JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

AMERICAN WATER RESOURCES ASSOCIATION

MANAGEMENT OF WATER SHORTAGE IN THE COLORADO RIVER BASIN: EVALUATING CURRENT POLICY AND THE VIABILITY OF INTERSTATE WATER TRADING[1]

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ABSTRACT: The water of the Colorado River of the southwestern United States (U.S.) is presently used beyond its reliable supply, and the flow of this river is forecast to decrease significantly due to climate change. A recent interim report of the *Colorado River Basin Water Supply and Demand Study* is the first acknowledgment of these facts by U.S. federal water managers. In light of this new stance, we evaluate the current policy of adaptation to water shortages in the Colorado River Basin. We find that initial shortages will be borne only by the cities of Arizona and Nevada and farms in Arizona whereas the other Basin states have no incentive to reduce consumptive use. Furthermore, the development of a long-term plan is deferred until greater water scarcity exists. As a potential response to long-term water scarcity, we evaluate the viability of an interstate water market in the Colorado River Basin. We inform our analysis with newly available data from the Murray-Darling Basin of Australia, which has used interstate water trading to create vital flexibility during extreme aridity during recent years. We find that, despite substantial obstacles, an interstate water market is a compelling reform that could be used not only to adapt to increased water scarcity but also to preserve core elements of Colorado River Basin law.

(KEY TERMS: water supply; water allocation; water law; water policy; water resource economics; water scarcity economics; climate variability/change; drought.)

Wildman, Richard A., Jr. and Noelani A. Forde, 2012. Management of Water Shortage in the Colorado River Basin: Evaluating Current Policy and the Viability of Interstate Water Trading. *Journal of the American Water Resources Association* (JAWRA) 1-12. DOI: 10.1111/j.1752-1688.2012.00665.x

INTRODUCTION

The Colorado River and its tributaries originate in the Rocky Mountains and provide much of the water that has allowed the economic, cultural, and political development of the arid southwestern United States (U.S.) (Powell, 2008). The water of these rivers is used by 30 million people and 4 million acres of farmland as the primary supply to several cities and $3 billion in agricultural productivity across seven states (USBR, 2011). Spring runoff from winter snow is vital to maintaining a reserve of water stored primarily in two large mainstem reservoirs, Lake Mead and Lake Powell. However, runoff in the Colorado River Basin (CRB) has been markedly below its long-term average in several years since 2000; plentiful runoff occurred only in 2005, 2008, and 2011. During this

[1]Paper No. JAWRA-11-0123-P of the *Journal of the American Water Resources Association* (JAWRA). Received October 2, 2011; accepted March 30, 2012. **Discussions are open until six months from print publication.**

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time, deliveries to water users continued undiminished, and so reservoirs reached record-low levels before rebounding somewhat (USBR, 2010). Continued low runoff coupled with steadily rising demand are forecast to exhaust reservoir storage in the coming decades (USBR, 2007; Barnett and Pierce, 2008; Rajagopalan *et al.*, 2009). Such a failure of the water supply system would lead to major economic and social disruption in the Southwest (Barnett and Pierce, 2008).

The U.S. Bureau of Reclamation (USBR) manages the dams of the Colorado River and its major tributaries and thus acts as the initial supplier of water to irrigation districts and municipal water supply agencies. In early 2011, it released the first interim report of its *Colorado River Basin Water Supply and Demand Study*. The purposes of this report are to quantify the reliability of the Colorado River to meet the needs of those who depend on it until 2060 and to formulate options for mitigating imbalances in the water supply system. The first interim report contains the concepts governing the study and quantitative forecasts for supply and demand in the CRB. The final report, which is scheduled for release in mid-2012, will include options for reform in the CRB (USBR, 2011).

The USBR adopts two important premises for the first time in this report. First, current demand in the CRB exceeds supply. The steadily growing annual demand first exceeded the 10-year running average of annual supply in 2003. Annual water deficits probably occurred earlier; for example, total water use across the Basin was 16.0 million acre-feet (maf; 1 maf = 1,233 gigaliters (GL); 16 maf = 19,700 GL) in 1999, whereas the long-term average flow in the mainstem of the Lower Colorado River (below the confluences of all major tributaries) is ~14.7 maf/yr (18,100 GL/yr) (USBR, 2011). Second, the USBR considers climate change explicitly for the first time in this report after having intentionally neglected its effects during previous planning documents that pertain to the CRB (e.g., USBR, 2007). The *Water Supply and Demand Study* states that climate change will lead to a "new mean state" of lower runoff in the CRB (USBR, 2011). Thus, the general management approach of the USBR now conforms much more closely to previous research implying a near-term transition to increased dryness in the Southwest (Seager *et al.*, 2007).

Australia has adapted to similar water scarcity by introducing an interstate water trading market in its Murray-Darling Basin (MDB), and thus its experiences may provide useful lessons to the CRB. Water markets allow water transfers at prices that respond to seasonal changes in demand and water availability (Howe *et al.*, 1986). Water rights are generally traded on either a temporary or a permanent basis, and, if desired, prices can be reset yearly at initial values before trading begins anew (Chong and Sunding, 2006). An optimally efficient water market is one in which trading of water rights allows each user to get as much water as it is willing to buy and for each user to pay for the true value of the water it receives (Freebairn, 2003). However, over- or underregulation, which frequently occurs when diverse political concerns must be placated at the inception of a market (Colby, 2000), impedes efficiency (Colby, 1990). Water markets depend on a diversity of water users. When all users plant the same crop, they all tend to be either buyers or sellers at a given price, and no trades occur (Nieuwoudt and Armitage, 2004). Thus, markets that cover large geographic areas may be likely to thrive because of a diversity of water uses. Water markets incur costs that relate to both the regulation and execution of transactions and the mollification of potential impacts on parties external to a water sale (Chong and Sunding, 2006).

