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Drought in urban water systems: Learning lessons for climate adaptive capacity

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ABSTRACT

In this paper we examine current policies to combat drought in urban areas in the United States to illuminate lessons learned for building climate adaptive capacity. We conducted interviews with practitioners involved in drought management at urban water utilities across the U.S. to understand: 1) both short- and long-term actions taken in response to drought; 2) perceptions of what constitutes an ‘effective’ drought response and whether and how this was measured; and 3) limitations to drought response. We apply criteria from a theoretical framing of adaptive capacity and then 'reason by analogy' to understand how adaptive capacity may be built or constrained in the future by such responses, including how future actions may be otherwise limited by political, social, physical and other factors. We find that drought responses overall are seen as successful in reducing water demand and helping to maintain system reliability, but can also reduce flexibility and introduce other limitations. Public perception, the multi-purpose nature of water, revenue structures, expectations and other social factors play a dominant role in constraining drought response options. We also find that some urban water utilities face challenges in measuring the effectiveness of demand reduction strategies because it can be difficult to attribute water savings, especially those related to outdoor water use. The limitations in drought policies experienced by urban utilities offer important lessons for the ability of systems to innovate toward more sustainable water systems for the future.

1. Introduction

Water is distributed unevenly across geographic regions and between seasons or years due to climate variability. Over millennia, humans have adapted to inadequate or inconsistent water supply by developing water infrastructure such as wells, reservoirs, and *trans*-basin diversions, and “soft” measures such as legal priority systems, water rights transfers, and demand management measures (Buurman et al., 2016). Drought is a particularly damaging climate extreme, ranking first among all natural hazards in terms of number of people affected (Wilhite, as cited in Mishra and Singh, 2010). As more and more people around the world live in cities,

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ensuring the sustainability of urban water supplies in the face of drought is becoming increasingly important (Birkmann et al., 2010, Hering et al., 2013). In the last several decades, it has been widely recognized that there is a need for increased preparedness to mitigate and respond to drought events at all levels of government in the United States (Fu and Tang, 2013) and among a wide variety of private sector stakeholders (Wilhite et al., 2014). City water systems also face broader challenges such as growing populations in some areas, new pollutant threats, mitigating environmental impacts of water use, and coping with end of infrastructure design lifetimes (Hering et al., 2013; Zeff et al., 2014).

Climate change poses another challenge for managing water resources, especially as cities plan for the future (Brown et al., 2013). Past water management strategies have assumed stationarity, or that baseline averages and "droughts of record" from the past were a good target for planning for the future, but this strategy is now in doubt as uncertainty increases and drought may become more intense (Milly et al., 2008, Trenberth et al., 2013). Projections of future climate also suggest increases in baseline water withdrawals due to increased evapotranspiration (Brown et al., 2013).

Some have argued that focusing on adapting to current climate variability is the most practical response in the face of an uncertain climate future (Wilby and Dessai, 2010). However, current measures used to adapt to drought do not always result in a well-adapted system (e.g. Christian-Smith et al., 2015), and furthermore, may not provide the type of adaptive capacity necessary to respond to climate change in the future. Engle (2013) suggests, for example, that there may be tradeoffs between the type of capacity needed to endure extreme droughts as currently experienced, and the capacity needed to be transformative and nimble over the long term in the face of environmental change. Some solutions to water shortage have even been called maladaptations because of their negative outcomes for other priorities such as conserving energy (Barnett and O'Neill, 2010). In addition, drought measures intended to increase coping capacity can have uneven benefits, even causing increased vulnerability and decreased adaptive capacity (Goldman and Riosmena, 2013).

We argue, as Glantz (1991) suggests, it is reasonable to examine past societal responses to environmental change as "analogies" that can help us learn how society might adapt to climate change in the future and build upon strengths while addressing weaknesses. This approach has been used to infer important lessons for climate change adaptation, from observing the response to extreme events of people and institutions in the agricultural sector (Adger, 2001), to flood response and planning (Naess et al., 2005), drought in urban water management (Engle, 2013), basin-wide water management (McNeeley, 2014), and municipal hazard planning (Dilling et al., 2017). One of the ways we can learn more from the lessons of past experience is to examine these responses in light of what we theorize to be important for successful climate adaptation in the future. By comparing past responses to drought, for example, to the characteristics that have been theorized to be necessary to support successful adaptation, we can understand how our likely adaptive actions can be more effective in the future—whether for climate variability or change.

Adger et al. (2005) suggest that climate adaptation success should not be measured by only a single objective such as whether or not it has met a stated goal (for example, helping a city cope with a drought event). They propose that success in adaptation must be appraised by the multiple criteria of effectiveness, efficiency, equity, and legitimacy across a range of spatial and temporal scales. Effectiveness is judged by whether or not the adaptation achieves its objectives, but there are several considerations for this criterion, including the extent to which an adaptation relies on individual behavior to achieve results, its 'robustness' to uncertainty, its flexibility and its potential for introducing unintended consequences on others, either spatially or temporally. Efficiency encompasses notions of the ratio of costs to benefits (whether market or non-market based), and depends on the timing of key decisions—decisions with short-term time horizons are more easily assessed without considering more distant climate change impacts compared to those with longer term horizons. Finally, Adger et al. (2005) recommend considering equity (fairness in the distribution of impacts) and legitimacy (are decisions acceptable to participants and non-participants?) as factors determining adaptation success—without them, adaptations are less likely to be implemented and may undermine future gains in welfare.

