e. through their **existing knowledge networks.** One manager specifically emphasized the importance of hearing about a product from a person or organization with hands-on experience managing large-scale systems:

> If we heard from someone who had been trying in practice, you bet, if I talked to the river basin forecast center who does this kind of stuff for huge scale reservoirs and operations, that have many moving parts and considerations, you bet I'm going to listen to those guys. (case 1)

Another manager similarly placed value on sources of information having hands-on management experience; he explained that, though they hear about information products from state government entities such as the Colorado Water Conservation Board (CWCB), he saw it was a downside that *"they've never operated a water system"* (case 2).

In addition to the dissemination process, one manager specifically mentioned the importance of how a product is tested and **proven to give better results**, specifically emphasizing the desire to see products **piloted within actual water systems** before adopting it into his own system:

> …What we really trust is when someone shows up and says, hey look, we started looking into, whatever parameter, and it has actually given us better results…if someone can come to me with that, that they had an idea, and they tested it, and they saw some positive results, you bet, we're going to look into that. (case 1)

6. Discussion

a. How different exactly are small systems from big systems?

While this study is not designed to directly compare characteristics of managers from small-scale with large-scale systems in a generalizable way, we can raise questions to be further researched by examining our results against the larger body of literature on determinants of information use. We find that, in many ways, the institutional and behavioral contexts of our small-scale managers are similar to those of larger water systems described throughout the literature, but there are some important nuances in their capacity limitations, knowledge networks, and adoption criteria that can advance our understanding of information usability and adoption.

Similarities: information needs, role of past experiences, windows of opportunity

Our results show that, when it comes to "intrinsic" qualities about information products, the small-system managers we interviewed held the same core priorities as are commonly discussed in the literature—specifically, that information at the local scale, reflecting their specific geography and management needs, is critically important, as is the skill and understandability of the product. In addition, the constraining or enabling effect that previous experience with innovation can have (Lemos, 2008; Pagano et al., 2001) was also validated by one of our cases (case 1) in which a negative past experience with using an external forecast product led managers to stop using external forecast products and develop their own internal model based entirely on snowpack monitoring data. We also found that in some cases our managers capitalized on windows of opportunity to change information use (Bolson & Broad, 2013) presented by staff changes (Rayner et al., 2005) or extreme events (Connor et al., 2005; Feldman & Ingram, 2009; Kirchhoff et al., 2013).

Nuanced capacity limitations for small systems

Our results confirm the barrier that lack of human and technical capacity poses for adopting information. Interviewees discussed both lack of technical capacity to integrate new products into their own management systems or conduct their own forecasting (Bolson & Broad, 2013; Callahan et al., 1999) and lack of financial resources to acquire this technical capacity through hiring staff or consultants (Jacobs & Pulwarty, 2003). However, these managers were clearly constrained by another underlying aspect of capacity limitation not raised in existing literature—the basic lack of staff capacity to keep an eye out and monitor for new information products on a regular basis. A lack of technical resources certainly constrains their ability to expand their information use, but may not matter as much as a fundamental constrain in their basic human resources to even consider the existence of information beyond what they already use. Additionally, even if staff have the technical expertise to interpret products effectively, they may be wearing so many hats that they cannot dedicated time to assessing, interpreting, and working with new products. Yet another way that small organizational scale influences information use practices among these managers is in the outsized impact of staff turnover. Staff turnover in small organizations that have only a handful of core decision-making staff can either create an opening for making needed changes to information use practices (e.g. case 1) or cause loss of institutional memory of how information products are best interpreted in the context of a system's particular operations (e.g. case 5).

Embedded and insulated knowledge networks

In terms of the role of knowledge networks in determining how and what type of information is disseminated and adopted, we find that knowledge networks across the region may be highly polycentric and differentiated based on organizational scale of water systems. We found that our interviewees heard about new information from a narrow range of sources, which for the most part drew heavily from their professional networks or directly from agencies that produce products widely established as industry standard (e.g. USGS streamflow, NRCS snowpack data). Interviewees' information sources largely did not include translational information platforms implemented by the primary boundary organizations in the region (the Climate Dashboard implemented by the Western Water Assessment or the NIDIS Upper Colorado River Basin Drought Early Warning System implemented by the Colorado Climate Center), suggesting that these traditional boundary organization efforts may be reaching a finite circle of decision-makers (Kirchhoff, 2013). Moreover, our interviewees' reliance on industry peers for their interpretation of emerging drought conditions confirms the essential role that sector-specific networks of industry actors and specialists play in translating information for decision-making in the water sector (Kalafatis et al., 2015; Lackstrom et al., 2014). However, our results suggest that managers at small-scale systems may actually be so embedded within and reliant on their professional networks, that in some cases interaction with boundary activities and information providers may not occur at all.

Small-scale system managers may be insulated from boundary activities for a number of reasons. For example, the systems we examined in this study are geographically distant from the active boundary organizations in the region that are located in the eastern part of the state. In additional to geographic distance, cultural and political differences may also play a role in shaping Western Slope water managers' interest in engaging with university-based boundary organizations that are located in the politically dominant, water-thirsty eastern region of the state. A more likely reason for this divide is the fact that boundary organizations in Colorado and elsewhere have disproportionately focused on engaging with higher-capacity systems in closer proximity to their boundary operations, causing managers of rural, small-scale systems to be less aware in general of boundary resources. Our results suggest that, perhaps more important than geographic and political/cultural factors, is the role of the capacity constraints. Certainly the lower transaction cost of following in the footsteps of industry peers from larger systems who, unlike themselves, have the capacity to vet, interpret, and integrate a product into an assessment of local conditions, plays an important role in perpetuating small-scale managers' insulation from boundary activities and embeddedness within professional networks.

Enabling adoption through emulation, replication, and assessment sharing

Criteria for adopting new information products, aside from the universal values of "fit" such as scale, skill, and understandability, were generally focused on the information source and the degree of trust in that source. Our interviewees generally trusted sources who have significant hands-on water management experience over other types of agencies. In some cases, managers relied on industry peers with hands-on experience and local knowledge, not as sources of information products but rather as sources of local assessments of conditions. In those cases, managers trusted the assessments and interpretations by their peers on face value without needing to personally look at the information products supporting those interpretations. This suggests that, for some managers, "adoption" of a new product will not take the form of direct use of the product but rather through early adoption (Rogers, 1995) and integration by their trusted industry peers into local assessments.

Additionally, for one system, managers strongly valued being able to see a product tested and proven predictive for another system as a motivator for adoption. This is reminiscent of recommendations from earlier studies on promoting seasonal climate forecast (SCFs) use (Callahan et al., 1999; Pagano et al., 2001). In this case, given the broader context of low capacity to look for existing products, let alone test, interpret, and assess them, as well as the apparent embeddedness within the industry and insulation from coproduction and boundary spanning activities, we find that piloting and disseminating successful examples of adoption may be an essential strategy and important guiding principle for scaling information adoption and reaching smaller scale systems more generally, not only for promoting SCFs. Moreover, piloting products specifically on larger scale systems may generate more trust among small-scale system managers. While studies have shown that some decision-makers are more likely to emulate peers at organizations of a similar scale to their own (Kalafatis & Lemos, 2017), our findings are consistent with the theorized influence of early adopters as being tied to their sophistication, local knowledge, and ability to absorb risk and uncertainty (Rogers, 1995).

b. What can we learn about alternative strategies to advance information use?

We find that scale, skill, and understandability of an information product are important factors that influence managers' ability and willingness to adopt a product, regardless of organizational scale; producers of operational hydro-climatic forecasts are putting significant effort into improving these characteristics of products (IPCC, 2012) and should continue to do so. Events like staff turnover and occurrence of hydro-climatic extremes (e.g. drought) also appear to provide windows of opportunity that decision support providers can capitalize on to promote new products, though the specific nature of those windows of opportunity in terms of how they motivate behavior change among water managers may be more nuanced than is typically theorized (Page & Dilling, 2018). However, taking what we've learned about our interviewees' insulation from boundary and coproduction processes (even boundary objects such as webinars and dashboards), capacity constraints in terms of basic availability to seek out information or apply technical knowledge, and trust in local knowledge and professional management experience, there may be scope for refining our existing conceptual models for scaling information adoption. The boundary chain model (Lemos et al., 2014), which focuses on leveraging existing networks and social capital of trusted, localized boundary organizations, still ultimately places the emphasis on the translational function of boundary spanning entities and still assumes a basic capacity among end users to engage in a co-productive process. Certainly boundary objects such as assessment reports, web portals, and webinars, assume a certain degree of capacity and connectedness on the part of end users, even with robust marketing efforts. These approaches may be missing the mark in the case of water systems that have not previously, do not currently, and may not ever engage in boundary processes. The linked knowledge networks model (Kalafatis et al., 2015) may be a more suitable conceptual framework for this context, which recognizes the role of professional networks and communities of practice, as opposed to a collection of boundary organizations, as fulfilling the translation and interpretation needs of end-users.

