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Theory to Practice

Left High and Dry? Climate Change, Common-Pool Resource Theory, and the Adaptability of Western Water Compacts

Efforts to reduce greenhouse gas emissions are falling far short of what a consensus of scientists argues is necessary to avoid potentially catastrophic increases in the mean global temperature. Increasingly, attention is devoted to understanding the vulnerability and adaptability of social and ecological systems to climate change in particular areas of the world. In the Western United States and other semi-arid regions of the world, possibly the most immediate, direct impacts of climate change involve the availability of water resources. Scientific evidence suggests that the West is likely to become hotter and drier and will experience greater variability in precipitation. These changes will affect tens of millions of residents in Western states, and nearly every sector of the economy, especially agriculture. The logic of common-pool resource theory is applied in this Theory to Practice *essay to assess the vulnerability and adaptability to climate change of interstate river compacts and to offer recommendations for coping with climate change. Future areas of research on this critical topic are also outlined.*

Expert e-commentaries by Richard Kashmanian and Roger Gorke of the U.S. Environmental Protection Agency, and by Elisabeth Graffy of the U.S. Geological Survey, can be found on the PAR *website (go to aspanet.org, click on the link to* PAR, *and then on the* Theory to Practice *link).*

As efforts to reduce greenhouse gas emissions fall far short of what a consensus of scientists argues is necessary to avoid potentially catastrophic increases in the mean global temperature, mounting efforts and attention are being devoted to understanding both the vulnerability and adaptability of our social and ecological systems to climate change (Adger 2000, 2006; Gallopín et al. 2001; IPCC 2007). Vulnerability is largely a function of populations' level of exposure and sensitivity to the different stresses resulting from climate change, such as increasing temperatures, rising sea levels, and more frequent and extreme weather events (Adger 2000, 2006; IPCC 2007). Vulnerability also depends on the adaptability of communities, or the changes undertaken to minimize the effects of climate impacts (Gallopín 2006; IPCC 2007).

In the Western United States and other semi-arid regions of the world, one of the most immediate and direct effects of climate change involves the availability of water resources (IPCC 2007). On average, states west of the 100th meridian receive less than 20 inches of rainfall per year (except the coastal region of the Pacific Northwest), with areas of the Southwest and Intermountain West receiving less than 10 inches per year. Moreover, scientific evidence suggests that the hydrologic cycles of the West are changing; not only may the hottest and driest region of the United States become even drier, but also the availability of water is likely to be much more variable (Climate Change Science Program 2008). Some Western reservoirs may be less reliable and sustainable (Barnett and Pierce 2008, 2009; Barsugli et al. 2009; Brikowski 2008; Wiley and Palmer 2008). For instance, Barnett and Pierce (2009, 7336) estimate that a 10 percent reduction in runoff in the Colorado River Basin will lead to requested water deliveries exceeding sustainable deliveries by 2040. If climate change impacts are greater—say, a 20 percent reduction in runoff—then water delivery shortfalls will occur by 2025.

Historically, interstate river compacts have been the primary means of resolving conflicts over competing water demands in the West by establishing allocation rules for stream flows, ensuring downstream water users a defined share of water from rivers. When the federal government began pouring billions of dollars into this infrastructure in the early twentieth century, interstate compacts helped states ensure that water resource development would be orderly, with minimal conflict. A majority of compacts also established rules for how water would be allocated from reservoirs built on interstate rivers. By capturing and storing snowmelt and spring runoff and making it available to water users during the summer months when demand is high, large-scale reservoirs also provide multiyear storage to minimize state vulnerability to droughts lasting up to a decade in the West.

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But will the current design of these interstate compacts be well matched to new conditions driven by climate change? How effectively can the institutions induce rule compliance through monitoring and conflict resolution? To what degree are they capable of adapting? To assist water managers in answering these questions, we turn to scholarship on the management of common-pool resources (CPRs) (Ostrom 1990; Ostrom, Gardner, and Walker 1994). After showing how common-pool resource theory (CPRT) applies to interstate compacts, we cull five propositions informed by CPRT and illustrate their validity with examples from an earlier comparative study of 14 Western interstate water compacts that focus largely on supply-side efforts (Schlager and Heikkila 2009). Four major institutional sources of vulnerability to climate change are identified: variations in the types of rules, the scope of rules, state capacity, and interstate commission rules. We conclude by offering four recommendations grounded in CPRT for adapting interstate water compacts to climate changes. We argue that state and interstate compact officials need to give greater thought to CPRT principles before designing water supply and demand solutions, and we offer some suggestions for future research on this topic.

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Common-Pool Resource Theory, Natural Resources, and the Importance of Institutional Arrangements

The theory of CPR management has been used to understand the factors that are associated with both the robustness and the fragility of governing arrangements for a range of natural resources such as water, fisheries, and forests (e.g., Agrawal 2002; Ostrom 1990; Ostrom, Gardner, and Walker 1994; Schlager 2004). CPRT, which is developed within a broader research framework on institutional analysis (Ostrom 2005), points to critical institutional features that can help explain how interstate river compacts might perform in the face of climate change and what institutional changes might improve interstate water management. Interstate rivers are CPRs. Excluding would-be water users from accessing a river is costly, and water withdrawn and consumed is not available for others to use (Ostrom and Ostrom 1977). These two defining characteristics of CPRs, costly exclusion and subtractability of resource units, mean that resources can be easily overused and severely degraded—thus creating vulnerabilities for the people who depend on them—unless their many uses and users are coordinated and governed.

