Reg Environ Change (2014) 14:1451–1461
DOI 10.1007/s10113-014-0585-0

ORIGINAL ARTICLE

A "toad's eye" view of drought: regional socio-natural vulnerability and responses in 2002 in Northwest Colorado

Shannon M. McNeeley

Received: 8 May 2013 / Accepted: 12 January 2014 / Published online: 28 January 2014
© Springer-Verlag Berlin Heidelberg 2014

Abstract Drought is a part of the normal climate variability and the life and livelihoods of the Western United States. However, drought can also be a high impact or extreme event in some cases, such as the exceptional 2002 drought that had deleterious impacts across the Western United States. Studies of long-term climate variability along with climate change projections indicate that the Western United States should expect much more severe and extended drought episodes than experienced over the last century when most modern water law and policies were developed, such as the 1922 Colorado River Compact. This paper will discuss research examining regional socio-natural climate vulnerability and adaptive response capacities to the 2002 drought in the Yampa–White Basins region of Colorado across sectors and will demonstrate how a bottom-up or "toad's eye" approach to understanding drought is paramount to complement top-down, instrumental data-driven analyses of drought. The results of empirical observations through interviews and participant observation in combination with analysis of drought indicators will be presented. Implications for adaptation research and planning for climate variability and change will be discussed.

Electronic supplementary material The online version of this article (doi:10.1007/s10113-014-0585-0) contains supplementary material, which is available to authorized users.

S. M. McNeeley (✉)
North Central Climate Science Center, Natural Resources Ecology Lab, NESB A309, Colorado State University, 1231 East Drive, Fort Collins, CO 80523, USA
e-mail: shannon.mcneeley@colostate.edu

Keywords Drought · Social-ecological vulnerability · Climate adaptation · Colorado · Water-energy nexus · Social capital

Introduction

In the Western United States, the early 2000s drought, and especially the drought of 2002, had widespread economic, environmental, and social impacts (Averyt et al. 2009; Tronstad and Fuez 2002). In Colorado, the 2002 drought was particularly damaging across the state and sectors, the extent of which came as a surprise to some (Hayes et al. 2004a; Pielke et al. 2005). However, in semi-arid regions such as the Western United States, including Colorado, drought is a normal climate phenomenon, which should not come as a surprise (Glantz and Katz 1977; Gray et al. 2011; Harding et al. 1995). Droughts in 2011–2012 again tested limits of society's coping capacity and challenged natural resource, particularly water resource, management. Studies on long-term climate variability indicate that the twentieth century was wetter than normal and that more extended droughts are very likely—even without the effects of anthropogenic climate change (Gray et al. 2011; Pederson et al. 2011; Pederson et al. 2006; Woodhouse et al. 2010; Woodhouse et al. 2006). Multiple year exceptional droughts or "megadroughts" are a looming threat in the region (Kallis 2008; Schwinning et al. 2008; Seager et al. 2007; Stahle et al. 2000). Anthropogenic climate change, over-allocated streamflow, population growth, increasing development, and energy extraction and use together create a high risk of increased competition among water users for limited resources (Ojima et al. 2012).

In western mountainous states that depend on snow pack and runoff for water supplies, scientists define drought as a period of insufficient snowpack and reservoir storage to provide adequate water to urban and rural areas (http://climate.colostate.edu/droughtqanda.php). Declining snowpack and earlier spring melt/runoff are increasing vulnerability, especially in certain sectors such as agriculture and recreation (Pederson et al. 2011; Wilhelmi et al. 2008). Drought is the type of "wicked problem" where competing values and differing risk perceptions lead to divergent ideas about when dry conditions are a "drought" and how to manage the impacts (Botterill and Cockfield 2013a). Drought vulnerability indicators are subjective and often driven by available data, which can oversimplify causation and impacts and miss more nuanced but key qualitative differences and nonlinear relationships (Kallis 2008; Travis and Klein 2011). Indicators that are data-driven and top-down can mask local physical, social, and ecological conditions and coping capacities. For example, one social vulnerability index shows northwest Colorado having low overall vulnerability based on county-level demographic and economic variables from census data (http://webra.cas.sc.edu/hvri/products/sovi.aspx). Similarly, the Colorado Water Conservation Board statewide drought vulnerability analysis (CWCB 2010a) used an index that did not incorporate irrigated agriculture, for example, which is a large portion of water use in Colorado and used a ranking system that was of limited use to water managers. What constitutes a drought is much broader than just the information provided by scientists on meteorological, hydrological, and numerical economic indicators (Botterill and Cockfield 2013b).

One analysis of the 2002 Colorado drought (Pielke et al. 2005) made generalized claims about demand and vulnerability without empirical evidence to support those claims, which masked what actually happened in specific locales. Combining top-down data-driven assessments with participatory "on the ground" methods that include both data and experience is important for understanding the full picture of climate and drought risk and vulnerability (Kenney et al. 2010). What can these bottom-up methods elucidate for the region to enhance the state's top-down, data-driven analysis? Here, we argue that a "toad's eye" view or "bottom-up" analysis that includes working closely with local water managers is necessary to complement top-down, data-driven assessments, and ideally both approaches should be used together whenever possible. This approach provides additional critical insights into local manifestations of drought risk and responses to better inform decision making for climate adaptation.

Analytical framework for understanding socio-natural vulnerability

The social implications and manifestations of drought impacts are complex and still not well understood or documented relative to other natural hazards (Wilhite et al. 2007; Wilhite 2005). An integrated social-ecological science approach to climate vulnerability and adaptive capacity assessment asks who and what "on the ground" were affected by a particular climate stressor, as well as where, how, and when (Ford and Smit 2004; Smit et al. 2000). The stakeholder-participatory approach is commonly used by social scientists examining vulnerability to climate variability and change as framed by exposure (climate stressors), sensitivity (a system's or population's susceptibility to harm), and adaptive capacity (potential to respond to or prepare for climate stress) (Adger et al. 2007; McNeeley and Shulski 2011; Polsky et al. 2007; Schroter et al. 2005; Turner et al. 2003). This approach has also been used to analyze the social-ecological dimensions of drought risk (Engle 2012; Fontaine and Steinemann 2009; Kallis 2008).

