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WATER MANAGEMENT DECISION MAKING IN THE FACE OF MULTIPLE FORMS OF UNCERTAINTY AND RISK[1]

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ABSTRACT: In the Wasatch Range Metropolitan Area of Northern Utah, water management decision makers confront multiple forms of uncertainty and risk. Adapting to these uncertainties and risks is critical for maintaining the long-term sustainability of the region's water supply. This study draws on interview data to assess the major challenges climatic and social changes pose to Utah's water future, as well as potential solutions. The study identifies the water management adaptation decision-making space shaped by the interacting institutional, social, economic, political, and biophysical processes that enable and constrain sustainable water management. The study finds water managers and other water actors see challenges related to reallocating water, including equitable water transfers and stakeholder cooperation, addressing population growth, and locating additional water supplies, as more problematic than the challenges posed by climate change. Furthermore, there is significant disagreement between water actors over how to best adapt to both climatic and social changes. This study concludes with a discussion of the path dependencies that present challenges to adaptive water management decision making, as well as opportunities for the pursuit of a new water management paradigm based on soft-path solutions. Such knowledge is useful for understanding the institutional and social adaptations needed for water management to successfully address future uncertainties and risks.

(KEY TERMS: path dependence; semi-arid and arid regions; water policy; water governance; climate change; water infrastructure; social-ecological change.)

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INTRODUCTION

In the Wasatch Range Metropolitan Area (WRMA) of Northern Utah (Figure 1 from Hale *et al.*, 2015), where over 85% of the state's population resides (Utah Governor's Office of Management and Budget, 2015), water management decision makers confront multiple forms of uncertainty and risk, complicating their ability to plan for the long-term sustainability of the region's water supply for human and nonhuman uses. Scientific consensus about the projected effects of climate change on Utah's water supply is coalescing at the same time the state is experiencing increases in water demand due to rapid population growth, aggressive economic development, and

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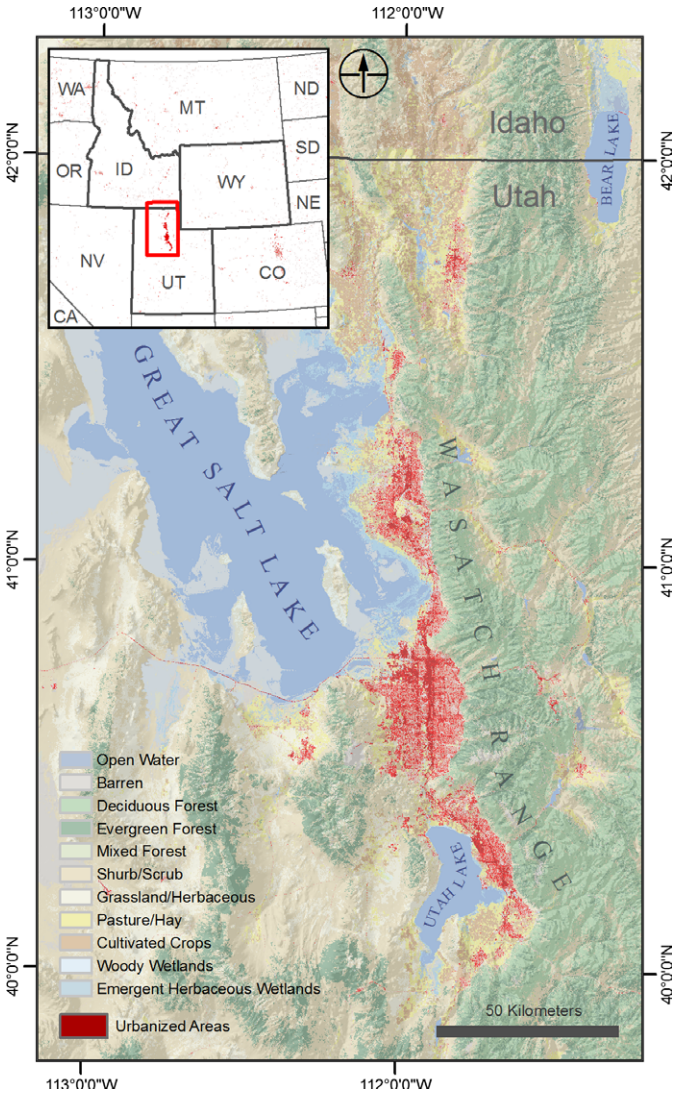

FIGURE 1. Wasatch Range Metropolitan Area from Hale *et al.* (2015).

concentrated urbanization in the WRMA (Utah Foundation, 2014). Shifting public values, growing recognition of the need for environmental flows, and changes to state water law and policy are challenging the state's traditional water management approach (Crimmel, 2014). At present, water is among a host of growth-related issues (including air quality, transportation, and education) vying for the attention of state lawmakers. These risks and challenges will require water managers and users to make difficult decisions and adapt their practices if water is going to be sustainably managed in the future.

Sometimes referred to as the "crossroads of the West," Utah is centrally located in and characteristic of the Intermountain West region of the United States (U.S.). The state lies at the intersection of several major physiographic provinces: the Great Basin or Basin and Range province, the Colorado Plateau province, and the Rocky Mountain province (Utah Geological Survey, 2015). Utah exhibits a great deal of climatic and hydrologic diversity, even though it is the second most arid state in the U.S. on a statewide average. After settlement by Latter-Day Saints (LDS) pioneers in the mid-19th Century, Utah territorial and subsequently state water management emphasized developing irrigation works and other water infrastructure to support permanent agricultural communities (McCool, 1995). During the 20th Century, Utah garnered significant federal subsidies that made large-scale water transfers possible to support the state's urbanization, which was concentrated in the WRMA, home to Salt Lake City (McCool, 1995; Crimmel, 2014). As Utah moved into the 21st Century, it became the third fastest-growing state in the nation, with its population growing by 23.8% from 2000 to 2010 (Mackun and Wilson, 2011), and is among the top 10 fastest-growing states in each subsequent year. Utah's economy and population have become highly diversified, with greater dependence on tourism and recreation that rely on water of sufficient quantity and appropriate quality being left in streams, lakes, and other water sources to maintain the state's natural environment.

The water system in Utah is an adaptation to the state's arid, drought-prone, and highly variable water resource context. Utah water law is based on prior appropriation, a doctrine that allocates water in a priority system based on which users initially and continually put water to beneficial use and that specifies which users receive water first in times of shortage. Several interstate compacts and agreements allocate the shared waters of interstate streams and water bodies divided by state boundaries. The state's water infrastructure is designed to capture and store spring snowmelt from mountainous regions and deliver it to agricultural fields and valley communities in late summer to extend the irrigation season. Large infrastructure projects store water on an interannual basis and collect water when and where it is more plentiful, often moving the water between watersheds to take it to areas where population and economic enterprises are concentrated.

Water management in Utah has long relied on the assumption of hydrologic stationarity (Matalas, 1998), which presumes the range of events observed in the past will be a good representation of future conditions. Engineered to deal with the high but somewhat predictable spatial and temporal variability in water supply experienced in the <170 years since LDS settlement, Utah's current water system can accommodate approximately five years of drought (Anonymous, May 2014, personal communication). However, climate change may result in hydrologic regimes not well represented by historically observed

records (Milly *et al.*, 2008; Woodhouse *et al.*, 2010), rendering the assumption of hydrologic stationarity no longer defensible for engineering, planning, and management applications (Craig, 2010). Observed temperatures in Northern Utah have risen significantly in recent decades, and this trend is projected to continue. Utah has also experienced more winter precipitation falling as rain instead of snow (Gillies *et al.*, 2012), and projections indicate a likely future decrease in low- and mid-elevation snowpack and earlier and potentially diminished runoff volumes (Barnett *et al.*, 2005; Bardsley *et al.*, 2013).