Coordination and governance occur through institutional arrangements. Institutional arrangements are rules and property rights systems that guide, direct, and constrain people's actions with respect to CPRs (Ostrom 2005). Rules define what actions must, must not, or may be taken in any given action situation, such as CPR use and management (Crawford and Ostrom 1995). As we will discuss in more detail, water allocation rules are the foundation of interstate river compacts, and they typically specify the actions that an upstream state must or must not take to ensure that a downstream state receives its water allotment.

When assessing how vulnerable or how adaptable compacts are to climate change, we begin with an analysis of these rules. In particular, CPRT posits that the performance of institutions depends on how well the rules are matched to the biophysical and social setting in which they are applied (Ostrom, Gardner, and Walker 1994). For instance, a water allocation rule that allocates more water than is available in a river is not well matched to its setting. Equally important is how well rules reflect important social norms and practices, particularly in how they distribute the benefits and burdens of governing a CPR (Ostrom 2005). In general, if benefits and burdens are proportionately distributed, a CPR institution will be viewed more fairly and will more likely be supported by resource users. Thus, in the case of interstate compacts, water allocation rules that focus the risk of water shortage on a single state or type of water user tend to generate conflict, whereas water allocation rules that distribute risk among water users tend to support more cooperative behavior.

Institutional performance also depends on whether people are following the rules. First, when the majority of resource users can participate in devising rules, and when the authority of resource users to make decisions is not likely to be usurped by higher authorities, people are more likely to buy into the rules. Second, rule-following behavior is encouraged and supported by monitoring systems that provide CPR users with information on how the resource responds to the rules that guide people's uses of it (Blomquist 1992; Ostrom, Gardner, and Walker 1994). In addition, monitoring systems are crucial for detecting whether most users are following the rules most of the time. CPR users are more likely to follow rules if they know that most resource users are also following the rules (Ostrom 2005). Consequently, we expect compacts that have developed the institutional capacity to monitor effectively will have greater capability to respond to the challenges of changing climate conditions and to comply with agreed-upon rules.

Third, the CPR literature recognizes that conflict resolution mechanisms are needed to settle differences over interpretations of rules and to hold accountable resource users and those administering the rules (Ostrom 1990). Developing and maintaining a common understanding of what rules do and do not require, especially in dynamic biophysical settings such as those occasioned by climate change, are essential to maintaining workable arrangements and commitment to the rules. In complex or large-scale CPR settings such as interstate watersheds, the theory adds that CPR institutions—their rules, monitoring, and conflict resolution mechanisms—should be nested and aligned across levels of governance (Ostrom 1990).

Finally, the literature on CPR management recognizes that the institutional arrangements that people devise to govern highly salient CPRs such as scarce water supplies are not static. Over time, as people learn about the CPR, each other's behavior, and how that behavior affects the resource, they revisit existing institutional arrangements and devise new arrangements to match the biophysical and social setting better (Ostrom 2005). Their success, however, hinges on overcoming a number of obstacles. Institutions are public goods, and thus they are subject to free-riding and haggling over fair distributions of benefits and costs (Ostrom 1990). Also, for

most resource users, the net benefits produced by new institutional arrangements must exceed the net benefits of existing arrangements and feasible alternatives.

Assessing Compact Vulnerability and Adaptability to Climate Change

What expectations does CPRT set regarding the vulnerability and adaptability of existing interstate water compacts in light of climate change predictions? Starting in the 1920s, Western states entered into more than 20 compacts to allocate water from interstate rivers, signing the majority of these prior to the 1950s. All remain in force, including the 14 in our 2009 study (see table 1). Many of them established active governance commissions comprising state water officials and, often, water users. The commissions administer the water allocation rules; address problems and conflicts; and engage in studies, monitor, and report on different water use and supply issues in the compact river basin. Other compacts eschew commissions and are enforced by state water agencies. Over time, as compact commissioners and states have faced disagreements over compliance with or interpretation of the rules because of changing hydrologic information or increased demands, they have responded, or adapted, in various ways. Two compacts have been modified, a few have faced revisions as a result of court cases, and a number have invested in new strategies and capacity building (Heikkila and Schlager 2008).

However, effective institutional change is not guaranteed. Premised on CPRT principles and variations in adaptation experiences, four general categories of expectations about the vulnerability and adaptability of existing compacts to climate change are discernible and offer analytical guidance to policy makers: those applicable to the nature of the rules, the scope of the rules, levels of state adaptive capacity, and the potential for interstate water commission adaptation.

Rule Types as a Source of Vulnerability

Compact water allocation rules consist of different "types" (e.g., fixed or proportionate), which may apply at different times of the year, and/or to different segments of rivers, and/or to different water users or states (see table 2). Each type of rule, in turn, has subcategories of rules within it. These features determine how well matched the different compacts are to the physical context imposed by climate change. Who is likely to be most vulnerable also depends on how the rules apportion benefits to the users in the CPR setting.

Proposition 1: Fixed allocation rules squarely place the risk of water shortages on specific states; which state depends on the particular design of the rule. Consequently, they may be less adaptive to climate change than proportional rules.