In light of the new attitudes put forth by the USBR in the *Water Supply and Demand Study*, this article analyzes the existing policy for low levels in the mainstem reservoirs of the CRB. This policy, articulated as the "preferred alternative" in the 2007 *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead: Final Environmental Impact Statement* (henceforth, "the *Shortage Guidelines*"), represents the result of negotiation between the seven states of the CRB and subsequent minor modification by the USBR (NRC, 2007; USBR, 2007). It is the only enforceable document that targets management of the Colorado River during times of low water (USBR, 2007). We find that the *Shortage Guidelines* are a stopgap solution. They introduce supply shortages by decreasing the volume of water that can be diverted from Lake Mead. This slows the depletion of Lake Mead before 2026 and does little to protect water users during prolonged periods of scarce water. They do little to address demand, providing incentives for conservation only to some parties. Finding the *Shortage Guidelines* lacking, our second purpose in this article is to draw from recent experience in Australia to evaluate the viability of an interstate water market as a possible reform for the CRB.

RESPONSE TO DROUGHT IN THE COLORADO RIVER BASIN

The *Shortage Guidelines* exist in the context of the legal framework that governs water use in the CRB. Briefly, the seven states of the CRB are divided into

FIGURE 1. The Colorado River Basin. Blue lines are rivers, and black lines are aqueducts where water is pumped out of the Basin for irrigation and municipal use. Not shown is a major diversion from the northwestern portion of the Basin to Salt Lake City, Utah. Image courtesy International Mapping Associates, used with permission.

an "Upper Basin" (Colorado, New Mexico, Utah, Wyoming) and a "Lower Basin" (Arizona, California, Nevada) (Figure 1). The Lower Basin is guaranteed 7.5 maf/yr (9,250 GL/yr) from the Upper Basin, and, based on their understanding of CRB runoff, the framers of the original Colorado River Compact believed that this would leave the same amount for yearly use in the Upper Basin. Guaranteed a volume of water each year, the Lower Basin divided it among its states such that Arizona receives 2.8 maf/yr (3,500 GL/yr), California receives 4.4 maf/yr (5,400 GL/yr), and Nevada receives 0.3 maf/yr (370 GL/yr). A subsequent treaty and policy statement obligates each Basin to provide 0.75 maf/yr (930 GL/yr) to Mexico, but Lower Basin division of water has not changed to reflect this. In each CRB state, rights to the consumptive use of water are granted to entities and organizations such as irrigation districts, municipalities, corporations, landowners, and Native American tribes. These rights are honored in the order of their creation, with "junior" rights holders potentially losing their entire yearly share of water to ensure that rights of more "senior" users are fulfilled. This system of "prior appropriation" was preserved in the federal Colorado River Compact: the USBR fulfills water rights of Lower Basin users in the order in which they were created. Further details of CRB law are described well in a review by MacDonnell (2009). Water appropriations are at or near their maximum in each Lower Basin state despite an estimated loss of 1.6-2.2 maf/yr (2,000-2,700 GL/yr) to evaporation from reservoirs, half of which can be attributed to each Basin (USBR, 2011). Thus, the Lower Basin suffers from a water imbalance that has been ameliorated by surpluses from the Upper Basin and storage in Lake Mead, the latter of which decreases when low runoff to Lake Powell induces minimum obligatory releases from Glen Canyon Dam.

The CRB has never experienced a shortage, and the three Lower Basin states have never received volumes below those promised for their consumptive use (see above). Federal law designates the USBR as the primary agency responsible for response to drought planning (NRC, 2007), and so the *Shortage Guidelines* were developed after years of below-average runoff in the CRB (USBR, 2007). The *Shortage Guidelines* provide revised management plans that decrease water deliveries from Lake Mead to when it is at low levels. As the water level in Lake Mead drops, the USBR will reduce withdrawals, augment supply, and encourage conservation. This is achieved through four specific approaches. First, water available for consumptive use in the Lower Basin will be reduced by 0.333, 0.417, and 0.5 maf/yr (411, 514, and 617 GL/yr, respectively) when the water level in Lake Mead falls to 1,075, 1,050, and 1,025 ft above sea level, respectively. At this lowest elevation, meetings between states will be convened with the purpose of writing additional guidelines. Second, water storage will be balanced between Lake Mead and Lake Powell during low reservoir levels. This provision has the practical effect of allowing increased deliveries from Lake Powell to Lake Mead. Third, a system of "intentionally created surplus" was created as a way of crediting water to Arizona, California, or Nevada when these states conserve water to leave it in Lake Mead. Fourth, previously negotiated guidelines that apply to times of surplus were suspended.

A variety of management options were considered in the *Shortage Guidelines*. Strategies ranged from declaring shortage earlier so that reservoir storage can be maximized to declaring no shortages until reservoirs are empty. The "preferred alternative" represents an effort to maintain water deliveries with minimal disruption while also protecting the drinking water supply of Las Vegas. In comparison with other management strategies, it is predicted to delay the probability of shortage declarations for Lower Basin states in the near term (before 2016) while having no significant impact on longer time scales (2030-2065)

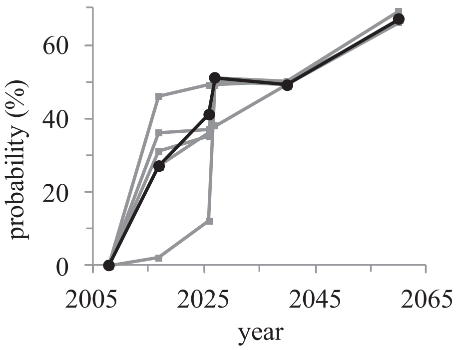

FIGURE 2. Probability of Shortage in the Lower Basin Under Various Management Scenarios. Black line: the "preferred alternative" in the USBR *Shortage Guidelines* that has become policy. Gray lines: other alternatives considered. From USBR (2007).