The ability to achieve adaptation success is partially determined by adaptive capacity, or the ability of a system to prepare for or respond to the impacts of stresses (Smit et al., 2001, Smit and Wandel, 2006, Engle, 2011). Following Glantz (1991), Engle (2011) argues for more empirical work on responses to past extreme events that would provide researchers "a good proxy for how systems might build and mobilize (or not) their adaptive capacity to prepare for and respond to future climate changes" (p. 253). Armitage (2005) calls adaptive capacity a "critical aspect of resource management that reflects learning and an ability to experiment and foster innovative solutions in complex social and ecological consequences" (p. 703).

Drought response provides a good empirical opportunity to examine how adaptation to climate variability has happened in the past, and how it may or may not foster adaptive capacity to cope either with future drought or climate change. Engle and colleagues (2012, 2013) examined drought responses in two U.S. states to uncover key heuristics for adaptive capacity in water systems, such as flexibility, appropriate scaling of decisions, planning, and collaboration, and to identify the tradeoffs in building and mobilizing adaptive capacity over time**.** The role of institutions in fostering adaptive capacity as well as beliefs and motivations has been shown to be important (Gupta, 2010, Grothmann et al., 2013). Institutional adaptive capacity depends on the rules, norms and beliefs that enable societies to adapt, and the degree to which these can be changed by actors as conditions warrant (Grothmann et al., 2013).

Birkmann et al. (2010) have argued that climate change adaptation in cities has too often emphasized a physical, structural response and must instead expand to include governance, the connections across different spatial and temporal scales and among formal and informal spaces, and the identification of conflicting strategies. Garrote (2017) also suggests that ecological and social concerns are increasingly driving the water management paradigm. In addition, Tyler and Moench (2012) argue that adaptation approaches that rely on "predict and prevent" are doomed to failure because impacts are increasingly difficult to predict, and such approaches cannot deal with surprises, neglect indirect effects and constraints, and pay too little attention to learning and governance. Instead, they recommend a focus on resilience, characterized as flexibility and diversity, redundancy and modularity, and "safe failure", meaning absorbing shocks in ways that avoid catastrophic failure. Learning and experimentation are also hypothesized to be critical elements of adaptive capacity (Armitage, 2005). Finally, as McFarlane and Rutherford (2008) and Pelling and Dill (2010) have pointed out, the political nature of local infrastructure decisions, disaster response, and hazard mitigation has been understudied and needs to be better considered as we consider how to best build more sustainable cities. Hornberger et al. (2015) describe how choices to manage water demand in the U.S. must not only be technically feasible but politically acceptable as well.

In this study, we undertook a scan of city water systems across the U.S. to gage perceptions of drought response by institutional actors across a variety of climate regimes. We then analyzed those responses for theorized components of adaptation success and adaptive capacity—in other words, to see what we might learn from current responses about how those responses position cities for building adaptive capacity toward future climate variability or climate change. We posed questions to key informants in each city's water utility about short and long-term measures they had undertaken because of past droughts, whether they felt the measures were effective and how effectiveness was measured, and what they perceived to be limits in implementing effective drought responses. We then analyzed those data using criteria suggested for successful adaptation to understand how they position cities for the future. While our study is more of a "scan" across the urban water utility landscape than a comprehensive survey of adaptive drought policies, we intend for this work to 'open up' the question of whether adapting to current climate variability sufficiently positions cities to respond to climate change.

2. Methods

After conducting a review of various literatures on drought, urban water systems, vulnerability and adaptation, the research team compiled a short list of potential cities to include in the interview sample to ensure geographic distribution, a range of population sizes, and inclusion of multiple climatological zones. We then conducted a systematic scan of newspaper articles in LexisNexis and ProQuest databases using a conjunction of the search term "drought" (eliminating references to "drought" in terms of sporting events or competitions) with the name of the city to identify places with an established history of drought events and response. Nineteen cities were chosen that had a well-established history of drought events, with representation across geographic regions, climate zones and population size (Table 1 Supplemental Information). The water utility or provider in each city was then identified. In cities served by multiple water utilities or retail water providers, interviews were conducted with representatives of the regional coordinating body if one existed or the largest water utility/entity. In cases where individuals involved in drought planning, water resources planning, or climate change adaptation were readily identifiable on the organization's website, we contacted respondents directly by email. In all other cases, we contacted the director or head of the organization by email identify the correct individual to participate in the interview.

Nineteen semi-structured interviews were conducted by phone with a participant from each city (Schensul et al., 1999). Interviews included questions related to three primary topics: 1) drought history and response; 2) effectiveness of drought response; and 3) limitations of drought response. Interviewers took notes during interviews and audio-recorded and transcribed verbatim when allowed (nearly all cases). Cities are identified by number (Case 1, Case 2, etc.). Transcriptions were thematically coded using NVivo software (Bazeley et al., 2013) with both *a priori* codes based on the literature and research questions, plus codes for themes that emerged during the analysis, to identify drought responses, perceptions of effectiveness, and limitations to drought response (Table 2 Supplemental Information). Coding was tested and refined by two analysts, but the final data set was coded by one person. We then assessed the coded data against measures of adaptation success as defined by Adger et al. (2005; discussed above). We recognize Adger et al. (2005) represent only one way to view adaptation success, but these criteria are well-cited in the literature and provide a useful heuristic to help examine how perceptions of drought responses and their effectiveness inform adaptive capacity and the ability of a system to adapt in the future to either climate change or climate variability. Because the design of our interview guide included specific questions about effectiveness, we naturally observed more detail on this criterion and our results reflect that. However, we were also able to find some empirical evidence for Adger et al.'s other criteria emerging from our interviews and do have some results for efficiency, equity and legitimacy as well.