Using a case study approach, this study contributes to an emerging body of knowledge on water management decision making in the context of adapting to social-ecological change. Specifically, our case study draws on interviews with water managers and other water actors in the WRMA to answer the following research questions: (1) What are the major challenges they face? (2) What are their perceptions of how various social-ecological changes will affect the water system in the WRMA? and (3) What solutions do they propose to deal with these changes and their associated challenges? Overall, our case study identifies the space in which adaptation decisions are made, and situates adaptation decisions within the interacting institutional, social, economic, political, and biophysical processes that enable and constrain sustainable water management. It also characterizes how water managers and other water actors understand climate change and climate change adaptation, and shows how climate change interacts with other ongoing social and environmental trends and stressors to create new management challenges and opportunities. Finally, our case study characterizes the path-dependent nature of the dilemmas water managers and other water actors confront in adapting to climate and other social and environmental changes. We conclude by discussing opportunities for pursuing a new water management paradigm based on insights offered by previous policy research.

INSTITUTIONAL WATER MANAGEMENT ADAPTATION

In this study we define climate change adaptation following Moser and Ekstrom (2010) as "changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting non-climatic changes." Much of the literature on water management adaptation to climate change has focused on clarifying the biophysical aspects of climate uncertainty through improved modeling (Gober, 2013), and on understanding how to effectively present water managers with climate data and information to aid their decision making. Recent work has identified the need to understand "the social dynamics of water systems" and how social uncertainties related to "lifestyle preferences, growth prospects, and public attitudes" impact the sustainability of water resources under climate change and influence adaptation decision making and capacity (Gober, 2013). Likewise, the broader literature on institutional adaptation to climate change has recognized the importance of understanding how structural forces and individual and institutional actions interact to shape the adaptive capacity of institutional actors and define the space in which adaptation decisions are made and implemented (Pelling, 2011; Wyborn *et al.*, 2015).

Observers increasingly recognize that the risks posed by climate change alone may not prompt sustainable water management decisions. The exact weight of climatic and nonclimatic factors in water management decision-making processes is determined by local context, including interactions between decision makers' jurisdictional and perceived authorities and responsibilities, existing institutional structures, and ongoing dynamics among public and private stakeholders at various scales (*e.g.*, Dyck and Kearns, 2006; Downard and Endter-Wada, 2013; Welsh *et al.*, 2013; Wyborn *et al.*, 2015). Several recent studies have empirically documented the process through which water managers develop and implement adaptation policies and strategies to deal with climate change (*e.g.*, Arnell and Delaney, 2006; Crabbé and Robin, 2006; Dessai and Hulme, 2007; Charlton and Arnell, 2011). These studies lend insight into the social-ecological contexts that shape the trajectory of adaptation processes and outcomes (Pelling, 2011), and signal an increasing recognition within research and management communities that many of the uncertainties in current water systems are social in nature. In addition to climate change, social factors such as population growth, economic development, land-use change, and shifts in public attitudes and policy all drive decisions about how water is used and how adaptation will take place (Gober *et al.*, 2010; Gober, 2013).

Other research has focused on understanding "what structures, relationships, processes, and other variables" (Engle, 2012) act as barriers or bridges to the ability of water management agencies to adapt to climate change (Clarvis and Engle, 2013). For example, Engle (2012) assessed the adaptive capacity of large urban community water systems in Arizona and Georgia by examining their preparations for and responses to recent drought events. The author found learning, education, information, knowledge exchange, finance, and research acted to facilitate

adaptation, whereas human perceptions and cognitive issues acted as important barriers to adaptation. Similarly, Gallaher *et al.* (2013) investigated how Colorado lawmakers adapted water policy to deal with changes in water demand and public values in the 20th Century. They found previous management decisions inhibited adaptive capacity while the development of new policy tools, such as collaborative forums for stakeholders to resolve their differences outside of the court system, increased it. Other studies have gone beyond assessing how certain variables such as access to information influence water managers' adaptive capacity to demonstrate the role local context plays in structuring adaptation actions and outcomes. For example, Endter-Wada *et al.* (2009) and Welsh *et al.* (2013) demonstrated water users' adaptation to drought in the Bear River Basin of Idaho, Utah, and Wyoming was enabled by mutual recognition of their linked interdependent water uses and vulnerabilities, which led to cooperative agreements among water users that permitted them to cope with drought. Furthermore, they demonstrated that in adapting to drought, water users were not only adapting to changed biophysical conditions, but also to each other's water uses and needs to achieve mutually agreeable solutions.

Although not specific to the literature on climate change adaptation, we also draw on the concept of path dependence in institutional processes in the final section of this study to interpret the context within which adaptation decisions are made. As described by Pierson (2000), path dependence demonstrates that institutional and technological infrastructure frequently becomes entrenched once decisions to pursue certain policy and management paths are implemented. As such, with "[e]ach step along a particular path" the relative cost of reversing course to pursue a new path becomes increasingly expensive and the relative benefits of taking "further steps" down the existing path increases, a phenomenon known as increasing returns. The concept of path dependence originated within the economics literature to explain industrial development (David, 1985) and how technologies become locked in through market choices and early adoption (Arthur, 1989). Over the past 30 years, research on path dependence has expanded to examine the self-reinforcing social, political, technological, and economic processes related to environmental decision making. For example, the concept has been used to examine lock-in of agricultural practices and technologies, such as pesticide application (Cowan and Gunby, 1996; Wilson and Tisdell, 2001; Vanloqueren and Baret, 2008). In the field of water, a recent study by Libecap (2011) employed the concept of path dependence to demonstrate the institutions that enable water delivery to agriculture in the arid American West can also restrict the ability of water transfers through market mechanisms to play a role in climate change adaptation.

The path dependence literature suggests reversing the current water management path will entail high social, economic, and political costs as the physical and policy infrastructure that underlie how water is managed involved large historical commitments of time and money, while creating social expectations for how and when water is delivered. Path dependence theory also suggests modifying existing physical and policy infrastructure to meet new needs is more attractive than reversing course and beginning anew (Ingram and Fraser, 2006). Building upon this literature, our discussion of path dependencies in Utah's water system is not intended to imply the current path is irrevocably locked in. Rather, we argue it is important to investigate path dependencies that affect the adaptation decision-making space in Utah to identify decision-making points where alternative paths may be possible, while remaining cognizant of the potentially high economic, social, and political costs of pursuing those paths. We argue it is important to evaluate whether climate change forces reconsideration of the existing water management path, especially in light of time frames needed for actions to address the risks climate change poses.

METHODS

The data used in this study were gathered from 41 semi-structured, face-to-face, key informant interviews conducted in the WRMA in the summer of 2013 under Utah State University Institutional Review Board approved procedures. The interview protocol can be found in Burnham *et al.* (2015). Interview questions focused on (1) the most pressing water management challenges in the WRMA; (2) major lessons learned from past experiences with drought; (3) planning for and adapting to climate, hydrologic, and social change; and (4) information needs for making decisions about adapting to climate and other changes. We used a qualitative approach to examine water management decision making in the context of social-ecological change because it provides a tool for gathering information not likely to be captured in a structured survey yielding easily quantified results (Prokopy, 2011). A qualitative approach provides participants with an opportunity to explain their answers in detail, which facilitates a deeper understanding of complex water policy and management decision-making processes (Sandelowski, 2000). While our case study does not allow for statistical

generalizability, it enables development of a more nuanced understanding of water decision making than does a survey approach and contributes to generalizable policy-related theory (Flyvbjerg, 2006; Yin, 2014). It also allows future researchers and practitioners to determine if sufficient similarities exist between case studies to make generalized statements about their findings (Wehlage, 1981).