(Figure 2). If continued shortages are necessary in the medium term (2020-2026), the "preferred alternative" stipulates that they be more severe than other alternatives (with the exception of the strategy that maximizes reservoir storage) to extend the time that Lake Mead is >1,000 ft above sea level, the elevation at which submerged intake pipes withdraw water for Las Vegas (USBR, 2007). Furthermore, the *Shortage Guidelines* represent an agreement in effect until 2026, and the "preferred alternative" features an abrupt increase in the probability of a shortage declaration between 2026 and 2027. It is important to note that these forecasts are based on water availability in 2007. Although the specific dates of these time horizons would be different if the calculation were redone for current reservoir levels and water consumption patterns, the qualitative trends described here would not likely change significantly.

Shortages in this plan would not affect the three Lower Basin states equally. The Central Arizona Project (CAP), a large municipal and agricultural irrigation system that supplies water to both farms and major cities in Arizona, was built on the condition that Arizona's water rights be subrogated to those of California. Consequently, after fulfillment of water rights established before June 25, 1929 to users in the three Lower Basin states, all of California's water rights must be met before any further water is delivered to Arizona (MacDonnell, 2009). Only 22.1% of the water rights in Arizona predate 1929, and these are mostly irrigators, small cities along the Colorado River, and Native American reservations (USBR, 2007). Thus, California will suffer reductions only during extreme shortages, whereas only a small subset of the population of Arizona is insulated from shortage. Nevada's share of overall Lower Basin deliveries will remain constant, and thus it will suffer shortages at the first shortage declaration (Table 1).

This agreement, which was codified in the 1968 Colorado River Basin Project Act (CRBPA), represented a compromise that brought expensive water infrastructure to Arizona and greater water security to California. However, it may make the *Shortage Guidelines* impractical and unmanageable because, consistent with a steady growth in urban water use across the CRB in the last several decades (NRC, 2007), water rights created in Arizona and Nevada after 1968 have largely been granted to municipal and industrial users. Consequently, the large population centers in greater Phoenix, Tucson, and Las Vegas rely on some of the most junior water rights in their states (granted to the CAP and the Southern Nevada Water Authority [SNWA], respectively). Thus, they will be the first to be affected by water shortages. After Arizona cancels deliveries of 16,223 acre-feet per year (af/yr) (20 GL/yr) to some small municipalities and farms (by itself a not insignificant action), its most junior water user is the CAP, which has rights to 1.7 maf/yr (2,100 GL/yr). In 2008, municipalities used ~750,000 af (925 GL) of Arizona's yearly Colorado River water (USBR, 2011). The CAP provides the vast majority of this, and thus municipalities are at risk during a shortage. The SNWA, the most junior user in Nevada, has rights to nearly the entire allotment of Nevada and distributes it to the ~2 million residents of the Las Vegas Valley (USBR, 2007).

TABLE 1. Effects of Water Shortages on Lower Basin States.

Shortage volumes and water deliveries (af/yr)				
Shortage	0	333,000	417,000	500,000
California	4,000,000	4,000,000	4,000,000	4,000,000
Arizona	2,800,000	2,480,320	2,399,680	2,320,000
Nevada	300,000	286,000	283,320	280,000
Volumetric reductions in water delivery (af/yr)				
Arizona	0	319,680	400,320	480,000
Nevada	0	13,320	16,680	20,000
Fractional reductions in water delivery (%)				
Arizona	0	11.4	14.3	17.1
Nevada	0	4.4	5.6	6.7

Note: All values from USBR (2007).

Both Arizona and Nevada have plans to replace water lost to curtailed deliveries from Lake Mead with other in-state sources. Arizona stores unused water in a groundwater bank. When that empties, it can protect its population by reducing CAP water deliveries to irrigators, essentially trading water security for economic security by supporting basic human needs at the expense of agricultural productivity. Nevada has been aggressively encouraging conservation by storing unused water in groundwater banks, which will yield 30,000 af/yr (37 GL) from separate banks in California and Arizona (SNWA, 2009) for as long as they last. Additionally, the SNWA has purchased 1.2 maf (1,480 GL) for $350 million from Arizona in a unique water transfer (Tavares, 2009). It has also designed a >500-km long, $3 billion pipeline to bring pumped groundwater from the center of the state. If approved and built, it is forecast to yield a maximum of 137,000 af/yr (169 GL/yr) (SNWA, 2009); the long-term sustainability of this yield is beyond the scope of this article. Thus, on a strictly volumetric basis, Nevada would seem able to withstand extended Colorado River shortages only on the condition that this politically contentious and expensive pipeline is built.