Vulnerability to climate stress is a convergence of social, ecological, and climatological factors that change over time and, therefore, are very difficult to capture through quantitative measurements (Luers 2005; Luers et al. 2003; O'Brien et al. 2004). Key determinants of water sector social-ecological-climate vulnerability are a function of several interacting and dynamic factors such as water rights and allocation, reservoir operations, water demands, and climate change (Kenney et al. 2010). Adaptive capacity is determined by having access to financial, social, institutional, natural and physical assets (Eakin and Lemos 2006; Eakin and Luers 2006; Smit and Pilifosova 2001; Yohe and Tol 2002).

Social capital refers to the formal and informal relationships and social networks, agreements, flows of information and features of social organization such as trust, norms, and networks that can facilitate coordinated actions to achieve social benefits and facilitate well-being and security (Adger et al. 2004; Brooks et al. 2005; Fukuyama and Hodgson 2003) and is a very useful concept for understanding how "communities of place" work together to adapt to climate change (Pelling and High 2005). A society's ability to act collectively allows it to utilize its inherent capacity to adapt to climate (Adger et al. 2005; Pelling and High 2005).

One useful approach for analyzing adaptive capacity is to look at past events as analogs (Engle 2011; Glantz 1991; Glantz 1988). Here, we look at the 2002 drought impacts in the Yampa–White Basins (YWB) region of northwest Colorado to understand baseline vulnerability and adaptive capacities to climatic changes. We also employ a participatory livelihoods approach, where vulnerability is assessed in the context of water management for key regional livelihoods, economic sectors and climatic threats to sustaining them (Hahn et al. 2009; Scoones 1998), and where local expert knowledge and observations play a key role in understanding drought manifestations (Knapp and Fernandez-gimenez 2008; McNeeley and Shulski 2011). This approach combines "top-down" with "bottom-up" methods to get a full picture of vulnerability and responses to climate variability and change.

Initial research questions included:

- How did climate impacts and social-ecological system vulnerabilities manifest in the YWB region during the 2002 drought?
- What were some of the responses or adaptations in the region during and after the 2002 drought?
- How does this provide an analog for future warming and drought events and seasonality shifts in the region?

Through the process of working closely with key experts in the YWB region, we were able to examine various aspects of these questions, the answers to which are presented in Section III. Working closely with expert stakeholders and water managers provides a unique "toad's eye" view of vulnerability and adaptive capacity that is often difficult to get because it is quite time and labor intensive (Malone and Engle 2011; NCVST 2009).

This paper focuses on local- and regional- scale climate vulnerability and responses in water resource management (it is worth noting that this paper does not address political theory or governance literature, which is beyond the scope of this analysis). This approach starts by empirically identifying (rather than assuming) past and current community vulnerability and adaptive capacity to climatic disturbances (Smit and Wandel 2006), which establishes a baseline upon which to build future scenarios involving potential changing climate conditions. We also identify how adaptive capacity is either enhanced or constrained by the institutional/regulatory setting for managing water. This assessment involves collecting data through quantitative and qualitative methods to document local observations of change and responses along with reviewing instrumental and historical records. Methods included:

- Semi-structured interviews with key water managers ($N = 45$). Interviewees were selected by working closely with the Yampa–White Basin Roundtable to identify water managers throughout the region. The target population for key informants was anyone who had management authority for water use and allocation in their respective sector. Sectors included municipal, energy, recreation and tourism, industrial, state and federal natural resource management, agriculture, and reservoir operators. A minimum of one representative from each sector was interviewed in each sub-region of the Yampa–White Basin, providing a highly representative sample of water managers throughout the region.
- Participatory observation of stakeholder meetings and forums
- Document content analysis of key peer reviewed and gray literature
- GIS analysis of water, climate, and socio-economic data (water allocation, streamflows, climate data, users, consumptive use)
- Incorporation of statistical analysis of relevant climate records—e.g., temperature, precipitation, snow fall/pack, and drought indicators

This research took a determinants approach to understanding socio-natural vulnerability, which involves understanding processes that underpin or determine vulnerability and adaptive capacity (Ford et al. 2010; Fussel and Klein 2006; Grothmann and Patt 2005). Analysis of interview data was performed using a modified grounded theory approach to identify the determinants of vulnerability and adaptive capacity (Bryant 2002; Charmaz and Bryant 2010; Mills et al. 2006). This approach provides structure to the analysis, while at the same time leaving enough flexibility for inductive reasoning based on the data itself. We use this "bottom-up" approach to establish current and baseline vulnerability, adaptive capacities, and responses to date with the stakeholders (Ford et al. 2006; Smit and Wandel 2006).

Context: the Yampa–White Basins region

The entire YWB region covers approximately 10,500 square miles in northwest Colorado and south-central Wyoming. The population of the region in Colorado is around 42,000 (2005 Census). The two most populated towns are Steamboat Springs in Routt County with approximately 10,000 permanent residents and the city of Craig in Moffat County with just over 9,000 people.

The YWB within Colorado is approximately 7,660 square miles (CWCB 2009a). Within the Yampa Basin, average annual precipitation varies dramatically from over 60 inches near Rabbit Ears Pass on the Continental Divide to approximately 20 inches near the western state line bordering Utah. Most of the water yield comes from high elevation snowmelt, over 60 % of which occurs in May and June (i.e., peak runoff). Average annual streamflow near Stagecoach Reservoir in the upper part of the Yampa Basin is approximately 62,000 acre-feet (AF), which increases to 1,623,000 AF on average at Dinosaur National Monument on the far western end (ibid). The Yampa River Basin is unique to Colorado and much of the Western United States because it is a relatively free flowing river with no large federally managed dams on the main stem of the river; rather the YWB has a system of small, locally managed dams and reservoirs. The White River Basin within Colorado is approximately 3,759 square miles, lying mostly in Rio Blanco County, with average annual precipitation variation of over 40 inches at the origin in the Flat Top Mountains to only around 10 inches in the lower, western portion near the town of Rangely (CWCB 2009b). Annual streamflow at the Colorado-Utah border is approximately 596,000 AF (about half of that at the Yampa) (ibid). Both the Yampa and White Rivers eventually flow into the Colorado River via the Green River in Utah, forming part of the headwaters for the Upper Colorado River Basin.