We find that, in addition to thinking of the community of practice as a venue for highly individualized information tailoring (Kalafatis et al., 2015), it may also behoove the usable science community to capitalize on water managers' tendencies to be influenced by their shared social identity (Pelling et al., 2008) and emulate their peers (Lemos, 2008), and broaden the way we conceptualize the community of practice to also serve as an arena for replication and assessment sharing. Given managers' tendencies to work off of their peers' assessments of drought conditions and preferences around seeing products proven predictive in other systems first, it may be more strategic and resource-efficient for knowledge producers and boundary organizations to selectively engage with respected higher capacity water systems in the region with the innovative leanings necessary to act as early adopters (Rogers, 1995); work with those systems to pilot, demonstrate, and integrate new products (Callahan et al., 1999; Pagano et al., 2001); and seek opportunities to document and disseminate successes and lessons from those experiences to the wider community of practice, leveraging existing professional information channels (Lackstrom et al., 2014). Adoption of products proven successful in systems managed by respected industry leaders, or direct use of drought condition assessments from industry peers, is likely to have a much lower transaction cost for small-system managers in terms of the vetting and trust-building process required for direct use of a new product. Products proven predictive and useful elsewhere may also be low-hanging fruit solutions welcomed by "one man show" managers at risk of or undergoing staff turnover and shifts in institutional memory. Of course, products piloted on large-scale systems may need additional tailoring if they are to be usable in the small-system context, and there is a clear need for low-cost, individualized tailoring services to making information products available and useable among resource-constrained water organizations. But, in the absence of these much needed services, having trust in the early adopters of a new product may go a long way in motivating small-system managers to work against their thick set of constraints and find a solution to integrating the product into their own decision-making. In this way, communities of practice not only serve a translational function in the boundary space between knowledge production and use (Kalafatis et al., 2015), but may also provide a critical venue for the demonstration, replication, and sharing of innovative information products.

c. Directions for future research

As an in-depth, case study analysis of five representative water systems across the Western Slope, the results of this study likely capture the realities of similar small-scale systems found throughout the region. Though our findings cannot be generalized beyond the Western Slope region, this study provides important insights and raises useful questions for guiding future research and efforts to scale information adoption. Additional research is needed to test our observations of our five water systems on a broader sample of small-system water managers in deliberate comparison to large-system managers, especially the relative insulation from boundary activities, the relative toll of institutional memory turnover, and the role of comparative organizational scale in influencing managers' trust in information sources. In addition, there is a need for richer empirical descriptions of communities of practice within the water management industry and of demonstration projects for new information products. Regional boundary organizations and knowledge producers would benefit from conducting in-depth social network analyses of water management professionals on a regional basis. Lastly, longitudinal evaluations of the effects of demonstration projects on replication across professional networks would provide needed insight into the validity of an alternative information dissemination model that prioritizes systematic documentation and dissemination of information adoption pilot projects above traditional boundary activities such as interpretation and tailoring.

7. Conclusion

Significant effort has been put into advancing the use and usability of information products to support adaptation to drought and climate variability, particularly for the water supply sector. This effort is warranted, as risks associated with drought and water scarcity are increasing across the western United States with population growth, changes to the volume and timing of snowpack runoff, and increased competition for different types of water uses. Usable science researchers to date have placed an emphasis on understanding various determinants that shape water managers' readiness to take up information, especially factors related to the information products themselves and to managers' decision contexts and institutional constraints, with an eye toward improving the interactive coproduction processes of boundary organizations and translational agencies. Our findings illuminate a missing piece of the usable science puzzle and help to answer the question of how to effectively scale information usability and uptake in a world in which resources available to support usable science efforts are highly limited. By looking specifically at small-scale water systems, we discover new insights that can help shape efforts to scale information usability across different types of users, not only among managers of smaller systems. We find that scaling usability in the water management sector may in fact require shifting away from an emphasis on producer-user interaction and translation, and toward a greater focus on capitalizing on water managers' shared social identity and professional community of practice. Boundary organizations and translational agencies must continue to do the important work of engaging with users to produce usable information products; however, they may be wise to also explore new strategies to encourage early adoption and dissemination of use experiences by well-respected water management organizations, as an alternate way of penetrating a new market of users. As the hydrologic cycle shifts with rising temperatures and as water scarcity risks evolve with changing supply and demand, our ability to find new ground for advancing the use and usability of scientific knowledge to support improved water management outcomes becomes all the more urgent.

ARTICLE 2: HOW EXPERIENCES OF CLIMATE EXTREMES MOTIVATE ADAPTATION AMONG WATER MANAGERS

1. Introduction

Extreme climate events are often theorized as "windows of opportunity" for addressing determinants of climate risks and reducing societal vulnerability to climate variability. In addition to providing windows of opportunity for mitigating risks associated with climate hazards (IPCC, 2012), extreme climate events are also thought to drive adaptation to climate change, either through motivating risk mitigation actions that widen society's coping capacity in response to an extreme event (Fussel, 2007) or through concerted efforts to reduce anticipated risks of worsening extremes in the future (McBean, 2004). Some studies have provided empirical examples of cases in which concrete changes were made by individuals, organizations and governments in reaction to an extreme climate event or disaster (Birkmann et al., 2010; Haigh & Griffiths, 2012; Penning-Rowsell et al., 2006; van Eijndhoven, 2001). Yet other studies have found that "windows of opportunity" do not always result in policy change as is commonly assumed (Birkland, 2006; Christoplos, 2006; Travis, 2014; White et al., 2001); that occurrence of extreme events can accelerate 'mal-adaptations', defined as actions taken with the intention of reducing vulnerability that inadvertently increase or displace vulnerability onto systems or groups (Barnett & O'Neill, 2010); and that other factors such as financial incentives and planning requirements may be more significant drivers of adaptation decision-making (Dilling et al., 2017) or may confound the role of climate signals in influencing decision-making (Berkhout, 2012). Still, calls for additional empirical research on how decision-makers and communities adjust and evolve in response to experiences of extreme weather and climate events can be found throughout the organizational learning, policy change, and adaptive resource management literatures (Birkmann et al., 2010; Busenberg, 2001; Diduck, 2010; Linnenluecke et al., 2012; Moynihan, 2008; Muro & Jeffrey, 2008), particularly place-based (Diduck, 2010) and sector-specific (Linnenluecke et al., 2012) studies.

This study contributes to the ongoing discussion of the role of extreme events in driving adaptation by examining the processes by which experiences of climate and weather extremes motivate organizational adaptation. Indeed, within the adaptation literature, the underlying socio-cognitive factors such as motivation that influence how societal actors respond to climate variability and change have been largely under-examined (Grothmann & Patt, 2005; Pelling et al., 2008) and have yet to be applied to organizations (Grothmann & Patt, 2005; Krömker et al., 2008), and most studies of adaptation focus on exogenous determinants of action, such as institutional, economic, and techno-scientific factors (Granderson, 2014). While those factors are certainly important, especially for highly institutionally constrained decision-makers such as water managers (Berkhout, 2012), there may be additional insights to be gained by examining the behavioral dimensions of responses to extreme events. After all, we know that water managers are also deeply shaped by industry-specific norms such as aversion to political attention and aversion to risks posed to water supply reliability (Lach et al., 2005; Rayner et al., 2005).

Using a comparative case study approach, this study examines the process by which water managers interpret, draw insights from, and become motivated by their experiences with past extreme drought events. Our study focuses on five systems in the Western Slope region of Colorado, in the Rocky Mountain region of the United States. Scholars of water resource management have increasingly recognized the need to shift away from an emphasis on techno-scientific improvements to assessing and forecasting impacts to water resources (Gober, 2013) and toward deepening our understanding of the social dimensions of water management adaptation (Burnham et al., 2016). Water resources in the Western United States in particular are tightly managed, and communities across this region are facing increasing drought risks, especially as demand increases and the timing and volume of snowpack runoff shifts with climate change (Lukas et al., 2014). Like many regions across the western U.S., the economy of Colorado's Western Slope region is closely tied to water resources, but the region also contains relatively little storage as compared to other areas, making water users across the region highly sensitive to inter-annual hydrologic variability and specifically drought (Callihan, 2013). Moreover, the region experienced two major drought events in the past twenty years (2002 and 2012) that some have said changed the mindset and behavior of water managers throughout the region. The 2002 drought in particular has been described as an event that "broke the usual pattern of responding to crisis and then returning to 'business as usual' until the next disaster strikes" (Klein & Kenney, 2006).

In the next section, we present an overview of relevant literature on the window of opportunity hypothesis, the role of motivation in adaptation generally and known motivations among water managers to adapt to drought, and then introduce the concept of sense-making from organizational theory as it relates to adaptation (section 2). We then summarize our methods (section 3) and case description (section 4). Next, we present a summary of the sense-making processes for each case and highlight key themes that emerge across the cases (section 5). We then present a discussion of how our findings a) problematize the window of opportunity hypothesis associated with extreme events, in particular the spatial and temporal dimensions of change, b) nuance our understanding of reliability and mitigating political tension as key motivations for water managers, and c) raise questions about the role of organizational ideology and outlook in shaping adaptation outcomes (section 6). We conclude with a discussion of limitations and future research directions (section 7).