Throughout this process, the research team consulted on an informal basis with an Advisory Working Group (AWG) made up of ten water resource managers and researchers from municipal, state, and regional water agencies, research centers, and universities to help narrow the field of cities and develop questions of highest relevance. We conducted multiple conference calls to interact with this AWG over the 2 years of project formulation and data collection. This iteration helped us ensure that our strategy, questions and approach would result in data that would be relevant to water managers as well as targeted at answering our research question (Weber et al., 2015). These conversations are not formally represented in the analysis, however.

3. Results and discussion

3.1. Drought responses

The interviewees with whom we spoke identified a wide range of water supply, demand and "other" responses (for examples and detail see Table 1). Reducing water demand was the most popular overarching category of drought responses mentioned, with only two utility representatives (both from the humid continental zone) not discussing it at all, compared to less than half discussing supply augmentation. More than half of the study participants mentioned public communication as a drought response strategy. Most water utility representatives mentioned relying on several strategies.

Table 1
Most commonly mentioned responses to drought across the cities sampled.

	Policy Instrument	Examples
Demand Focused		
Mandatory Outdoor Use Restrictions	Watering schedules	Limited to certain days of the week
	Prohibiting certain uses	Filling ornamental fountains, pools, or washing car
	Enforcement	Ticketing, hotlines to "report" neighbors
Voluntary Outdoor Use Restrictions	Customer education, outreach	Advertising, targeted meetings, using local media
Incentives for Permanent fixture or landscaping changes	Rebates, fixture give aways,	Low flow toilets, money toward efficient appliances, money for removing turf
Rate adjustments	Tiered water rates, drought surcharges, raising water rates	
General public education on saving water	Customer education, outreach	
Planning	drought triggers, drought plan	Lake or reservoir levels, regional plan, interruptible supplies
Supply Focused		
New reservoir/increasing size of reservoir		
New long term contract		
New connection		New pumping connection, new way to alternate between sources
Diversifying water sources		Adding surface and desalination
Upgrading infrastructure		Fixing aging wells
Purchasing new water rights		Agricultural water
New ways of reusing wastewater		Pumping into lake to be retreated, use of greywater
Governance Changes	Complete reorganization of water delivery into centralized authority with obligation to provide water in return for agreed price, and environmental safeguards	
No action taken/solidarity		Sympathy program; or does not think about drought

3.2. Analyzing 'adaptation success'

3.2.1. Effectiveness

3.2.1.1. Meeting policy objectives. Beyond system reliability, which is a primary goal of water utilities in the U.S. (Hashimoto et al., 1982), most of our study participants stated that reduction in water use (whether per capita or overall) was an indicator of effectiveness in drought policies. Of those that had taken action during recent drought, nearly all representatives felt they had been successful in this metric. Many specifically discussed success in terms of reductions in gallons per capita per day or overall system reductions (15 of 19 cases), although these are not always permanent (Case 9).

Beyond the amount of water used, several interviewees judged effectiveness by whether they avoided the use of mandatory restrictions—interviewees felt that it was preferred to avoid imposing behaviors on their customers (Case 8, 9, 11, 12). This was sometimes reflected as staying within a threshold level of supply that avoided drought plan triggers or otherwise having "*little impact to customers*" (Case 12), being able to "meet deliveries," and perhaps even creating a cushion between water supply and demand (Case 9). For example, as one representative stated: *"[It's been] the worst drought year on record, they haven't even had to enact restrictions." (Case 8)*.

The importance of customer acceptance of policies was also captured by interviewees who described having to implement restrictions, whether mandatory or voluntary. About a third of interviewees addressed effectiveness by discussing how the public was supportive in various ways of the policies implemented during drought, such as this reflection: *"…it was kind of a London Blitz kind of situation. Everybody pitched in and people took showers standing in buckets so that they could collect the water and use it on their plants, because we decreed no outdoor watering at all. No washing cars, no nothing like that" (Case 9).*

In another example, a participant noted how the public was unhappy with restrictions, but in the end the city "*didn't issue any citations and we made it through*" (Case 20). Other signs of effectiveness were mentioned in terms of policies utilities could discontinue, such as summer pricing and restrictions on which days customers were allowed to water their yards (to help manage peak demands; Case 3 and 6), rebates for toilets (having reached saturation; Case 5), and even avoiding building new supply, such as abandoning plans for desalination plants (Case 9) or adding other forms of new supply (Case 15). Effectiveness was also expressed in terms of ability to act quickly and achieve consistency in communication about drought measures to all parties affected across a large system (Case 19). Getting a response to communication efforts was also noted as a measure of effectiveness. One study participant stated: *"We had tremendous support. We pulled together our 100 largest users in a one-day workshop and we got 100% compliance from those people"* (Case 14).

3.2.1.2. Robustness. Adger et al. (2005) define robustness as being less sensitive to changing conditions. We observed examples where interviewees felt that their drought measures had *strengthened* robustness in two particular arenas: water supply/demand balances, and the timeliness of water resource decision making. As noted, these measures included instituting drought plans, implementing "best practices," making infrastructure repairs, creating provisions for accessing additional supply during drought, and reducing per capita water use, and allowed them to avoid restrictions and rationing in the face of extremes, making their systems more robust overall. Such practices created a "cushion" between needed water and available water, which in some cases was banked for later use either in underground aquifers, surface reservoirs, or by agreement with companion water system entities (Case 1 and 4). One interviewee even stated that the agency was now "*set up for the next drought. Can't wait. (laugh)*" (Case 2). Experiencing drought created new ways of thinking about their systems, as one participant described: "*That's when [they] said, we need to turn our thinking around a little bit, not just thinking about when demand is exceeding supply, but thinking about if we have a capacity problem…with the reservoir, the pumps break, the wells fail*" (Case 20).