There are two kinds of fixed allocation rules that differentially affect Western states' vulnerabilities and adaptive capacities to projected climate change. One type of fixed rule allocates a specified amount of water to each state. The Republican River Compact originally allowed Colorado and Nebraska, the two upstream states, to take their fixed allocation regardless of whether sufficient water remained in the river to meet the fixed allocation of Kansas. Thus, Kansas was vulnerable to the actions of the upstream states. In particularly dry years, even if the upstream states only used their compact allocations, it was possible that Kansas would not receive its full allotment.

A more commonly used fixed allocation rule is the minimum flow rule. Upstream states commit to delivering a specified amount of water to downstream states. Consequently, the upstream states bear the effects of a changing hydrologic regime. In the case of the Big Blue Compact and the South Platte Compact, upstream states commit to providing minimum daily stream flows during the irrigation season. During particularly dry years, even if the upstream state fully complies with all of the administrative requirements of the compact, it still will be out of compliance. This very scenario occurred in the Big Blue River Basin for the first time in 2003 as a severe drought unfolded. Even though Nebraska limited intrastate water use, as required by the compact, for three years, it consistently failed to deliver the required minimum flows to Kansas during the irrigation season (Big Blue River Compact Commission 2004, 2005).

Table 1 Interstate River Compacts

Compact	Member States	Date Formed	Governing Structure	Jurisdictional Scope
Arkansas	Colorado, Kansas	1942	Commission	Surface water, Groundwater
Bear	Idaho, Utah, Wyoming	1958, 1980	Commission	Surface water
				Groundwater
				Water quality
Belle Fourche	South Dakota, Wyoming	1943	None	Surface water
Big Blue	Kansas, Nebraska	1971	Commission	Surface water
				Groundwater
				Water quality
Costilla Creek	Colorado, New Mexico	1944, 1963	Commission	Surface water
Klamath	California, Oregon	1956	Commission	Surface water, water quality
La Plata	Colorado, New Mexico	1922	Commission	Surface water
Pecos	New Mexico, Texas	1949	Commission	Surface water, water quality
Republican	Colorado, Kansas, Nebraska	1943	Commission	Surface water, groundwater
Rio Grande	Colorado, New Mexico, Texas	1938	Commission	Surface water, water quality
Snake	Idaho, Wyoming	1949	Commission	Surface water
South Platte	Colorado, Nebraska	1923	None	Surface water
Upper Niobrara	Nebraska, Wyoming	1962	None	Surface water
Yellowstone	Montana, North Dakota, Wyoming	1950	Commission	Surface water

Table 2 Water Allocation Rules of Western Interstate River Compacts

Compact	Rule Type	Seasonality	Users Subject to Compact Regulation
Arkansas	Stream flows fixed; reservoir proportionate	November 1–March 31 (winter storage); April 1–October 31 (summer storage)	Post-1948 Colorado water users
Bear	Stream flows proportionate; reservoir fixed	Low flows trigger regulation	All water users
Belle Fourche	Proportionate	none	Post-1943 water users
Big Blue	Stream flows fixed	May 1–September 30 (irrigation season)	Post–November 1, 1968, Nebraska water users
Costilla Creek	Proportionate	May 16–September 30 (irrigation season); October 1–May 15 (storage season)	All water users
Klamath	Prior appropriation	None	Post-1957 water users
La Plata	Proportionate	February 15–December 1	Colorado water users
Pecos	Fixed	None	New Mexico water users
Republican	Fixed	None	Post-1948 Nebraska water users
Rio Grande	Proportionate	None	Colorado and New Mexico water users
Snake	Proportionate	None	All water users
South Platte	Fixed	April 1–October 15 (irrigation season)	Post–June 14, 1897, Colorado water users, Washington County east to state line
Upper Niobrara	Prior appropriation	None	Post-1957 water users
Yellowstone	Proportionate	None	Post–January 1, 1950, water users

Proposition 2: Proportionate allocation rules can be effective in sharing the risk of water shortages among states, and thus are more adaptive to climate change conditions, but global warming still may render upstream users vulnerable to shortages compared to their historical use.

Proportionate allocation rules spread the risk of water shortages among the states rather than concentrating them on an upstream or a downstream state. These rules can provide either a set percentage for each state, or the proportion may vary depending on water flows. The Bear River Compact of 1958, for example, has been quite active in allocating supplies under its proportionate rule system, which is a set percentage for each state. Its allocation rules are implemented when stream flows drop below a specified level. The allocation rules have worked well in sharing the risk of water shortages in the basin, and the states regularly comply with the allocation rules negotiated (Bear River Compact Commission 1958–70; Jibson 1997).

Under a drier and more variable climate, however, fixed proportionate rules lead to new vulnerabilities, particularly for water users in upstream states who may have to forgo historical water usage in deference to downstream users. For instance, the La Plata River Compact requires Colorado, the upstream state, to shepherd 50 percent of the flow of the river to the New Mexico border. Colorado must absorb all water transit losses in getting this flow to the border. During the middle of the summer, transit losses may be quite high. Furthermore, Colorado water users who have very "senior" (or long-standing and historical) rights to water are located near the border, and they must be prevented from diverting the water before it reaches New Mexico, something that they resist (Knox 2001). While the compact allows some leeway for the states to manage extreme water shortages, the number of times that Colorado is unable to deliver any useable water supplies to the border is likely to increase throughout the year under climate change, even if Colorado limits water diversions by its own citizens.