2. Theoretical Framework

a. Window of opportunity hypothesis: the relationship between extreme events and adaptation

The extent to which extreme climatic events actually drive adaptation is contested. Policy studies offer perspectives on this topic (Birkland, 2006; Kingdon, 1995; Sabatier, 1988) and primarily focus on the role that events play in enabling political mobilization and agenda-setting within public policy processes. Assumptions embedded in the window of opportunity, also sometimes referred to as policy window, hypothesis is that a) decision-makers and stakeholders become aware of new risks and build consensus, b) agencies and actors already responsible for mitigating disaster are reminded of the risks, and c) political will and resources are mobilized and become available (Pulwarty & Sivakumar, 2014). Organizational theory also offers insights on event-induced change and generally focuses on private decision-making processes within a firm (Linnenluecke et al., 2013), which may more closely match the realities of organizational decision-making by water managers. According to organizational theory, organizations will make adjustments through "internally oriented responses" (p. 20) that optimize their performance in response to perceived changes in their environment (Linnenluecke et al., 2012). Though few studies have examined organizational response to extreme weather and climate events (Ibid), studies of organizational response to crises or unexpected events generally theorize the occurrence of an extreme event as revealing underlying weaknesses in existing practices and providing an opportunity for an organization to address those weaknesses (Carley & Harrald, 1997). Within policy and organizational change theories, change is thought to be determined and influenced by a combination of institutional factors and individual agency or leadership (Beckert, 1999; Huitema & Meijerink, 2010).

Numerous conceptual models for event-induced adaptation have been proposed throughout the hazards and adaptation literature. Birkmann et al., 2010 specifically proposes a model for identifying changes that occur from disasters and extreme climate events. Their model draws a distinction between the impact of an extreme event (e.g. community disruption, infrastructure damage, ecosystem damage, trauma) and the changes that occur as a result of an event (e.g. organizational change, establishment of new networks, change in legislation, resettlement), depicting a linear relationship between the two. Travis 2014 also proposes a typology of 'pacemaker effects' of extreme events on adaptation, including effects that lead to change (e.g. incremental adjustments that widen coping capacity, transformational change) and effects that do not lead to change (e.g. mal-adaptation, mis-cueing of underlying climatic trends).

In the water management context, some scholars have observed that, due to the conservative nature of water managers and water management institutions, most significant changes within water management result from some type of crisis (Huitema & Meijerink, 2010; Jacobs & Pulwarty, 2003), including drought events. Water managers base much of their decision-making on historic hydrologic records, embedded in which are memories of how certain years "went" in terms of operational decisions. Pulwarty & Melis, 2001 specifically found that risky operational decisions made and proven successful in past extreme events legitimized those operational choices in future extreme events and called for more research in this area. Much of the literature focused on changes induced by climatic extremes within the water sector specifically focuses on the use of scientific information among water managers. Studies have found that water managers are more likely to adopt new information such as seasonal climate forecasts (SCFs) if they have recently experienced an extreme event such as a drought (O'Connor et al., 2005; Feldman & Ingram, 2009; Kirchhoff et al., 2013), though these studies have largely focused on large-scale municipalities that have the capacity to absorb forecast uncertainties. To date, empirical studies of water managers' responses to drought have either a) observed the influence of an extreme event on operational changes within a single case study (Pulwarty & Melis, 2001), b) examined water managers responses to an extreme event as a proxy for understanding processes of mobilizing adaptive capacity (Dilling et al., 2018; Endter-Wada et al., 2009; Engle, 2013; McNeeley et al., 2016), or c) examined extreme events as one of several variables that explains a particular outcome or behavior such as information adoption (O'Connor et al., 2005; Feldman & Ingram, 2009; Kirchhoff et al., 2013). Few studies have sought to understand the role of extreme events in driving adaptations by systematically characterizing how decision-makers across multiple cases respond to the same set of drought events.

b. Motivation as an element of adaptation

Brooks, 2003 defines adaptation to environmental change as "adjustments in a system's behavior and characteristics that enhance its ability to cope with external stress" (p. 8). Adaptations can be anticipatory vs. reactive, autonomous vs. planned, and conducted privately (individuals or households) vs. publically (administrative bodies) (Smit et al., 2000). Much of the adaptation literature has focused on describing and taking stock of adaptive actions (Pelling et al., 2008) and identifying "objective and easily quantifiable" determinants of adaptive capacity (Granderson, 2014). There has been increasing interest in better understanding the underlying processes of adaptation (Granderson, 2014; Pelling et al., 2008), specifically the subjective dimensions of adaptation that, together with objective factors, determine whether adaptive actions are adopted (Grothmann & Patt, 2005). While exogenous institutional factors such as regulatory requirements and water rights systems invariably play a significant role in shaping response capacities (Tompkins & Adger, 2005) especially for organizations such as community water systems (Berkhout, 2012), socio-cognitive dimensions also play an important role in determining adaptation outcomes (Burch & Robinson, 2007). Models of adaptation processes tend to converge around the following theorized stages of the adaptation process, as synthesized by Berkhout, 2012: detection of a climate signal, appraisal of the risk posed by the signal, appraisal of response options, and enactment. Studies that have explored the socio-cognitive dimensions of adaptation processes specifically focus on the risk appraisal and adaptation appraisal stages of this theorized process and have largely examined these within the context of individual-level adaptation (Grothmann & Patt, 2005; Krömker et al., 2008; Kuruppu & Liverman, 2011; Larson et al., 2009; Wolf et al., 2010). However, similar analyses can be applied to organizational decision-makers (Grothmann & Patt, 2005; Krömker et al., 2008) and can shed new light on the varying ways in which organizations are propelled to respond to external stress.

c. Sense-making as a conceptual framework for examining adaptation motivation

Though socio-cognitive dimensions of adaptation to-date have not been widely applied to organizational decision-makers within the adaptation literature, scholars of organizational theory have long treated organizations as behavioral agents (Berkhout, 2012). One widely used theoretical construct from organizational theory is the idea of sense-making (Maitlis & Christianson, 2014), which describes the social process by which organizations attach meaning to an unexpected or surprising event (Weick, 1995) and by which "external pressures are interpreted and acted upon" (Linnenluecke et al., 2012). Sense-making is generally conceived of as a process that is triggered by "cues", often in the form of a surprise or violation of expectations that prompts a need for explanation, due to the uncertain or ambiguous nature of the cue. Cues are interpreted to create a rational account of the world that enables action in the face of uncertainty or ambiguity (Maitlis, 2005). While a cue can take many forms, often sense-making is discussed in the context of responding to some type of crisis or extreme event. In order for a crisis or extreme event to trigger a cue, there must be a sufficiently large "discrepancy between what one expects and what one experiences" such that decision-makers "ask what is going on, and what they should do next" (Maitlis & Christianson, 2014). The sense-making process resulting from the detection of cue, however, is thought to be strongly shaped by organizational ideology, which is comprised of "beliefs about cause-effect relations, preference for certain outcomes, and expectations of appropriate behaviors" (Weick, 1995). While sense-making is generally conceived of as a messy, iterative, and non-linear process, the elements of the sense-making process can generally be theorized as: 1. The occurrence of a cue, propelling the organization into a state of needing an explanation; 2. Interpretation of the cue, which involves creating a rational explanation or account that serves as a basis for action, and 3. Construction of understanding of what needs to happen, setting the stage for action (Maitlis & Christianson, 2014). Similar to the theorized socio-cognitive stages of risk appraisal and adaptation widely applied to the individual adaptation context, sense-making conceptualizes interpretation of a signal or risk as preceding the appraisal of response options, but also considers the sense-maker's own role in the making of the extreme event, thus bringing in the idea of responsibility into the appraisal process.

d. Water managers' motivations to adapt to drought

It has been observed that water managers within the United States exhibit industry-specific values and norms in terms of their propensity to adapt to climate signals and risks. Past studies examining water managers' behavioral norms and common measures of drought management success can provide clues for what motivates managers to address vulnerability during and after drought events. For example, we know water managers strongly prioritize system reliability (Hashimoto et al., 1982; Lach et al., 2005) over other considerations, with financial considerations and water quality important secondary considerations (Lach et al., 2005; Rayner et al., 2005). In a comparative study of water managers from two regions in the eastern United States, (Dow et al., 2007) found that managers associated future drought risk with concerns related to meeting regulatory requirements, financial concerns, and water quality, as opposed to concerns around water supply reliability. Public support has also been found to be an important measure of success among managers or their elected Boards (Dilling et al., 2018; Hornberger et al., 2015; Lach et al., 2005), as well as a desire for political cover in terms of avoiding pressure from regional stakeholders (Dilling et al., 2018). Given the role that public support plays in shaping water management decision-making, public values, such as ecological citizenship (Brien & Wolf, 2010) or perceived fairness or efficiency of water policy options (Glenk & Fischer, 2010), may also play a role in shaping water managers' responses to drought (Kiparsky et al., 2012). Systematically comparing how managers across several water systems make sense of, attach meaning to, and rationalize responses to the same drought events can further test the relative importance of these known motivations.

3. Methods

We employed a comparative case study design for this study (Yin, 2014), which allows for identifying themes that emerge across multiple units of analysis (water system organizations) and for a broader understanding of the phenomenon of sense-making from extreme events, beyond what a single case study design could offer (Ibid). Data was collected through two rounds of field work in 2017. Semi-structured one-on-one interviews (n=14) were conducted with decision-makers (e.g. general managers, water engineers), across the five cases in spring 2017 and semi-structured focus group discussions (16 participants across 5 discussions; 2-5 participants per discussion) were conducted with each of the five case organizations in fall 2017. While the one-on-one interviews allowed us to capture in-depth individual perspectives on perceptions and concerns related to drought absent of group dynamics, the focus groups provided a venue for collecting shared narratives across each organization about how past drought events have influenced organizational change. As sense-making is inherently a social and interactive process (Maitlis & Christianson, 2014), we chose a group discussion format to allow managers to collectively recall and reconstruct their sense-making processes of past drought events.