Interviewees also mentioned another form of robustness, a type of robustness to changing regional politics introduced by their drought response measures. One described how being part of a regional plan provided a sense of solidarity: "*No one wants to be the first guy who doesn't follow the plan or who opts out of a regional decision*" (Case 19). In a sense, this provides political cover for entities and makes the system as a whole more uniform in its response to drought.

In a few cases, utility representatives described situations where drought measures had actually increased sensitivity (i.e. decreased robustness) to environmental variability. One participant from an entity that had diversified its water sources from 100% groundwater to including surface water collected in reservoirs and desalinated water, felt that they were now more vulnerable to climate variability, even while appreciating the flexibility that diverse supplies brought them (see below Case 10). Another study participant recognized that in seeking to store more water in reservoirs to buffer against drought events, they were possibly increasing their vulnerability to flooding and potentially not being able to meet instream flows for fish stocks (Case 18). Finally, building robustness to drought by having planning, awareness raising, and contingency planning in place, while positive overall, could influence perceptions negatively if it raises new questions about the local viability of certain water-reliant industries (Case 14) or discourages tourism if drought conditions are widely publicized (Case 7). While we do not have data on whether these concerns are warranted, simply raising concerns could possibly even increase the sensitivity of local businesses to drought (decreasing robustness) if they amplify public or corporate perceptions in negative ways.

3.2.1.3. Flexibility. Flexibility can be defined as the ability to change in response to altered circumstances (Adger et al. 2005). We found many instances in which drought actions and policies had increased flexibility, but also found instances in which flexibility was reduced, or the result was more complicated, including unintended consequences.

3.2.1.3.1. Increased flexibility. Many of the interviewees commented on how their drought actions and policies had increased flexibility. On the supply side, diversifying the sources of supply for one system "*has given us the added benefit of flexibility and dexterity in responding to whatever Mother Nature might throw at us in any given year*" (Case 10). Not only did this interviewee refer to having multiple sources, but also an interconnected system allowed them to be "nimble" in response to water shortages. Several interviewees spoke of the flexibility afforded by having the authority to act in a timely way on drought measures. This authority was imparted in different ways. Several interviewees commented that a separation between the elected officials such as city council and the water department leadership (sometimes even in funding streams) allowed them to make changes that were needed to manage water effectively in a drought (Case 6, 17). Others specifically mentioned that having a drought plan often imparted flexibility (Cases 11, 20)—for example, as one said "*…we keep the council informed but don't need their blessing to institute something… we don't have to get a quorum of them to vote on anything. One of the goals was not having to wait two weeks* [when the council might next be meeting]" (Case 20).

A final area where interviewees mentioned that their drought-related actions created flexibility was in cultivating trust and a relationship with their publics through ongoing communication and customer education (Cases 14, 15, 19, 20). As previously mentioned, public acceptance of drought policies is a critical factor that enables decision making, whether in setting water rates, enforcing watering restrictions or pursuing new supply options. These communication efforts, particularly when sustained through ongoing efforts beyond the drought event itself, "prime" people to be better prepared to respond to drought, which gives water entities more flexibility to act if and when they need to implement specific drought measures (Case 19). As another participant put it: "*the public can dig deep to conserve, but they have to be able to relate to the drought*" (Case 15). Another participant confirmed that this ability to relate is best built throughout the year, "*We used to have water conservation seminars and education in the off season. If you want to change behavior you have to start early and that means getting people used to conserving during non-drought situations so when drought does happen, you've already established that behavior*" (Case 21).

There are cases when creating more flexibility may cut both ways, creating positive and negative implications for drought management. One entity created flexibility by not defining physical drought triggers: "*It was a conscious decision not to include triggers in the contingency plan. The idea was to build flexibility into the plan,*" (Case 18). However, while this strategy allowed for flexibility, they subsequently experienced the unintended consequence of what the interviewee called "*politically-derived*" drought declarations which, they thought also resulted in remaining in drought status for too long (Case 18). Another participant pointed out the double-edged nature of pre-defined drought triggers in describing a workshop they held: "*having more specific triggers can make going into a drought watch more politically defensible…having it ambiguous can help everyone out at times but it can also be a disadvantage*" (Case 21).

3.2.1.3.2. Decreased flexibility and "demand hardening". Some of the actions that utilities have taken to respond to drought have resulted in less flexibility for the system. Five participants discussed the concept of demand hardening, or having less flexibility as wasteful or "excess" water use was permanently eliminated, but did not agree about its overall importance (Cases 2, 9, 10, 12, 18).

We are using the term demand hardening in this paper as meaning "the reduction in the ability of a customer to achieve further water reductions after the relatively easy and inexpensive water reductions have been implemented" (Howe and Goemans, 2007). As one put it, they "*don't have quite the same flexibility to save water as we did in 1976–1977* [an earlier major drought event] *because of the fact our water fixtures are so much more efficient now*" (Case 9). Another participant definitely felt that demand hardening was a problem, because their city did not have much outdoor water use in their customer base, and their customers (both residential and commercial, such as hotels) had already become very efficient users; they had to develop "*an allocation plan that doesn't punish conservation*" (Case 2). Given this situation, the representative felt that anything more than a 20% cutback in use would have required difficult behavior change and significant production loss, and it was not economically viable to ask for more reductions. Another interviewee acknowledged that: "*when supplies are stressed and we have water restrictions that are put in place to help reduce demand, it can help us in the short run but hurts us in the long run because we get to a place where there is no flexibility left in demand and the regulator believes the people should just use less, that there should be some flexibility remaining in the demand curve when in fact there isn't*" (Case 10). Such dilemmas impact perceptions of fairness (discussed under *Equity*, below).

