"We Got in the Pilot Program to Learn from It:" Features of Social Learning in Drought Contexts along the Arkansas River in Colorado

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ABSTRACT: Unintended consequences from decisions made in one part of a social–ecological system in response to climate hazards can magnify vulnerabilities for others in the same system. Yet anticipating or identifying these cascades and spillovers in real time is difficult. Social learning is an important component of adaptation that has the ability to facilitate adaptive capacity by mobilizing multiple actors around a common resource to manage collectively in ways that build local knowledge, reflective practices, and a broader understanding of contexts for decisions. While the foundations of social learning in resource management have been theorized in the literature, empirical examples of unintended consequences that trigger social learning are few. This article analyzes two cases of drought decisions made along the Arkansas River basin in Colorado; in each, social learning occurred after actors experienced unanticipated impacts from others' decisions. Methods include interviews with actors, both individual and institutional representatives of different sectors (recreation, agriculture, etc.), and a review of relevant historical and policy documents. The study identifies four features of social learning that aided actors' responses to unanticipated consequences: governance structures that facilitated more holistic river management; relationship boundaries that expanded beyond small-scale decisions to capture interactions and emergent problems; knowledge of others' previous experience, whether direct or indirect; and creation of spaces for safer experimentation with adaptation changes. Results identify empirical examples of actors who successfully learned to adapt together to unexpected consequences and thus may provide insight for others collectively managing drought extremes.

KEYWORDS: Social Science; Drought; Adaptation; Communications/decision making

1. Introduction

Drought is a chronic and complex issue for much of the western United States. Vulnerability to its impacts is multifaceted and inextricably confounded by the details of social institutions, trade agreements, differential access to markets, the degree of economic competition and the sensitivity of an industry to drought (Leichenko and O'Brien 2002; Adger et al. 2005). Additionally, how decision-makers—be they individuals, organizations, or governments—choose to manage drought can unintentionally generate differential outcomes that reduce adaptive capacity for others in the same social–ecological system (SES) (Pulwarty 2003; Adger et al. 2005; Harris 2009; Goldman and Riosmena 2013). It is often difficult to anticipate precisely which actions may negatively impact others through unintended consequences or will create maladaptation over time (Magnan et al. 2016; Atteridge and Remling 2018).

In drought management contexts, adaptation—or an ability to withstand, absorb, and mitigate future stressors (Adger et al. 2005)—can take many forms. Some adaptation activities focus on single scales, such as reducing demand through conservation or efficiency measures or creating new governance arrangements that enable effective responses to drought in the moment. Others span systems, such as common decision rules that allow actions to be taken in a drought across connected but separate water systems for quicker and more consistent action when drought arises (Smit and Wandel 2006; Engle 2013; Grothmann et al. 2013; Dilling et al. 2019). The scale of how adaptation actions are constructed and evaluated can mask the implications of particular actions on others (Dilling et al. 2015). Adaptation, then, is not a static outcome or set of actions that once completed are final. It is iterative, requiring decision-makers to engage processes that allow for swift detection of emergent problems and ongoing, reflective decision-making (Bours et al. 2014). At its most successful, adaptation is also generative (Grandori 2020), facilitating adaptive capacity and transformation of a system beyond one that merely "bounces back" to the status quo (Few et al. 2017). Adaptive capacity, then, is "the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (Levina and Tirpak 2006, p. 9). How a system takes advantage of opportunities or copes with consequences can be challenging when multiple motivations, decision contexts, and resource needs are at play.

Social learning has emerged in the climate change adaptation literature as a framework for building just this sort of potential. Through a process of "learning together to manage together" (Mostert et al. 2008), social learning facilitates the ability of actors bound by a common potential threat to build the capacity to be reflective about various needs and to

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nimbly respond to surprises throughout the adaptation process (Fisher and Dodman 2019). Local knowledge aggregated over time and from different perspectives can help minimize tradeoffs and unintended consequences before they emerge (Koontz and Johnson 2004; Berman 2017; Natarajan 2017). While there is growing evidence in multiple areas of resource management about the value of social learning in adaptation processes (Kumler and Lemos 2008; Ananda et al. 2020) and the need to remove obstacles to its success (Mostert et al. 2007; Ernst 2019), research suggests that there is a gap in identifying empirical examples of those circumstances that trigger this collective understanding (Van Epp and Garside 2019). Our research asks the following questions related to such triggers: What role do unintended consequences generated by drought decisions play in social learning? And what features of social learning facilitate adaptive capacity and mitigate future unintended consequences?

In what follows, we explore two case studies in the Arkansas River basin in Colorado as empirical examples of social learning. In both cases, local actors working across sectors have successfully mitigated maladaptive processes that, at one time, unintentionally magnified harm to others. Specifically, we identify four features of social learning that facilitated this adaptive capacity: first, collaborative governance structures that facilitated more holistic river management; second, relationship boundaries that expanded beyond small-scale decisions to capture interdependencies and emergent problems; third, collective knowledge based on previous experience, whether direct or indirect; and fourth, spaces for safer experimentation with adaptation activities. We discuss how these features highlighted local connections ahead of time and helped actors anticipate and manage negative unintended consequences more effectively and equitably in their communities. Our aim is to help others evaluate adaptation options available to them in real time to better plan for a changing climate.

2. Theoretical framework

Social learning originates in theories of psychology and organizational development literature, which emphasize process-oriented rather than goal-oriented outcomes in the management of uncertainty and change (Bandura and McClelland 1977; Pahl-Wostl 2002; Hinkel 2011). For actors central to the learning process (e.g., stakeholders of a particular resource), these theories identify a match, or lack thereof, between the intention of the actor's decision and outcomes of action—what are known as single loop (matched) and double loop (unmatched) learning (Diduck et al. 2005). Unmatched processes create errors that may materialize as unintended consequences, externalities, or spillovers (Adger et al. 2005), which must then rectified. Correcting mistakes through collective action involves identification of values, sites of misalignment, alternative actions, and conflict resolution to enable actors to "encode" cocreated knowledge in social memory (Diduck et al. 2005). Since its appropriation by scholars in resource management as a framework for mutual governance of common resources and stakeholder engagement (Reed et al. 2010), social learning has become increasingly central to theorizing about adaptation efforts at local, community, and statewide scales.