Our interviewees were primarily federal, state, and conservancy district water managers; planners, legal, and agricultural experts; water industry representatives; and staff members of environmental and recreation organizations in the WRMA. We first contacted water policy researchers at Utah State University to identify an initial set of key informant interviewees whom we invited to participate in our interviews. Subsequent interviewees were identified through snowball sampling. Snowball sampling is effective for identifying study participants in a target community and building rapport and trust between the researcher and participants, but it is nonrandom and may lead to a homogenous sample of individuals involved in a particular social network (Browne, 2005; Noy, 2008). To minimize this potential bias and ensure broad representation of water expertise in the region, we asked interviewees to recommend additional individuals from different sectors of the water system (*e.g.*, government agencies, industry, nonprofit organizations, urban water actors, agricultural water actors) and individuals who may not share the same opinions about water management.

Two researchers attended each interview. Each interview lasted between 45 min and 3 h, was recorded with the permission of the interviewee, and was transcribed verbatim before being analyzed. Two researchers independently coded each transcript manually to ensure intercoder reliability (Hruschka *et al.*, 2004). Each transcript was analyzed using a three-step coding scheme (Neuman, 2011). In the first step, each transcript was coded to identify the major themes and insights relevant to water management adaptation to climate change and other social-ecological changes. These initial codes were compared between the two coders to identify agreements and disagreements, then revised and combined into one set of codes *(i.e.*, the codebook). This step identified the following five major themes: (1) major water management challenges facing water managers and other water actors; (2) factors interacting with water management challenges; (3) the role of climate change in water management challenges; (4) proposed solutions to water management challenges; and (5) the path dependence of water management dilemmas and decisions. A second round of coding was conducted using the codebook to organize key ideas and identify subthemes within the initial set of five major themes, with a focus on deeper understanding and characterization of the interactions, causes, and consequences of water management adaptation decisions. The final step involved selectively identifying direct quotes to highlight themes and subthemes drawn out in the first two steps to provide contextual richness to the findings (Sandelowski, 1994; Prokopy, 2011). In the next section, we present our results, focusing primarily on major findings from our interviews but also relying on supplemental secondary, publicly available data to fill in contextual details, and interpret competing perspectives when necessary.

RESULTS AND DISCUSSION

Major Nonclimatic Water Management Challenges

We asked water managers and other water actors to identify major challenges facing water management in the WRMA. Several challenges were consistently reported by interviewees. One was climate change, which we discuss independently below (see The Role of Climate Change in Water Management Challenges). In this section, we report on four sets of nonclimatic challenges consistently emphasized by interviewees. It is worth noting that interviewees commonly stated the challenges they face are not new per se, but the pressure to address them simultaneously is, resulting in what one water manager described as a "perfect storm." Moreover, these four sets of nonclimatic challenges are not independent. They are linked with one another, illustrative of the multifaceted and complex nature of water management in Utah.

The first and most frequently cited challenge was finding additional water supplies to meet the demands of a growing and increasingly urban population and a rising number of legitimized beneficial uses of water (*e.g.*, environmental flows, recreation, and other uses are now recognized). As one water manager framed it:

> How are we going to accommodate these larger demands that will eventually exhaust our capability to use our resources the way we have been using them?

This challenge was discussed by interviewees in the context of two primary corollaries. First, interviewees noted water in Utah is nearly fully appropriated and the current water supply infrastructure is aging and in need of repair. Many interviewees explained that because the federal government's subsidization of water infrastructure has declined dramatically,

obtaining funds to build and restore water infrastructure has become increasingly challenging. Relatedly, they were also concerned that the burden for financing infrastructure has fallen on Utah citizens through increased taxes or water prices, and these funding mechanisms are highly contested and unlikely to provide enough capital to fund future water infrastructure projects. Second, our interviewees explained that building new water infrastructure projects has become even more difficult because nearly all of the easily accessible water has been developed and because the public is generally opposed to the potential environmental impacts of water development. These findings suggest the decision-making space water managers work within has shifted, rendering the infrastructure-based solutions they have primarily relied on in the past difficult. As one water manager tersely posited, "[building new water infrastructure] just ain't going to happen."

The second nonclimatic challenge discussed by interviewees was population growth, which most interviewees suggested was the underlying trend driving the challenge to find additional water supplies. However, they noted population growth is considered a "given" within the current political, religious, and cultural milieu of Utah. The following quote illustrates the nature of this challenge:

> The whole thing is population growth, [but] no one wants to tackle that. We've kind of built in we have to grow, but really we've got these limited resources. And why do we need all this [growth]? We haven't had the basic most fundamental conversation [about it]. How do we produce that growth? That's just kind of a 'you-can't-have-that-conversation topic'.

Two divergent framings of the population growth challenge were present in our data. Representatives of environmental and recreational organizations tended to interpret this challenge in terms of excessive water consumption, as evidenced by the fact Utah has one of the highest per capita municipal water consumption rates in the country. In their view, Utah has sufficient water but meeting future needs requires using the water already developed wisely, as evidenced in the following quote:

> There is a preponderance of focus on supply. There is a lack of focus on demand. . . . Addressing demand is one of the most basic first steps we could take, [but] we refuse to even acknowledge that demand has any correlation or relationship to supply.

On the other hand, water managers from water conservancy districts or state and federal government agencies were more likely to frame the challenge as a problem of future shortages in water supply. In their view, Utah has reached its limit in water supply and the question has become where does the new water needed to support population growth come from, as evidenced below:

> But you can't conserve your way into the future. There just isn't enough water. It just won't work. . . . it's part of that package, but that's what you do [find new sources of water through infrastructure projects].

As we discuss below (see Proposed Solutions to Water Management Challenges), these two framings led to two different sets of proposed solutions by the different sets of actors.

The third nonclimatic challenge noted by nearly all interviewees was that water allocation is becoming increasingly political as more water uses are legitimated and new stakeholders' claims to water are recognized. The increased politicization of water allocation has made it more difficult to meet and balance the water needs of all users and to reach consensus among different user groups. Some interviewees argued such difficulty is caused partly by the fact that less water is available now than in the past and far more competition exists for the limited supplies.

Interviewees frequently noted managing water to meet the needs of the environment and people simultaneously has created a new water decision-making paradigm in which water decisions are increasingly driven by negotiation among water interests. Interviewees further noted reaching consensus among different water users and stakeholder groups is a major problem:

> I think sometimes one of the problems with water [management] is you have separate interests. You have agricultural interests, municipal interests, environmental interests, and whatever other interests that are subcategories of those. And they think that a good fight is better than understanding and coming to consensus about what ought to happen with water. And that's probably the biggest challenge that water managers have, is that those varied interests look after their own interest, rather than the interest of everybody.

The nonwater managers we interviewed shared this view and discussed its implications for water policy and decision making. They argued that reaching consensus has become increasingly difficult, although it was seen by all interviewees as a prerequisite to developing equitable and effective water policy and management. These interviewees argued "[the] ability to coordinate effectively among all stakeholders and to get all stakeholders to come to the table with real

agendas instead of position statements" may be the biggest problem water management in Utah faces. These nonwater managers identified the need for water managers to be "sufficiently inclusive in defining stakeholder groups" to ensure all interests are represented. However, water managers themselves argued that getting various publics to participate in the first place is a challenge to incorporating stakeholders into decision-making processes. As one interviewee described:

> When we talk and visit with people, when we prepare basin plans and present those plans, darn it, we'll have a basin plan meeting and nobody will come. So we're talking to the walls.

The fourth and final nonclimatic challenge noted by our interviewees relates to the aforementioned challenges, and points to the need for more equitable and effective policy to guide water transfers. As previously discussed, developing new water infrastructure to physically move water from Utah's rural areas to the highly urbanized WRMA is increasingly difficult. Thus, the majority of water managers we interviewed discussed the idea of transferring water from local agriculture to meet municipal demands, but in their view this approach changes water management decision making from an arena concerned with distributive politics to one concerned with redistributive politics, a situation in part created by agricultural water transfers increasingly becoming the new source of urban water supply.