Criteria for inviting interviewees in the spring 2017 interviews was that individuals had to play some role in operational decision-making related to water supply and drought management. Snowball sampling was used to identify additional employees at each entity who fit these criteria; we were able to interview 100% of the employees recommended through this snowball sampling process. For the fall 2017 focus groups, criteria for inviting participants were that managers had to have been present for a past drought event and/or have some perspective on how past droughts have affected some aspect of the organization, as well as played some active decision-making role in managing drought (a slightly broader group than who participated in the interviews). We similarly asked our main points of contact at each organization to recommend a group of employees to participate in these focus groups, including administrative and legal employees who were employed at the organizations during past drought events. The organizations selected as cases are relatively small and each have as few as 2-5 active personnel tasked with management and decision-making related water supply and drought. Therefore, though our overall sample of interviewees (n=14) and focus group participants (n=16) is relatively small, we were able to capture the views and collective memories of the central decision-makers at each organization.

Interviews covered questions about general drought concerns, available drought measures, and constraints related to drought preparedness, as well as a handful of questions of individual managers' past experiences of drought. Focus group discussions were used to collect shared narratives of past experiences with drought, impacts from those past experiences, and lessons drawn and/or enacted from past experiences. Interviews and focus groups were recorded with participant consent and manually transcribed; transcripts were coded using qualitative coding software NVivo (Bazeley & Jackson, 2013). An open coding framework was developed to guide the data analysis process, based on a combination of a priori themes derived from relevant literature and emergent codes. Definitions were developed for each a priori code to standardize the coding process.

While our unit of analysis is on the organization level, we recognize the risk that this introduces in "concealing the action of individuals operating within the organization" (Argyris & Schon, 1996; Pelling et al., 2008) and strive to make clear any discrepancies between responses of individuals from the same organization. Using the organization as the unit of analysis acknowledges the fact that while motivation and sense-making is experienced and decisions are made by managers as individuals, within an organizational context these processes are "stored in and brought forth from organizational memory" (Diduck, 2010) and thus examining each group of managers as one unit of analysis is warranted. Obtaining multiple perspectives from individuals at each organization allowed us to look for the organizational perspective and ensured that we were not only obtaining one individual's perspective.

Finally, we acknowledge that responses that arise from experience of an extreme event invariably have "multiple points of origin" (Birkmann et al., 2010) and that any change purportedly attributed to a specific extreme event is also likely influenced by other institutional and political factors (Berkhout, 2012; Penning-Rowsell et al., 2006). We acknowledge this limitation and base our analyses on what our study participants' judge to be attributable to a specific extreme event, as other scholars examining event-induced change have done in the past (Penning-Rowsell et al., 2006).

4. Case Description

a. Colorado Western Slope

This study focuses on Colorado's Western Slope region, which encompasses much of the Upper Colorado River Basin (UCRB). The UCRB originates in the headwaters region (Livneh et al., 2015) where the hydrology can be categorized as snowmelt dominated, with complex topography (Livneh et al., 2014). The principal economic sectors across the Western Slope include ranching, irrigated agriculture, natural resource development, recreation, tourism, and mining, which are all tied to water (Gordon & Ojima, 2015). The Western Slope region, like the rest of the Upper Colorado River Basin, contains relatively little storage as compared to other areas in the western U.S., making water users across the region highly sensitive to inter-annual hydrologic variability and specifically drought (Callihan, 2013).

Much of the water originating from the Western Slope is allocated for use elsewhere, either via the Colorado River to meet water demands of other states downstream, or routed through trans-mountain diversions that bring water to the more populous and agriculturally intensive areas of eastern Colorado. The Western Slope can thus be vulnerable to drought in two ways—directly, through lack of precipitation and surface water supply on the local scale and indirectly through drought outside the region that produces a higher demand for water elsewhere. Future water demand is expected to triple across the Western Slope, with the majority of that demand coming from the municipal and industrial sectors (Gordon & Ojima, 2015). Simultaneously, climate change is expected to cause earlier snowmelt and peak runoff (Ibid.). Reduced flows not only affect irrigation and municipal users, but also affect tourism and recreation, such as rafting and fishing.

The Western Slope, like the rest of the state of Colorado, is governed by the prior appropriation system, a legal system that gives senior water rights priority over more junior water rights; seniority is determined by the time when the water rights were purchased (Getches, 1990). During a period of shortage, if a senior water right holder is not receiving their share of water, junior water rights holders are considered out of priority and the senior rights holder can place a 'call' on the river, requiring junior rights holders to curtail their use of water until the senior rights holder receives their entitled water. One work-around available to junior rights holders to avoid being curtailed in times of shortage is obtaining an augmentation plan, which allows a junior water user to continue to divert water out of priority during shortage, by contracting with a senior right-holder to replace the junior user's depletions in time, amount, and location. Well users in some parts of Colorado must obtain an augmentation plan in order to obtain a well permit, effectively protecting them from being curtailed during shortage (Colorado Foundation for Water Education, 2004).

Water rights are decreed for a specific 'beneficial use', which in the state of Colorado includes domestic, municipal, agricultural, industrial, and recreation use (Getches, 1990).

Instream flows, or water intentionally kept in a stream for the purpose of preserving or improving the natural environment of that stream, were later established as a legal type of beneficial use in the 1970s. A water right decree can be changed through a formal legal process, such that water originally decreed for one specific beneficial use can be used for a different beneficial use (Colorado Foundation for Water Education, 2004).

b. Western Slope Community Water Systems (CWSs)

The Western Slope of Colorado is comprised of a large number of small community water systems (CWSs) that serve develop, manage, and supply water for domestic, industrial, agricultural, and environmental uses. Water systems have long dealt with the high hydrologic variability that occurs from year to year across the Western Slope as well as across the broader western U.S. (Bales et al., 2006). An assumption of hydro-climatic variability is baked into all aspects of water management decision-making, from managing reservoir operations to balance current needs with future risk of shortage, to calculating and planning for a water system's 'firm yield', i.e. 'the volume of water guaranteed with acceptable shortage' (Srdjevic et al., 2004). While Western Slope water systems have distinct service district boundaries and utilize unique combinations of water supply sources from different drainages, many of them are hydrologically interdependent with other regional water users and stakeholders, often requiring coordination and collaboration in times of shortage (McNeeley, 2014; Ray, 2004).

We selected five water systems across Colorado's Western Slope region to examine in this comparative case study. The selected systems generally represent the range of systems found throughout the Western Slope region, which supports a large agricultural sector, industry, power production, recreation, as well as a growing population of small cities and towns. Local water systems across the Western Slope include municipal utilities, regional retail water suppliers, wholesale water suppliers (such as water conservancy districts), and ditch companies. The amount of storage available to these entities is also varied, with some entities managing and benefiting from large federal reservoirs, and some entities depending solely on snowpack as their form of storage.

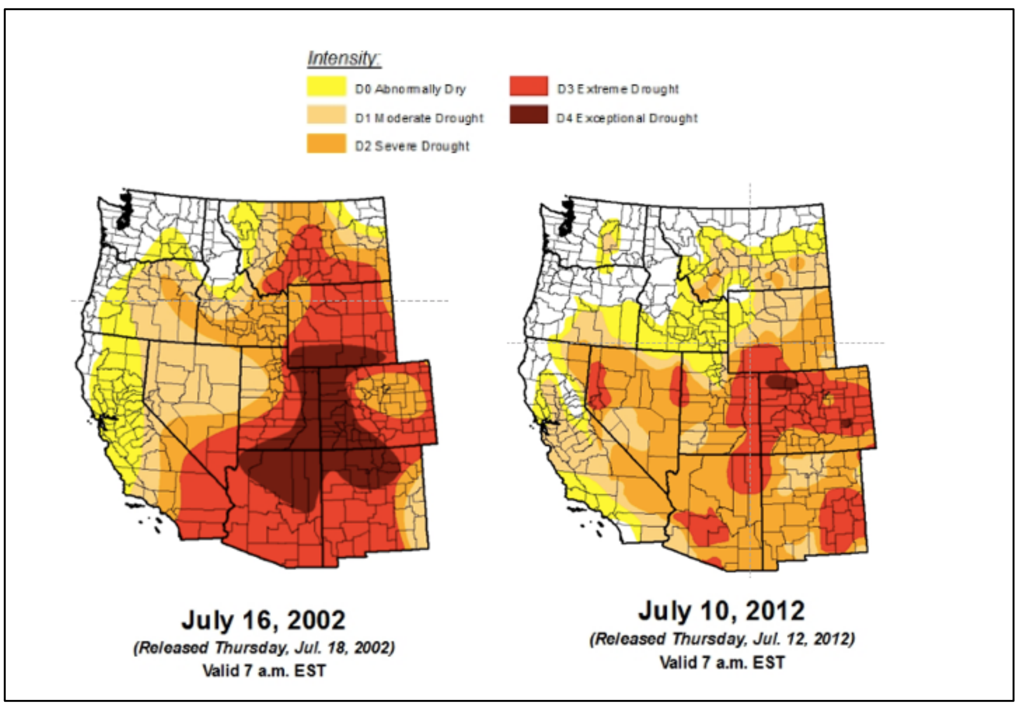
Table 3. Summary of Selected Cases by Attribute