Some compacts, such as those of the Rio Grande and Costilla Creek, use "variable" proportionate rules, which stipulate that the amount of water allocated differs depending on water flows. Although these rules may appear more flexible to changing climate conditions, their percentages are based on hydrologic models that may be ill tuned to new climate conditions. For instance, under the Rio Grande Compact, Colorado is subject to a schedule of water deliveries to New Mexico, using a model that estimates the relationships between inflows at the head of the river and outflows at the state line with New Mexico. Under climate change, droughts may be more frequent or rainfall and snowmelt patterns may change, meaning that the actual relationships between inflows and outflows are less likely to fit the model. The upstream state will then find it more difficult, if not impossible, to realize the expected water delivery schedules based on relationships that no longer exist.

Rule Scope as a Source of Vulnerability

CPRT also indicates that how well matched water allocation rules are to climate change, as well as the vulnerability of water users subject to the rules, is shaped by the scope of the rules. That is, when do compact rules apply, how much water do they apply to, and which water users are affected? Our analysis suggests that climate change in the West can have serious implications for the abilities of interstate compact regimes to adjust in timely and useful ways depending on their scope.

Proposition 3: When the scope of compact rules targets particular seasons, encompasses a large portion of river flows, or targets particular users over others (i.e., surface and not groundwater), vulnerabilities to climate change are likely to be greater, as such rules are not likely to be well matched to future climate conditions.

As noted, most compact water allocation rules are particularly restrictive during the irrigation season or summer season. Outside of the irrigation season, a number of compacts devote stream flows to filling reservoirs. As climate change unfolds, however, the dates defining seasons may no longer correspond to the actual seasons. With warmer temperatures, farmers may want to irrigate into the fall, or farmers may need to start planting and irrigating earlier in the spring. Yet compacts with seasonal rules restrict such options, and those with seasonal fixed allocation rules may be particularly vulnerable. With earlier snowmelt and runoff, upstream states may no longer be credited with providing minimum flows guaranteed during a particular season by the upstream state, as peak flows may begin occurring out of season.

How much water a compact rule encompasses may also prove to be as important as the seasonality of the rule. Consider, again, the Big Blue Compact and the Republican Compact. The Big Blue Compact's minimum flow rules apply only during the irrigation season from May through September. During those months, Nebraska is required to deliver to Kansas between 3 percent and 17 percent of the mean monthly flow of the Big and Little Blue rivers, providing Nebraska with a larger "water cushion" to meet the compact requirements. In contrast, in 1947, the Republican Compact water allocation rule divided about 75 percent of the average annual surface flows among the states, providing much less leeway for states to meet their compact requirements.

Between the two compacts, Nebraska has had a much easier time complying with the Big Blue River Compact. It has struggled, however, especially during drought seasons, to comply with the Republican River Compact. This places Kansas in an even more vulnerable position with respect to the challenges Nebraska will face in complying with the Republican River Compact's allocation rules as climate change exacerbates drought conditions.

In addition to when the rules apply and how much water they apply to, the scope of compact rules depends on whom they target. When signed, many compacts explicitly excluded any water users with allocation rights prior to the agreement from facing use restrictions. The idea was that only new water users would need to be limited in order to ensure future interstate "comity." For instance, the 1947 Arkansas River Compact states that the flows of the river may not be materially depleted. This has been interpreted to mean that after 1947, new water uses that depleted the river, such as groundwater pumping, had to replace the depleted water, thus limiting the compact's scope. Still, under changing climate conditions, the vulnerabilities of those who are subject to the compact are likely to increase.

A related challenge for some compacts is that very few of them originally included both surface water and groundwater users in the allocation rules. As several compact members have already found, the hydrologic connection between groundwater and surface water means that groundwater pumping, which often increases during drought years, can reduce flows downstream. The Republican River, for example, is hydrologically connected to the Ogallala groundwater aquifer; pumping in the Republican River Basin has been slowly reducing surface water flows so that the total amount of water that the allocation rule governs exceeds the average annual discharge of the river (Szilagyi 1999). This led to a lawsuit by Kansas against Nebraska and Colorado, the upstream states, that went all the way to the U.S. Supreme Court. The lawsuit settlement required the two upstream states to count a portion of their groundwater pumping against their compact water allocations. Counting groundwater placed both states out of compliance with the compact and required them to attempt strict regulation of groundwater wells. Such strategies may enhance adaptability for the states; Nebraska, for instance, invested in integrated ground and surface water modeling expertise to enhance its capacity to administer the compact's water allocation rules. However, placing new regulations on established water users increases tensions. The Nebraska Department of Natural Resources has worked for almost a decade with groundwater users to align them with state compact commitments.

State Capacity as a Source of Vulnerability

A fundamental take-home message from CPRT, however, is that there is no single best allocation rule that is applicable to all river basins or even the same river basin over time (Ostrom 1990, 2005). Many of the problems identified earlier, such as seasonality mismatches or the nature of the hydrologic connection between rivers and groundwater basins, became apparent only after years of administering the water allocation rules and learning how they work in practice. Consequently, another key issue identified by CPRT is whether learning can inform rule revisions or new strategies so that rules perform better. This is especially true in upstream states because they are likely to be the first responders to climate impacts, and even more so for states in compacts with allocation rules requiring minimum flows to downstream users.

Proposition 4: Under climate change conditions, upstream state water officials likely face increasing and intense conflicting pressures from their own water users demanding more water and/or resisting additional water administration, while at the same time fielding demands for more water and stricter water administration from downstream states. Thus, upstream states likely will be challenged to ensure that they are able to induce rule-following behavior to comply with compacts. States with a history of adaptation to groundwater and surface water allocation shifts, prompted by established administrative capacities, are more likely to induce compact compliance and thus mitigate vulnerabilities.