Two problems related to water transfers were noted. The first relates to the need to develop an equitable process for determining how water transfers should be managed to ensure when water moves between users, sellers are granted fair compensation and impacts to other users and to the environment are ameliorated. Currently, about 80% of Utah's developed water is used in agriculture, and many agricultural water rights are held by private irrigation companies (Utah Foundation, 2014). Several water managers, agricultural professionals, and representatives of development interests believed transferring water out of these private irrigation companies or away from other agricultural users to municipal uses would entail major difficulties because the policies necessary to do so smoothly are not in place. This was exemplified by the following statement from one water manager:

> The problem that exists is that there isn't adequate compensation when it's occurring and we don't have a method to make it be adequate. I mean, we're starting to go into water markets a little bit more, but the markets in the state are not well-defined and they're managed by individuals who make their deals and they make money.

A second problem related to water transfers was noted by our interviewees who represent environmental, recreational, and agricultural interests. These interviewees were concerned water transfers would pose threats to accomplishing their goal of increasing the quantity of water reserved for Utah's natural environment (through instream flows and maintenance of lake levels). As one interviewee explained:

> The Farm Bureau has in their policy 'willing buyer, willing seller.' You can predict what's going to happen. All that water, all that land is going to go out of ag[riculture]. And that doesn't really necessarily help our interests, because our partners in many cases are agricultural users. They're the ones that have the flexibility to do some stuff, municipal to a certain extent, yes, but not as much. … Plus a lot of our best [wildlife] habitat is still in these [areas] – not in these heavily built up areas, but in agricultural areas.

While our interviewees representing environmental, recreational, and agricultural interests generally identified similar challenges as water managers, several differences also emerged. Specifically, the majority of environmental organization representatives asserted Utah's water is not being managed in a way that adequately supports wildlife populations, the Great Salt Lake, and other environmental uses. According to one state employee,

> Water planning processes are strongly biased to building more structures, to providing more water, the same amount of water or as much water as possible for each person, ignoring the environmental costs, ignoring the loss of species, ignoring the stresses and strains of various systems, various biological systems. They really don't care if they dewater a stream.

Several other interviewees argued water managers are oriented toward water development because the state strongly promotes economic growth, and they suggested such development and growth is at odds with the public good, as indicated in the following quote:

> What about the public trust doctrine? What about the common good and what about wildlife who have no vote with the Utah Legislature?

For interviewees representing environmental interests, making the environment a bigger part of Utah's water management discussions was identified as a challenge and an imperative. They noted a pervasive mindset in Utah that "any water that goes to the Great Salt Lake is water wasted." They frequently

cited the challenge of changing this mindset to one where the Great Salt Lake is seen as an inherently valuable ecosystem that needs to be protected. Associated with this challenge of changing public perceptions about the need to provide water for environmental uses were constraints posed by Utah's water law and policy in terms of allowing people to legally protect instream flows. With instream flows having limited legal protection and no legal provisions for protecting water rights for the Great Salt Lake, some interviewees expressed great concerns that "fish and wildlife populations would suffer, especially given climate change and population growth," and important ecosystems would remain unprotected.

Two Contextual Factors Interacting with Water Management Challenges

Our interviewees identified two contextual factors linked to and, in some cases, exacerbating the four major water management challenges discussed in the previous section (*i.e.,* identification of additional water supplies, population growth, increasingly politicized water allocation decisions, and lack of equitable and effective policy to guide water transfers). First is a general sense state legislators and stakeholder groups are less familiar with water issues than in the past. In relation to legislators, this decline in familiarity with water was attributed to a reduced number of legislators with agricultural or water management backgrounds and an increased number of legislators allied with development and real estate interests. However, interviewees had different interpretations of the consequence of such a shift in the state legislature. Some interviewees were concerned about water policy decisions being heavily influenced by nontraditional water interests in the state:

> We used to have several legislators. . .in the agricultural industry or they were water attorneys. They were involved [in water policy decisions] pretty heavily. [Someone] told me this year that 70% of our legislature is tied to the development industry right now. There is some real influence going on through the legislature about what we should do [with water]. We have lost a lot of our farming interests through the legislature [as well].

A few interviewees acknowledged such concerns but considered the shift in the makeup of the legislature as an opportunity, as one environmental organization representative stated:

> There is a concern about loss of a little bit of brain trust in terms of people that understand water in the legislature. I think that's a concern, but it's not an insurmountable concern. I mean people are going to learn this stuff as they go on. . . . [when I started] almost every leadership position was occupied by a rural legislator, because they've been there a long time and they get returned to office consistently. . .Now we have almost none. . .but is that a concern for us? No, honestly not really, because in some ways it's easier to work with the new faces than it is with some of the old guard.

In relation to the decline in familiarity with water among general stakeholders, some water managers we interviewed pointed out that stakeholders making claims to Utah's water increasingly fail to recognize water as a constitutionally recognized public trust resource that must be managed for the public good in a way that promotes cooperation between users. They also pointed out stakeholders frequently do not understand how their own use and appropriation of water impacts other water uses in the system, and thus they ignore the hydrologic interdependencies between users. Many interviewees attributed the difficulties they face to stakeholders' insular conception of themselves within the water system. As one noted:

> [Stakeholders] all seem to want to protect what is theirs and don't have a lot of understanding of how their water right relates to everybody else's.

In the view of water managers, this lack of understanding of the interdependencies between water users has fractured the water community and made management and policy decisions challenging. They saw a need for water managers to educate the public and various stakeholder groups about the water system and to develop strategies to catalyze knowledge building, as well as cooperation and coordination. However, this effort is largely an unfamiliar role for water management agencies and, as many interviewees noted, they are not trained to undertake it.

The second exacerbating contextual factor is the changing policy and legal environments for addressing water management challenges in Utah. Illustrative of this challenge is a series of controversies and changes enacted through Utah legislation and Supreme Court rulings over the past five years. Nearly all interviewees argued some of these policy changes would compromise water managers' ability to manage water for the benefit of the public good. While describing the details of various legislative bills and court rulings is beyond the scope of this study, we note here how our interviewees interpreted these changes and their broader implications for Utah's water law and policy context. In particular, we discuss one court ruling cited by nearly all interviewees

as being indicative of the challenges to developing a fair and equitable water transfer process in Utah. The ruling also exemplifies how certain water interests have attempted to change the basic prior appropriation tenets of Utah water law, which under Utah Code Title 73 holds: (i) all water in the state is public property to which water rights holders are granted usufruct rights; (ii) beneficial use is the measure and limit of rights to use water; (iii) proposed uses of water cannot impair existing uses or other more beneficial uses of water; and (iv) water rights are forfeited if the right has not been continuously put to beneficial use.

In 2011, a case brought before the Utah State Supreme Court (*Jensen v. Jones*) sought to change rules surrounding the retirement of unused water rights by challenging "the State Engineer's authority to declare forfeiture of a water right as the basis for denying a change application." Ultimately, the court held the State Engineer was not entitled to consider nonadjudicated forfeiture when making a decision about approval or denial of an application to transfer a water right to a new user (*Jensen v. Jones*, No. 20090742, October 28, 2011, 2011 UT 67).

According to interviewees, the *Jensen v. Jones 2011* court ruling significantly shapes their future decision-making space. In particular, the ruling potentially allowed formerly abandoned but sometimes senior water rights to be put back into the system when there was not enough actual water available to serve those rights without impairing existing rights that had been continuously put to beneficial use as required by state law. Concern was expressed that the ruling would allow development interests to buy up "paper water" and make abandoned or forfeited rights valid again, leaving it to market-based mechanisms or cities to decide how to mitigate the hydrological impacts and determine fair compensation. Several interviewees questioned how they could manage water because the ruling made it difficult to know how much water was demanded within the system. As one water lawyer noted:

> If people try to take all of this paper water right out there to put it to use, [and] there is not enough water…this complicates distributing water to those who hold later rights, especially in time of shortage.