The potential shortages for which Arizona and Nevada must prepare contrast starkly with the uninterrupted water supplies to the other CRB states. The water supplies of the two Basins are separated legally, and, in 2008, no Upper Basin state consumed close to its maximum allotment (MacDonnell, 2009; USBR, 2011). Certainly, a sustained Basin-wide drought could require reductions in consumptive use in Upper Basin states for the Upper Basin to meet its required deliveries to the Lower Basin, but this scenario is not nearly as likely as the continued decline of Lake Mead due to overallocation of Lower Basin water, although this was interrupted by a significant rise in 2011 that resulted from extra releases from Lake Powell after bountiful inflows there. In California, senior water rights (2.7 maf/yr [3,300 GL/yr] were created before 1929) and the CRBPA ensure that it will not suffer shortages during conditions stipulated by the *Shortage Guidelines*. Consequently, whereas Arizona and Nevada have ample reason to conserve water, take advantage of the intentionally created surplus feature of the *Shortage Guidelines*, and maintain water levels in Lake Mead, the other five CRB states have no such motivation. If shortages continued for many years, Arizona and Nevada could face extremely difficult choices that may involve reductions in population or economic activity, whereas agricultural irrigation in the California desert and development of new water projects in the Upper Basin could continue unabated. This inequality, although consistent with existing laws, seems sufficiently glaring to spark political outcry by the governors and federal representatives of Arizona and Nevada. If Lake Mead falls to 1,025 ft above sea level, the *Shortage Guidelines* offer no plan other than a meeting of the seven CRB states. Such a meeting is sure to feature insistence by Arizona and Nevada that the other CRB states share in the suffering created by low reservoir levels, despite their worsening bargaining position and existing legal protections for the other states. Because the *Shortage Guidelines* contain no long-term plan for Basin-wide adaptation to aridity, they present a threat to the legal framework of the Colorado River by potentially creating a scenario in which an increasingly desperate Arizona and Nevada may use every means at their disposal to force hasty changes to Colorado River law. Moreover, the *Shortage Guidelines* are designed to react to shortages forecast up to 2026, and this seems short-sighted given their assertion that shortages become significantly more probable immediately thereafter under the enacted "preferred alternative."

A significant additional shortcoming of the *Shortage Guidelines* is their approach to reduced Colorado River flow as an ephemeral problem. The document was written as a response to drought (USBR, 2007), although its planning considers neither the possibility of a multidecade drought in the CRB, which is not without precedent (Meko and Woodhouse, 2005), nor evidence that severe multiyear droughts have occurred multiple times during the last 500 years (Woodhouse *et al.*, 2006). Moreover, as the *Water Supply and Demand Study* acknowledges, low river flows may be due to a long-term shift to increased aridity in the CRB, not temporary drought. Climate change is likely to lead to significant reductions in long-term average runoff in the CRB (NRC, 2007; Seager *et al.*, 2007; Barnett and Pierce, 2008; Cooley *et al.*, 2009), which is very sensitive to small increases in mean annual air temperature (McCabe and Wolock, 2007). After extensive consideration within the *Shortage Guidelines*, the USBR chose to neglect the effects of climate change in its runoff forecasts because global climate models at the time of publication could not provide sufficiently specific information about individual river basins. Although the USBR cited multiple studies that pointed to notable long-term changes in surface runoff in the western U.S. and thus knew that accepting the premise of no effect due to climate change would be flawed, the *Shortage Guidelines* were based only on the measured record of Colorado River flows (USBR, 2007). Thus, their forecasts probably overestimate future water supply and underestimate the need for long-term adaptation to decreased river flows. The *Shortage Guidelines* state that errors due to neglect of the effect of climate change are acceptable because that document plans only to 2026 and thus requires an update relatively soon (USBR, 2007). The lack of a plan for Lake Mead elevations below 1,025 ft above sea level is a particularly glaring example of this optimistic, short-term approach. However, a pessimistic, long-term fate may await the Lower Basin: when flow reductions due to climate change were taken into account, a Monte-Carlo simulation indicated a 50% probability of total reservoir storage depletion as early as 2021, relative to 2007 conditions (Barnett and Pierce, 2008). This undercuts substantially the claim that there is sufficient time to plan by using projections that neglect climate change and then revise nearer to 2026. The reforms stipulated in the *Shortage Guidelines* are likely inadequate even if the premise of no effect due to climate change is correct. If the several forecasts of lower runoff due to climate change are correct, the *Shortage Guidelines* are even weaker. There appears to be a strong possibility that they will only delay an inevitable and painful confrontation between competing interests of the CRB.

AUSTRALIAN IMPLEMENTATION OF AN INTERSTATE WATER MARKET

Whereas the *Shortage Guidelines* have focused on progressive reductions in supply as a means of conserving water in Lake Mead, the MDB has instituted water reforms in the last decade that have moved existing water supplies to meet demands most efficiently. These reforms, which center on the creation of an interstate water market, have created the flexibility that has allowed both municipalities and a variety of irrigators to manage significant reductions in total supply that have prevented the failure of the MDB water supply. If prolonged aridity in the CRB leads to increasingly strict reductions in supply, important new information emerging from Australia's experience with water management reform in the last two decades may provide an effective example for future reform in the CRB.

The MDB covers 10.6 million km^2 and is drained by Australia's two longest rivers, the Darling (2,740 km long) and the Murray (2,530 km long), and their tributaries. Like the CRB, agricultural irrigation is the primary consumptive use of water; the MDB contains 65% of the irrigated land in Australia. Average runoff is 17.2 maf/yr (21,200 GL/yr), and several large reservoirs have a total storage capacity of just under 28.3 maf (34,900 GL) in preparation for recurring periods of aridity (MDBA, 2008; CSIRO, 2008). Climate change is likely to reduce long-term average runoff in the MDB. Such effects may have already started: flows in the Murray River reached historic lows during a long dry period from 1995 to 2009 (Pittock and Connell, 2010).