Key to social learning is the notion of "managing together to learn together" (Cernesson et al. 2005; Ridder et al. 2005) and doing so within a particular context (Mostert et al. 2007). Applications to SES research suggest that social learning is an important facet of adaptation building within "communities of practice" (Armitage 2005; Pahl-Wostl et al. 2007), increasing adaptive capacity through reflective decision-making across scales (Hinkel et al. 2009), and flexible governance mechanisms (Ananda et al. 2020). As with many conceptual frameworks, social learning is polysemous, resisting rigid definitional and theoretical articulations (Reed et al. 2010; Siddiki et al. 2017). Some studies emphasize the mechanisms of collaboration used to generate social learning, such as participatory environmental processes (Ernst 2019); others highlight the various contexts and processes for which collective learning takes place, such as workshops around water management in food security (Van Epp and Garside 2019) or sustainable development (Kristjanson et al. 2014). For our purposes, we define social learning similarly to Reed et al. (2010) as "a change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks." We also use the term "actors" to mean those with decision-making power within the two communities of practice that form the basis of our case studies.

In arguing that social learning is a tool for building adaptive capacity, scholarship highlights important common features. For instance, the ability of an organization to be flexible and experiment has been suggested as a key aspect of adaptive capacity for resource management (Pahl-Wostl 2002, Engle 2013, Armitage 2005; Dietz et al. 2003). Likewise, issues of adequately matching scales of assessment and management, understanding cross-scale dynamics (Cash and Moser 2000), and accounting for institutional interplay (Young and Gasser 2002) are also important considerations for successful mitigation of tradeoffs. Sites where social learning occurs are equally important. Institutions can both inhibit and facilitate transformational outcomes in response to change, and thus can play a role in accelerating the processes that contribute to social learning and adaptive management, if organized to do so (Pahl-Wostl 2002, Armitage 2005). Importantly, social learning as a normative outcome should improve the impacts within an SES and build resilience to future disturbances, whether external or internal (Cumming et al. 2013). How such cascading impacts from others' decisions relate to social learning in real time is less well understood. Here our case studies offer two perspectives of cascading impacts as the trigger for social learning.

Theorizing about social learning often originates from analysis of intentionally constructed communities of practice that manage uncertainty around specific resources. To date, there is limited empirical evidence for how social learning emerges organically on the ground (Van Epp and Garside 2019). Further, few studies examine the motivations for communities to self-convene or the features of processes that help them learn how to learn or respond to maladaptation (Muro and Jeffrey 2008).

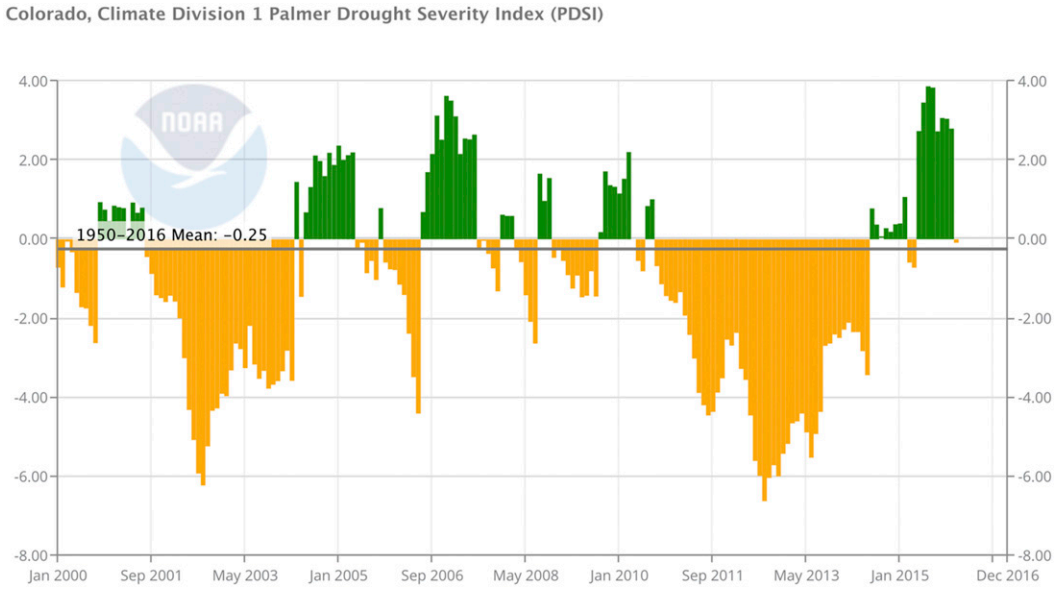

FIG. 1. A divisional time series graph of the Palmer drought severity index from 2000 to 2016 for the Arkansas drainage in Colorado illustrating the recent multiyear droughts of record, 2002–05 and 2012–14, which were the focus of interviews. The vertical axis reflects wet (+) and dry (−) conditions, with values below −3 indicting severe or extreme drought. The image is used through the courtesy of the NOAA National Centers for Environmental Information *Climate at a Glance: Divisional Time Series*, published May 2021 and accessed 28 May 2021 (https://www.ncdc.noaa.gov/cag/).

Our work fills this important gap by investigating empirical examples of social learning often only hypothesized in the literature. By analyzing two case studies, we identify unintended consequences that arose from decisions made during significant periods of drought in Colorado. Within each case, we then trace these cascades to their historical origins and contexts, revealing the mechanisms and motivations for social learning by actors within their respective communities of practice. Our analysis of these two cases contributes to the literature by illuminating those features of social learning that enable swifter, more holistic responses to unanticipated sources of harm.