Organization type	Business type	Customer use	Storage	Total water/people served
Water conservancy district	Wholesale	Irrigation Augmentation	Total reservoir storage 44,000 AF	26,000 AF in annual contracts
Water conservancy district	Retail	Domestic use	Total reservoir storage 11,960 AF	33,000 accounts 80,000 people 10,000 AF per year
Water conservancy district	Wholesale	Irrigation Augmentation	Total reservoir storage 108,087 AF	1857 AF in augmentation 106,230 AF available for irrigation (amount used varies year to year)
Municipality	Retail	Domestic use Irrigation	No storage	3500 accounts 2000 AF per year
Municipality	Retail	Domestic use Irrigation	No storage	10,000 people 3377 AF per year

c. 2002 and 2012 droughts

In the early 2000s, Colorado experienced a multi-year drought event that has been described as "the worst drought in Colorado history", due to a combined effect of high temperatures, low precipitation, and higher than average water demands (Pielke et al., 2005). The drought began during a dry fall and winter in 1999, followed by multiple consecutive dryer-than-normal years, peaking in 2002. This extended dry period resulted in an exceptionally long wildfire season, widespread water shortages, severe crop losses, and adverse environmental impacts. The 2002 drought resulted in a number of legislative changes. For example, the drought illuminated the need for water users to be able to transfer water quickly in times of critical shortage without seeking judicial approval as is required under normal conditions (Kuranz, 2014). New legislation was passed in the years after the drought allowing water users to temporary loan water for instream flows (i.e. Short Term Leasing (STL)) without risking their own water rights. The next dry period experienced in Colorado began in the spring and early summer of 2012 and extended into the spring of 2013 for some areas (McNeeley et al., 2016). The 2012-13 drought was not as persistent as the early 2000s multi-year drought but resulted in water shortages and agricultural damage in many parts of the state (Ibid). The first STL for instream flows was implemented during the 2012-13 drought (Kuranz, 2014).

Figure 2: U.S. Drought Monitor Maps for mid-July during 2002 and 2012 droughts.



5. Results

In this section we present a general description of the five systems' experiences of the 2002 and 2012 droughts, including a) challenges that arose and b) how manager responded to them. We then present six key findings in section c that emerge from a cross-case analysis of the sense-making processes of the five systems.

a. Drought Narratives: Sources of Stress, Surprise, Concern

As described one by manager, every drought has a unique *"signature"* (case 1). Indeed, each group of managers across the five systems experienced the droughts of 2002 and 2012 in unique ways. Generally speaking, the 2002 drought had a larger impact on the five water systems than the 2012 drought, with the 2012 drought serving as an opportunity for some managers to test out and receive feedback on organizational adjustments and system improvements made in the aftermath of 2002. In one case (case 2), the 2002 drought served as an opportunity to test out improvements that a past generation of managers had made after the previous extreme drought event in 1977; improvements made after the 1977 drought allowed the system to withstand the 2002 drought without needing to take any drought response measures.

Across the five cases, stakeholder pressure related to protecting and prioritizing different water uses was a major source of stress and concern, in most cases more so than the actual implementation of drought response measures. During drought events, competition over water uses increases, and constituents expect managers at water systems to protect their particular uses, including consumptive and non-consumptive uses. One group of managers (case 4) described the *"ongoing miscommunication and misinformation"* with downstream residents who were concerned about low streamflow in their local creeks. Another group of managers (case 1) described stakeholder pressure as follows:

> No good deed goes unpunished. We've experience it this year and other years, no matter what you do, no matter how flexible you try to be, someone will criticize. (case 2)

Some systems experienced additional sources of surprise, stress, and concern that were not directly related to water shortages. Operational issues unrelated to the drought itself (case 4, case 2), subsidiary demands on water supply caused by occurrence or risk of wildfire (case 4, case 5), and financial impacts of conservation efforts (case 5), were all mentioned by managers. These additional sources of stress compounded the fundamental challenges associated with physical shortage of water supply and implementation of drought response measures. In describing these compounding factors, managers referred to their drought experiences as *"the perfect storm"* (case 4, 5), *"bad timing"* (case 2), and a *"pressure cooker"* (case 4).

b. Drought Responses

During the drought of 2002, though managers at the five systems encountered unique stresses, surprises, and concerns, they had similar experiences in terms of dealing with the first major drought in the region in 25 years with underdeveloped drought management systems and/or relying heavily on off-the-cuff response measures. For two of the domestic water providers (case 4, 5), they similarly described having existing drought management plans in place going into the drought that had *"been sitting on the shelf"* (case 5) and that they *"had never really used before"* (case 4). For one set of managers (case 5), they had no tiered rate or shortage surcharge structure in place to encourage conservation via pricing, and resorted to implementing a reward-based system that awarded customers with a certain amount of cash back at the end of the use season based on how much water they had conserved. For another set of managers (case 4), implementing mandatory use restrictions per their drought management plan did not generate the outcomes they desired and resulted in increased consumption among their customers. Emergency water supplies were also delivered to neighboring communities by two of the systems.

For two water conservancy districts that provide wholesale water from large on-stream reservoirs (case 1, 3), managers' primary concerns were related to releasing any extra water stored in their reservoirs to ensure downstream senior rights holders (e.g. irrigators, power plant, instream flows for environmental protection) received sufficient volume of water and to avoid a 'call' on the river that would curtail junior rights holders in their sub-basin. In both cases (case 1 and 3), this required active communication and coordination with other water users and stakeholders in their sub-basins. In one of these cases (case 3), releasing stored water to maintain delivery of water to downstream senior rights holders was "not consistent with the authorized purposes of the reservoir" which was primarily for recreation and fishery purposes, but they were able to work closely with the district engineer and local stakeholders to manage releases that were not technically codified.

c. Three findings from analysis of sense-making processes

Next we present three themes that emerge from a cross-case analysis of the sense-making processes for each of the five systems.

Finding 1: Extreme events can motivate adaptive response, especially when system reliability is threatened

We found that three of the cases we examined (case 1, 3, 5) demonstrated sense-making processes that align with the "window of opportunity" hypothesis, in which managers' experiences of past drought revealed underlying system weaknesses that then motivated them to make improvements and expand or adjust their available drought measures. The cues (i.e. sources of surprise) detected and interpreted by managers of each of the systems revealed that threats to system reliability, specifically to water supply reliability, was a central concern and trigger for adaptation appraisal processes. These threats looked different for each case—including not successfully filling reservoirs, to lacking formal mechanisms to reduce consumption—but were all fundamentally related to managers' ability to balance supply and demand and maintain available water supply throughout the drought event.

The managers at case 3 *"had never really thought about [shortage] before"* and in 2002 were faced for the first time with the risk of agricultural and well users in their district being curtailed by downstream senior rights holders (their "cue"). In terms of interpreting this cue, managers at this system looked inward at their own systems and concluded that *"the systems we had in place weren't functioning properly"*. Managers took a number of actions to address the underlying system vulnerabilities that emerged from their experience in the drought. The most significant changes made by managers at this organization were that they purchased and built new reservoir storage and created a *"new role"* for their organization: selling augmentation plans to well users with whom the district had previously not engaged as a customer base. The new storage, which holds replacement water that is released in times of shortage to offset the diversions made my well users, was critical to allowing well users in their district to continue to divert water and to avoid curtailment in the 2012-13 drought. Managers at case 3 provide a clear example of how experience of drought can illuminate and provide an opportunity for addressing underlying system vulnerabilities related to water supply reliability.

For managers at case 5, their "cue" from the 2002 drought was related to their supply and demand curves coming close to crossing and the fact that they had no mandatory mechanism in place to reduce water consumption among their customers, such as a drought restriction plan or a conservation-incentivizing rate structure. Similar to managers at case 3, the managers at case 5 interpreted these cues by turning inward and determining that they were *"too reliant on surface supplies"* and that the informal "*reward structure*" to incentivize conservation was worse than ineffective, calling it a "*headache*" and a "*great expense*". Ultimately, these managers took a number of actions to address these vulnerabilities, including developing groundwater sources and introducing new mechanisms for encouraging conservation (tiered rate system) and reducing demand during drought events (drought surcharges). Similar to managers of case 3, these managers directly drew from their experiences in the 2002 drought to making organizational adjustments that allowed for shoring up reliability in future drought conditions and ultimately allowed them to handle the next drought of 2012-13 with more ease.

For managers at case 1, while they had a similar experience to managers from case 3 and case 5 described above in terms of their experience of drought motivating them to make adjustments, they were specifically motivated to change their drought monitoring practices, as opposed to response measures. The current managers at case 1 had long desired to improve the scientific information and decision-support tools they depend on to increase accuracy in reservoir operations. Though the current managers were either not present or in decision-making roles during the 2002 drought, they maintain a clear narrative of the "cue" from their district's experience during the 2002 drought in terms of how priorities among staff at the time influenced drought management outcomes. Specifically, their impression of the key decision-maker at the district in 2002 was that he was *"comfortable getting [reservoir management] wrong half of the time"* and basing reservoir operations decision-making on average hydrologic conditions, which led to not successfully filling the reservoir. Since coming on board, the managers we interviewed have *"had a different expectation of the science [they] could use"* to inform their reservoir operations, and specifically concluded that they *"needed [their own] operational model",* though in the meantime relied on operational streamflow forecast products provided by regional agencies to manage their reservoir. During the 2012 drought, the reservoir did not fill for the first time during their time as key decision-makers at the organization, which prompted a sense of *"need[ing] to figure out this drought management stuff right away"* and developing an alternative to relying on forecast products that were leading them to make inaccurate reservoir management decisions. The 2012 drought experience ultimately motivated them to build a snowpack-based operational model that is "more conservative than relying upon early season forecasts". In this example, the cumulative experiences of the 2002 and 2012 droughts motivated these managers to improve the accuracy with which to manage their reservoir, by substituting use of forecast products with a more *"conservative"* model based on snowpack monitoring data.