The two upstream riparian states of the Murray River, New South Wales and Victoria, share its yearly flow equally (i.e., the volume of water available to each state varies annually) after guaranteeing a fixed volume to South Australia, which lies downstream. During low river flow, the volume delivered to South Australia was reduced to bring it in line with its historical percentage of overall flows. After the yearly share to each state is announced, states declare the percentages of permanent water rights that will be delivered to each user. These "seasonal allocations," which are volumes of water delivered to users per month or year, are based on volumes stored in reservoirs. If necessary, they are small fractions of the volumes declared in permanent water rights, which are known as "entitlements." Thus, yearly consumptive use is tuned to the available water of that year (Crase *et al.*, 2004; Turral *et al.*, 2005).

Entitlements and seasonal allocations are traded in a regulated interstate water market that was created in 1989. Trading was insignificant until consumptive use of MDB water was capped in 1996 in response to drought conditions and increasing demand (Connell and Grafton, 2011). Then, yearly trading increased to <1% of entitlements and ~10% of allocations (Crase *et al.*, 2004). Intense aridity from 2005 to 2009 sharply curtailed allocations and spurred interstate water trading, which represented 19.9% of all water trading in Australia in 2008-2009 (Australian National Water Commission, 2010). Patterns have since developed in the interstate market (Figure 3). In times of shortage, irrigators of opportunistic crops (e.g., rice, cotton) in New South Wales, particularly the Murrumbidgee River Basin, sold water to horticulturalists, viticulturalists, and dairy farmers in South Australia and Victoria, who require yearly supplies of water to prevent the death of plants and cows (Crase *et al.*, 2004; Australian National Water Commission, 2009). The largest buyer of water was South Australia, which acted on behalf of Adelaide (Australian National Water Commission, 2009). When extremely wet conditions came in 2010-2011, all allocations across the MDB were ≥100% of entitlements. Irrigators had surplus water for their crops, and so large volumes of water were sold at low prices to regions that could store water for future years (Australian National Water Commission, 2011).

During recent dry years, these reforms appear to have provided essential flexibility to both sellers and buyers. The sales from New South Wales to irrigators in other states led to incomes in regions that did not

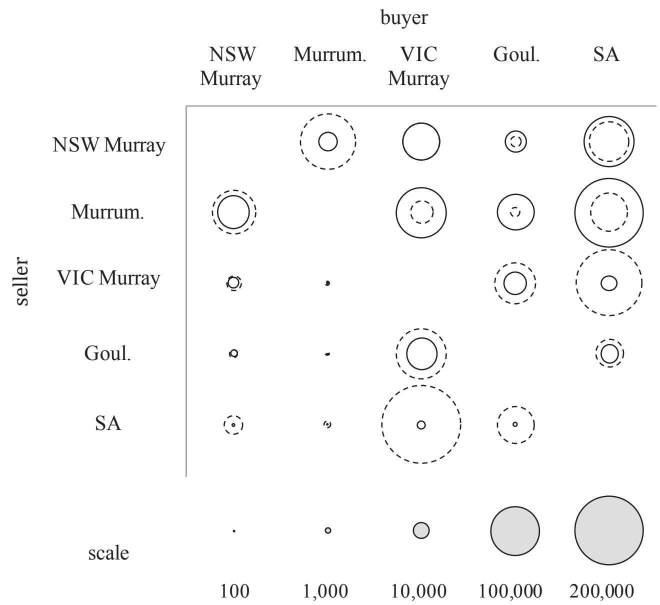

FIGURE 3. Water Transfers in the Murray-Darling Basin During the 2008-2009 (solid circles) and 2010-2011 (dashed circles) Growing Seasons. Buyers and sellers are abbreviated as follows: NSW Murray = the mainstem of the Murray River shared by New South Wales; Murr. = Murrumbidgee River subbasin, New South Wales; VIC Murray = the mainstem of the Murray River shared by Victoria; Goul. = Goulburn River subbasin, Victoria; SA = South Australia. Sizes of circles represent volumes transferred, in megaliters. Adapted from the Australian National Water Commission (2009, 2011).

have adequate water to raise their water-intensive crops, probably preventing recession (Pittock and Connell, 2010). In South Australia, the Murray River usually supplies ~40% of the municipal supplies for 1.525 million people (Adelaide, South Australia, is easily the largest city depending on the MDB system), with the remainder coming from small surface water sources, groundwater, and a desalination plant (SA Water, 2011). However, monthly allocations during the extremely dry 2008-2009 growing season ranged from 2 to 18% in South Australia, and so the state relied on the Murray River for 86% of its municipal water supply that year. Interstate water trading allowed the state to purchase 187,000 af (231 GL) for municipal uses (Australian National Water Commission, 2009); this accounted for nearly all of the municipal water delivered that year, which was 175,000 af (216 GL); (SA Water, 2009). Thus, interstate water trading was essential in preventing a municipal water supply emergency because the necessary volume of water did not exist within South Australia during 2008-2009. Conversely, the net volume of water purchased by South Australia in 2010-2011 was just 2% of that purchased in 2008-2009 and it was the largest gross seller in the MDB. In a wet year, interstate water trading allowed South Australia and other saturated regions to gain an economic benefit from surplus water. In addition to responding to yearly variations in flow, Australia has used interstate water trading to accommodate two environmental protection measures: a cap on total water diversions from the MDB (Pittock and Connell, 2010) and a federal water purchasing program designed to leave additional water in the river (Connell and Grafton, 2011).

Water supply and water trading in the MDB are administered by multiple federal agencies such as the Murray Darling Basin Authority (MDBA), which is charged with the development of a Basin Plan to set long-term withdrawal limits for surface and groundwater, and the Australian Competition and Consumer Commission (ACCC), which monitors water trading and enforces market regulations (ACCC, 2011). Historically, Australian states operated with near-total independence with regard to their water resources, although they consulted with each other via the Council on Australian Governments (COAG) to form similar regional water management plans. However, Australian water reform has concentrated increasing power at the federal level, with the 2007 Water Act granting substantial interstate power to the newly formed MDBA and the ACCC in order to manage an increasingly limited resource amidst acrimony between states (Connell and Grafton, 2011). This was the outgrowth of successive basin-wide commissions formed by a coalition of states, yet its inception at the federal level has presented a challenge in that it brought long-standing tensions between states and the federal government into water management (Connell and Grafton, 2011). Concentration of power in a central, basin-wide authority is consistent with theoretical work that describes ideal water markets (Matthews, 2004).