3. Methods

We selected Colorado as our research site since some areas of the state had been recently impacted by two significant, multiyear droughts, the first during 2002–04 and the second from 2012 to 2014 (see Fig. 1). We used the U.S. Drought Monitor to identify regions of Colorado with persistent extreme drought designations during 2002 and 2012 (https://droughtmonitor.unl.edu/) and used the Social Vulnerability Index (SoVI) product that is freely available for Colorado to identify areas of higher social vulnerability (http://artsandsciences.sc.edu/geog/hvri/sites/sc.edu.geog.hvri/files/attachments/Colorado_0610.pdf; accessed 10 March 2017) and interfaces between urban/rural areas, the latter revealing potential tensions between communities over water use (Colorado Water Conservation Board 2015). A combination of drought severity, social vulnerability, and urban/rural designation led us to select Pueblo, Otero, Crowley, and Bent Counties, which stretch along the lower Arkansas River basin, as our entry points for data collection (see Fig. 2). Studying areas where actors would have significant experience with drought over time allowed our interviewees to reflect back on decisions they made, to note individual and community impacts they witnessed, and to identify others who might have been unexpectedly affected.

Much of the analysis presented is based on data collected by the lead author from 16 semistructured interviews with actors in the agricultural, industrial, private, and municipal sectors along the Arkansas River in Colorado, including individual farmers, water utilities, and company owners (Table 1). Interviewees were selected through a combination of purposive and snowball sampling, with a goal of collecting data from representatives of different sectors in the region who had experienced major impacts from one or more recent droughts. As the study evolved, we also expanded our interview sample using theoretical sampling, that is, seeking additional interviewees who might address theoretical gaps in knowledge (Draucker et al. 2007). From interviewee suggestions, the first author also attended events relevant to water use in the Arkansas River basin, including local agricultural tours and sector-specific conferences (Table 2). These events provided contextual insight into drought-related policies and management activities at various scales and helped to identify additional participants. Interviews were conducted over a 6-month period, from April 2017 to November 2017, and lasted an average of 56 min.

While the initial interviews highlighted several individual and community-wide impacts of drought in the Arkansas River basin, we attended specifically to those interviewees who offered insight into the unintended consequences of drought decisions on others. Based on initial analysis, we identified two

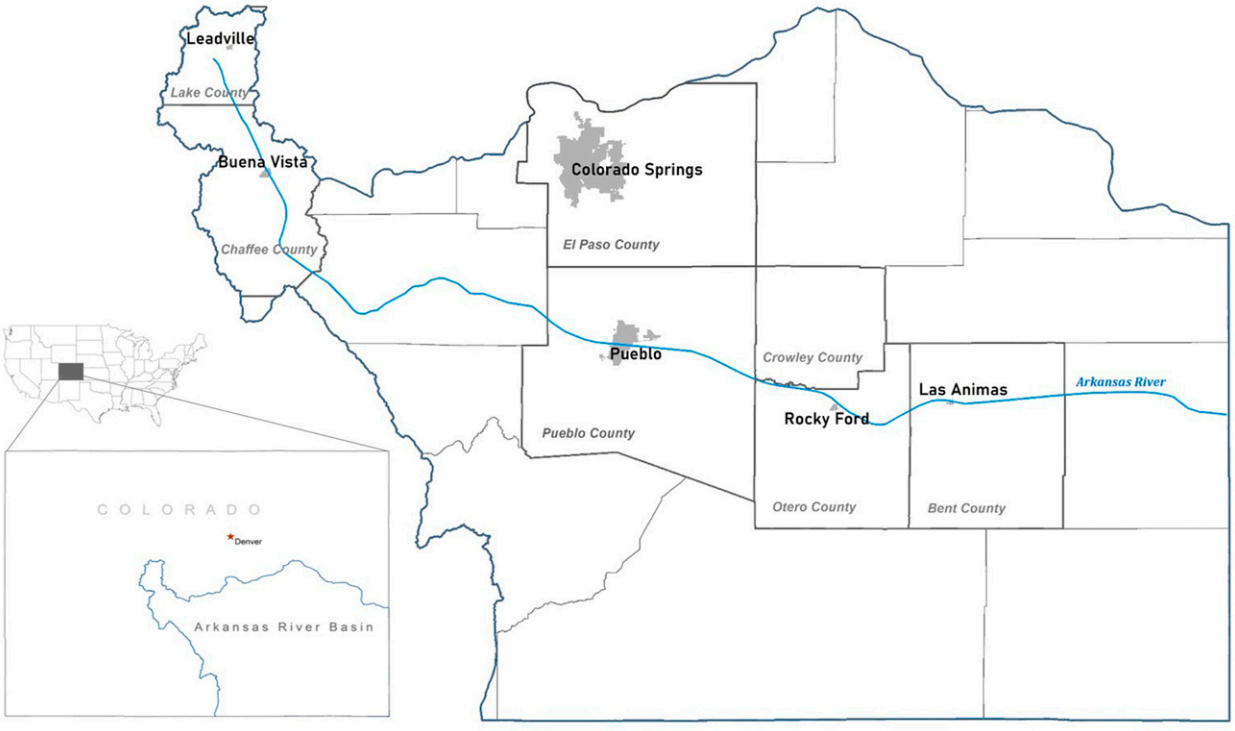

FIG. 2. The Arkansas River basin area of interest for this study, with the inset map showing the Arkansas River basin relative to the state of Colorado. The blue line indicates the Arkansas River, and the counties and towns indicate sites where data were collected.

examples that we then developed into more in-depth case studies. The first case involves decisions made by actors in Crowley County about water sales in the 1980s and 1990s, which have shaped experimental drought management strategies today along the lower Arkansas River; the second involves new collaborative arrangements made in the early 2000s between actors along a small stretch of the upper Arkansas River. Once these case studies were identified, we focused on developing them further through historical research, analysis of newspaper articles and policy documents, and additional interviews. Our aim in selecting these case studies and in gathering data to investigate them was to not to generate representative findings, but rather to develop deep, contextual understanding about small-scale but richly illustrative instances of social learning (Creswell et al. 2007). Thus, we triangulated in-depth data collection from multiple methods to build knowledge across sector perspectives and different spatial and temporal scales (Stake 2008; Fusch et al. 2018).