Finding 2: Not all impacted systems take action, and not all systems that take action are impacted

We also found that among those water systems that were negatively impacted by a past drought event, managers from one system (case 4) have not made any major changes since the drought in terms of their supply or demand management measures. Simultaneously, we found that among those systems that took notable adaptive actions in reaction to a past drought event, one of those systems (case 2) was not actually directly impacted at all by the 2002 or 2012 droughts in terms of needing to implement restrictions, draw on backup sources, or implement other major response measures.

The managers at case 4 described their experience of the 2002 drought as *"a worst case scenario"*. Many things *"went wrong"* for their system, including a local wildfire that increased demand for fire protection water and threatened some of their water system infrastructure, operational failures, and misunderstanding and tension with customers and constituents over drought restrictions and flow levels in local waterways. One particularly salient cue from the 2002 drought was their experience implementing use restrictions (odd-even outdoor watering days) for the first time, only to be met with an increase in water consumption by their customers due to a sense of entitlement to use water on their allotted days despite their needs. The managers ultimately interpreted this cue as evidence that their prior assumptions of *"what [their] customers are likely to do"* in reaction to use restrictions were *"prove[n] wrong"*.

Despite this *"worst case scenario",* upon reflecting on the overall experience, managers felt they "did a pretty good job" managing the drought and were *"just glad [they] survived"*; "*nobody died"* from the more acute threats (wildfire); and other entities in their sub-basin struggled more than they did and even *"called [them] to see what [they] were doing"*. Ultimately, these managers interpreted their experience during the 2002 drought as having *"dodged a bullet"* and concluded that, in spite of the challenges with increased consumption by customers and other operational issues, they were sufficiently prepared for a worst case scenario because they did not need to tap into their emergency water supply source. As one manager put it:

> That's why there haven't been any changes…because we went through a worst case scenario, and still we had something in our back pocket. (case 4)

As for learning from their experience implementing use restrictions, managers have taken actions to promote awareness of drought and conservation among their customers in the hopes that the same customer response would not happen in a future drought. However, since the 2002 drought, they have actively avoided implementing restrictions out of fear of repeating their experience in 2002:

> We had some years that were close, but, we chose not to go down that road again, because of our experience in 2002. We're going to have to wait it out and see.

Another manager explained that he *"doesn't even know"* what it would take to *"pull the trigger again"*. Ultimately, these managers have taken actions to address the underlying issue of conservation awareness, but have resisted taking actions that would allow them to evaluate whether their awareness raising efforts have been effective in achieving desirable use restriction outcomes.

Case 2, on the other hand, reacted very differently to a similar "cue" of not being strongly impacted by the drought. At case 2, as one manager explained, they *"were literally fine"* throughout the 2002 drought and *"kind of breezed by",* in contrast to other entities throughout the region that *"didn't do as well"* in comparison. Managers at case 2 explained that the 2002 drought showed them that the *"homework"* they had done between the previous drought of 1977 and the drought of 2002 allowed them to *"[get] through it with no skin off [our] nose"* and confirmed that they were prepared for a 2002-type drought. Despite the fact that their system was not at all impacted by the drought, they still saw the 2002 drought as *"an eye opener"* in terms of increasing their awareness of the need to *"stay ahead of the curve"* and continue to diversify and grow their water supply sources as they had continuously worked on since the prior 1977 drought. As one manager explained: *"[The 2002 drought] reinforced that we need to continue to buy water when it becomes available…We better be diligent."*

Notably, these divergent conclusions drawn related to not needing to use backup or emergency water sources are mirrored by distinct differences in the two groups' organizational outlook and sense of responsibility related to regional drought risk. For example, managers at case 2, in describing their rationale behind their aggressive water planning strategy, emphasized their interest in maintaining their own legacy as managers and in leaving their system better than they found it: *"We don't want to leave here in fifty years from now, someone cussing us, because we didn't' buy enough water"* (case 2). Another manager rationalized their forward-looking water supply planning as a way of mitigating overall drought risk and ensuring their own protection in the event that others in their region suffer shortages:

> There's no one out here that can help us. We can help them, we're bigger, they're going to look us, we're their back up…There's nobody here that's going to rescue us. (case 2)

Managers at case 4 spoke to a very different outlook on their role in mitigating regional drought risk and their strategy for ensuring their own preparedness. In explaining why they generally are not looking to expand their water supply sources, one manager at case 4 explained:

> Certainly we have a finite supply and a finite ability to provide both domestic [water] and fire protection [water]. So, we don't try to be everything to everybody. We know that we've got some limitations, and we try to be reasonable about what we take on. (case 4)

Contrary to the managers at case 2, managers at case 4 are mitigating their drought risk not by taking on others' drought risk but by focusing inwards and setting boundaries around how much they're willing to accommodate increasing water demands in their area. These insights into each groups' approaches to mitigating risk and outlooks on regional responsibility help to explain their drastic differences in responses to the 2002 drought.

Finding 3: Political pressure alone can motivate action, and political motivations can both help and hinder drought adaptation outcomes

We also found that, for one group of managers (case 2), political pressure alone was enough to motivate them to make significant investments in demand management. As described above, this system was not impacted by the 2002 drought (they *"breezed by"*) and was driven to invest in augmenting and diversifying their water supply after seeing the impacts the drought had on neighboring communities and out of a desire to *"stay ahead of the curve"*. However, in terms of demand management, these managers were purely motivated by a desire to deflect political pressure they received from entities throughout the region because it was perceived that case 2 *"didn't do enough"* and did not implement use restrictions while other communities were suffering. As one manager put it, case 2 managers were *"getting heat"* from other water systems higher up in their watershed and they wanted to *"do something"* to *"shut them up"*. Their tactic for mitigating this pressure was to form an alliance with three other water entities in their sub-basin and form a regional drought plan that dictates all four systems' drought measures such that if one system faces shortage, they all implement drought restrictions in a coordinated fashion. Though the impetus for forming this alliance was to mitigating political pressure that arose from other entities during the 2002 drought, the managers feel that the alliance *"has been really good"* and has been effective in both staving off political pressure and helping the systems to build better rapport and relationships in general.

Moreover, we found that motivation based in avoiding political pressure can both enhance and hinder drought preparedness. For case 2 (described above), managers forged a regional partnership and developed a regional drought plan, out of a desire to reduce political pressure from regional stakeholders. Though this action was politically motivated, the regional drought plan has been very successful in building their own drought preparedness as well as advancing their sub-basin's overall resilience to drought. As one manager explained, *"when one of us has a problem, we all have a problem"*, which he felt was an important perspective to have in building regional preparedness.

On the other hand, managers at case 4 provide an example of how motivation based in avoiding political pressure, in their case tension and push back from customers, can result in avoidant behavior that postpones taking measures to address drought vulnerabilities. As described above, managers at case 4 have avoided implementing use restrictions out of fear of customers increasing their water use as they had in 2002. However, in addition to their concerns about a physical inability to lower their water demand curve in a time of crisis, their ongoing decisions to avoid implementing use restrictions is also motivated by a desire to avoid political pressure from their customers, specifically the *"pushback"* and *"miscommunication"* that posed a significant challenge to them during the 2002 drought. For both systems (case 2 and 4), averting political tension was a motivating factor that has heavily influenced the actions they have chosen to take (or not) in the aftermath of past drought experiences, and demonstrate that, as a motivating factor, avoiding political attention can both serve to boost and hinder overall drought preparedness.