Regional and local water allocation and use

Colorado is a party to nine interstate compacts and agreements with multiple states. Approximately 10 million acre-feet (MAF) of water must leave Colorado pursuant to these legal obligations, the largest of which is the Colorado River Compact or "Law of the River" that outlines the allocation of water throughout the entire Colorado River Basin and its seven states (and Mexico). The Upper Colorado River Basin Compact of 1948 divided the Colorado, Wyoming, New Mexico, and Utah portions of the Colorado River Compact (1922) and made the Yampa Basin responsible for delivering (or technically "not depleting" below) 5 MAF over any 10-year period (approx. 500,000 acre-feet per year on average). Average historical consumptive use of the Yampa River is approximately 160,000 acre-feet/year (1.6 million acre-feet over 10 years), which constitutes only a fraction of the delivery obligation. To date, there has never been a call by the Lower Basin for the Upper Basin states to curtail their water usage, thus, the "Law of the River" has not yet impacted the YWB (aside from the Little Snake River, to be discussed in Section III). However, the threat of a severe, sustained drought and a Lower Basin shortage creates a great deal of uncertainty for Colorado's portion of the Colorado River Basin (CWCB 2010b; Kuhn 2012; Pulwarty et al. 2005). Experts are unsure how the Upper River Basin Commission and, hence, the state of Colorado would handle a call or how water allocation in Colorado or other states would be impacted (Kuhn 2012).

Under the prior appropriation system that governs water allocation and uses in Colorado, often referred to as "first in time, first in right," older, "senior" water rights have priority over more recent "junior" water rights (Getches 1990). This means that when a senior right holder determines they are not getting their full water right, they can place a curtailment call on junior users to reduce their water use—otherwise known as a "call on the river." The state water division engineer and regional water commissioner then make a determination as to which users can still use water and how much they are legally allowed to use. They then notify users how much they are allowed to divert, and in some cases, take control of the diversion head gate to turn off users who are "out of priority" and unable to divert any water in times of shortage.

Water in the YWB region is primarily used to irrigate pasture, hay, and alfalfa crops to feed livestock (largely cattle and horses). The total *irrigated* acreage in the Yampa Basin within Colorado was estimated in 2000 to be approximately 89,800 acres (CWCB 2009a). In the White River Basin, oil and gas extraction are a major part of the economy, and culture with the Piceance Creek and Roan Creek Plateau containing some of the largest oil shale and coalbed methane reserves in the country (CWCB 2009b). As such, many conditional water rights are held by energy companies in the White River Basin for future development, which could have significant implications for water use and availability if there is a major transition from agricultural to industrial uses. At present, energy companies have purchased many ranch properties to acquire the associated water rights; then, they lease the land back to ranchers to maintain the "beneficial use" for agriculture until the water is needed for industrial purposes. The Piceance Creek is already regularly administered for water shortages; so, it is uncertain what the future will hold under various climate change and development scenarios.

The Yampa River is known by Colorado's water resource management community as one of the few major rivers that have never had a formal legal curtailment call on the main stem of the river. After the severe drought of 1977, the water resources division engineer predicted that, given various pressures on the region, there would soon be a formal curtailment call on the river. Yet, as of 2013, over 35 years later, this still has not happened. However, this does not necessarily indicate low or no vulnerability. One can understand this seeming paradox by talking to the region's water managers. The next section will outline what occurred during the exceptional drought of 2002, and how the YWB again barely avoided a formal curtailment call on the river.

Anatomy of the 2002 drought in the Yampa–White Basins Region

The water managers we interviewed point to the 1977 and 2002 droughts as the major drought-related events in recent history that led to water shortages and the need for adaptive responses in the YWB. Climatologists identify the fall of 1999—which was dry after a "very wet spring" and "soggy August"—as the start of the Colorado drought of the early 2000s (Pielke et al. 2005). The winter of 1999–2000 had below-average snow accumulation and unusually warm temperatures followed by a hot summer and high soil moisture transpiration rates (ibid). This was followed by consecutive drier-than-normal years, and by 2002, the entire Western United States was experiencing a "severe drought" resulting in the largest wildfire season in the twentieth century, widespread water shortages, and crop losses (Figure S2 in Online Resource).

Conditions in the summer of 2000 in the region were "so drastic" that ranchers' water use on Little Snake River was cut back under the Upper Colorado River Compact with Wyoming *for the first time since it was signed in 1948*. In a "normal" year, summer precipitation can offset a lower-than-normal spring runoff; however, the summer of 2000 was dry, and the "magnitude of the drought was severe" (see similar for July and August "severe drought" according to the Colorado Modified Palmer Drought Index in Table S2 in Online Resource). In the YWB region, the Colorado Modified Palmer Drought Index indicated a "severe" drought began in July 2000 and became extreme to exceptional in May 2002 and was severe or worse until December 2004 (Table S2 in Online Resource).

2002 was one of the driest years in recorded history in the YWB region, causing a severe to exceptional drought there and throughout the Western United States 2002 rivaled 1977 in terms of low snowpack, low stream flows, lack of summer precipitation, and administration of water rights. Estimates of Colorado's economic losses include $1.1 billion in the agriculture sector and $1.7 billion in the tourism sector (Hayes et al. 2004a). Many of the water managers interviewed are also ranchers, and they reported that in 2002, their hay crops were about half of normal. For some, this meant having to sell off livestock and/or buy hay from outside producers at higher costs than usual. In 2002, all of the major rivers experienced administration of water allocations and uses, including a formal curtailment call on the White River (the only call since 1977) and administrative curtailments on the main stem of the Yampa River to ensure owners of reservoir water received the water they released. It is important to note that these were curtailments by the water commissioner to administer water, and shepherd reservoir releases to owners of storage water; however, this was still not a formal call on the river from any senior water right. Therefore, administration occurred almost as if there had been a formal curtailment call by a senior water right holder.