CPR research clearly shows that climate change vulnerability and adaptability are a function of both state physical features (needs) and administrative capacities, and that these will vary across states and times. Take Colorado, which is an upstream and "headwater" state in five compacts in our study (Arkansas, Costilla Creek, Republican, Rio Grande, and South Platte), as a case in point. In each of these five river basins, Colorado's water supplies are either fully allocated or overallocated. This means that Colorado's water users have legally established rights to all of the water available in these rivers, and in some cases, either these rights or the actual demand for water exceed the physical supply of water in a river. In the Arkansas River Basin, water users who established rights after 1900 rarely receive an allotment of water, no matter the time of year. Consequently, water compact administrators in Colorado have little flexibility to ensure that more water flows downstream to meet interstate compact requirements as they face climate vulnerabilities.

While Colorado largely is constrained by its commitments to surface water rights, it has demonstrated some degree of adaptive capacity when issues surrounding groundwater have come into play. Beginning in the 1960s, conflicts emerged over access to increasingly scarce water supplies, primarily between Colorado's groundwater and surface water users, and between Colorado and downstream states. At the heart of the intrastate and interstate conflicts have been the effects of groundwater pumping on surface water flows. Colorado's policy makers, water users, and state engineer's office invested in policy changes creating restrictions on pumping groundwater that is "tributary" to surface water. Also created was a mechanism whereby groundwater users could continue pumping at certain times of the year if they provided "replacement" water for the portion of the surface water that pumping depleted from the stream.

Additionally, the state of Colorado invested tens of millions of dollars in decision support systems that carefully track water rights and water diversions from the major river basins in the state. Basin-centered arrangements have been developed that also foster water governance capacity. Citizens in the Arkansas River Valley created a conservancy district with taxing powers. The revenues are used to purchase or lease Arkansas River water rights that would otherwise be sold to water users in other river basins, thus keeping the water in basin to meet basin and interstate water demands (Lower Arkansas Valley Water Conservancy District 2010).

Most importantly, however, Colorado has used and invested in institutional arrangements that align with CPR principles and support rule compliance. First, water users have actively participated in designing the rules governing ground and surface water allocation and use. Opportunities to engage in water governance occur through a variety of venues. Those with water rights or those who want water rights have access to water courts to create, revise, enforce, and extinguish existing water rights. The state engineer actively engages water users in devising rules and regulations. Once the state engineer finalizes rules and regulations, a water court is asked to rule on the validity of the rules, providing water users another opportunity to weigh in on the rules. The Colorado legislature and Colorado law also allow water users to devise their own governing arrangements, as the water users in the Arkansas River Basin did in creating a conservancy district. Second, careful attention is paid to resolving conflicts among competing water users and between water users and state water officials. Water courts are used not only to devise water rights and rules, but also to address and resolve conflicts among water users and officials. Third, as CPRT advises, Colorado has invested in extensive water monitoring systems, from local water commissioners who administer water rights on the ground to sophisticated decision support systems that track water rights and their use in real time.

In comparison, Wyoming—another upstream state in multiple compacts (Bear, Belle Fourche, Upper Niobrara, Upper Snake, and Yellowstone)—is positioned in relatively small portions of the interstate river compact basins, with the exception of the Yellowstone River. As such, it does not face the same problems that Colorado faces of having overappropriated water rights in its compact basins. In fact, in 2001, Wyoming predicted that it was in a position to develop more storage and new water allocations while remaining in compliance with compact obligations (Wyoming Water Development Commission 2001).

Despite the fact that Wyoming has much more "wiggle" room to adapt to climate change from a physical perspective, it is not clear how long that will last. The state has recently begun paying closer attention to the potential effects of climate change on its water supplies, especially given its arid climate and reliance on snowpack to feed its rivers (Gray and Andersen 2009). Moreover, while Wyoming has a small population, its water demands from the energy sector are growing. Additionally, in the Bear and Yellowstone river basins, increasing water scarcity is beginning to place pressure on Wyoming to administer water rights more actively so that downstream states receive compact allocations.

Thus, although Wyoming has not had to invest in the same types of institutional and policy adaptations as states such as Colorado, it may require more rapid investments in administrative capacity surrounding interstate compacts to respond to climate changes. But if Wyoming engages in institutional and policy adaptations to address water scarcity, the state will be well served by paying attention to the same sorts of CPR governing issues that its counterparts in states such as Colorado did—providing many opportunities for water users to engage in developing rules; providing venues for resolving conflicts; and monitoring, measuring, and making information on water rights and water use widely available.

Interstate Commission Rules as a Source of Vulnerability

Upstream states, of course, did not enter into compacts alone. While they may be forced into the position of first responders to the effects of climate change, they also have the opportunity to work together with downstream states via interstate commissions to adapt to the challenges facing compacts. In the process, several principles of CPRT should guide their efforts.

Proposition 5: How adaptive compact commissions are and how effectively their rules are nested with states' rules will shape where particular basins or states may be more or less vulnerable to climate change.