Consequently, many interviewees argued that when a "bogus right" comes back into the system, water users who hold valid rights would be harmed.

From a broader political perspective, interviewees discussed this court ruling and other similar court challenges and legislative actions as the outcome of certain water interests seeking to reinterpret Utah's water law and policy to maximize their own benefit at the expense of the public good. Many interviewees, including both water managers and nonwater managers, felt these legal controversies signaled a changing political environment for addressing water management challenges in Utah, and represented "an erosion of the legal principle" that water rights are usufructuary in nature. Furthermore, they argued such court rulings indicated a movement toward water rights being treated as abstract property decontextualized from hydrologic interdependencies that shape the social-ecological context in which water is used. They also interpreted the controversies as a challenge to the long-held prior appropriation tenet of "use it or lose it" that guides the management of water in Utah and other Western states. Interviewees argued the water policy changes were creating a new model of water governance in which monetary interests drive who has access to and control over water, with certain sectors competing for water without consideration of how their water use would affect other users and the greater public good. As one water manager put it:

> [Utah's water law and policy is] going from beneficial use being the limit of the right to powerful actors paying lots of money for a water right and being able to obtain it just because a city wants it.

Legislative and court actions since the time of our interviews reveal these issues are far from settled. The 2015 Utah Legislature addressed the *Jensen v. Jones* case by reinstating some of the "gatekeeping" authority of the State Engineer to allow consideration of quantity impairment in change applications through House Bill 25. However, various bills to modify sections of Title 73 of the Utah Code indicate the balance between public and private rights to water and the policies that dictate how competing private rights and interests in water are handled will likely continue to change.

The Role of Climate Change in Water Management Challenges

In addition to the aforementioned nonclimatic challenges facing water managers and other water actors, climate change was frequently mentioned as a challenge by our interviewees, although different types of interviewees conceptualized the nature of problems posed by climate change in distinct ways. A majority of water managers stated climate change does not present a fundamentally new challenge or set of biophysical conditions but rather exacerbates the other management problems they are working to solve. In

their view, climate change will entail increased drought severity and higher year-to-year uncertainty. While most interviewees acknowledged climate change is happening and needs to be addressed, many of them argued Utah already experiences a large amount of interannual variability, with both very wet and very dry years being common and often occurring back to back. They also posited Utah's current water law and policy infrastructure are adequate for dealing with any water scarcity caused by climate change. This view was well characterized by one water manager who told us:

> So we are sensitive that there are changes coming, that there have been changes. Our general discussion is that we know there are going to be changes, but we know we are going to have to administer based on priority systems. When things drop, then junior appropriators are going to be cut off. . .we just say, 'Hey, if we drop 30%, here is where 30% cuts.' That is what we are going to have to do. We know we are going to have to plan for that, but more of it is just that there is a warning out there that we are going to have to be aware of [and] that you are going to have less water some years. You are just going to have to deal with it.

Furthermore, a majority of water managers characterized the problems posed by climate change as water availability and storage problems, biophysically similar to problems caused by drought. They noted climate change will cause shifts in the timing and availability of runoff as more precipitation falls as rain rather than snow and winter temperatures increase. Water managers noted these shifts mean there will be less snowpack to act as a natural reservoir, more water will be available earlier in the irrigation season when people need it less, and less water will be available in late summer when it is crucial for meeting multiple environmental, agricultural, and urban needs. As one interviewee stated, "climate change is just one more variable that affects the supply curve." Consistent with this framing, nearly all water manager interviewees argued Utah already has limited water storage capacity and these storage limitations will interact with shifts in the timing of precipitation to decrease annual water availability.

A minority of water managers stated climate change presents a fundamentally new challenge. They explained three forms of novelty introduced by climate change into the water system. First, several interviewees noted climate change forces them to shift from making primarily reactive decisions to a more proactive decision-making paradigm. They frequently mentioned climate change will need to be taken into account in future reports and planning processes. However, it is important to highlight the challenges interviewees associated with incorporating climate change into their planning and decision-making processes are driven as much by concerns over budget constraints and lack of time and personnel as they are by a lack of appropriate climate data and information.

The second form of novelty interviewees associated with climate change was it creates new uncertainties and interacts with and exacerbates other ongoing challenges such as population growth, the need for and cost of water development projects, and water quality issues, making their impacts more acute. As one water manager explained, climate change will intensify the population growth challenge for which they already have "to replicate the water supply that we have been working on for 150 or 160 years . . . in the next 30 years." Another water manager explained:

> Those new water projects, if we do put some of those variables in there of climate change, all of a sudden [they] become much bigger and more robust than they would have been otherwise, and cost a lot more money.

These statements reflect the fact water managers seem to assume per capita water use will remain static or increase into the future. Furthermore, they see little need to reduce per capita water use, thus ignoring society *can* adapt to climate change and population growth, in part, by changing social expectations surrounding how water is used. Similar findings have been reported from Arizona, where water managers were not generally concerned with per capita water use in the region but were concerned about increasing water supply to address future water challenges (Larson *et al.*, 2009). Interestingly, a more recent study by the same research group (White *et al.*, 2015) found a majority of water decision makers in Arizona expressed support for demand management, perhaps signaling a shift away from the supply-side orientation identified by Larson *et al.* (2009). However, such a shift was not observed in our case study in Utah.

The third form of novelty interviewees associated with climate change was, while the challenge posed by climate change may not be biophysically new, the solutions devised to deal with it will need to be. As one water manager stated, "I don't think it's a new problem. I think there's just going to be new ways to handle it." In this framing, the uncertainty climate change introduces into Utah's water system is not biophysical but rather social as hard-path engineering solutions, such as building new reservoirs or other water infrastructure projects, become less viable, and soft-path governance solutions such as

involving the public in deliberative decision-making processes, become the norm (Wolff and Gleick, 2002).

However, several water managers expressed concerns and were not optimistic about their ability to deal with water scarcity and increasing interannual variability related to climate change and other societal challenges. These water managers argued climate change poses not only a water supply challenge of ensuring adequate water is available to meet user needs but also a water demand challenge where institutional and policy infrastructure must facilitate cooperation between users exercising different demands. As one interviewee stated:

> [With climate change] I think they [stakeholders] are going to have problems, because everybody is going to be demanding their portion that they had associated with their property and their stretches of streams. It is just not [about] providing, but also how does everybody work together? How do you know who gets to have what?

When comparing the views of our water manager and nonwater manager interviewees, four differences emerged. First, in contrast to the position held by the majority of water managers, all interviewees who represent environmental and recreational organizations posited climate change presents a new set of challenges to Utah's water system. In part, this is because they viewed climate change in the context of multiple interacting natural resource management domains, as explained by one interviewee:

> It is going to happen in different conditions and different places than we are used to dealing with. You will see it in more fires and the kinds of things that wildfires lead to, sedimentation and flashy runoffs after storms and clogging the river, the tributaries or reservoirs.

Second, nonwater managers viewed water storage differently from water managers, even though they generally agreed Utah's current water infrastructure is inadequate to deal with shifts in the timing and availability of runoff associated with climate change. Specifically, environmental and recreational organization representatives viewed Utah's current reliance on surface water storage infrastructure as an inadequate water management strategy given the hotter and drier conditions and increased evaporation rates associated with climate change. Several of them pointed out the limited discussion on climate change in various water meetings held across the state in 2014 is indicative of how the problem is not taken seriously in Utah. They argued water managers and the state legislature are in denial, and worried if action was not taken soon, problems will ensue:

> I think the latest projections we have seen, that are sort of the collective consensus of studies on the Colorado River, are that we are going to see a 20% reduction in flows over the next period of time. Well, 20% is a lot, but it is not an impossible amount to accommodate. We can live within 20% less if we all get about that effort now. If we piss away the time and don't do anything but argue amongst ourselves for the next 20 years, then maybe we are going to have a problem here on the water side. (Note: a recent review of research conducted in the Colorado River Basin indicates the reduction in flow will likely be closer to 9% (Vano *et al.*, 2014)).