Many ditches throughout the region were never able to divert water because there was physically no water to divert. Contrary to the statement by Pielke et al. (2005) that "March did not give many hints of the drought ahead," local YWB water managers indicated that by March they knew they were going to have a bad summer drought. The YWB region usually gets most of its snow in December and January, and less in February and March, compared to other regions in Colorado, so by March users typically have a good idea about how the spring and summer will fare. A water manager from the city of Craig said, "I was getting worried in January and got more worried at about the end of the March. It was like well, these rivers are gonna be running dry if we don't get moisture. And they were, they pretty much did. We had no moisture for a long time." This demonstrates the importance of understanding the idiosyncrasies of local climate patterns and local understandings of climate (i.e., seasonality).

Runoff on the Yampa River in 2002 started about a week to 10 days earlier than average due to warm spring temperatures. Peak flows were about 1/3 of average (Table S3 in Online Resource). Calls that began on April 19th on tributaries of the Yampa River lasted the entire irrigation season and in some cases, the entire year (Colorado Division of Water Resources 2002). Early calls and low runoff resulted in several of the larger irrigation and recreational reservoirs high in the Yampa Basin (Stillwater, Yamcolo, and Stagecoach—See Figure S1 map in Online Resource) not filling and running out of available irrigation water to release by mid-July (ibid). Local water managers and ranchers reported how early runoff means that the water goes by before they can use it, which negatively impacts their ability to start watering their grass for hay crops at the right time. This is particularly problematic in the smaller tributaries in the region. They also talked about implications of early runoff later in the summer season, and how with climate change "a longer-term shift where the runoff is moved into the spring by a couple of weeks, 2 to 3 to 4 weeks, they may be more vulnerable because for late season—September, October, early November—because of the lack of system wide storage." Downstream users in the basin also reported how the lack of early spring/summer season irrigation means they have less return flows to the river that they depend on in the later summer season.

In July and August of 2002, the Colorado Department of Wildlife (now called Colorado Parks and Wildlife) and the City of Steamboat requested a voluntary ban on any use of the Yampa River through town, including all fishing activity. Flows in mid-July in town were as low as 17 cubic feet per second (cfs). One water manager reported that there was a period of time where there was essentially no water in the Yampa River for a week or two or more, not enough water for the fish populations.

As early as April 2002, after it became clear to local water managers that the region was facing a bad summer, the leadership of the Upper Yampa Conservancy District (which manages Stagecoach Reservoir, the largest reservoir in the region) called an "all hands" meeting with water managers throughout the region to work together to avoid a legal curtailment call on the Yampa. The District voluntarily began releasing water from Stagecoach, and these releases continued until water contract holders called for reservoir releases. The social capital that the UYWCD leadership utilized in bringing together water managers to negotiate a voluntary, shared response strategy was a primary reason they avoided a formal call on the river.

In 2002 in the White River Basin, a call was placed on the Piceance Creek on April 19th, which lasted all summer. Many of the tributaries went on call and/or there was so little water that only users with the most senior water rights were able to divert water. The main stem of the White River had the first formal call since 1977. Co-operative, voluntary reductions by many ditch owners prevented an earlier call by over 6 weeks, which allowed junior rights holders extra time to use water. In mid-July, many of the same ditch companies informally agreed to allow the Colorado Division of Wildlife to release water for threatened fish in the White River. Water managers reported that many of the ranchers are also in the fishing business as guides, suppliers, tour operators, etc., so, agricultural ditch owners voluntarily reduced their use for the health of the fishery.

The real story of the 2002 drought was how close the Yampa River came to a first-ever formal curtailment call by the city of Craig. A large portion of the water in YWB reservoirs is owned by energy companies. Because the Tristate power plant was calling for water releases to be delivered to its diversion structure downstream from the city of Craig, the division engineer was faced with having to curtail Craig to "shepherd" that water to Tristate, and Craig would experience a water shortage as a result. The city water engineer reported that "we were out [of water] there wasn't any water in the system. The only water in the system was what was being released from the reservoirs." Craig's engineer was in the process of filing the request for a call to curtail water users with rights junior to theirs when rain finally came for one weekend in mid-August and brought enough water to fill the river so that the call was avoided. So, while local water managers avoided a call, first and foremost, by utilizing social capital to find co-operative response strategies in the Basin, the other key factor was a lucky precipitation event. This demonstrates the importance of understanding both social and physical factors (i.e., the combination of exposure, sensitivity, adaptive capacity) (Downing et al. 2005; Hinkel 2011; McNeeley and Shulski 2011). Few water managers in the basin were aware this happened and how close they actually came to the first-ever formal curtailment call on the Yampa River in 2002.

Conditions improved "dramatically" in 2003 despite a dry summer; however, 2004 saw a return to drought conditions that lasted into 2005 (Plaska 2004). For the second time since 2002, the city of Steamboat Springs implemented a voluntary closure of the river within city limits from early August through early September (ibid). Informants indicated that the local recreation and tourism industry such as the tubing, rafting, boating, and fishing operators in Steamboat were hurt, and the cumulative effects of consecutive years of drought nearly ran them out of business.

After experiencing 40–50 % transit water losses from reservoir releases in 2002, discussions began in the spring of 2004 among the region's water managers about swapping water from reservoirs to provide releases closer to users. After 10 years of negotiations, the Yampa River endangered fish management plan was signed in 2004, and expansion of the Elkhead Reservoir was completed in 2006 (Roehm 2004). This allowed for storage closer to where it was needed for the endangered fish as well as for the Tristate power plant, resulting in water swapping and innovative short-term water leasing that are discussed in more detail in Section IV.