Interviews were audio recorded and transcribed. The transcripts were then coded by the lead author in NVivo software based on concepts, such as adaptive capacity and unintended consequences, as well as insights that emerged through the data analysis process, such as governance arrangements. Initial results from interviews helped the authors search for related documents to obtain complementary and cross-sector perspectives and to build deeper understanding of the dynamics within each case. For example, mention of the 2002 drought led the team to read state reports about its impact on agriculture in the Arkansas River basin and newspaper coverage of water sales in and around Crowley, which helped to clarify the details of impacts to communities mentioned by the interviewees. These documents, as well as notes from the events attended, were incorporated into NVivo and coded and analyzed together with the interview data to develop the results presented below.

4. Regional background

a. *Economics of agriculture and tourism*

In Colorado, agriculture contributes annually to nearly 170 000 jobs and over $41 billion to the state's economy

TABLE 1. List of interviewees across multiple sectors.

Interviewee type	No. of interviews
River Forecast Center employee	1
Colorado state agriculture employees	2
National Resources Conservation Service expert	1
Agricultural farmers	3
Marijuana farmers	2
Municipal water employee	1
Recreation operators, angling and rafting	2
Risk assessor at energy/power companies	2
Local steel mill operator	1
Rancher	1
Total	16

TABLE 2. List of Colorado events attended by the lead author.

Event type	No. attended
Conference: Society for Range Management	1
Public Tours: ''Water and Land Tour of Lower Arkansas River Basin'' and ''Agricultural Tour of Otero County''	2
Monthly meeting of the Arkansas Basin Roundtable	1
Total	4

(State of Colorado 2020). This includes producers of a variety of crops irrigated largely by surface water, ranchers who utilize natural and irrigated grassland forage and groundwater to maintain their herds, and dairy and hog farms. In southeastern Colorado, the Arkansas River basin is the economic engine of the region, fueling the existence of agriculture and recreation in this semiarid region through a system of ditches, rivers, and transmountain diversions and providing significant revenue from both crops—including 4661 agricultural jobs and almost $700 million in direct economic activity—and tourism—including $349 million from water recreation alone (Salcone 2013, see especially chapter 5). Multiyear droughts, then, have the potential to magnify loss and damage the state economy. Assessing the more comprehensive economic impacts of drought on a region can be challenging given the number of factors that go into computing the direct and indirect impacts (Freire-González et al. 2017); however, state officials note that multiyear droughts like the one from 2011 to 2013 caused over $633 million in damages to producers in Colorado (State of Colorado 2015). Learning to collectively manage drought in efficient and equitable ways (e.g., quickly minimizing impacts to others) benefits individuals and communities beyond specific sector interests.

b. *Two case studies: Historical context*

Our interviews revealed two case studies of drought adaptation decisions that triggered unintended consequences. The first examines the legacy of agricultural water sales in Crowley County along the lower Arkansas, which were, in part, motivated by chronic drought conditions. In this case, unacknowledged connections between actors led to negative cascading impacts at community scales, which then, decades later, influenced others adjacent to Crowley to consider alternatives to water sales so as to avoid similar circumstances. The second example is of a small-scale collaborative arrangement formed in the wake of chronic drought to assist one recreational sector along the upper Arkansas River with adjustments to river flows, which resulted in unexpected benefits for others in the region. Each example illuminates how unintended consequences motivated social learning and the adaptive capacity that emerged at various spatial and temporal scales.

1) CROWLEY COUNTY: IMPACTS OF BUY-AND-DRY

Crowley County is located in central, southeastern Colorado (see Fig. 2). In 1900, water speculators in New York invested money to build the Twin Lakes Reservoir and Canal Company, some 100 000 acre feet (1.23×10^8 m^3) of water transported from the western slopes to the plains east of the Front Range. Here they sold water rights to the Colorado Canal to farmers who were just beginning to imagine the land as a productive agricultural area (Sanchez 2014). The 1930s and 1950s, however, saw significant, multiyear droughts, which necessitated the search for more water. Transbasin diversion tunnels, canals, and ditches moved additional water from one side of the state to the other, contributing to the area's ability to produce onions, tomatoes, corn, melons, sugar beets, and other crops (Crowley County Heritage Society 1980). Many canal companies included in their bylaws the requirement that farmers keep water and land rights tied together legally, ensuring that water stayed in agriculture. It was an institutional decision that instantiated in policy the value of agriculture as an important way of life.

By the 1960s, after decades of chronic drought, Crowley faced economic struggles that stressed agricultural producers. According to Squillace (2013) in 1968, speculators like the Crowley Land and Development Company (CLADCO) again began buying from individual farmers water rights to the Colorado Canal, a main vein that fed farms in the county. In 1972, CLADCO owned two-thirds of the canal and went to court to get the land and water rights severed so they could sell the water to growing cities along the Front Range (McMahon et al. 2011). They won their court case, and, by 1974, water rights could be sold separately, creating new institutional arrangements between municipalities and farms centered on a political ecology of water (Swyngedouw 2009) that benefitted individual municipalities and farms. This process of buying up agricultural water for municipal use became known as buy-and-dry.

2) VOLUNTEER FLOWS MANAGEMENT PROGRAM

In Colorado, the Arkansas River is divided into the upper and lower basins, where the upper feeds world-renowned recreation, including river rafting and gold medal trout fishing, and the lower feeds rural agricultural communities and municipalities connected to the river, like Crowley County, through a network of tunnels, ditches and canals, and reservoirs. Colorado law states that surface and groundwater in the state must be put to beneficial use, or the ''lawful appropriation that employs reasonably efficient practices to put that water to use without waste'' (Brown 2004). Historically, users in the recreation sector—for example, fishing, kayaking, and rafting—have had no rights of their own to use or augment river flows. Instead, they could only take advantage of the river as other water rights owners used and released water based on their specific needs. This had not been a problem through the early 1980s when water in the river was plentiful and the rafting and kayaking industries boomed.[1] However, a multiyear drought from 1985 to 1987 spurred the rafting company Arkansas River Outfitters Association and the angling group Trout Unlimited to come together with other actors along the

[1] In 2017, the Colorado legislature passed House Bill 17–1990 protecting direct-flow, instream rights for recreational use (Hughes 2017).

upper Arkansas River to create an informal water management arrangement that would alter river flows to benefit all of them (Arkansas Basin Roundtable 2017).