It is important to acknowledge that the efficiency of water allocation in Australia has been impeded by noneconomic barriers to trading water between sectors of its economy. In addition to potential externalities that pertain to all water markets (Chong and Sunding, 2006), Australian culture includes a strong predisposition toward agricultural life, as a countryside of small farms was part of governmental plans to both settle the Australian interior during colonial times and to repatriate soldiers after the large wars of the 20th Century. This led to the development of Australia's water market only after drought persisted for several years and the inclusion of impediments to transfer of water away from agriculture in market rules (Crase *et al.*, 2007). Additionally, state endorsement of water transfers from farms to cities counteracts a tradition of state sponsorship of irrigation infrastructure that is meant to offset precipitation variability, and so Australian state governments have tended to respond to drought first with new infrastructure projects, not with policy reforms (Crase *et al.*, 2007).

AN INTERSTATE WATER MARKET IN THE COLORADO RIVER BASIN

Probable Features

Water trading is not unprecedented in the western U.S. Intrastate water markets are common, although they vary in their implementation. An early water market began in the Central Valley of California, which does not use Colorado River water, in 1992. Created in response to drought, it led to the sale of water from farmers to cities, with large profits made by the former (Loomis, 1994). In Arizona, only permanent yearly water rights established before 1919 can be traded, and transactions require a 420-day waiting period. In New Mexico, water rights must predate 1907 to be sold, and transactions can require up to 1.5 years. In the Northern Colorado Water Conservancy District, standardized water rights, small transaction fees, and short processing times have led to a vigorous water market in which sellers are nearly always irrigators who usually sell to municipalities (Brookshire *et al.*, 2004; Brewer *et al.*, 2007; Donohew, 2009). Across the western U.S., the number of transactions has been increasing over time due to increasing sales of permanent water rights (Brewer *et al.*, 2007), although sales of seasonal water deliveries have historically been much greater (Brown, 2006). Prices paid by agricultural users tend to be significantly lower than prices paid by urban users due to differing levels of utility for a unit volume of water. Both agricultural and urban prices have been steadily climbing over the last decade (Brown, 2006; Brewer *et al.*, 2007; Donohew, 2009).

The stable operation of water markets at the state level suggests that an interstate water market could be a viable option for the CRB. To date, isolated interstate agreements have been limited in scope and have transferred unused Arizona water to cities of southern Nevada or farms of southern California (U.S. Bureau of Reclamation *et al.*, 2002; MacDonnell, 2009). Given that both Arizona and Nevada have limited in-state water resources, intrastate water markets do not provide sufficient water security in these states. Furthermore, water is only used for municipal and industrial uses in Nevada, so an intrastate market would be useless due to a lack of diversity of users (Nieuwoudt and Armitage, 2004; USBR, 2011). Conversely, an interstate market would give these arid states access to agricultural trading partners with different crops, planting patterns, and water needs. The CRB is large enough to contain a wide diversity of users, and the infrastructure exists to allow the physical transfer of water between most potential trading partners. The large sums of money offered by Nevada for additional sources of water indicate a clear willingness to pay, and California agriculture and unused Upper Basin water may be more practical sources than unused Arizona water or groundwater from central Nevada. In addition to a decrease in the long-term average runoff, interannual variability of runoff is likely to increase due to climate change (IPCC, 2007). Although the large reservoir capacity in the CRB mitigates interannual variability, water trading can also help alleviate it as it has in Australia. Thus, an interstate water market may not only be viable in the CRB, but the flexibility it provides may also become essential as scarcity and runoff variability increase.

An interstate water market will likely increase the economic efficiency when willing buyers in arid southwestern cities connect with potential agricultural sellers across the CRB. Generally, water allocation based on seniority without trading is extremely inefficient, with irrigators paying much less for their water than municipalities (Chong and Sunding, 2006). In the Colorado market from 1987 to 2005, the median prices of single-year agriculture-to-urban and agriculture-to-agriculture transfers were \$40/af (\$0.0324 per 1000 L) and \$10/af (\$0.0081 per 1000 L), respectively (Brewer *et al.*, 2007). By contrast, the purchase of unused Arizona water cost the SNWA \$291.67/af (\$0.2366 per 1000 L) (Tavares, 2009). This high price appears to be a function of a paucity of sellers willing to meet the demand of Las Vegas due to the lack of a functioning market for water.

The potential for any new water management practice to improve upon existing policy depends on understanding the costs of available alternatives. Implementing interstate water trading would bring new costs to the water supply of any participant, and so the magnitude of the benefit of a new interstate water market will vary by location and by water user. Thus, it will require a careful, site-specific study; although the costs of market regulation (see below) should be rather constant across the CRB, transaction costs could vary substantially between basin states. Such costs arise from any impediment to a water transfer. They tend to be higher in arid regions, and policy-induced costs are often desirable because they monetize externalities of trading (Colby, 1990). As a simple example, if water trading moved net consumptive use either upstream or downstream of Lake Powell and Grand Canyon during a given season, this could affect hydropower revenue at Glen

Canyon Dam, the health of (endangered) species in the sensitive Grand Canyon ecosystem, and recreational benefits in both locations. Although there is a clear need for research to quantify such costs and, consequently, the net economic benefit of the initiation of interstate water trading, the large difference between the prices of water in routine sales in the Colorado market relative to that of the SNWA-Arizona agreement indicates that interstate water trading offers strong potential for an increase in availability and a decrease in price for some willing buyers.