Discussion: adaptive capacity for drought risk

The use of case study analogs for understanding local climate vulnerability and capacity to respond is a useful approach to understanding the "on the ground" or "toad's eye" experience of drought risk and responses (Engle 2011; Ford et al. 2010; Glantz 1991). Here, the analysis of how the 2002 exceptional drought manifested in the YWB region provided insights into the regional sensitivities to climate-induced water stress. By doing so, we can identify adaptive capacities and better prepare for future drought risk (Brooks and Adger 2005; Kallis 2008). The YWB ranching and recreation/tourism sectors are the main components of the regional economy and both are at high risk to severe, sustained drought exposure and climate change impacts, in large part because of high sensitivity due to inadequate water storage. Many ranchers in the mainstream of the Yampa and White Rivers, especially those with senior water rights, have adaptive capacity to withstand the normal range of climatic variability and could survive 1 year as severe as 2002 because of their experiences, knowledge, and access to financial and physical capital. However, those with junior rights and on certain vulnerable tributaries are at higher risk to severe, sustained drought. And, under scenarios of water shortages due to severe, sustained drought and climate change, it is possible they would not be able to cope because of requirements to keep water in the stream for endangered fish and for shepherding water to the thirsty power plants. Because the energy companies own such a large portion of stored water in the region, they have a lot of control over reservoir releases and resultant streamflow during times of drought. Therefore, water for endangered fish and for energy (both in terms of thermo-electric power generation and resource exploration/extraction) also adds to the regional social-ecological vulnerability. However, co-operation through strong social capital (relationships and trust) and mechanisms for negotiation are an important tenet of adaptive capacity (Adger 2003). Strong social capital provided a successful means to collectively respond to climate stress in 2002 when the Upper Yampa Conservancy District leadership negotiated an alternative for water distribution, thereby avoiding costly legal battles. Further, some adaptations to climate-induced water scarcity are occurring with co-benefits to these historically competing uses. Yet, there is still concern among local water managers about future water scarcity, the need to acquire more storage, and the limitations imposed by Colorado water law. In order to acquire new water rights, “beneficial use” must be demonstrated, which is a barrier for preparing for future scarcity. As a result, there has been some talk about the need to change water law.

Regulatory barriers can hinder adaptation to climatic stress when the system is unaware or too inflexible to respond (Ekstrom et al. 2011; McNeeley 2012). In such cases, strategies for overcoming barriers need to be found to turn adaptive capacity into action (Burch 2010). In Colorado and the Western United States more broadly, proposed adaptation strategies include water conservation, market-based tools such as water banking, and rotational fallowing, to name a few (Knutson 2008; Lempert and Groves 2010; Lord et al. 1995). These strategies have not yet taken hold in the YWB for a variety of reasons such as lack of incentives, physical limitations, and local cultural preferences. To date, water storage and policy changes are the two adaptive strategies that YWB interviewees favor to minimize drought risk.

Water storage

When societies are exposed to climate stress, they find ways to minimize the climate exposure or reduce sensitivities to that exposure (Kelly and Adger 2000). In the Western United States, water storage is a primary mechanism utilized for reducing sensitivity to fluctuating amounts of water due to climate variability and change (Brekke et al. 2004). As discussed in Section III, the ability to keep enough water in the system during drought depends on reservoir releases. The Yampa and White Rivers are somewhat unique in that they do not have any federal or other large storage facilities in the basin, and the Yampa River is the largest mostly unregulated tributary of the Colorado River with near natural flows. Of the existing small to medium reservoirs in the region, each has a unique mix of management and ownership of the water for recreation and multiple consumptive uses.

Through a partnership between the Upper Colorado Endangered Fish Recovery Program, the Colorado River Water Conservation District, and the city of Craig, among others, the Elkhead Reservoir on Elkhead Creek near Craig was expanded to provide an additional 5,000 acre-feet of water for four species of endangered fish in the stretch of critical habitat from Craig to the Utah-Colorado border. The expansion not only provided additional water for endangered fish, but also located more stored water closer to both the Tristate power plant and the city of Craig (the reservoir was expanded from 13,800 acre-feet to 25,550 acre-feet). Transit water losses between Stagecoach and Steamboat Lake reservoirs higher in the basin were problematic during the 2002 drought since the water had to travel many miles to get to users in the lower part of the basin. Estimated water losses in the Yampa River of approximately 40–50 % (pers comm. John Sanderson and Kevin McBride) meant that water users are not able to get all of the water they paid for and released.

A confounding climate change issue is that warm water non-native predator fish in the reservoir are known to prey on native endangered fish in the river. As water temperatures warm, and as drought episodes weaken native species and strengthen non-native species populations, efforts to protect native fish become increasingly difficult. Water managers in the region are most concerned about the ability to make it through consecutive drought years that are as severe to exceptional as 2002. One manager of the endangered fish recovery program said “We might be winning small battles to save the native fish in the Yampa River, but if we have a severe, sustained drought of multiple years like the 2002 drought, I’m afraid we might lose the war.”

Since the YWB region is almost entirely dependent on surface water supplies, if runoff does not provide enough water for users, they are dependent on the small amount of storage in the basin. Additionally, if spring runoff is not sufficient because of a lack of winter snow, they are reliant on the summer monsoon season to keep water in the system.

A recent USFS report concluded that many of western reservoirs will be unable to fill under future climate scenarios (Foti et al. 2012). These types of scenarios are very concerning for water managers in the YWB who feel they need to secure more storage for future water scarcity. However, Colorado water law requires that new water projects demonstrate need and beneficial use, which makes building any new storage in the region difficult. One example of this was the failure of the proposed Morrison Creek project that was denied in 2011 by the Colorado

Supreme Court (Case No. 09SA118) for this reason. To date, future climate change scenarios have not been used in court to demonstrate need.

Short-term water leasing for instream flows

A recent change in water policy involves short-term, temporary water leasing for instream flow (ISF) rights. ISF rights are for in-channel, non-consumptive use to maintain riparian ecosystem health. The ISF Program in Colorado was created in 1973 and is administered by the Colorado Water Conservation Board exclusively for the protection of the riparian natural environment.

After experiencing the deleterious ecological impacts of the 2002 drought, a 2003 state statute was enacted to provide a tool for the CWCB to lease water on short notice for instream flows (HB03-1320). This short response time is a way to provide more flexibility than the conventional system that has to go through the Water Court and can be a very slow and expensive process and does not allow for "in-season" management. The statue also protects water rights holders from being penalized for not using the water for the decreed use (i.e., the historical consumptive use), which helps eliminate possible disincentives. The 2003 statute allowed for available water originally decreed for some other use to be decreed for an ISF that would be short of water for 3 years out of 10. The statute went unused until 2012 when another very severe drought struck Colorado. This adaptive mechanism was then used in five cases throughout Colorado in 2012; one of which was in the YWB region in an unprecedented water exchange between the Upper Yampa Water Conservancy District and the CWCB. By March 2012, when low snowpack indicated another bad summer for Colorado, the Colorado Water Trust released a "Request for Water" to acquire senior rights to lease water for dry streams in priority instream flow areas throughout the state.