6. Discussion

By shedding empirical light on specific, organization-level sense-making processes that arose out of past drought events across five water systems, this study helps to nuance our understanding of the role of extreme events in driving adaptation, the processes by which water managers become motivated to adapt, and the ways that different types of motivation and organizational outlook and ideology influence drought adaptation outcomes.

a. Extreme events as a driver of adaptation

First and foremost, our findings confirm that extreme events do not consistently drive adaptive change in these small water systems. We saw two examples of water systems that did not follow the linear conceptual models of event-induced change in which extreme events reveal vulnerabilities that can then be systematically addressed (Carley & Harrald, 1997) or in which impacts of an extreme event lead to change (Birkmann et al., 2010). Managers from a system (case 2) that experienced no negative impacts from a drought were prompted to make significant investments in water supply augmentation and diversification, and managers from a system (case 4) that experienced notable hardship during the 2002 drought did not feel motivated to make changes after the experience because they interpreted their survival of the event as confirming their own preparedness. Our finding that political pressure alone can motivate adaptive actions among managers also nuances the idea that impacts of a disaster leads to change (Birkmann et al., 2010)—one of our cases (case 2) shows how regional impacts can drive change at the organizational level among organizations that were not impacted, via political pressure to proactively participate in regional drought management and recovery efforts.

b. Dynamics of drought adaptation

In addition, the fact that one of our cases (case 2) was not directly impacted by the 2002 drought but still implemented substantial adaptive actions (e.g. supply augmentation, regional drought plan) in the years following the drought, suggests that actions driven by extreme events may not occur in space and time as we would expect from theory of change models suggested by (Birkmann et al., 2010). Adaptations may appear in unexpected places or at unexpected times; our results suggest that some water managers in the Western Slope region share a sense of responsibility to address drought that binds them together and results in an expectation to act collectively in response to drought despite who is impacted and who is not. Studies have documented similar types of collective approaches to drought management in the region (McNeeley et al., 2016) among water systems trying to avoid curtailment within the same sub-basin, but our results reveal that water systems may put pressure on each other to act in times of drought for a less tangible goal such as solidarity. It may be the case that the peer pressure that arose for managers at case 2 was also practically and politically tied to the Western Slope water systems' collective responsibility to keep enough water flowing downstream to the lower Colorado River Basin to meet the obligations of the Colorado River Compact, even in times of local shortage. Understanding specific motivations behind this pressure is beyond the scope of this study. Still, our results suggest that political and hydrologic inter-dependencies among water systems may result in non-linear, dynamic drought adaptation processes that may be more difficult to track in time and space than the typical theory of change behind extreme events might suggest (Henderson et al., 2018).

c. Mitigating political tension as a mediator of drought adaptation outcomes

Our results also shed light on the factors that specifically motivate water managers and how those factors interact with drought preparedness goals. Our results confirm that system reliability (Hashimoto et al., 1982; Lach et al., 2005) and mitigating political pressure (Dilling et al., 2018; Hornberger et al., 2015) are major motivating factors for water managers and feature significantly within the causal pathway that connects experience of extremes with adaptive action. However, our results also help to add nuance to an otherwise established literature on motivation within water management, by illustrating how these motivations, specifically political motivation, can interact with adaptation outcomes in variable ways. We see in our results an example of political pressure actually driving managers to take significant and proactive drought preparedness actions such as forging a regional alliance and coordinated drought plan with other local systems and "operating as one system". Yet, for another system, a desire to escape negative political attention resulted in a return to the "status quo" as innovations (use restrictions) that were politically unpopular (and ineffective) were abandoned. These results help to illustrate how a desire to mitigate political tension that arises during drought events, a known motivation among water managers, can shape and influence drought adaptation in varying ways and in some cases can help to explain a lack of adaptive action and persistence of avoidant behavior.

d. Adaptation from extreme events can manifest as limiting use of drought measures and tools

Lastly, we see evidence that, unlike what other studies have shown (Feldman & Ingram, 2009; Kirchhoff et al., 2013; O'Connor et al., 2005; Pulwarty & Melis, 2001), experience of an extreme event does not necessarily lead to expansion of drought measures, tools, and/or information use among water managers. Managers from one system (case 1) stopped using runoff forecast products in reservoir operations decision-making after the occurrence of drought and made a formal decision to base all decisions on observed snowpack levels only. Though these managers' awareness of drought risk was heightened after the experience of a drought event as has been shown in other studies (O'Connor et al., 2005), these managers ultimately became less tolerant of the risk and uncertainty inherent to forecast products rather than more open to using forecast products as is shown elsewhere (O'Connor et al., 2005). This may be due to the fact that systems like case 1 have less excess capacity in their system and therefore less wiggle room for absorbing the consequences of a poor forecast, as compared to the larger-capacity systems often examined in studies of forecast use (see Page and Dilling 2018 for further discussion on the role of system capacity in shaping information adoption among water managers). Ultimately, these results suggest that forecast products should not necessarily be prioritized above real time monitoring products, in terms of investments made by the scientific community.

e. Explaining differential adaptation outcomes with organizational ideology

Lastly, our results raise important questions about the role of organizational outlook and ideology related to risk and responsibility as a potential explanatory factor for understanding why water systems act differently in reaction to similar drought circumstances. Organizational ideology is considered to play a central role in sense-making and in shaping what organizational decision-makers "see" in terms of acceptable actions in response to a cue (Berkhout, 2012; Linnenluecke et al., 2012); in this study we see specifically the role of perceived responsibility for regional drought risk as a type of ideology that influences managers' risk management strategies and appraisal of post-drought responses. While other factors undoubtedly play a role in shaping these managers' differing responses, such as organizational scale, access to financial resources, and different management priorities between conservancy districts and municipal water providers, our results suggest that the socio-cognitive dimension of ideology and outlook may also play an important role in influencing adaptation outcomes.

7. Conclusion

Extreme events are often theorized as providing "windows of opportunity" for addressing determinants of climate risks and reducing societal vulnerability to climate variability. Extreme events are commonly discussed as a key driver of adaptation, but the extent to which this bears out in reality is contested. Deepening our understanding of when and how adaptations to climate variability unfold today is important for a) revising societal expectations of progress that autonomously evolves from the occurrence of extreme events and b) predicting how adaptation will occur in a future climate in which frequency and magnitude of extremes are predicted to increase. This study contributes sector-specific empirical descriptions of how extreme events influence adaptation on the organizational level and deepens our understanding of what motivates water management organizations to adapt to drought. Though our results are not generalizable to all water managers, our findings raise important questions about the linear assumptions behind event-induced change in which impacts and adaptation are linked together and in which impacts of extreme events lead to a broadening of drought measures, tools, and information. In addition, we find that political motivations that often drive decision-making among water managers can both help and hinder drought adaptation process and that the political forces that bind water systems together across a region may cause adaptation progress to happen more quickly due to an expectation of collective action in the face of drought risk. Our results also raise important questions about the potential role that organizational ideology and outlook, specifically beliefs about risk and responsibility, plays in influencing adaptation outcomes.

Additional research examining a larger population of water systems would allow for further testing and validation of the questions and observations raised here. In addition, in this study we specifically examine rural water systems; it may be interesting to compare rural water systems with larger municipal systems to better understand the role that organizational scale might play in shaping how managers react to and think about drought risk. Similarly, examining a more homogenous group of water systems (e.g. all municipalities or all irrigation districts) would allow for controlling for organization structure/operational mandates/management priorities, which vary drastically between a municipal domestic water supplier and a wholesale irrigation district (for example) and which may play a role in how managers make sense of drought experiences. Future research in this area should also more systematically examine the role of organizational ideology and outlook in shaping collective conceptions of appropriate adaptations. Ultimately, this study helps to nuance existing theory behind extremes as a driver of adaptation as well as contributes important practical context for state agencies and other types of organizations interested in finding windows of opportunity to support local water systems to build drought preparedness.

CONCLUSION

Researchers and stakeholders alike are eager to understand the extent to which communities across the western U.S. are prepared for increasing drought risk and to identify opportunities to improve adaptation outcomes. This concern is warranted—demand for water resources is on the rise, water supply availability is projected to decrease with rising temperatures and a shifting hydrologic cycle, and communities through the aid of water supply organizations are basing long-range water supply plans on 20th century hydrologic variability unrepresentative of the true risk of future drought. The adaptation research community has built a robust literature on the social dimensions of adaptation to climate variability and change, including the determinants of adaptive capacity and adaptations. This thesis adds to this literature by contributing place-based, sector-specific empirical descriptions of drought adaptation processes and decision contexts among community water systems (CWSs). CWSs play a critical role in ensuring society's sustainable management of water resources, and their role is ever-more important in arid regions such as the western U.S. that are seeing rising competition over water resources.

Using a comparative case study design, this study examined five Western Slope water systems in depth. Conducting in-depth, qualitative analysis of a handful of systems allowed for extensive exploration of the various institutional and behavioral factors that shape managers' adaptive actions; for gaining insight into the headspace and decision-making shoes of managers that would not otherwise be possible through quantitative means; and for identifying and raising important questions about how the research community could benefit from thinking about social response to drought risk and extreme events. This thesis examined multiple aspects of water managers' capacity, propensity, and rationale for implementing adaptive actions for drought; here we define adaptive actions to include adoption of hydro-climatic information to better monitor and identify the onset of drought conditions; implementation of drought measures to augment supply or mitigate demand; and even the choice to *not* take action such as augment supply or use forecasts as a potentially adaptive action in and of itself.

Regarding the use of scientific information, this study finds that water managers' willingness and ability to adopt information products is dependent on how an information product is disseminated and proven successful in other water systems and that managers of smaller-scale water systems are embedded within strong communities of practice in which information use practices are replicated and shared across professional networks. In terms of the role of past experience with extreme drought events as a driver of adaptation, this study finds that adaptation arising from extreme events does not occur in time and space in consistent ways, that political motivation that arises from drought events can both serve to help and hinder drought preparedness goals, and that organizational beliefs about risk and responsibility may help to explain variable responses to drought events.

Ultimately, contained within this study are important theoretical contributions about societal response to hydro-climatic variability and the social, behavioral and institutional forces that shape societal actors' ability to adopt new adaptations to reduce vulnerability. More practically, this study provides essential context for state agencies, boundary organizations and other entities interested in finding windows of opportunity to support drought preparedness, including advancing the adoption of drought information, among local water systems. May the insights of this study guide and add value to researchers and practitioners alike as we collectively chip away at the challenge of attaining sustainable and equitable management of water resources in the face of an uncertain future.