The third difference is nonwater managers frequently discussed their concerns about impacts of climate change on the Great Salt Lake and fish and wildlife populations, whereas water managers' comments were focused on outcomes for humans. They noted increased droughts and floods will put certain fish populations at risk, and climate change will exacerbate the negative effects of river fragmentation on cold-water fish populations. Another concern was climate change will potentially have major impacts on the Great Salt Lake's fish, bird, and brine shrimp populations by changing the amount of water flowing into the lake and altering salinity levels. They also argued it is not only climate change itself that presents threats to the environment but also the way humans decide to adapt to it:

> If you take the people out of the equation, the rest of these ecosystems will adapt pretty well. There are innumerable buffering systems in natural ecologic systems that protect against really sharp changes. But you introduce people into the equation and you get wilder swings and the systems just don't have time to adapt to the changes. So if we start building dams and dewatering rivers, that doesn't give the plant community a chance to shift to less water-demanding species. It doesn't give critters, animal populations, a chance to move elsewhere to find water where they can. Humans introduce really dramatic and quantum shifts.

The fourth and final difference between water managers and nonwater managers is they viewed the role of potential crisis or catastrophic events differently. Several water manager interviewees argued:

> When we have our crisis, it will probably change people's opinions about the value of reservoirs and storage.

However, environmental and recreational organization representatives tended to argue crisis would invoke a paradigm shift in water management away from existing engineering solutions toward strategies more inclusive of environmental water needs:

> Crisis is going to sharpen the mind. If we have more years of drought like we have had, people will demand leadership and will acknowledge we have to change. The water managers should be hoping for another drought, because it gives them the chance to move us into the next chapter of understanding what we are doing [with water] and to change our [management] systems and change our thinking.

These interviewees' belief that crisis will be necessary to induce change is similar to findings in other studies (*e.g.*, Wyborn *et al.*, 2015). However, as one federal water manager noted, waiting for a crisis to occur to act on climate change is problematic:

> We wait until it breaks. That is a very American way of doing things. We wait until it is a crisis and then we are going to throw resources at it. But the problem is you can't do that with water [because water projects take a long time to develop].

Proposed Solutions to Water Management Challenges

In this section we report the results from our interview questions about planning for and adapting to future social-ecological change. As noted above, because the challenges climate change and population growth pose to water management were framed differently by the various actors we spoke to, each framing led these actors to suggest distinct solutions to the challenges they elucidated (see Brugnach and Ingram, 2012). In our interviews with water managers about what needs to be done, five interrelated solutions themes emerged.

The first solutions theme relates to how our interviewees perceive the need for more water development projects (*i.e.,* "an old-paradigm solution") and the potential for water conservation to address water management challenges. The most frequently mentioned solution was to build more storage and "develop more water." Most water managers noted to accommodate projected population growth and ensure per capita water use equivalent to what Utah has become accustomed to, municipal water supplies would need to be doubled in the next 30 years, and climate change would only exacerbate this need. As one water manager noted, "most [climate change and population growth] scenarios mean we need more storage." In contrast to this identified need for water development projects, their view on water conservation as a potential solution was much less sanguine. Nearly all water manager interviewees acknowledged water conservation and increasing water use efficiency are important but inadequate for addressing future climate change and growth-related challenges. As one manager declared, "[I just] do not know how to make things better without additional storage." Interestingly, this argument that climate change is "all about storage" was prevalent across our interviews with water managers, even though nearly all of them stated elsewhere that building new storage projects was financially, politically, and socially difficult.

In contrast to the view of water managers, nearly all interviewees representing environmental and recreational organizations posited a stronger commitment to water conservation would yield enough water to solve most of Utah's water problems into the foreseeable future. Relatedly, many of them argued water managers are unable to think outside of the old paradigm in which supply-side engineered infrastructure, such as surface storage reservoirs, is seen as the only solutions to water shortage challenges. As one interviewee explained:

> The old guards who have been working in water for decades want the same solutions ... a new supply, new projects, more dams, more diversions from the rivers ... to solve the problem. It really seems a lot of that won't change until you get the next generation of water managers to come and step in.

Furthermore, in comparison to water managers, nonwater managers were far more likely to suggest demand-side solutions, including increased water rates and tiered pricing structures, to reduce per capita water consumption.

The second solutions theme to emerge from our interviews relates to how strategies to address growth-related challenges were discussed. As previously noted, population growth and Utah's imperative for economic development were mentioned as major water management challenges. However, solutions to the problem of growth itself, as opposed to solutions that would accommodate growth, were rarely explicitly discussed by interviewees, particularly among water managers. When asked about what can be done to address growth-related challenges, water managers consistently posited engineering solutions, such as increasing water storage, as the only path forward rather than pointing toward solutions based on conservation, policy, and planning to shape growth-related trajectories differently. In part, the favoring of engineering solutions can be explained by the fact

that population growth in Utah is somewhat of a political third rail. Indeed, one long-time environmental organization representative pointed out shifting water managers' attitudes away from a mindset that growth must be accommodated through water development is of prime importance to solving Utah's water challenges. The absence of considering limits to growth in proposed solutions is noteworthy, given that providing water for a growing population was defined by most interviewees as the central challenge they face and that our discussions about challenges often centered on issues related to how much should Utah grow, where, and what that growth should look like.

The third solutions theme relates to a need to develop solutions for mediating conflict inherent in managing water for varied and often competing interests. As noted above, some managers believe facilitating cooperation and mediating conflict between stakeholders is equally important to determining how to provide Utah's growing population with water in the face of a changing climate. According to one manager, solutions to providing water for relatively new uses such as instream flows within the context of climate change and population growth need to go beyond typical engineering solutions. Instead, solutions need to foster deliberative discussions between stakeholder groups and among Utah's public to decide how water can be used in ways that meet the needs of all stakeholders without causing too much injury to any particular stakeholder group:

> We have to understand each other's needs and learn to subordinate our wants to others' needs if we are going to put in place institutions that facilitate cooperation. The question is how to create institutional trust between stakeholder groups so people are aware of each other's needs and the acceptable solutions to scarcity before crisis happens. There are a lot of stakeholders and it takes a lot of time to build up trust and listen to their ideas and reach a consensus about how to manage water in a way that is fair and doesn't cause excessive harm to any one group.

Related to the argument that Utah's water law and policy need to be adapted to facilitate cooperation between stakeholders was water managers' argument that it is imperative to fix problems introduced into the water transfer process through court cases such as *Jensen v. Jones*. In particular, our interviewees argued water transfer policies need to ensure adequate compensation is provided to all involved parties so everyone "remains whole."

While the need for fair water reallocation was commonly supported, interviewees disagreed about the best mechanism to determine how water reallocation decisions should be made and what Utah's water and landscape future should look like. Interviewees who represented development and legislative interests frequently posited market-oriented solutions to resolve conflict and allow for a diverse set of water needs to be met in a way that reflects monetary values society places on each water use. They also tended to support the argument water rights should be formalized as a private property right rather than being usufruct rights held as part of a public trust.

Several interviewees questioned this way of thinking about water and instead argued it is the public that needs to make reallocation decisions and determine how the public good should be realized through ways water is put to beneficial use. These interviewees expressed several concerns about privatizing water rights well reflected in the literature. For example, applying individuated property rights and market-based solutions to common-pool resources could lead to declines in the resource's sustainability through increased overuse and conflict (Mansfield, 2004; Robbins *et al.*, 2012). Similarly, market-based solutions and firmer property rights could make it possible for actors with high caches of financial and political capital to control local decision-making processes, shutting out local voices of people who lack these capitals, as well as the interests of state and federal government (Beder, 1996; Robbins *et al.*, 2012). Furthermore, when monetary valuations of water are used to solve water allocation challenges, "equity, sense of place, and communal values related to water" often lose out, especially in rural places (Ingram, 2013).