Two other study participants thought that there had been a reduction in per capita use, and that demand had hardened, but neither felt that their ability to respond during a drought had been compromised; in one case because they focus on securing a robust, redundant supply (Case 12), and in the other because the reductions were not yet hardened enough to prevent further reductions during future droughts (Case 18). No one across any of the cases suggested reversing their policies to encourage conservation and reduce wasteful water practices—but several suggested the need to build solutions that rewarded conservation and allowed for other creative new practices to emerge, such as graywater re-use (Case 2).

These examples of demand hardening and reduced flexibility reinforce the need to examine unintended consequences of adaptation policies, as suggested by Adger et al. (2005). Some spoke positively of "best practices" in drought response becoming permanent (Case 2) and transitioning staff who had been involved in an emergency drought response team into permanent conservation positions (Case 2). A more negative unintended consequence of drought watering restrictions occurred in one city that found imposing water schedules actually increased overall water use, possibly because customers watered on a set schedule regardless of landscape need (Case 6). Voluntary outdoor watering restrictions have been found to be less effective in some cases and can even lead to increased water use (Kenney et al., 2004).

Drought triggers or definitions have also reduced flexibility. One participant felt their drought definitions were outdated, but that they were difficult to change because the triggers were embedded into many regulations and operational procedures (Case 7). While this may be a sign of "robustness" or even "mainstreaming" of drought awareness, rigid triggers might reduce an entity's ability to change in response to altered conditions. Another participant mentioned that some indicators used to declare the end of a drought were too temporally coarse—they had a long time horizon (e.g. 4 or 6 months for streamflow), which was "*too long a picture, because it's a lagging indicator*," which meant that their system stayed in drought restrictions beyond when the drought had eased up (Case 19). Lack of efficient stand-down rules, and staying in drought status unnecessarily can have financial repercussions for businesses and utilities alike.

Some constraints to flexibility in dealing with drought did not directly arise from previous drought measures, although they can be related. Several mentioned the difficulty of setting rates that were sufficient to run the utility and plan infrastructure upgrades, given that conservation measures and restrictions often reduce the income to the water utility if customers pay for water on a per unit basis. In one city, the interviewee reported that changing rates is "*really, really difficult*" and a slow process (Case 20). There are strong limits to setting prices for water: "*people who are not politicians are not going to jump in and say let's make the water $8 per 1000 gallons or something. They're not going to go to extremes. The public really doesn't want to see those kinds of extremes*" (Case 1). This difficulty of balancing revenue needs against supply reliability is reflected by another entity representative: "*We would not want to reduce our revenue too much. But again, our supply reliability is job one. And we couldn't risk running the reservoirs dry because we wanted to keep the revenue stream going*" (Case 7). This mirrors the priorities found with respect to reliability and cost by Rayner et al. (2005). Furthermore, it is difficult to raise rates when rates are already perceived to be high (Case 14). This difficulty is compounded when the public has been encouraged to save water, "*the customers do what we ask* [reducing water use]*, and then feel like they are penalized* [if we then ask for money to make up the shortfall]" (Case 19).

Regulations in place to protect the environment such as minimum stream flow requirements can also reduce flexibility for dealing with drought. Reservoirs can serve at least four purposes: storing water for use later (and also therefore help with drought), preventing flooding during runoff season, generating hydropower, and providing sufficient flows for species habitat and for recreational use (Cases 6, 9, 10, 18, 19). Balancing all of these is a complex task. Preserving environmental values meant that some systems could not pump what their systems were physically capable of (Case 10). One interviewee mentioned that relicensing of their system's dam resulted in updates to environmental flow requirements that were much more "prescriptive" and required larger releases. This meant that less storage was possible, reducing their buffer for drought (Case 19).

Another limit that constrained the flexibility of systems to respond to drought was the seasonality of precipitation, when much of the water falls in a short time during the year (Cases 10, 12, 18, 20). One interviewee reported that droughts tended to manifest exactly at the time of year when outdoor use was tapering off anyway, further limiting the amount of water savings that could result from reducing outdoor watering (Case 18).

Other aspects that reduce flexibility are being reliant on a single supply (Case 4), and attitudes about limiting growth that play out in the arena of water supply (Case 9). Surprisingly, even something designed to make life easier, such as automated sprinkler systems, can limit flexibility in outdoor water use, as described by this interviewee: "*The one that really gets me is people who water when it's raining. They just can't get a grasp on their automated system and they're out there just going at it while it's raining*" (Case 14).

3.2.1.4. Uncertainty over how policies will work. As Adger et al. (2005) note, uncertainties in effectiveness can be introduced if the measures rely on actions taken by others (rather than being under direct control of the utility). In the case of reducing water demand through modifying behavior, utilities must rely on the actions of others to achieve the goal. Interviewees mentioned the uncertain nature of the policies they were implementing especially on the demand side.