The UYWCD until that year had been fully subscribed for all of the water stored in the Stagecoach Reservoir. Because of the expansion of Elkhead Reservoir described above, Tristate power plant did not renew a 30-year old contract with UYWCD for 4,000 acre-feet of water after acquiring water closer to them in Elkhead. UYWCD negotiated a short-term lease for the 4,000 AF for the ISF program, and it was released in July (the water was leased at $35 per acre-foot totaling $140,000). Through multi-stakeholder co-operation and the assistance of the division engineer's office, the water ultimately benefited several users including fishers, recreationalists, agricultural producers, municipalities, and power generation. This policy innovation provides a precedent for future arrangements for "in-season" management that can maintain the health of rivers and avoid costly conflicts in times of water shortages.

Conclusions and next steps

Steps have been taken in the YWB region (as well as throughout Colorado and the Western United States) to reduce vulnerability to climate variability and change. Yet, the question remains whether adaptive capacities and preparedness measures will be enough to reduce vulnerability to future climate change and drought in the YWB and the Western United States (Botterill and Cockfield 2013b; Pulwarty et al. 2005; Wilhite and Pulwarty 2005). Adaptive capacity does not always translate into action (i.e., adaptation) where barriers exist (Adger et al. 2007; Ekstrom et al. 2011; McNeeley 2012). Local YWB water managers do not believe the region is prepared for consecutive years with a 2002-like drought. One water commissioner said, "If we had 2 years in a row [like the 2002 drought], I think you'd see agriculture probably disappear, because it's completely dependent on growing. They'd get by a year, maybe two, but if you can't get enough water to grow hay or pasture, you have to ship your animals out or buy feed and bring it in, and that's not viable for more than a year. I don't think most ranchers have a lot of reserves where they could do that for more than a couple years."

Drought vulnerability is not simply a quantitative end game based on temperature and precipitation data but rather has to do with both physical and legal water availability as well as what users are accustomed to and how much they have to alter their behaviors when there is less water. "Drought" is not the same in the Yampa Basin as it is in other basins.

In conclusion, social-ecological vulnerability to drought is complex and multi-faceted (Wilhite et al. 2007). In the YWB region, this includes the agricultural/ranching and recreation/tourism sectors generally, but to fully understand vulnerability we must know a) how drought exposure manifests locally, and b) the sensitivities and adaptive capacities on the local level in terms of how much water was *both physically and legally* available and how it was *distributed and used.* The latter determination involves an understanding of the complex relationship between climate, water availability, water rights, and the division engineer and water commissioners' allocation and administration of those rights. This necessitates utilizing social science methods to document local and regional knowledge, understanding, and observations of system dynamics, impacts, risks, vulnerability and responses, along with more conventional "top-down" approaches that rely on scientific data and drought indicators. This analysis includes understanding how social capital and networks resulted in voluntary use reductions and reservoir releases, which allowed the region to avoid a formal call on the main stem of the Yampa River despite predictions by the division engineer as early as 1977 (Colorado Division of Water Resources 1977).

The next step of this research will be to look in detail at regional social-ecological vulnerabilities and responses during the 2012 drought. This work will examine (a) how the drought of 2012 compared to the 2002 drought in terms of regional impacts and vulnerabilities; (b) what types of responses were implemented; and (c) did any adaptations after 2002 result in reducing vulnerabilities in 2012. The goal is to provide insights for future adaptation research and climate and drought planning that complements existing literature on bridging drought research and practice (Hayes et al. 2004b). The research can inform the feasibility of adaptation strategies in the region such as water banking, fallowing, and water policy innovations. Outcomes will also inform drought and climate social-ecological systems research for other regions.

Acknowledgments The author thanks the National Center for Atmospheric Research (NCAR) Integrated Science Program, Advanced Study Program, and the Climate Science and Applications Program and their sponsor, the National Science Foundation, for supporting this research. Also, thanks goes to the Yampa–White Basin Roundtable and other water managers in the region who provided critical guidance and interviews for the research. The findings and perspective remain those of the author alone. Two anonymous reviewers and Will Steffen also provided suggestions to greatly improve this article, and Bobbie Klein provided valuable edits.

References

Adger WN (2003) Social capital, collective action, and adaptation to climate change. Econ Geogr 79:387–404. doi:10.1111/j.1944-8287.2003.tb00220.x

Adger WN, Brooks N, Bentham G et al (2004) New indicators of vulnerability and adaptive capacity, technical report 7. Tyndall Center, Norwich, England

Adger WN, Arnell NW, Tompkins EL (2005) Successful adaptation to climate change across scales. Glob Environ Chang Policy Dimens 15:77–86. doi:10.1016/j.gloenvcha.2004.12.005

Adger N, Aggarwal P, Agrawala S et al (2007) Summary for Policymakers. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate Change 2007: Impacts, Adaptation and Vulnerability Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report, IPCC. Cambridge University Press, Cambridge, pp 1–13

Averyt KB, Lukas J, Alvord C et al (2009) The “dealing with drought: adapting to a changing climate” workshops: a report for the Colorado Water Conservation Board. p 34

Botterill LC, Cockfield G (2013a) Science, policy, and wicked problems. In: Botterill LC, Cockfield G (eds) Drought, risk management, and policy: decision making under uncertainty. CRC Press, Boca Raton, pp 1–14

Botterill LC, Cockfield G (2013b) Drought, risk management, and policy: decision making under uncertainty, p 208

Brekke LD, Miller NL, Bashford KE et al (2004) Climate change impacts uncertainty for water resources in the San Joaquin River Basin, California. J Am Water Resour Assoc 40:149–164. doi:10.1111/j.1752-1688.2004.tb01016.x

Brooks N, Adger WN (2005) Assessing and enhancing adaptive capacity. In: Lim B, Spanger-Siegfried E, Burton I et al (eds) Adaptation policy frameworks for climate change. Cambridge University Press, New York, pp 165–182

Brooks N, Neil Adger W, Mick Kelly P (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Glob Environ Chang Part A 15:151–163. doi:10.1016/j.gloenvcha.2004.12.006