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APPENDICES

Appendix 1: Interview Guide and Questions

To start, I'm going to ask you some basic questions about <u>your role and your organization</u>.

1. What is your current position at your organization?
2. How long have you held this position, or any related positions, at your organization?
3. What are your main job responsibilities, particularly as they relate to drought decision making?
4. [Clarify any details about system parameters not available from doc review, e.g.: makeup of customers, amount of water delivered annually, etc]

Next, I'm going to ask you some general questions about your <u>concerns related to drought</u>.

5. What does "drought" mean for your system?
6. How long does a drought have to last to pose a significant threat to your system?
7. Does your system have storage or other buffering to drought?
8. What specific outcomes are you most trying to avoid when managing drought?
9. What historic or recent drought years or periods have been the most challenging to your system and why?
    a. Did you have timely information about the drought?
    b. What actions did you take at that time to mitigate drought impacts?
    c. What lessons did you learn from that drought, and what changes have you made in your operations since then?

I'd now like to ask a few questions about <u>how your organization manages drought risks.</u>

10. Walk me through the timing of decisions you make throughout the year with regards to water management. What are the key decisions to be made, and when do you typically make them?
    a. What are the key decisions to be made?
    b. When do you typically make them?
    c. Who makes them?
    d. How are they communicated/implemented?
11. Do you have an operations model (system model, spreadsheet, etc.) or other decision-support tool that you use to support this decision making? What do these look like and how do you use it?
    a. What information does the model/tool provide you?
    b. What are the key model/tool inputs?
    c. How often do you refer to/run the model/tool?
    d. Who manages the model/tool?
12. Do you have any models or decision-support tool that you use for long-term water supply planning?

    a. What information does the model/tool provide you?
    b. What are the key model/tool inputs?
    c. How often do you refer to/run the model/tool?
    d. Who manages the model/tool?
13. What specific indicator levels, system conditions, or other triggers tell you that you need to start managing for drought, rather than being in normal operations?
14. How frequently do you monitor those indicators? Does this change once you are in drought conditions?
15. At what point is it critical to know if drought may be on the horizon?
16. Assuming you have sufficient and timely information about a drought, what actions are available to you to mitigate drought impacts?
    a. Do you have enough time to implement these actions once a drought event is known? If not, when would you ideally be able to take these actions?
    b. Are these actions sufficient to mitigate drought impacts?
17. During a drought event, how do you know whether you've been successful in managing drought risks within your system?
    a. What consequences do you face if you are not successful?

Now, I'm going to ask you some questions about the <u>types of information you use to anticipate and manage drought.</u>

18. What information do you use to try to anticipate the emergence of drought conditions? [1a, 3] (get indicator names, names of organizations/information platforms)
    a. Any snowpack monitoring and runoff forecasts?
    b. Any climate forecasts?
    c. Any soil moisture information?
    d. [show drought information list and walk through together]
19. Is there some information that is essential or more important to your decision-making?
    a. Why is the essential information so important?
    b. For non-essential information, why do you track non-essential information?
    c. What is the value of non-essential information? What does it tell you?
20. How frequently do you monitor/consult this information?
21. Where do you get this information from?
    a. Do you ever use or participate in the Upper Colorado Basin Drought Status Briefings (Nolan's webinars/website)?
    b. How about the National U.S. Drought Monitor updates?
22. Why do you choose to consult the [information sources discussed above]? What do you find valuable about them?
23. From whom would you be most likely to hear about a new drought tool or information source? What particular people, listservs, or meetings are most important for keeping you informed?
24. How would you decide whether or not a new tool would be useful to you? Would it matter how you heard about it?
25. What type of information would lead you to make a different decision about water supply planning / drought management?

26. Have you seen recent trends or changes in your basin that have made any of your system indicators behave differently than in the past? If so, what are they?

I'm now going to ask a few questions about <u>opportunities and barriers to managing drought risk at your entity and across the region.</u>

27. Do you have the flexibility and capacity to incorporate new types of information or indicators into your drought planning or management?
    a. Do you have a specific example of a new type of information being incorporated in your drought planning or management recently?
    b. Why did you decide to add that information?
    c. Were there barriers to incorporating it?
28. Are there actions to prepare for or respond to drought that you wish you could implement, but currently cannot?
29. Are there actions that you wish the broader community of water users and agencies in your basin could take?
30. What allows your region to respond to drought and recover from the impacts of drought?
31. How do you define resilience for your organization? For your basin?
32. How does climate change feature in your organization's planning and decision process?

Wrap up.

33. Is there anything else you want to add that we haven't touched on yet?
34. Are there other water entities or water managers you think I should talk to about this topic?

Appendix 2: Focus Group Discussion Guide and Questions

1. In your collective memory, tell me which drought in the past affected your system the most?

    - <u>If they name several, ask:</u> Let's start with the drought that you feel had the biggest impact on your system.
    - <u>If they say they haven't been impacted by drought, ask:</u> Which drought affected your sub-basin the most?

2. Why was this the worst drought? What made it the worst?

3. What happened during that drought?
    - <u>Follow-up prompts:</u>
        - Did you know it was coming?
        - What information did you use to anticipate the drought?
        - What impacts did the drought have on your system? On your constituents?
        - How did your organization respond?
        - How did the community respond?
        - In retrospect, was your organization prepared?
    - <u>If they weren't directly impacted by the drought, ask:</u>
        - Did you think it would impact your system at any point?
        - What information did you use to anticipate the drought?
        - What impacts did the drought have on other water systems and users in your sub-basin?
        - What activities or conversations did you participate in?
        - What allowed your organization to weather the drought?

4. Before that particular drought occurred, how did you think your system would be affected by a drought? Did your understanding change after?
    - <u>Follow-up prompts:</u>
        - How about for your sub-basin? What was your impression before the drought of how your sub-basin would fare, and did your understanding change after?

5. What changes did your organization make after the drought?
    - <u>Follow-up prompts:</u>
        - What plans or policies did you introduce or eliminate?
        - What tools or products did you start or stop using?
        - What partnerships did you form?
    - <u>If they do not offer any explanations for WHY they made those changes, ask:</u>
        - Why did you make those changes?

6. How did your organization decide to make these changes?
    - <u>Follow-up prompts:</u>
        - What was the process for making changes? Who was involved?

7. Were there any changes you considered but didn't make?
    - Wait for answers, then ask: Why didn't you make them?

8. Do you think you are better prepared now for the next drought?
    - Wait for answers, then ask: Why do you feel that way?

9. After the drought, what changes did you observe among other stakeholders within your basin?
    - Wait for answers, then ask: How have those changes influenced your operations?

10. Have your long-range planning efforts changed at all as a result of recent drought events?

If time permits:

11. What do you see as your key tactics or strategies for managing future drought?

12. Were there any other droughts that affected your system? (Ask same set of questions)

Appendix 3: Coding Framework

Article 1

Nodes / Sub-Nodes	**Node Description**
1. Decision Calendar	
a. Action	
i. Information Used	Any mention of hydro-climatic information used to support decision-making
ii. Key Decision	Specific management or operational decision related to drought monitoring or response (including decisions take action or to not take action)
b. Decision Timing	
i. Fall/Winter (Oct-Dec)	Code any action (information use or decision) that is described to typically occur in winter
ii. Early Spring (Jan-Mar)	Code any action (information use or decision) that is described to typically occur in early spring
iii. Spring Runoff (Apr-Jun)	Code any action (information use or decision) that is described to typically occur during runoff
iv. Summer (Jul-Sep)	Code any action (information use or decision) that is described to typically occur in summer
2. Drought Response Options	
a. Available	Any measures available for managers to take to prepare for or respond to drought, e.g. use restrictions, reservoir releases, pricing tools, etc
b. Unavailable	Any measures managers wish they could take to prepare for or respond to drought but cannot
3. Information Use	
a. Information Used	
i. Instrumental	Information product actively used to trigger a management or operational decision
ii. Contextual	Information product used to provide context and better understanding of conditions but not directly tied to a decision
iii. Justifying	Information product used to communicate with or justify decisions to stakeholders
b. Value of Information	Reasons mentioned by managers for choosing to use an information product, i.e. desirable characteristics of the information
c. Information Sources	Where managers find out about information (people, organizations, websites, etc)
d. Factors Influencing Adoption	Conditions that allowed for information adoption to happen in the past / conditions that managers

	identify as shaping their likelihood of adoption in the future

Article 2

Code	**Definition**
1. Drought Event	
a. Drought event	
i. 1977 Drought	Label all discussion of 1977 drought using this code
ii. Early 2000s Drought	Label all discussion of early 2000s drought using this code
iii. 2012-13 Drought	Label all discussion of early 2012-13 drought using this code
b. Event Description	
i. Monitoring/prediction	Description of managers' experience monitoring, predicting, and identifying onset of drought
ii. Response description	Description of what happened during the event (problems that arose, actions managers took)
iii. Source of stress	Specific reasons mentioned related to what made the drought challenging
c. Sense-making	
i. Cue	Mention of specific characteristics of the drought event that were surprising and/or violated managers' expectations
ii. Cue Interpretation	Specific meaning or lesson attached to a specific cue , i.e. what a manager perceives the cue to have revealed to them about their environment or their system
iii. Construction of Response	Conclusions drawn by managers about specific actions (or non-actions) to take, as justified by cue interpretation