In 1990, the upper Arkansas Voluntary Flow Management Program (VFMP) was formed, which included representatives from recreation, agriculture, the Colorado Parks and Wildlife, Southeastern Colorado Water Conservancy District, Chaffee County, and the U.S. Bureau of Reclamation (Arkansas River Outfitters Association 2015). Initial goals of the VFMP were designed to support recreational needs for high river flows through an experimental compromise between actors. The group agreed to increase flows in the river during the summer while ensuring sufficient flows for water rights owners. Formal rules were developed about a trial length of the program and the details of its execution. The program involved a 5-yr commitment from actors managed by the U.S. Bureau of Reclamation (WestWater Research 2014).

5. Results

a. Crowley County: Unintended selling out of community

Dynamics across scales posed significant challenges for Crowley County as farmers engaged in buy-and-dry sales. Interviews with actors along the Arkansas River revealed that for many in agriculture, the motivation to sell water rights was personal, bounded by an individual's specific circumstances. As one water manager noted of the process for these sales:

> [G]enerally speaking, it's usually the farmers who initiate [a water rights sale]. They decide—either they're in difficult financial straits or sometimes maybe they're at the end of the generational line. They've farmed for a few generations but their kids want nothing to do with the farm and so they look to their most valuable asset, which is their water rights.

In this decision process, actors were not required to consider the impact of water sales on others. The prior appropriation doctrine, or "first in time, first in right," allocates water by seniority in Colorado. Sales transactions for these rights were designed to involve only the seller, the buyer, and the Water Court that redesignates the water use from agricultural to municipal. One municipal worker summarized: "The city buys the right, the water gets diverted, and their farms have to be dried up, no longer irrigated." The consequence of water loss for these farms can be more dire. "If you sell off the water rights, farm ground basically becomes worthless," one farmer said, a great "blank space" of dried up, valueless land.

Interviews suggest buy-and-dry practices continued in Crowley County until 1980, at which point nearly 90% of all water from the Twin Lakes Reservoir had been sold to cities like Pueblo and Colorado Springs. The number of sales was so significant that they touched nearly all residents of Crowley. One state official who works in agriculture noted the accumulation of impacts:

> [Buy-and-dry] decimated towns—there's ghost towns you can drive through in the kind of middle-to-lower Ark . . . If you're an ag community you start losing your tax revenue because farmers don't have money to buy seed, service their tractors, go out to dinner—then you decimate your tax base.

Others noted similar cascading impacts:

> [Farmers] lost the ability for that land [with no water rights] to bring in income, so people aren't going to be able to live off the land. Families leave . . . and pretty soon schools are closing. You can't support the grocery store anymore. You can't support the hospital anymore. You can't support your Main Street anymore, so it has this ripple effect.

Interviews reveal that interdependencies of a system are difficult to detect at the scale of an individual decision and become especially problematic when single decisions aggregate over time and generate unintended consequences at a larger scale. It took time for the larger community to be impacted before these system connections became visible; by then, however, much of the devastation was irreversible. As one state agriculture employee noted: "The farmers didn't realize it then but by selling out individuals—selling themselves out, selling their water out—that they were kind of selling out their community." At its peak in the 1960s, more than 50 000 acres (~20 000 ha) were irrigated in Crowley County; today, just under 2500 (~1000 ha) remain. Crowley County, once one of the most productive farming communities in the state, is also now one of the poorest (U.S. Census Bureau 2012). As the original site of unintended consequences, Crowley itself continues to struggle to recover.

Decades later, lessons learned from these negative impacts triggered new social arrangements and adaptation decisions by other actors in proximate counties [see Devine (2015) for an in-depth account of Crowley County and results of these water sales]. Interviewees acknowledged that Crowley County is not unique in the economic pressure drought continues to place on individual actors to sell water rights. Many face these difficult decisions due to ongoing drought, rising water rights value, and population growth in urban areas. One farmer said: "I mean there are some ranches that are doing the buy-and-dry thing—that's disheartening. The smaller communities that don't have a lot of water are very active looking for that kind of thing . . .Where's their water coming from?" While buy-and-dry is still a current mechanism for water transfer in Colorado, the majority of interviewees noted their desire to avoid this type of worst-case scenario of water management. As one state official explained: "Now we're [exploring] alternative ag transfers because we realize that we don't want to decimate agriculture not just because of the economic impact but [to help] the—their social networks, their communities." These alternative strategies are detailed in Colorado's Water Plan, which suggests that "Such alternative transfer methods can keep agriculturally dependent communities whole and continue agricultural production in most years, and if such arrangements can be made more permanent in nature, they will provide certainty to both municipal water providers and agricultural producers" (Colorado 2015, p. 15).

One example of using the lessons learned from buy-and-dry to build resilience is an experimental pilot project called the Super Ditch, which is a collection of seven ditch companies along the Arkansas River. Several interviewees who were involved in this project discussed how they have entered flexible, lease-based negotiations with municipalities that help them to

shore up their water supplies in times of droughts but preserve water rights in agriculture. Farmers agree to lease water to municipalities for 3 of 10 years during a drought, fallowing fields they otherwise would have cultivated. One fourth-generation farmer credited previous consequences from the sale of agricultural water in Crowley with his decision to join one of the experimental programs: ''We've seen buy-and-dry be just devastating to the community—so we got in the pilot program to learn from it.'' Another farmer in Otero said he felt similarly motivated to experiment: ''The loss of water through buy and dry in Crowley left people more open along the lower Ark to lease because of the extremes of the sales.'' He also pointed out that others along the South Platte are more skeptical of leasing water since they have not experienced the consequences of buy-and-dry firsthand. Geographic proximity to a community that had recently experienced negative impacts of individual water sales decisions motivated collaborative efforts to mitigate similar future outcomes.