Bryant A (2002) Re-grounding grounded theory. JITTA J Inf Technol Theory Appl 4:25

Burch S (2010) Transforming barriers into enablers of action on climate change: insights from three municipal case studies in British Columbia, Canada. Glob Environ Chang 20:287–297. doi:10.1016/j.gloenvcha.2009.11.009

Charmaz K, Bryant A (2010) The SAGE handbook of grounded theory, Paperback Edition. SAGE Publications

Colorado Division of Water Resources (1977) Division of water resources division no. 6 1977 Annual Report. 56

Colorado Division of Water Resources (2002) Water Resources Division 6 2002 Annual Report. 54

CWCB (2009a) Yampa River Basin Information. 57

CWCB (2009b) White River Basin Information. 23

CWCB (2010a) Drought vulnerability assessment technical information: Annex B to the Colorado drought mitigation and response plan. p 25

CWCB (2010b) Colorado River water availability study, Phase I Draft Report

Downing TE, Aerts J, Soussan J et al (2005) Integrating social vulnerability into water management: NeWater Working Paper No. 5. New Approaches to Adapt Water Manag under Uncertain 37

Eakin H, Lemos MC (2006) Adaptation and the state: Latin America and the challenge of capacity-building under globalization. Glob Environ Chang Policy Dimens 16:7–18. doi:10.1016/j.gloenvcha.2005.10.004

Eakin H, Luers AL (2006) Assessing the vulnerability of social-environmental systems. Annu Rev Environ Resour 31:365–394

Ekstrom JA, Moser SC, and Torn M (2011) Barriers to adaptation: a diagnostic framework. PIER Research Report CEC-500-2011-004. Public Interest Energy Research (PIER), Sacramento, CA

Engle NL (2011) Adaptive capacity and its assessment. Glob Environ Chang 21:647–656. doi:10.1016/j.gloenvcha.2011.01.019

Engle NL (2012) The role of drought preparedness in building and mobilizing adaptive capacity in states and their community water systems. Clim Chang 118:291–306. doi:10.1007/s10584-012-0657-4

Fontaine MM, Steinemann AC (2009) Assessing vulnerability to natural hazards: impact-based method and application to drought in Washington State. Nat Hazards Rev 10:11–18. doi:10.1061/(asce)1527-6988(2009)10:1(11)

Ford JD, Smit B (2004) A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change. Arctic 47:389–400

Ford JD, Smit B, Wandel J (2006) Vulnerability to climate change in the Arctic: a case study from Arctic Bay, Canada. Glob Environ Chang 16:145–160. doi:10.1016/j.gloenvcha.2005.11.007

Ford JD, Keskitalo ECH, Smith T et al (2010) Case study and analogue methodologies in climate change vulnerability research. Wiley Interdiscip Rev Chang 1:374–392. doi:10.1002/wcc.48

Foti R, Ramirez JA, Brown TC (2012) Vulnerability of future United States water supply to shortage. Gen. Tech. Rep. RMRS-GTR-295. (in review: p 147

Fukuyama F, Hodgson GM (2003) Social capital and civil society. In: Ostrom E, Ahn TK (eds) Foundations of social capital. Edward Elgar Publishing, Northampton, pp 291–308

Fussel H-M, Klein RJT (2006) Climate change vulnerability assessments: an evolution of conceptual thinking. Clim Chang 75:301–329

Getches DH (1990) Water law in a nutshell. West Pub. Co., St. Paul

Glantz MH (1988) Societal responses to climate change: forecasting by analogy. Westview Press

Glantz MH (1991) The use of analogies in forecasting ecological and societal responses to global warming. Environment 33:10

Glantz MH, Katz RW (1977) When is a drought a drought? Nature 267:192–193. doi:10.1038/267192a0

Gray ST, Lukas JJ, Woodhouse CA (2011) Millennial-length records of streamflow from three major upper Colorado River tributaries. J Am Water Resour Assoc 47:702–712. doi:10.1111/j.1752-1688.2011.00535.x

Grothmann T, Patt A (2005) Adaptive capacity and human cognition: the process of individual adaptation to climate change. Glob Environ Chang Policy Dimens 15:199–213. doi:10.1016/j.gloenvcha.2005.01.002

Hahn MB, Riederer AM, Foster SO (2009) The livelihood vulnerability index: a pragmatic approach to assessing risks from climate variability and change—a case study in Mozambique. Glob Environ Chang Policy Dimens 19:74–88. doi:10.1016/j.gloenvcha.2008.11.002

Harding BL, Sangoyomi TB, Payton EA (1995) Impacts of a severe sustained drought on Colorado River water resources. Water Resour Bull 31:815–824

Hayes MJ, Svoboda MD, Knutson CL, Wilhite DA (2004a) Estimating the economic impacts of drought. 14th Conference Applied Climatology

Hayes MJ, Wilhelmi OV, Knutson CL (2004b) Reducing Drought Risk: Bridging Theory and Practice. Nat Hazards Rev 5:106–113

Hinkel J (2011) "Indicators of vulnerability and adaptive capacity": towards a clarification of the science-policy interface. Glob Environ Chang Policy Dimens 21:198–208. doi:10.1016/j.gloenvcha.2010.08.002

Kallis G (2008) Droughts. Annu Rev Environ Resour 33:85–118. doi:10.1146/annurev.environ.33.081307.123117

Kelly PM, Adger WN (2000) Theory and practice in assessing vulnerability to climate change and facilitating adaptation. Clim Chang 47:325–352

Kenney D, Ray A, Harding B et al (2010) Rethinking vulnerability on the Colorado River. J Contemp Water Res Educ 144:5–10

Knapp CN, Fernandez-gimenez M (2008) Forum knowing the land: a review of local knowledge revealed in Ranch Memoirs. Rangel Ecol Manag 61:148–155

Knutson CL (2008) The role of water conservation in drought planning. J Soil Water Conserv 63:154A–160A. doi:10.2489/63.5.154A

Kuhn E (2012) Risk management strategies for the Upper Colorado River Basin. p 45

Lempert RJ, Groves DG (2010) Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American west. Technol Forecast Soc Chang 77:960–974. doi:10.1016/j.techfore.2010.04.007