Water-scarce regions outside Arizona and Nevada stand to benefit from expanded interstate trading. For example, although California will not experience shortages under the *Shortage Guidelines* and enjoys the largest share of Colorado River water of any CRB state, the majority of this water is used on farms; the water supplies for metropolitan Los Angeles and San Diego are not plentiful. Although no intrastate market for Colorado River water exists in California, San Diego has purchased 0.2 maf/yr (247 GL/yr) from the Imperial Irrigation District starting at $258/af ($0.2092 per 1000 L) (San Diego County Water Authority, 2011). This demonstrates a strong willingness to pay for water in a state that receives a large volume from the Colorado River. Just as active trading in the Australian market occurs within states, junior rights holders across the CRB would likely be active participants in a freer water market, purchasing both in-state and out-of-state water.

The concept of prior appropriation and the seniority of certain water rights could be preserved in an interstate water market, as it has been in Australia. There, water rights are separated into two tiers known as "high security" or "low security" entitlements, which are more or less likely to receive their full seasonal allocation (e.g., Bjornlund, 2004). The trading of permanent or temporary water rights in the U.S. neither implies nor rejects the adoption of the Australian system of allocations. If desired, the CRB could maintain prior appropriation in a water market by classifying the seniority of a water right to reflect the date of its creation, not the date of its possession by its current owner. In this case, market participants could control the reliability of their water supplies as well as the size of their supplies. Presumably, senior water rights would sell (i.e., a permanent transfer) or lease (i.e., the purchase of a volume of water for a fixed time period, such as one year) for much higher prices than junior ones as they currently do in the Colorado intrastate market (Brookshire *et al.*, 2004; Brewer *et al.*, 2007). Preserving seniority of water rights should make interstate water trading attractive to senior rights holders across the CRB due to the strong potential for profit. Coupled with the access to new sources of water for junior rights holders, it may make interstate water trading more universally appealing across the Basin. Thus, interstate water trading is not a threat to prior appropriation, one of the bedrock principles that has guided Western water law since its inception.

Barriers to Interstate Water Trading in the Colorado River Basin

Several barriers exist to the implementation of an Australian-style water market in the CRB. A merger of existing intrastate water markets would be problematic because regulations pertaining to water trading vary widely across the CRB (Colby, 1988; Loomis, 1994; Brookshire *et al.*, 2004). The water market in Colorado is the most efficient, whereas rules in Arizona and New Mexico seem intentionally restrictive to trading. The laws of Colorado thus provide the best model for standardization. The Australian innovation of "tagged trade," in which the features of a water right are honored in the state of purchase, even if they are inconsistent with the rights created in that state (Australian National Water Commission, 2010), could allow for an interstate water trading system that does not necessitate the political and economic costs of full standardization. However, in the MDB, state laws were similar before the inception of interstate trading due to coordination through the COAG (Connell and Grafton, 2011), but, in the CRB, state laws vary to the extent that even the basic terminology of water rights depends on different definitions in different states (Colby, 1988).

The success of a water market depends on regulation by a central authority that can apply rules fairly to all participants, execute trades in a time frame that allows users to respond to changing water needs and availabilities, and protect third parties from potential negative effects of water transfers (Chong and Sunding, 2006). Consequently, Basin-wide standardization and subsequent market regulation would almost certainly require states ceding some authority to an entity with interstate jurisdiction. The states of the CRB hold strong authority over their water supplies, yielding only to legal agreements negotiated with other basin states or to federal laws that were not designed explicitly to control water, such as the U.S. Endangered Species Act (MacDonnell, 2009). The USBR provides a poor U.S. analogy to the Australian federal agencies; the former merely manages water infrastructure and does not set CRB-wide conservation or use policies. No other Basin-wide entity exists, and the creation of an authority that could operate above the CRB states would require delicate negotiation given the disquiet between states of the two Basins as well as negativity related to perceptions of unnecessary new regulation by nonlocal government entities, which has been observed in Texas (Colby, 2000). The national economic and cultural significance of the Colorado River and the current involvement of the USBR suggest that a CRB Authority might lie within a federal agency. In addition to the MDBA, rough analogies for such an entity exist in those that regulate interstate electricity trading, and thus an Independent System Operator or a Regional Transmission Organization could serve as a model for some elements of a regulatory agency that oversees interstate water trading in the CRB.

Just as cultural factors have been an impediment to agricultural-urban water transfers in Australia (Crase *et al.*, 2007), an additional, significant barrier to creation of an interstate water market in the CRB is strong resistance to change among Upper Basin states that is derived from fear that water transfers could remove water from economic use in the Upper Basin in favor of economic use in the Lower Basin. In 2008, then-Colorado senator (and the current U.S. Secretary of the Interior) Ken Salazar called any modification of the laws that divide CRB water between the Basin states "an anathema to the fundamental principles of Colorado's water rights." He believed that renegotiation of Colorado River law might lead to less water for Colorado and more for Lower Basin states, and Colorado "did not want California to gobble up all of the water supply on the Colorado River" (Ashby, 2008). Furthermore, survey data indicate that CRB water managers consider water law to be an important influence on local water supply yet have little understanding about how potential regulatory changes might affect them (USBR, 2011). Such distrust and uncertainty may delay meaningful CRB reform, including the implementation of interstate water trading, until the cities of the Southwest face certain crisis, at which point the flexibility provided by a water market would be largely diminished. Management of the psychological and emotional costs of the instability brought by institutional change has received attention in the field of sustainability theory (e.g., Senge, 1990; Senge *et al.*, 1999). A detailed discussion of the principles of change management with respect to water managers across the CRB is beyond the scope of this article, but the concerted application of these principles as well as effective public communication would be an essential part to any meaningful regulatory reform in the CRB. An interstate water market could be the reform that best suits the distrust in the CRB, because participation would be optional and Coloradoans (or others) could refuse to sell their water downstream. This may be preferable to entering into negotiations during a water crisis and receiving reduced access to the Colorado River with no option for amendment once an altered Compact is finalized. Furthermore, interstate trading could be phased in gradually by first creating separate markets in the Upper and Lower Basins and then merging them after several years.