We illustrate this proposition by again looking at the interstate administrative capacities of the two compacts in which Wyoming, as an upstream state, is likely to have less physical wiggle room to adapt to climate change—the Bear and Yellowstone river compacts. Over time, the Bear River Compact Commission has invested in establishing real-time automated monitoring of stream flows (from U.S. Geological Survey gauges paid for by the commission) over the length of the river, combined with regular communication between state watermasters, who monitor intrastate water rights diversions, and the compact water administrator (Barnett 2006; Jibson 1997). Based on real-time stream flow information, the compact administrator readily determines whether flows have dropped below a level that triggers regulation. He then communicates to the state watermasters which water users to shut down and when. When flows exceed the "trigger" level or when the end of the growing season is reached, administration of interstate allocation rules ceases. This administrative capacity demonstrates the type of nested, multilevel rule sets that CPRT expects to foster rule compliance because it facilitates transparency, consistent expectations among the states and water users, and quick responses to changes in resource availability while meeting compact obligations.

In contrast, the Yellowstone River Compact Commission has not invested in nested administrative capacity to account for water use and to monitor water allocations. Supplies have generally been more than sufficient to meet water demands in the basin, so the states historically have not had to administer the compact. However, concern has periodically arisen among the commissioners that supply limitations are on the horizon and that procedures and mechanisms will be needed to administer the compact more actively before these limitations are realized (Yellowstone River Compact Commission 1950–2005).

Starting in 2000, drought in the basin brought these questions to the forefront of discussions at the commission, with Montana raising concerns that Wyoming may not be effectively complying with the compact. While Wyoming argues it has not violated the

compact, the state openly admits that the "official gauging stations established by the Compact to effect a regulation" are inadequate to determine when water supply conditions should trigger water administration (Wyoming Water Development Commission 2002, I-9). Thus, this compact lacks the design principles offered by CPRT that induce rule compliance or foster adaptation.

Toward CPRT-Informed Institutional Adaptation to Climate Change

To mitigate future vulnerabilities and tensions between and among compact states, we offer four CPRT-based alternative approaches that compact administrators, water managers, and water users could pursue in light of their vulnerabilities, capacities, and fiscal realities.

Recommendation 1: States should not wait to reopen and renegotiate the water allocation rules of compacts.

One option that might make compacts more robust and less vulnerable to climate change would be for states to redesign water allocation rules. This option, however, is unlikely to be chosen by the states. First, states would have to identify water allocation rules that make them and their water users better off than they are under existing rules. When compacts were initially signed, all participants anticipated being made better off, or at least not worse off. Most compacts also grandfathered in existing water rights, providing water users more secure rights in the process. In addition, many compacts resulted in the federal government building large surface water storage projects that provided more water and more reliable sources of water to states and their citizens. Even with the expectations by states that they would be better off entering into compacts, however, it often took a decade or more for compact adoption. Moreover, the compact negotiating context is very different today. The federal government is unlikely to entice compact revisions by investing in new surface storage facilities. Also, in attempting to make water allocation rules better match a drier environment, states will be attempting to reallocate less water. How states will gain sufficient support to reduce or eliminate water rights is unclear.

Second, the different processes for negotiating and renegotiating compacts present states with the worrisome possibility that they could lose control of the process. If initiated by states and commissions, compacts must still be ratified by the states' legislatures and Congress. This opens the compact to the scrutiny of disaffected farmers who feel that their water rights are being taken from them, of municipalities who want more water for their growing populations, and of environmentalists who seek to protect riparian areas and endangered species. Another approach is for Congress to redesign the water allocation rules, but states are even more likely to lose control over this process than the previous one. Both of these processes are also likely to expose compacts to the requirements of federal environmental laws. As noted, most compacts were adopted prior to the enactment of federal environmental laws. As environmental issues have arisen in compact-governed river basins, they have largely been addressed through means separate from compacts. That would almost certainly change if either states or Congress tried to revise compacts.

The third possible mechanism available to the states for altering existing compacts is a U.S. Supreme Court case. No state has ever attempted explicitly to revise water allocation rules in this manner, and it is not clear that the Supreme Court would accept this role. In the interstate river compact cases that it has decided thus far, the Court has accepted compliance, monitoring, and penalty proposals by states, but it has refused to redesign what it has considered key aspects of compacts, such as the structure and voting rules of commissions.

Recommendation 2: Press for investments in well-developed and transparent monitoring systems, compliance mechanisms, and information-sharing procedures among stakeholders.

Given these realities, states should invest in creative solutions within the context of existing compacts. When they do so, they should incorporate one of the principle insights from CPRT into their thinking: the necessity of adequate monitoring systems to support robust governance—especially when water supplies are scarce. Monitoring lessens the mistrust and tensions between states that are likely to result when they face differing degrees of climate vulnerability. As the hydrologic systems of the Western United States change and become drier and more variable, downstream states will find it difficult to determine whether compact violations are attributable to (1) upstream states allowing additional water development, (2) upstream states failing to limit intrastate water use effectively, (3) a changing hydrologic regime, or (4) a combination of all three. Most existing compacts also need to be much clearer about how upstream states may come into compliance with water allocation rules in a timely fashion, as well as make up the water that was due the downstream state but not delivered. Both of these issues hinge on more complete and transparent monitoring systems.

Developing additional information and investing in more extensive monitoring networks will, over time, address some of the uncertainty. However, how well they do depends on the design of monitoring networks and the sharing of various types of information. CPRT suggests that any extensive monitoring networks developed need to be transparent across all member states and provide assurance that upstream states are acting in good faith to comply with compact allocation rules. Most compact commissions operate an extensive system of gauges that monitor surface water stream flows. However, few compact commissions have access to data on intrastate water diversions or water consumption. Nor do they have detailed information on the operation of reservoirs that they do not directly control, or on groundwater pumping and its effects on surface flows. In addition, most compact commissions have not invested in developing hydrologic models that further understanding of the interaction between surface and groundwater diversions, the operation of reservoirs, and water consumption on the behavior of river systems.