Lord WB, Booker JF, Getches DM et al (1995) Managing the Colorado River in a severe sustained drought—an evaluation of institutional options. Water Resour Bull 31:939–944

Luers AL (2005) The surface of vulnerability: an analytical framework for examining environmental change. Glob Environ Chang 15:214–223

Luers AL, Lobell DB, Sklar LS et al (2003) A method for quantifying vulnerability, applied to the agricultural system of the Yaque Valley, Mexico. Glob Environ Chang 13:255–267

Malone EL, Engle NL (2011) Evaluating regional vulnerability to climate change: purposes and methods. Wiley Interdiscip Rev Chang 2:462–474. doi:10.1002/wcc.116

McNeeley SM (2012) Examining barriers and opportunities for sustainable adaptation to climate change in Interior Alaska. Clim Chang 111:835–857. doi:10.1007/s10584-011-0158-x

McNeeley SM, Shulski MD (2011) Anatomy of a closing window: vulnerability to changing seasonality in Interior Alaska. Glob Environ Chang 21:464–473

Mills J, Bonner A, Francis K (2006) The development of constructivist grounded theory. Int J Qual Methods 5:25

NCVST (2009) Vulnerability through the eyes of the vulnerable: climate change induced uncertainties and Nepal's development predicaments. p 114

O'Brien K, Leichenko R, Kelkar U et al (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob Environ Chang 14:303–313. doi:10.1016/j.gloenvcha.2004.01.001

Ojima D, Steiner J, McNeeley S et al (2012) Great Plains Regional Climate Assessment Technical Report for the 2013 National Climate Assessment

Pederson GT, Gray ST, Fagre DB, Graumlich LJ (2006) Long-duration drought variability and impacts on ecosystem services: a case study from Glacier National Park. Earth Interact, Montana. doi:4

Pederson GT, Gray ST, Woodhouse CA et al (2011) The unusual nature of recent snowpack declines in the North American Cordillera. Science 333:332–335. doi:10.1126/science.1201570

Pelling M, High C (2005) Understanding adaptation: what can social capital offer assessments of adaptive capacity. Glob Environ Chang 15:308–319

Pielke RA, Doesken N, Bliss N et al (2005) Drought 2002 in Colorado: an unprecedented drought or a routine drought? Pure Appl Geophys 162:1455–1479. doi:10.1007/s00024-005-2679-6

Plaska RM (2004) Division of Water Resources 2004 Annual Report Water Division VI Yampa, White, & N. PLatte River Basins. 45

Polsky C, Neff R, Yarnal B (2007) Building comparable global change vulnerability assessments: the vulnerability scoping diagram. Glob Environ Chang Policy Dimens 17:472–485. doi:10.1016/j.gloenvcha.2007.01.005

Pulwarty R, Jacobs K, Dole R (2005) The hardest working river: drought and critical water problems on the Colorado. In: Wilhite D (ed) Drought and water crises: science, technology, and management. Taylor and Francis Press, New York, pp 249–285

Roehm GW (2004) Management plan for endangered fishes in the Yampa River Basin and environmental assessment. p 214

Schroter D, Polsky C, Patt AG (2005) Assessing vulnerabilities to the effects of global change: an eight step approach. Clim Chang 10:573–596

Schwinning S, Belnap J, Bowling, Ehleringer JR (2008) Sensitivity of the Colorado plateau to change: climate, ecosystems, and society. Ecol Soc 13:28

Scoones I (1998) Sustainable rural livelihoods: a framework for analysis. p 22

Seager R, Ting M, Held I et al (2007) Model projections of an imminent transition to a more arid climate in southwestern North America. Science 316:1181–1184. doi:10.1126/science.1139601

Smit B, Pilifosova O (2001) Adaptation to Climate Change in the Context of Sustainable Development and Equity - Chapter 18. In: McCarthy JJ, Canziani OF, Leary NA et al (eds) Clim. Chang. 2001 Impacts, Adapt. Vulnerability - Contrib. Work. Gr. II to Third Assess. Rep. Int. Panel Clim. Chang. Cambridge University Press, Cambridge, UK, pp 877–912

Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Glob Environ Chang Policy Dimens 16:282–292. doi:10.1016/j.gloenvcha.2006.03.008

Smit B, Burton I, Klein RJT, Wandel J (2000) An anatomy of adaptation to climate change and variability. Clim Chang 45:223–251

Stahle DW, Cook ER, Cleaveland MK et al (2000) Tree-ring data document 16th century megadrought over North America. EOS Trans AGU 81:121–125. doi:10.1029/00eo00076

Travis WR, Klein R (2011) Assessing measures of drought impact and vulnerability in the intermountain west. p 26

Tronstad R, Fuez D (2002) Impacts of the 2002 drought on western ranches and public land policies. West Econ Forum 1:19

Turner BL, Kasperson RE, Matson PA et al (2003) A framework for vulnerability analysis in sustainability science. Proc Natl Acad Sci USA 100:8074–8079. doi:10.1073/pnas.1231335100

Wilhelmi OV, Hayes MJ, Thomas DSK (2008) Managing drought in mountain resort communities: Colorado’s experiences. Disaster Prev Manag 17:672–680

Wilhite DA (2005) Drought and water crisis: science, technology, and management issues. p 406

Wilhite DA, Pulwarty RS (2005) Drought and water crises: lessons learned from the road ahead. Drought Water Cris

Wilhite DA, Svoboda MD, Hayes MJ (2007) Understanding the complex impacts of drought: a key to enhancing drought mitigation and preparedness. Water Resour Manag 21:763–774. doi:10.1007/s11269-006-9076-5

Woodhouse CA, Gray ST, Meko DM (2006) Updated streamflow reconstructions for the Upper Colorado River Basin. Water Resour Res 42:W05415. doi:10.1029/2005wr004455

Woodhouse CA, Meko DM, MacDonald GM et al (2010) A 1,200-year perspective of 21st century drought in southwestern North America. Proc Natl Acad Sci 107:21283–21288. doi:10.1073/pnas.0911197107

Yohe G, Tol RSJ (2002) Indicators for social and economic coping capacity—moving toward a working definition of adaptive capacity. Glob Environ Chang 12:25–40

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.