3.2.1.5. Difficulties measuring effectiveness. Not all utilities had a good sense of whether their measures were effective, or which measures were more effective than others (Cases 2, 6, 12, 21). One participant mentioned that it was a bit difficult to tease out the impacts of conservation measures in the short term (Case 12). As another participant said: "*The one thing that I never really understood through reviewing our archives was whether or not we were getting the response we were looking for or we were hitting our target. And so that's one thing I don't really know*" (Case 2). One method cited to assess the uptake of demand management options was counting how many businesses and developers took advantage of rebate programs or other support provided for water-efficient appliances or practices, although further analysis would be needed to know how these actions affected water use (Kenney et al., 2008, Quay, 2014). Indeed, few studies have evaluated the effects of urban water conservation measures and the details of how efforts reach particular consumers or not (Hogue and Pincetl, 2015). It is often difficult for water utilities to differentiate indoor and outdoor use to do evaluation, and consumers themselves do not always have a good understanding of optimal watering strategies for their landscapes (Ibid).

3.2.2. Other adaptation success criteria: efficiency, equity and legitimacy

3.2.2.1. Efficiency and cost-benefit. Efficiency refers to the cost and benefit of actions, including the distribution of costs/benefits and the non-market benefits such as ecological, aesthetic and nontraded goods, as well as the balance between public and private costs and benefits.

Restrictions on water use, whether voluntary or mandatory, cause utilities to lose revenue, all else being equal, and affect water-sensitive businesses particularly. Before water supply adequacy was a concern, dry periods were a time when water utilities could make up for low revenues and save for infrastructure maintenance costs, as customers needed to use more water to compensate for lack of natural rainfall. Two interviewees from different cities described significant losses between $46–54 M during drought periods, which was in part attributed to the drop in per capita water consumption (Cases 14 and 5). As another participant put it: "*We have to walk the line. On the one hand, we have to protect the water supply and make sure there's enough. But at the same time, if we discourage use too much, then revenues drop*" (Case 7). Yet another participant also talked about this issue: "*There's always the revenue concern. There are always folks that would say [our city] is not really in trouble. Our system has plenty of capacity. We can still withdraw water. We really should be selling as much water as we possibly can because we've got these bonds to pay*" (Case 14). While reducing demand for water does impact revenue, it has also resulted in avoiding the need for new supply, or delayed the need for it (Case 9), saving substantial capital costs.

When a utility does implement either mandatory or voluntary restrictions on water use, these can have a disproportionate impact on particular industries that are heavier water users, such as landscaping businesses, golf courses, car washes, hotels, and industrial users, such as beverage makers (Case 14, 4, 2, 7, 20). Often, these interests negotiate different accommodations to requests for reductions, or utilities exempt them from requirements altogether, cognizant of the fact that "*it's their livelihood*" (Case 20). Many of these heavier water users have made gains in efficiencies and are targets of utility efforts to promote additional efficiency. The cost of water is also larger proportionately for some of these businesses, and changes to water rates can also be felt economically: "*We think a lot of the industrial belt-tightening has occurred because of pricing*" (Case 3). In some areas hard hit by the recession in the late 2000s, water conservation has been driven by general economic concerns as well (Cases 16, 20).

Certain non-market benefits of water were mentioned in our interviews, such as preserving environmental flows and maintaining the ecological health of wetlands. In one case a major reorganization to increase the diversity of the local water supply and change the governance associated with allocating water was justified on environmental benefits: "*We've done this [reorganizing and diversifying water supply] to primarily preserve the wetland in our region*" (Case 10). Finally, as noted previously, the non-market overriding "job one" of ensuring public safety and the reliability of the water supply was clearly underpinning all of the complex decision making around preparing and responding to drought.

3.2.2.2. Equity. Adger et al. (2005) speak of equity in terms of outcome, who wins and who loses, and the distribution of impacts. Fairness is a major theme that ran through our interviews. Several participants mentioned public perception as a key factor that limited their response to drought, and in the end, it came down to various arguments about fairness for many of them. The first dimension of fairness related to how drought restrictions were applied—several interviewees mentioned the importance of making sure everyone was subject to the same rules or at least involved in doing their part to help the situation. As one representative said: "*The way we enact our drought response measures is intended to create a 'share the pain' mechanism, meaning everyone is expected to play their part in bearing the brunt of the shortage. But 'sharing the pain' is very subjective so the public has to buy in to this. If the public doesn't think the other sectors are sharing the pain, they may not cut back*" (Case 18). "Sharing the pain" extends as well to neighboring communities—having different rules apply can lead to friction as another representative explains: "*their mandatory is to do two days a week. And their folks probably aren't too happy about it when we're [a different municipality] at one day a week*" (Case 5). In a tradeoff between effectiveness and fairness, equity seems to be a higher priority for at least one system, as reflected by this interviewee: "*We'd rather have a weaker policy with broader acceptance than a stringent policy in one jurisdiction and a more moderate policy in the neighboring jurisdiction because of the confusion it creates and, really, the resentment it creates*" (Case 1).

A second dimension of fairness was the sense of wanting to give credit or at least not to penalize those who had already taken steps to become more efficient when it came time to ask for reductions during a new drought or to raise revenue to cover shortfalls. If actions already taken to increase efficiency are not acknowledged, simplistic formulae for reductions in use (e.g., X percent reduction from the previous year's usage) during drought can unfairly penalize those who have already become efficient, leading to a disincentive for conservation (Kenney, 2014). As one participant said: "*we didn't want to be punitive* [e.g. by raising rates] *against the very people who were responsive and helped us out*" (Case 14). Another added that "*people feel penalized* [if the utility tries to recover lost revenue by raising rates]" (Case 19). Incentivizing conservation is difficult if people think they may be asked to cut back in the future: "*we've really tried with our wholesale customers to develop an allocation plan that doesn't punish conservation*" (Case 2).