Although interstate water trading is not incompatible with prior appropriation, it could challenge other core principles of CRB water law. For example, the guarantee of a minimum flow from the Upper Basin to the Lower Basin could, in principle, be undermined if great volumes of water were voluntarily sold from users below Glen Canyon Dam to those above it, although this seems highly unlikely in the coming decades. Additionally, laws invalidate water rights if water is not put to beneficial use, and environmental flows are not considered as beneficial uses in all CRB states (Colby, 1988). Although advocates of ecological health might wish to purchase water to increase instream flows (as in Australia, see above), such an action runs counter to the values espoused in CRB water law. A complete review of the legal complexities induced by interstate water trading is beyond the scope of this article, but these examples indicate that responding to scarcity by creating an interstate water market may challenge some long-held beliefs that are embedded in the Basin's laws. However, the existence of such conflicts does not negate the value of an interstate water market, which may be necessary to prevent desperate, poorly conceived, more significant challenges to CRB law from states suffering from shortages.

Should the CRB acquiesce to change and create an interstate water market, the attendant emotional fears should be easier for the new CRB-wide entity to address. Concerns such as entities being forced to sell and then experiencing financial ruin, farms losing all their water to wealthy cities, and farming towns depopulating have been debunked as existing water markets have been studied (Chong and Sunding, 2006). For example, based on data from California, Colorado, and Australia, it would seem unlikely that the sale of water at market prices from agricultural areas in Colorado and Utah to Lower Basin cities would have exceptionally deleterious effects to the economies or cultures of upstream regions. Other impediments to successful introduction of markets can arise if regulations are poorly written (cf., Colby, 2000), although ample legal precedent for the application of state water law exists (Colby, 1988). This should ease the adjustment to an interstate market somewhat.

CONCLUSIONS

The 2011 interim report of the *Water Supply and Demand Study* marks the first official acknowledgement by the USBR of facts that nontechnical and peer-reviewed publications have reported for some time: supply in the Colorado River exceeds demand, and that supply is expected to decrease substantially due to climate change (USBR, 2011; e.g., Powell, 2008; Barnett and Pierce, 2008). Climate change cannot be ignored in reservoir management (Viers, 2011), and so this new stance by the USBR would seem to render obsolete an important premise that underlies the reactions to drought described by the *Shortage Guidelines* (USBR, 2007). Although the *Shortage Guidelines* are based on an outdated and flawed premise, their reaction to aridity persists as policy. They are consistent with the many laws governing the Colorado River, but they place the burden of low water availability on the cities of Arizona and Nevada and agriculture along the CAP. Were the reduced withdrawals from Lake Mead likely to prevent further shortage, then the *Shortage Guidelines* would offer some water security to Arizona and Nevada at high cost. However, the fall of Lake Mead to <1,025 ft above sea level remains a real possibility, and so current policy imposes high, targeted costs yet addresses the root problem inadequately, merely postponing contentious negotiations until less water is available.

It is unlikely that the impending water-shortage crisis of the Southwest can be managed by conservation alone, either at the regional level (i.e., as reduced deliveries from Lake Mead to Lower Basin states) or at the municipal level. During more than a century of water development in the CRB, demand has changed from the solely agricultural economy of the early 20th Century to a mixture of lucrative agriculture and large, economically and politically strong municipalities. However, the legal division of the Colorado River has not evolved. Allowing market forces to redistribute supply so that it matches demand will offer vital flexibility in the face of declining average yearly flows and steadily increasing the population while, if desired, also preserving the system of prior appropriation that is central to water rights in the American West. Recent data from active interstate water trading in Australia show that basin-wide water trading improved the well-being of both agricultural and municipal users during a time of prolonged aridity.

Currently, should forecasts for long-term aridity come true, Arizona and Nevada are extremely unlikely to have enough water to sustain their growth rates of recent decades. Under a market system, the price of water everywhere would rise when water becomes scarce and water will move to those most able to pay for it. This allows Arizona and Nevada to have water security, at a cost, and senior rights holders will have a new source of income during times of scarcity. Such a market would depend on effective regulation to ensure fairness in transactions and limit negative third-party effects. Although the barriers to trading water across state lines in the CRB are not trivial, the potential benefits of an interstate water market there are too significant and numerous to ignore. The final report of the *Water Supply and Demand Study* is sure to spark conversations about updating water allocation policy in the CRB. Creation of an interstate water market there should be a meaningful part of that discussion.

ACKNOWLEDGMENTS

Wildman was supported by the John and Elaine French Environmental Fellowship Fund at the Harvard University Center for the Environment. The Australian dimension of this work was supported financially by the Harvard Australia Studies Committee and intellectually by John Langford (University of Melbourne). John Briscoe and the Harvard Water Initiative provided intellectual support. Jason Robison, Beth Landis, Jacob Krich (each Harvard), and four anonymous reviewers provided important comments on earlier versions of this article.

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