Efforts to minimize or prevent ongoing water sales reflect a collective desire to build new capacity for the agricultural community to survive. As a farmer in Crowley noted of ongoing experimentation with water: ''We need to develop processes to knit together farmers, drought and municipalities . . . We're not trying to save every water right and farm but building an ethos of farming as important.'' Advocating the value of agriculture as a way of life and a preservation of the state's rural heritage motivates local- and state-scale social learning, a process that is as much about how unintended consequences have affected identity preservation as future economic viability.

b. Voluntary flows program: New collaborative structures

Those actors engaged in the VFMP worked together to identify mutually beneficial stream flows for agricultural and tourism activities. Actors who owned water rights set a minimum of 700 cubic feet per second (cfs; 1 cf = 29.3 L) at Wellsville, Colorado, between 1 July and 15 August each year, an amount that could not be guaranteed every year. As an angler explained, ''In a year where there's a drought, that means there's not enough water—we're dipping into their reserves so there's zero amount of water available for the Flows program.'' Instead, recreation only benefited ''when the water is pretty good.''

Motivations to engage in this type of compromise were also reported, focusing on two dimensions: economics and trust. Interviewees cited community revenue as a key rationale for those outside recreation to agree to alter water flows in support of an actor without water rights. Growth of recreational companies functioned both as a novel resource and as a replacement for other losses. As an owner of a rafting company explained:

> By the late eighties, the whitewater rafting economy was really well under way on the Arkansas River. And it had gotten to a point where the local communities were starting to recognize both rafting, and just tourism in general, as a viable alternative to reliance on one big mine in particular, the Climax Molybdenum mine, which they shut down. And so the area was kind of depressed in the eighties and there were people with a little foresight, I guess, thinking, well maybe this is when we push the tourism button and really start getting things going.

Individual recreation actors benefited from this initiative without harming water rights owners, and communities benefited from increased tourism and the ripples of economic revitalization in the area.

Interviewees further pointed to strong relationships between the actors as the foundation for the VFMP. They not only valued one another's contributions to the regional economy but recognized, as others have (e.g., Wilhelmi et al. 2008), how partnerships across sectors help one another manage hazards. As one angler pointed out:

> Recreation benefits from the movement of that water, so . . . [we] don't own anything but if we move water at this time or we hold water that's here—whatever we might do in the bigger picture without compromising anybody's water rights—why wouldn't we do that?

Anticipatory arrangements and the trust strengthened within this experimental framework facilitated an awareness of possible negative impacts on one another and allowed actors to take advantage of emergent problems on the river.

Results also indicate that two unintended consequences arose from the VFMP, both positive. One was the more comprehensive vision of the river that such partnerships enabled, a view that shifted from the more fragmented use of the river as a mere resource into a site for cross-sector collaboration. Interviewees suggest the VFMP is now a model for possible river basin management partnerships across the state. As explained in a brochure about the VFMP by the Southeastern Colorado Water Conservancy District, the program is a ''national example of what can happen when people take the time to listen to one another, understand each other's needs and then work with that knowledge to attain as much good as possible from every drop of water we receive.'' Other interviewees highlighted the need for relationships to be formed before a crisis occurs. Importantly, this example demonstrates how actors might build into their organization the kind of flexibility with policies, arrangements, and infrastructures that enable different sectors who normally might not consider one another's concerns to learn about each other's needs and contexts, both during climatological norms and extremes.

In thinking about the value of the VFMP to the river system itself, interviewees highlighted how recreation helped reframe this common resource with a more unified vision. As one rafting company operator explained, ''People now understand that recreation is a huge part of the holistic approach of the river, asking: What does a river mean? What does a river mean to a community? What does a river mean to a region?'' Interviewees suggested that the resulting outcome of their arrangement created a less fragmented view of water management, one that might better represent the role that water resources have in the lives of the greater community. As with the previous case of Crowley County,

local decisions produced outcomes that reverberated in unexpected ways.

The second unanticipated consequence involved the rapid identification of emergent problems on the river during a crisis, which could be addressed in near real time, preventing future harm to others in the system. The problem became apparent during the 2002–05 drought. Many interviewees referred to this multiyear drought as the worst they had experienced, or as one municipal water employee said, ''No one had water. It was as bad as it can get.'' All sectors reliant on the Arkansas River were affected. Senior water rights holders diverted what little water flowed in the river to agriculture and municipalities, which left river recreation without the ability to run their businesses. As one municipal water employee explained:

> As far as a single, super severe year, 2002 is the benchmark. It's the driest year on record in the Arkansas Valley. The Arkansas River here through Pueblo actually dried up. Anything that was coming into Pueblo Dam was being diverted either by the Bessemer Ditch or by [water managers for the town], so there was basically just a trickle of water.

Even with the VFMP in place, interviewees noted that the drought ''knocked them flat,'' from some estimated 265 000 customers taken down the river before the drought to around 150 000 during its first year in 2002.

Yet, as other interviewees discussed, the VFMP provided an unexpected benefit for angling. Wild brown trout, which are not native to Colorado, make up a large segment of the fish population in the Arkansas River. Low water levels revealed that the wild brown trout were one of the few species to do well in drought. One angling company operator explained the value of this discovery:

> [Trout] benefit from lower flows . . . [the drought] provided kind of like a scientific experiment that you could never replicate, where flows were just naturally really low. There basically was no runoff. Flows were extremely low all summer long and the brown trout population just did fantastic.

Because the VFMP had already been established for nonconsumptive uses with rafting and kayaking, it was able to take into consideration the needs of the angling industry and ecosystem services.

Having the VFMP in place before this drought allowed actors to dynamically adapt their practices to new information. In this case, they were immediately able to support the fish's life cycle. The originally agreed upon compromise of 700 cfs during summer months was problematic for these fish:

> The higher flow augmentation actually has a negative impact on brown trout because you're keeping flows higher than their optimal range [of 250–400 cfs]. And when [the trout] come out of spring runoff, which is typically late May and the month of June, they're usually in kind of poor condition and depleted.