3.2.2.3. Legitimacy. Legitimacy as defined by Adger et al. (2005) addresses the question of whether the decisions made are acceptable to participants and non-participants affected by those decisions. As one participant said when we asked about if there were any limitations to drought response: "*the only barrier that comes to mind is public perception*" (Case 17). Indeed, public perception and public acceptance of drought policies was a common thread running through many of the interviews, whether about effectiveness or about limits on their ability to adapt to drought. Neither water supply side responses nor demand side responses were immune from public criticism, depending on the context of the system in question. Several interviewees mentioned the difficulty of raising water rates and the distaste the public has for high water rates. Drought surcharges were rarely utilized as they were seen to be quite unpopular. Water utilities can get feedback from their customers directly, or a city council involved in approving a departmental budget can be another source of feedback about how policies are received by the public: "*they may come back later and not approve a budget if they don't like something*" (Case 6). Restrictions on water usage can cause "*political unrest*" (Case 3) and can galvanize publics like few other issues. One interviewee described the situation in their city: "*folks were pretty contentious about the cutbacks. We had very long lines at our customer service, people challenging their allocations, trying to justify requiring more water for their households by bringing in birth certificates…*" (Case 2). According to another interviewee, one drought policy even managed to stir up birders: "*It's kind of a silly thing, but probably our biggest backlash was, believe it or not, people that had bird baths. That's hardly worth even talking about. We got more complaints from the bird lovers because there was a 'no ornamental fountain filling' part of the ordinance…So I think we excluded bird baths in the following one*" (Case 4). As previously discussed, voluntary measures or community education initiatives were vastly preferred compared to mandatory restrictions.

Two participants mentioned controversies that arose around new infrastructure that had been planned. In one case, debate around adding new supply to a water utility became a debate by proxy about growth in the community, with political advocacy centered on stopping the new supply connection in order to control the size of the community. This of course affected the ability to obtain emergency supply during drought as well (Case 9). While debates over growth in this community began in the 1970s, there is still controversy today about buying water because of concerns about growth. Another system found itself in the middle of controversy when opposition arose to a new water treatment plant, and opponents instead called for increasing attention to conservation and reducing demand, but because some efficiencies had already been implemented, it became more difficult to achieve savings (Case 5).

A drought event itself may galvanize political will to implement some of policies that in normal years may not be publicly acceptable. As one participant put it: "*the* [drought] *allowed us to put in place a lot of demand management policies that had been looked at previously, but there wasn't the political will to put them in place*" (Case 1). Political "cover" or increased legitimacy for somewhat unpopular policy decisions was achieved in other cases by the development of plans that set standard indicators by which drought stage responses could be declared or ended. As mentioned above, those systems without defined triggers appeared to wish they had them to lessen the chances of a "*politically-derived drought*" or to make a drought watch "*more politically defensible*" (Case 18, 21). While drought plans can afford increased flexibility, as discussed above, there can be "*political rumblings*" if a system is in drought too long (Case 19) and, thus, deciding when to declare a drought to be "over" can be just a problematic as declaring that it has begun.

Finally, our interviewees thought that ongoing communication and education efforts enhanced legitimacy for drought actions when needed. "*An ongoing relationship with customers*" primed people to be better prepared to respond to drought (Case 19). Nonetheless, this relationship can still be fragile especially if perceptions of fairness are violated in some way, as discussed above.

3.3. Intersections across criteria for success and weighing tradeoffs

As Adger et al. (2005) note, organizations and planning processes may choose to weight some of these four main criteria more than others. They examined some of the original scenarios included in the Intergovernmental Panel on Climate Change's (IPCC) Social Report on Emissions Scenarios (SRES), which are used to generate projections of possible future climate change, and found that economic efficiency was weighted more in some, and less in others, for example. In our cases, it is clear that success is judged primarily on achieving water reductions during drought (in other words, effectiveness) but also that mandatory requirements to do so were less preferred (achieving legitimacy), and that cost-effectiveness (i.e. effects on revenue streams) was a tradeoff that was negative for some. Space prohibits a thorough analysis of tradeoffs across these four criteria, but it is clear that there will be some differences in how they are weighted for urban water management.

4. Lessons from drought responses for future adaptive capacity

Our analysis of the urban water management landscape suggests that policies being used to combat drought might support adaptation in the face of climate change, but might also create some obstacles. While each utility representative with whom we spoke felt that they were better positioned for an uncertain climate future as a result of the measures they had implemented, they also pointed to limitations, with implications for climate adaptive capacity. For example, permanent reductions in demand allowed for a cushion between water supply and demand that could allow for banking water, but made it difficult to achieve additional reductions in highly urban, low outdoor use contexts. Furthermore, if the cushion of water savings achieved by conservation is absorbed by new construction that uses that water, then no additional system robustness has been achieved (Klein and Kenney, 2009). The revenue imbalance caused by water use restrictions also introduced new vulnerabilities in terms of fiscal health of the utility and the ability to conduct needed maintenance. The local political context represents another constraint on the utility's ability to reconfigure water rates to support a sustainable water system. Moreover, urban water systems responding to droughts have already pursued some of the "low hanging fruit" available to them, such as leak and pump efficiency repairs. Finally, as Gober et al. (2016) point out, as the focus for water savings in cities shifts from indoor efficiencies to reducing outdoor water demand, the problem becomes more complex, involving issues of urban form and lifestyles, climate sensitivities, difficulties in anticipating customer responses to policies, and engaging more directly in underlying conflicts about growth, climate risk, and social justice.