A number of our interviewees recognized the above arguments, as well as a "willing buyer, willing seller" approach to water reallocation decisions may redistribute water in ways that ignore third-party effects or are anathema to the public interest. They also argued Utah lacks an appropriate deliberative decision-making forum where a functional and fair decision-making process can be undertaken to decide and manage Utah's water future. As we were conducting our interviews, Utah Governor Herbert appointed six water experts to oversee and attend eight "public listening sessions" across Utah and produce white papers on the results (http://www.utahswater.org). These "public listening sessions" initiated a statewide effort to involve Utah's diverse public in sharing their concerns about water challenges and charting Utah's water future. While such an effort holds promise, many interviewees admitted public involvement needs to go further. A number of our interviewees shared their pessimism about how public input from these meetings would be used and to what effect. They noted that to provide usable information, public decision-making fora need to be designed to do more than solicit brief, one-time input. Concrete steps need to be laid out in advance

that detail how public input will be incorporated into long-term decision-making processes, and how conflicts between the needs and wants of diverse publics will be mediated. In short, this position points to a need recognized by all interviewees to develop the long-term and transparent *political infrastructure* necessary to balance water use across interests and compensate losers fairly to achieve a water future in Utah that mitigates stakeholder conflict and injury to the greatest extent possible.

The fourth solutions theme present across our interviews was the question of what the public's role should be in solving water management challenges. It was frequently mentioned that the public needs to be educated about water law and policy, hydrology, and the role they can play in water conservation so they become more efficient water users. More importantly, our interviewees frequently accorded the public a more prominent role in water management adaptation decision-making processes. A majority of interviewees noted that without direction from the public to determine Utah's "desired landscape ethic" (*i.e.*, what Utah's landscapes should look like in the future) and their assistance in delineating water wants *v*. water needs, water managers would not know what values, preferences, and priorities to manage for in the water system. For example, interviewees noted a deliberative decision-making process is needed in which the public provides direction on how much agricultural *v*. urbanized landscapes Utah should have, and whether or not Utah should continue to provide water for municipal outdoor landscaping to support lawns and nonnative trees. In addition, while most interviewees framed the challenge of population growth as determining how to supply water to meet growth-related needs, a few interviewees framed the challenge as how the State of Utah can begin a discussion on limiting population growth. One water lawyer asked:

> If Washington County is going to get up to about a third of a million people, are you going to try to give them a drink or are you going to just close the doors and say, no, we don't want [people] anymore?

Water managers' declaration that water-related issues such as population growth and urban landscape design need to be decided by the public arose from their conviction that their role is to "secure, preserve, and protect" the uses of water determined by the broader public. In this way, water managers positioned their decision-making authority as being located within the decision-making space the public carves out for them, rather than defining for themselves the nature of their decision-making space. As several water conservancy district personnel noted, their charter is to provide water as demanded by their wholesale customers, so entities such as cities need to decide what the demand for water will be. As one water manager explained,

> We can't sit up in our office and make those decisions for the public... we have to get feedback on what's acceptable and what is not in terms of how much water we allow them to have in their yards... [We cannot say], 'as of next year we're going to plan for cactus and gravel' ... that isn't the water district's decision.

So far, our results are in line with recent research calls for a new paradigm in water management to promote collaboration and planning across sectors (Gober *et al.*, 2010) and incorporate diverse stakeholders and the public into participatory decision-making processes (Pahl-Wostl, 2002). However, our interviewees also pointed out several reasons why engaging water users in these deliberative discussions is difficult. For example, many of the threats future water scarcity poses are to landscape features of high cultural value to the public, such as trees and lawns, and moving away from them to what a water manager termed "responsible landscapes" was seen as an intractable problem as it would require "huge cultural shifts." High turnover in local government leadership was also pointed out as a barrier to engaging cities and towns in more continuous and effective lines of communication with water conservancy districts. Furthermore, several managers noted when they tried to encourage public involvement in water planning in the past, participation was low. Finally, as previously discussed as part of the third solutions theme, organizing meaningful public deliberation is no easy task as many people are not interested or unable to participate.

The fifth and final solutions theme to emerge from our interviews was a major lesson learned by water managers for mitigating drought impacts: it is best to allow the impacted community to decide on the policies and steps to take in response. This result echoes what has been discussed in previous research (Ender-Wada *et al.*, 2009; Welsh *et al.*, 2013). As one former water manager told us:

> I learned a long time ago that if you talk about something, you can sit in your desk in Salt Lake City and say, this is what should happen in Koosharem. But the best thing to do is go to Koosharem and talk to those people and say, what have you done in the past and how did grandpa handle this? Then you start to resolve the real issue. That is public awareness and the public involvement in solving the problem.

However, several of our interviewees questioned whether or not state-level water decision makers are sincere in their claims they need public input to decide on Utah's water future. Some of them characterized the water management decision-making process as opaque and nontransparent, with water managers acting as if they know the best course of action and being unreceptive to outside suggestions. As one environmental organization representative stated:

> They are looking for input as if no one [has been] giving input, right. . .But boy we have been giving this input for decades and it is not reflected [in their water management decisions].

The Path Dependence of Water Management Dilemmas and Decisions

Our interview results call attention to several dilemmas faced by Utah's water managers that complicate adaptation decisions. In this section, we employ the concept of path dependence to lend insight into the nature of the primary decision-making dilemmas discussed in our interviews. Our results highlight how these dilemmas might in fact provide a space for changing the old water management paradigm and pursuing a new, more sustainable water management path.

Building upon Pierson's (2000) concept of path dependence, Utah's water system exhibits three features that render it path dependent and subject to increasing returns. First, when large up-front, fixed costs, as well as recurring maintenance costs are associated with the physical infrastructure such as the dams and reservoirs on which water management relies, there is a strong incentive to continue to invest in the same type of physical infrastructure (*i.e.,* repairing, replacing, redesigning, and expanding it). As previously discussed, when asked what needs to be done to adapt to climate change and meet future water demands, the near unanimous response from water managers was additional water storage and infrastructure development. The development of water storage in Utah has been an adaptive response to high year-to-year variability in water availability. Through building storage facilities, water managers have been able to store water in wet years and use storage water to supplement natural flow in dry years. Significant money and time have been invested in the physical and institutional infrastructure to operate water systems in this way. Although a number of water managers simultaneously questioned whether continued development of this type of physical infrastructure is viable given social opposition and lack of federal funding, these interviewees generally struggled to imagine alternative solutions, and several pointed out whatever alternative solutions there may be would be subject to political and social resistance (*i.e.,* high start-up costs). Thus, a paradox arose in our interviews, pointing to a major dilemma facing Utah's water system: discussions on the need for a new water management paradigm were common but no alternative paradigm was presented or indeed even seemed possible.

This paradox is related to the second feature of path dependence exhibited in Utah's water system that helps to explain why Utah water managers have difficulty either switching paths or identifying solutions which fall outside the current path of reliance on storage and delivery infrastructure to solve water management challenges. In part, alternative paths would force water decision makers to face qualitatively different types of decisions than they have made in the past, and these decisions would have high start-up costs that they may or may not be able to deal with effectively. Significant investment has been made to develop not only physical infrastructure but also the knowledge and data streams required to operate the storage systems in ways that meet current expectations of water users. As water managers accumulate knowledge about their water systems, they tend to become more effective at managing those systems, engendering increased returns in further investment in their continued use. Such investments in specific skill sets on the part of water management agencies to operate the current systems further increases the "attractiveness of existing institutional arrangements relative to hypothetical alternatives" (Pierson, 2000, p. 259). In addition, institutional infrastructure in the form of laws and policies such as prior appropriation have been developed and modified to determine how water is distributed among users in times of shortage. Because the development of current institutional rules to govern water delivery and use entailed high start-up costs (mostly political and social), a strong incentive exists to maintain rather than change these rules and incur transition costs, even if such rules may have become insufficient to address current and future water management problems.