Without hydrologic models, it is difficult for compact commissions to determine, or at least begin to pinpoint, the sources of declining flows. Moreover, conflicts over water sharing that wind up in court are likely to produce decisions that mandate model building anyway. For instance, Kansas filed a lawsuit with the Supreme Court against Colorado, claiming that Colorado had violated the water allocation rules of the Arkansas River Compact. Specifically, Kansas claimed that the operation of two reservoirs built after the adoption of the compact plus groundwater pumping led to the long-term decline of surface flows into Kansas. Before the Court could determine the issue, it first directed the states to develop hydrologic models of the basin, ultimately selecting the model developed by Kansas. Using the

Kansas model, the Court determined that groundwater pumping, not reservoir operations, was the source of declining Arkansas River flows.

To comport better with CPRT principles, most compacts also need to be much more specific about what compliance actions the offending state or a third party will undertake to restore the functioning of the compact. As part of the settlement of the Arkansas River Compact Supreme Court case, for instance, Colorado promised to make up any shortfalls in deliveries to Kansas revealed by the hydrologic model by releasing water from a reservoir located near the state line. More proactively, one compact with an effective compliance mechanism is the Pecos River Compact, whose allocation rule is monitored by an independent river master. If the river master determines that New Mexico, the upstream state, is not delivering the required amounts of water to Texas, the river master may intervene and take over the administration of water rights from the New Mexico state engineer. Nebraska also is in the process of developing dry year contracts with local natural resources districts whereby water users are paid for leaving water in the stream to flow to Kansas so that Nebraska may remain in compliance with its Republican River Compact requirements—even during droughts.

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While well-designed and extensive water monitoring systems and hydrologic models seem reasonable and practical, a number of hurdles must be overcome to put them in place. First, the benefits and costs of such systems are unevenly distributed among the states. The costs of extensive monitoring systems are largely borne by the upstream state, as it and its water users invest in measuring (e.g., metering wells), monitoring (e.g., additional watermasters), and reporting. The benefits of such systems largely are enjoyed by the downstream state, which is provided with better information, allowing it more ably to assess the sources of increasingly variable flows. Second, well-designed and extensive water monitoring systems expose the upstream state to additional water regulation or at least demands for it by downstream states. As downstream states demand more stringent water regulation, upstream states bristle at perceived incursions into their state sovereignty. Third, while allowing greater insight into the interactions of the various parts of the river basin, hydrologic modeling does not remove all uncertainty, thus allowing downstream states to continue making demands for more water from upstream states. Still, the benefits of having these systems in place outweigh the risks, especially if accompanied by conflict resolution approaches to resolving the disagreements that do arise.

Recommendation 3: Press for investments in conflict resolution mechanisms that are relatively low cost and easily accessible, rather than only relying on commissions or the courts.

Investing in monitoring and compliance may help minimize distrust, but it cannot eliminate disagreements over the interpretation of monitoring and compliance activities and requirements. One long-standing CPR principle is the necessity of relatively low-cost conflict resolution mechanisms. Presently, most compacts have two forms of conflict resolution—compact commissions and the Supreme Court.

Both types of mechanisms have strengths, but they also have limitations. Commissions, even though they utilize unanimity rules and address a wide range of conflicts, consistently fail to address claims made by downstream states that upstream states are violating water allocation rules (Schlager and Heikkila 2009). In terms of judicial mechanisms, the Supreme Court is the court of original jurisdiction in disputes among states. Thus, on the positive side, states can use the authority of the Supreme Court to bring their very reluctant partner(s) in a dispute before the bench to settle the issue. Also, the Supreme Court has considerable latitude to fashion equitable solutions. However, a Supreme Court case is usually very costly to the states, both in terms of time—such cases may last a decade or more—and money—tens of millions of dollars are spent developing hydrologic models and rounding up expert witnesses.

Consequently, we argue that different forms of mediation and arbitration are better alternatives that compact commissions could experiment with to supplement the conflict resolution efforts of commissions and the Supreme Court. In particular, an independent third-party option may allow states to identify and explore acceptable solutions to more challenging conflicts that commissions struggle with, in the process avoiding time-consuming delays and exorbitant court costs. Attention, however, will have to be paid to how compact members may access alternative dispute mechanisms and how such processes are structured.

Access to conflict resolution mechanisms should be made relatively simple, but not so simple that every conflict leads to alternative dispute resolution. This would undermine the conflict resolution roles of commissions. By the same token, CPRT suggests that the processes should be relatively flexible so as not to re-create the discovery and burden-of-proof requirements of a full-fledged court case. In the end, however, alternative dispute resolution mechanisms work only as well as the participants want them to. In the compact that allows for binding arbitration (Arkansas River), the states have not agreed on the issues to use it for and thus have not used it. In the compact that allows for nonbinding arbitration (Republican River), the states have used arbitration but have rejected the proposed solutions. Thus, the Supreme Court and commissions will continue to play an important conflict resolution role as climate changes accelerate in the West.

Recommendation 4: States and commissions must look for opportunities to coordinate actions that limit water demand and/or increase water supply.