Despite these observations, the conclusion to be reached is not that urban water systems should ignore water conservation or should deliberately build in wasteful water practices. Nearly every manager we talked to considered demand management an integral part of their practices: "*Our customers expect us to be in the business of encouraging efficient and environmentally sound use of resources*" (Case 15). At the same time, our scan of cities revealed that local context matters, and the physical, economic, political, and cultural aspects of place and water systems determine what systems are able to do to adapt both to short-term drought and long-term climate change.

Climate change suggests that the pace of innovation and development of new ways to creatively and flexibly meet urban water needs to accelerate (Armitage, 2005, Huntjens et al., 2012, Widener et al., 2017). Our study did not provide evidence, however, that change in policy at the local level was particularly rapid, even for the fairly conventional function of water provision. Rather, interviewees spoke of how difficult it was to change policies, such as regulations, that would support increasing graywater reuse, reforms of revenue structures, and new requirements for information use and uptake. Moreover, as Quay (2014) points out, because of changing urban forms, customer practices, and climate, it is difficult to predict future demand for both indoor and outdoor water, and the outcomes of policies—that is, how customers will respond to policy signals for managing urban water demand—is also uncertain.

As Engle (2013) suggests, there may be a tradeoff between what is needed for coping with droughts and what might be needed to build a decision process that can respond to climate change or social pressures and even support transformations. It is clear from further in-depth case studies (unpublished data) that most utilities are not yet weighing the tradeoffs that may be present in dealing with drought risk in the near term and climate change in the long term. There are usually tradeoffs when decisions are made to manage hazards, and these do not always support a reduction in vulnerability in the long run (Dilling et al., 2015). Further work is needed to examine the tradeoffs between multiple dimensions of adaptation success in greater detail, including how these tradeoffs manifest across temporal scales. In addition, future work could examine to what degree these findings are relevant for urban water use in the developing world, where the context of policy, infrastructure, economics, and political dynamics can be very different (Ziervogel et al., 2010).

We found positive signs that policies used to combat drought could be helpful for climate adaptive capacity in the utilities that had built an ongoing, deliberate effort to interact with their communities and, thus, were changing awareness about water. These relationships were seen as key to "priming" communities to be responsive if and when a drought might occur in the future. They could also serve as the foundation on which to build a conversation about changes that might be needed as climate change unfolds.

Nonetheless, there are some cautionary tales in how these relationships are built and constructed by drought events. Voluntary drought measures, for example, are preferred over mandatory ones (see also Stoutenborough and Vedlitz, 2014), even though they can be less effective (Kenney et al., 2004, Wichman and Taylor, 2014). Restrictions are also more effective than pricing policies, and tend to be more equitable across different income groups than pricing measures are, which fall more heavily on poorer households (Wichman and Taylor, 2014). In addition, households with irrigation systems tend to be insensitive to price measures (Ibid.). This points out the complexity of how individual households respond to different policies related to urban water demand.

The "fairness" of drought policies and associated revenue shortfalls are clearly points of contention between water utilities and their customers. Utilities are designing new means, through instituting drought plans, group decision processes, and flexible drought triggers, to navigate the tradeoffs between the flexibility needed for responding quickly to evolving events and the political legitimacy of those decisions. It is also clear that some policies that seemed fair and sensible up front, such as preventing the filling of birdbaths during drought, can have outsized impacts on the perceived legitimacy of a policy. Political retribution can be swift for policymakers who implement unpopular water pricing measures (Hornberger et al., 2015). Rather than promoting positive learning toward what works and what does not, this might discourage the needed experimentation and innovation processes that Huntjens et al. (2012) call for (also see Rayner et al., 2005). Furthermore, Adger (2013) suggests that going forward, communities may begin "to resist plans and policies that policymakers perceive as being completely rational for adaptation and sustainability. This is going to be an emerging issue, if not a "battleground" (p. 73). If, as Adger (2013) suggests, fairness becomes the central issue for hard decisions about climate change adaptation, the politics of urban drought adaptation described here reinforces the difficulty for adaptation that lies ahead.

5. Conclusions

As is evident throughout the study results, managing drought in a local, urban context relies on a complex relationship among water utility decision makers, elected officials, organized civic groups, residential customers, commercial and industrial users and regulating legal institutions. Much of a utility's decision making in responding to drought involves concerns about public perception, public acceptance and, ultimately, public participation in measures or at least tacit approval of strategies not involving direct wateruser actions (such as pursuing new supply). Thus, effectiveness in adaptation to drought can be a moving target, as these relationships are forged and evolve with physical and social changes in the urban utility's context. As one of the study participants stated:

> "*The issue of certainty in supply that we all grew up with no longer exists and we don't know how different it's going to be in the future, but we do know it's going to be different. From a public policy perspective, we do well to prepare our organizations and our infrastructure to be flexible enough to deal with whatever comes at us, because we have that unequivocal obligation to meet demand. It's not only a contractual obligation. We're the people who produce the supply that puts out the fires and washes babies, so we've got to have the supply no matter what. When we fail, there's a whole lot of problems. We've got to be in a position to not fail.*" (Case 10).

As exemplified by this quote, water utilities are under pressure not to fail. This "no fail" position can often be at odds with fostering adaptive capacity, which Armitage (2005) emphasizes is the ability to learn and experiment. Quay (2014) adds that urban water management policies treated as experiments would also benefit from more deliberate attempts to evaluate the results of those policies. It is hard to experiment and be innovative if you also cannot fail. Nonetheless, water utilities are gaining valuable experience from the frontlines of drought response in how to build flexibility as well as robustness in the complex environment in which they operate.

Conflict of interest statement

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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Appendix A. Supplementary data

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