One farmer noted that the program contracted to ''move more water in the middle of the winter and then reduce the flows in the spring, like early spring, April and early May, before runoff comes to allow the brown trout fry to emerge.'' He continued, noting that ''the program established optimal flows for fish spawning, incubation, and insect hatching,'' reducing the flows for rafting to 450 cfs as a compromise. Interviewees likewise noted the challenges of compromise: ''Moving water between reservoirs is a balancing act of managing evaporative loss in the move and the needs of agriculture or wildlife.'' This reference to a balancing act underscores the need for careful negotiations between sectors to prevent unnecessary harm and the value of trusting infrastructures to facilitate ongoing adjustments.

Interviewees noted great pride in how the VFMP helped set the stage today for the rare gold medal rating that angling now enjoys along a 100-mile-plus stretch of the Arkansas River. One angler highlighted the success of multiple recreational uses of water coexisting, providing economic benefits to the state: ''There's some of the best fisheries of trout in one river coinciding with the busiest rafting river in the country, if not the world, living side-by-side is a very tangible economic contribution [to the community].'' Institutional or governance arrangements built on compromise and flexibility, like the VFMP and the pilot programs in Crowley County, illustrate productive in situ experiments in adaptation that illuminate a more holistic understanding of water resources across sectors, account for cross-scale interactions, and draw on past experience that can generate social learning and more successful adaptations to unexpected consequences in the future. Implications of these results are discussed below.

6. Discussion

Our analysis of these two cases highlights four features of social learning that enabled actors to build adaptive capacity and adapt in real time as cascading impacts occurred: managing holistic governance, drawing expansive boundaries, learning from past experience, and enabling safer experimentation.

a. Managing holistic governance

Governance regimes can enable or foreclose policies and practices, as well as the kinds of decisions actors might individually or collectively make (Pahl-Wostl et al. 2008; Folke et al. 2005). In the case of Crowley County water sales, the primary governance structure, the doctrine of prior appropriation, permitted actors to make decisions without knowledge of impact on others. This structure also did not enable other actors to provide input into these decisions, beyond the limited interactions between individual sellers and buyers mediated through water court. It is a structure that helped maintain imperceptible interdependencies throughout the system (Borowski and Pahl-Wostl 2008). Because there was not an effective institution in place to help to foster social learning, system blind spots developed, especially at individual scales where agricultural and municipal actors were unable to see others in the system as a material extension of their socioeconomic world. This fragmented management of the river (Friedman and Paladino 2018) became maladaptive, creating a cascade of unintended consequences that hindered the decision-makers' ability to effectively respond to emergent vulnerabilities (Zaidi 2018).

The VFMP created an informal governance structure that connected actors in a common vision of river management to

benefit the greater good. While it still respected the individual rights of prior appropriation, policy changes developed within the structure allowed the specific actors not accounted for in past management practices, like recreation, to benefit. It also allowed the system to respond to harm to ecosystem services, like wild brown trout, more quickly. This flexibility created an anticipatory capacity in the system, one that expedited corrective actions before the situation became catastrophic. The more comprehensive view of different actors' needs created by the VFMP facilitated system reflexivity and timely adaptations amid unexpected environmental stressors. Arrangements that cultivate social connection, awareness, and nimbleness, then, support a more integrated approach to resource management (Emerson and Gerlak 2014; Tschakert and Dietrich 2010). The case likewise highlights how, as Ostrom (2009, 2010) has argued, actors who use a common resource can successfully construct informal governance structures that allow them to collectively regulate the resource and generate systemwide economic development.

b. *Drawing more expansive boundaries*

The spatial and temporal scales at which one examines adaptation decisions play an important role in identifying unintended consequences for drought in an SES (Peters et al. 2007a,b). Impacts from individual decisions may reverberate beyond the localized temporal scale of the decision, necessitating a longer view of—and thus a longer timeline for tracking—outcomes. Similarly, effects of a small-scale decision can be difficult to trace if the extent of the decision space is too narrowly circumscribed, such as a particular household. This can be seen in the case of Crowley County, where actors in the system initially considered spatially narrow outcomes, such as a specific water sale or a particular farm in the basin. As those municipalities within the larger lower Arkansas basin would come to realize, impacts may only be identified longitudinally and at regional or even statewide scales. Such a narrow scoping of the decision can pose problems for creating immediate interventions to forestall negative impacts on others (Scholes et al. 2013). The same is true for a community's capacity to anticipate or quickly identify differential impacts (Adger 2006) that may unexpectedly cascade or compound vulnerabilities. Drawing a more expansive spatiotemporal boundary around who counts as part of a system and tracing longitudinal outcomes may lead to an earlier awareness of problems as they emerge (Broad et al. 2002; Dilling et al. 2015).

If individual and community actors cannot directly witness negative impacts of their decisions, especially as they unfold in real time, how might they appreciate detrimental tradeoffs? Our results suggest that one way is to build more robust networks of spatially distributed, multisector groups who can collaboratively monitor and manage the system during times of high stress or change. In the case of the VFMP, interdependencies were more visible in this governance structure as adaptations were made or during times of crises for the system. Further, collective commitment to mitigating harm for the larger system allowed quick action to alter flows to address problems for wild brown trout identified during the 2012 drought. Thus, not only can a more expansive network of actors allow for broader vision of the system—including historical antecedents that shape current practices—but more agility in addressing unanticipated challenges and opportunities as they arise. Shifting to collaborative frameworks can generate new connections across sectors within existing governance structures and allow different choices informed by knowledge of system interdependencies. To help actors instantiate in common management practices those changes that support social learning, well-crafted policy instruments (Zipper et al. 2017) and terminology that better reflect interconnected systems (e.g., sociohydrology via Sivapalan et al. 2012) can help. For example, policies that align farmers' interests more closely with local and regional interests rather than global markets may reduce the likelihood of unintended consequences from water sales.