A third feature of path dependence exhibited in Utah's water system relates to both the coordination and learning effects between water users. According to Pierson (2000), coordination effects happen as water users increasingly participate in the water system and use existing infrastructure and as investments in infrastructure increase, which in turn increases the number of individuals and organizations who use and rely on it. In the case of a public good such as water on which many users rely, one outcome of these coordination effects is a complex set of hydrological interdependencies. Relatedly, learning effects, or the knowledge water users gain about using the system, also create

increased returns. Not only have water users come to understand the rules and how the water system works, but through these rules a series of expectations on the part of water users have become entrenched. According to Pierson (2000), even the mental maps, ideologies, and social identities of individuals as they relate to water are subject to increasing returns, which makes alternative paths difficult to pursue. Several of our interviewees suggested Utah's public has certain expectations about what the urban and suburban landscaping should look like, how water should be delivered, and for what water can and should be used. In particular, the public has come to expect reliable, inexpensive water without having to think about the systems that deliver it. As one water manager stated:

> We have done such a good job of providing a 24/7, safe, reliable supply, that no one thinks they ought to pay anything for it.

Other interviewees extended this statement to explain why public awareness of water issues is so low, arguing their success at delivering water has rendered the process of water management nearly invisible to the public. Thus, the public expects water to be provided with minimal participation in the decision-making and funding processes. These results point toward the path-dependent expectations harbored by most of Utah's public that may make incorporating alternative public opinions regarding sustainable water planning and catalyzing behavior change among water users even more challenging.

The current institutional rules to govern water delivery and use and attendant expectations of guaranteed water have allowed for investments in agricultural enterprises and urban property development, among other things, creating dependencies on the existing set of rules and rights across multiple sectors. Changes in the rules and rights that govern Utah's water system create uncertainties about how an alternative water system would work and what the future viability of investments made based on the existing path would be. Such coordination and learning effects lead to an important dilemma elucidated by our interviewees, which was the recognition that any solutions implemented to address climate change and population growth will likely require new institutions and policies, which will be costly, will need to deal with complex social interdependencies between water users, and will entail tradeoffs between water uses, including the environment. As was noted repeatedly in our interviews, Utah currently lacks the political infrastructure to undertake the process of negotiating these tradeoffs efficiently and equitably, creating a situation where pursuing an alternative path would entail high start-up costs while benefiting certain water users at the expense of others.

The path-dependent nature of water management dilemmas and decisions is not unique to Utah. Ingram and Fraser (2006) provided a detailed account of how water systems in California are also path dependent. They used the example of water policy changes related to the San Francisco Bay Delta Watershed to demonstrate circumstances under which, instead of gridlock and crisis among various water users, sharp departure from past water policy was accepted. Specifically, they used punctuated equilibrium theory (Baumgartner, 2006) to explain the water policy change process, starting from exposure of policy failure, to problem reframing, to social mobilization facilitated by policy entrepreneurs, to the creation of public pressure for solutions, to casting a policy innovation as experimental, and to the eventual institutionalization of the policy innovation—the adoption of a market-based water transfer mechanism. However, even in such a "successful" case, subsequent observations reveal the transition has not been easy and significant controversies, such as debates over reengineering the California State Water Project, are ongoing.

In addition to this work, other policy research also offers insights into opportunities for switching paths or identifying solutions outside the current path. For example, Easton (1965) suggested that a political system responds to both "demands" arising from within the system and from the wider environment. Thus, a political system is self-motivated to distribute resources in ways that maintain both "specific" and "diffuse" support from members of the system (Easton, 1975; Burns *et al.*, 2013). As the population and the number of legitimized, nontraditional water uses in Utah continue to grow, water managers and the broader political system within which they operate will face various competing "demands," which will stimulate competition in the political system, leading to a cycle of changes and feedbacks. Even though we cannot predict based upon our results how various competing water demands will interact and produce policy "outputs" over time, our results reveal a need for more equitable institutional arrangements and policy infrastructure to facilitate cooperation, examine a wider array of water management alternatives, and mediate conflicts between water users.

CONCLUSION

Our study provides insights into the challenges facing water managers and other water actors, including identification of additional water supplies,

population growth, increasingly politicized water allocation decisions, and lack of equitable and effective policy to guide water transfers. Climate change was also identified as a water management challenge, although it was conceptualized differently by various types of water actors. Importantly, these climatic and nonclimatic challenges were seen to interact with various political and social factors to exacerbate Utah's water challenges. In particular, state legislators have become less familiar with water issues; the public does not have an adequate understanding of the hydrologic interdependencies between water users that would enable them to understand their own needs in relationship with others; and recent court rulings and policy changes regarding water transfers further reflect a changing state legislative environment responding to multiple challenges of urbanization and population growth. Several solutions were discussed by our study participants. However, these solutions mostly reflect "an old paradigm" which relies on water development projects to address growth-related water management challenges and undermines the potential for promoting water conservation and changing water user expectations and behaviors. Furthermore, it became clear a path forward to mediate conflicts inherent in managing water for varied and often competing interests, and to determine and facilitate the public's role in solving water management challenges, is needed if a new water management paradigm is to be realized.

In this study, we used the concept of path dependence to help interpret our results and to counter reliance on the information deficit model (Sturgis and Allum, 2004), which tends to use lack of belief in or information about climate change to explain the inertia apparent in adaptation to climate change and population growth in Utah and the broader arid and semi-arid Western U.S. Path dependence suggests high economic, social, and political transition and start-up costs are entailed in developing new infrastructure, institutions, skills, expectations, and forms of social understanding between water users required to adapt to social-ecological and climate changes.

Our study demonstrates the water management challenges Utah faces transcend the traditional jurisdictional and knowledge capacities and boundaries of water management institutions in Utah. Dealing with the risks posed by the interacting stressors of climate change, population growth, and changing water policy will require water managers and other decision makers to confront a qualitatively different set of decisions than they have made in the past. Our results show water managers tend to fit problems such as climate change and population growth into the solutions enabled by the existing path rather than entertain options for developing a new path to solve them. Indeed, the increasing returns associated with the old paths and the high start-up costs that would attend reversing the current water management paradigm help to explain why, as one water manger put it, "we continue to look in the wrong direction for the right answers." However, as water managers' ability to engineer their way out of growing water crises reduces over time, finding other ways to address water scarcity and the tradeoffs posed by the water reallocation process will become increasingly important.

It is clear from the debates that played out in our interviews that many of the dilemmas facing Utah's current water management path are acknowledged and that various water actors recognize the need to consider possible alternative paths. The intent of highlighting the path-dependent nature of Utah's water system is not to suggest the current path is irrevocably locked in place. Rather, by pointing out the dilemmas inherent in changing the current water management path, we hope to call attention to the processes that create increased returns and to provide insight into potential change opportunities in the water system where adaptation can occur *if* strategies can be developed to decrease the costs associated with switching paths. In addition, as our study shows, the economic, environmental, social, and political costs associated with continuing down the current water management path that heavily relies on new water infrastructure have increased over time. Who bears such costs has also changed, from subsidization from the federal government to being largely borne by Utah citizens at a time when they confront budgetary tradeoffs related to multiple growth-related challenges, including air quality, transportation, education, preservation of agricultural land, and other issues. By taking a holistic, hard look at the real costs of continuing down the current path *v*. switching paths, society may realize that at some point in time the costs of continuing down the current path will become higher than the costs of switching paths, and under such circumstance a window of opportunity for change would emerge. Another insight from the path dependency literature is the significance of decision-making points. Utah is currently involved in a high-level, structured policy decision-making process concerning its water future, which provides an opportune time to comprehensively consider the long-term costs involved with various paths forward.

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