The challenge for compacts facing climate change will be to identify flexible management opportunities that are workable under new supply constraints while still reliably meeting the water demands of member states (e.g., Blomquist 2007; Gleick 2003; Lall et al. 2008). The key here, however, is to integrate supply-and-demand approaches to dealing with the water problems occasioned by climate change. According to CPRT, these opportunities, in turn, require coordination (i.e., nesting) of approaches with state and local water managers who face similar challenges.

One option is to move water toward more "higher-valued" uses in order to encourage more efficiency in use both within and between states, such as through water leasing. States that have high-value demands, such as municipal or industrial use, may be able to pay other states to refrain from using their water for lower-valued uses (e.g., certain crops). This allows more water to be available for higher-valued uses in times of shortage. Alternatively, compact commissions might consider seasonal or interannual storage programs, such as interstate water banking, whereby one state that has excess resources in a wet season or year is paid by another state to store that water so that it can be made available in times of shortage. In addition, compact commissions could assist states in saving more water by investing in water demand reductions or efficiency improvements in irrigated agriculture, which consumes nearly 80 percent of Western water supplies. For instance, compact states could share the costs of lining the canals of irrigation systems and, in turn, share the water that is saved, which could be devoted to compact purposes.

In basins that have not yet faced overappropriation and still have sources of supply to develop, states also may need to invest over the long term in more storage capacity to buffer the increasing variability of stream flows and longer-term droughts. In the Bear River Basin, Wyoming has acknowledged the need for more storage in the coming years to ensure compact compliance during low-flow scenarios (Wyoming Water Development Commission 2001). Utah also has been looking for more upstream storage on the Bear River for years, and recently, it has been feeling increasing pressure from growth in Salt Lake City to capture more of those resources. The rub is that gaining political approval for new dams has proven difficult at best in the West since the 1970s. This certainly has been the case in the Bear River Basin, as disputes over the proposed Oneida Narrows dam (initially proposed in the 1960s by the Bureau of Reclamation) have created long-standing tensions and disputes in the basin. Limited alternative storage options exist. Storage of surface water in groundwater basins is one option for enhancing long-term storage in such settings, depending on local hydrogeology and institutional feasibility (Blomquist, Schlager, and Heikkila 2004).

Among the lessons for the future of interstate water management, this last one—developing more water—is the one most likely to be realized. Leasing water rights, operating water banks, investing in irrigation efficiencies, and developing groundwater recharge projects are all familiar types of projects to Western states. To be sure, compacts already in place provide the institutional setting for realizing these projects. However, it is a matter of states contributing the necessary resources in time to meet the vulnerabilities they are experiencing with changing climates—hardly a given in today's era of fiscal stress. Regardless, demand-side solutions focused on water conservation must aggressively complement supply-side strategies—whether by individual states or commissions—if institutional adaptation is to have any hope of keeping up with the challenges of climate change in the region.

Conclusion

Little doubt exists among climate scientists, hydrologists, and water managers that the availability of water supplies in the Western United States, especially in the Southwest and Intermountain West, is going to be more limited and more variable in the coming decades. The vulnerability of different basins, states, and water users to these changes depends not only on the degree of the physical changes but also on the institutional arrangements that Westerners have developed to govern water supplies. In this article, we have argued that CPRT, with its emphasis on the design and performance of institutional arrangements, provides a useful starting point for assessing vulnerabilities, adaptation capacity, and institutional responses to climate change.

CPRT alerts policy makers to the importance of having rules align with the physical and social settings in which they are applied. Thus, among other things, compacts with fixed water allocation rules and seasonal rules are more vulnerable to climate change because they provide little leeway or flexibility in dealing with a changing hydrologic regime. Moreover, CPRT posits that such mismatches are more readily addressed if resource users participate in meaningful ways in revising the rules. States such as Colorado have been able to respond to increasing water scarcity in part because water users have access to different venues that allow them to participate in rule design. CPRT also reminds us that rules are not self-implementing or self-enforcing.

Looking to the future, we expect that institutional investments to enhance monitoring, compliance, and conflict resolution mechanisms in interstate compacts will be essential to their ability to deal with vulnerabilities, as the likelihood of renegotiation of existing compacts is low. We are not unaware, however, that many of these types of investments have been made only after the Supreme Court found the upstream states out of compliance with their respective compacts. Moreover, while such investments have proven helpful for some compacts facing challenges already, they may only take interstate compacts so far. Still, in light of ongoing changes in Western state climates, interstate compact officials are going to have to (1) make such investments; (2) work closely with states and local water users to promote, integrate, and nest more flexible supply- and demand-side water management strategies; and (3) encourage more efficient water use and conservation to ensure that the West's precious water resources will fuel their economies. And to do so, ignoring CPRT insights is to court disappointment, if not failure.

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Among the lessons for the future of interstate water management, . . . developing more water . . . is the one most likely to be realized.

CPRT also points to future research possibilities. For instance, markets often are believed to be effective and efficient mechanisms for moving water to higher-valued uses. Are compacts whose members allow or support water markets more adaptable than compacts whose members have not supported water markets? In addition, compact compliance requires state governments to ensure that their water users are abiding by compact water

allocation rules. Are some forms of state water administration more effective at ensuring compliance than other forms of water administration? Does this translate into greater responsiveness to different types of natural and social disturbances? Regardless of the agenda pursued, however, a robust research agenda that further tests the validity of CPRT principles as they relate to institutional capacity, adaptation, and evolution in light of climate change challenges awaits rigorous empirical scholarship.

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