c. *Learning from past experience*

Framed by some as a feature of anticipatory governance (Quay 2010) or anticipatory learning (Tschakert and Dietrich 2010), previous experience forms a foundation for planning, preparedness, and responses that are more resilient to change. Our two cases illustrate how lack of previous experience with specific decisions and maladaptations can play a significant role in unintended consequences, a stumbling block to flexible systems noted in other work (Termeer and van den Brink 2013). Previous experience that shapes future scenarios for planning can be both direct (e.g., first-hand), or indirect (e.g., mediated through someone else), and can be challenging to define or measure (Demuth 2018). In terms of planning, past experience can enable actors' ability to anticipate possible scenarios for the future (Smit et al. 2000). For Crowley County, the novelty of laws in the 1970s permitting a separation of water from land in water sales meant farmers and municipalities also had no prior knowledge of long-term outcomes from individual and aggregate decisions to sell to speculators. As an "unknown unknown" that can create blind spots and surprises (Longstaff and Yang 2008), agricultural and municipal actors could not anticipate what they could not yet know. Crowley County never fully recovered from the impacts of water sales (Devine 2015). Yet as a cautionary tale, aggregate knowledge about Crowley County has positively shaped other actors' decisions about water sale practices for the future, like those involved in the Super Ditch experiment (see 4.4, Dilling et al. 2019). Thus, this case demonstrates how even indirect knowledge of interactions and government policies can accumulate over time and offer a shortcut to social learning (Pahl-Wostl et al. 2008).

For the VFMP, the advantages of direct experience occurred on a shorter temporal span. Having benefitted from regional economic growth made possible, in part, by river recreation via altered river flows, members of the VFMP gained first-hand knowledge of how their governance structure created advantageous compromises for actors across recreational, agricultural, and municipal sectors. When the 2002 drought revealed the benefits of low flows for wild brown trout—a discovery that was quickly made known to members of the VFMP through sector relationships, including with ecosystem advocacy organizations like Trout Unlimited—they were able to act on this

new knowledge with increased speed by altering existing policies to codify and thus institutionalize collective learning. While originally intended to assist an individual industry, the constitution of the VFMP created a regional and cross-sectoral view of emergent problems for actors in the program. This direct experience helped actors address what Cumming et al. (2013) characterize as ''mismatches of scale between ecosystem services and societal demand'' (p. 1142), which can mean inadequate solutions to complex problems. Cross-scale interactions are likewise important considerations in making decisions and assessing decision spaces (Peters et al. 2007a) since they can account for the nonlinear dynamics that create ''surprising and far-reaching consequences'' for a system (Cravens et al. 2021). Such accounting is crucial to social learning as it builds community capacity to respond to environmental change and complex system interdependencies. As these cases demonstrate, learning from past vulnerabilities and resiliences, whether directly or indirectly, can help those in a system avoid catastrophic outcomes in the future and is thus a strong motivation for actors to build relationships that generate meaningful knowledge based in common past experiences.

d. Enabling safer experimentation

Creating spaces that facilitate experiments in resource management can open up possibilities to minimize or reveal negative consequences. Experiments can produce alternate future scenarios for decision-making, reveal unexamined elements of the system, and encourage generative problem solving among actors (Cook et al. 2004; Ansell and Bartenberger 2016). In areas around Crowley County, for example, agricultural, municipal, and government actors collaboratively created a pilot experiment, the Super Ditch, to explore other mechanisms for water transfers that preserve agriculture as a way of life but provide water to municipalities during drought. As an alternative to decisions of buy-and-dry, this experiment provides a safer context to learn from mistakes, to make adjustments along the way, and to do so with participation from actors who have mutual interest in the plan's success.

While there is no way to prepare every community for all possible vulnerable futures, experiments can serve as a proxy for direct experiences that may have maladaptive outcomes; knowledge learned from more experiments can be quickly incorporated into new policies and practices, creating more iterative approaches to adaptation (Armitage 2005). Experiments can also encourage innovative thinking about management approaches, such as scenario thinking (Bathke et al. 2019), and relationship networks that might not otherwise occur. And, because they are experimental, such activities can be conducted longitudinally, allowing for consideration of unintended consequences and cascading effects (Loucks 2015; Wickham et al. 2019). Social learning, then, is built into experimentation both in the process (e.g., learning to learn) and its outcomes (e.g., learning from results).

7. Conclusions

Individual and community actors face major challenges as they plan ways to adapt to changing climates and environmental extremes. As our analysis shows, one seminal challenge is the ability to build collective understanding of how decisions made in one place or time shape negative consequences that affect others elsewhere. These unintended impacts are difficult to identify in real time as decisions are being made, and they can be difficult to track as they propagate through the system and emerge in surprising ways. Yet, these same impacts can also become the impetus for social learning and build future community adaptive capacity, a central component of adaptation.

One of the implications of our study is that there are effective ways to foster social learning that do not depend on learning the lesson ''the hard way'' from the unanticipated consequences. In other words, actors can create a ''shortcut'' to social learning that might otherwise have had to happen through the negative impacts. In particular, our findings point to the possibility of creating opportunities for social learning that can anticipate and perhaps forestall some of the decisions that are likely to have ripple effects over time. It is clear that one way to accelerate social learning is to enable flexible, inclusive governance arrangements that can be nimble in action, even while representing multiple interests. Leveraging others' previous experience—including indirect experience—likewise points to ways a community might avoid costly and tragic maladaptations. Together our study offers examples of communities of practice envisioned by scholars who study social learning and that echo the experimentation, flexibility, and institutional arrangements needed to effectively govern other types of common pool resources.

While these small but locally important case studies are useful in understanding the particular contexts and features of governance structures that enabled social learning in the Arkansas River basin, our study is limited in its representativeness of social learning generally in resource management in Colorado. Since social learning is context dependent, future research should emphasize developing multiple case studies in a given SES of successful social learning for different resource management contexts. Additionally, measures that help characterize successful social learning and to do so across contexts are needed, especially those that identify mechanisms of social learning that might intervene in maladaptation. As our study suggests, it is easier to see these processes in hindsight; we know less about decisions made in real time. Still, when tracing unintended consequences, revealing historical contexts and internal perspectives across multiple sectors is key—as is the acknowledgment that no one adaptation or mitigation action is free from consequences or cascades throughout a system.

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