Water conservation opportunities and challenges in the Colorado Basin

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Abstract

Colorado River water is a critical resource for cities and agriculture in the Southwest United States. However, demand for Colorado River water exceeds supply, and that gap will worsen over coming decades. Basin states and water managers have an opportunity now to craft responses that minimize environmental damage and economic suffering. However, doing so will require navigating turbulent political waters and integrating knowledge from many academic disciplines. The goal of this paper is to present an assessment of opportunities for conservation in the basin along with challenges likely to be encountered in pursuing those opportunities.

1 Water supply and demand in the Colorado Basin

The development of Colorado River water has enabled the desert Southwest United States to support tens-of-millions of people and billions of dollars in annual agricultural production (Reisner, 1993). The Colorado River currently runs dry before reaching the Sea of Cortez in all but the wettest years (*ibid*), and demand will continue to increase over the coming decades (Figure 1; US Bureau of Reclamation, 2012). Furthermore, climate change will very likely accelerate increasing demand (Figure 2; *ibid*).

Agricultural use of water is predominant in the Colorado Basin (Figure 3). While municipal and industrial water use is projected to increase and take some share of water from

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agricultural use, irrigation will continue to be the predominant water user in the Colorado Basin for many decades (US Bureau of Reclamation, 2012). Consumptive use is concentrated in Arizona and California, with Colorado also using a significant fraction of water; Utah, Wyoming, New Mexico, Nevada, and Mexico receive much smaller allotments of water (Figure 4).

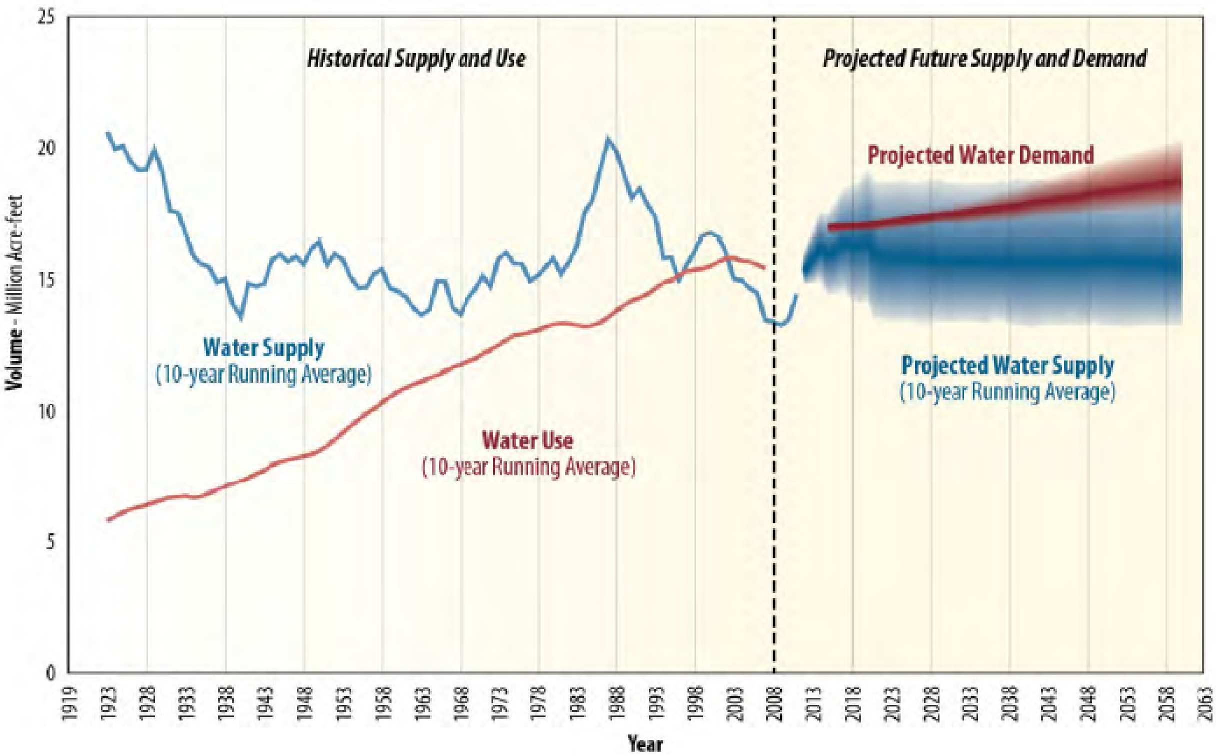

Figure 1: Historical and projected Colorado River water supply and demand (US Bureau of Reclamation, 2012).

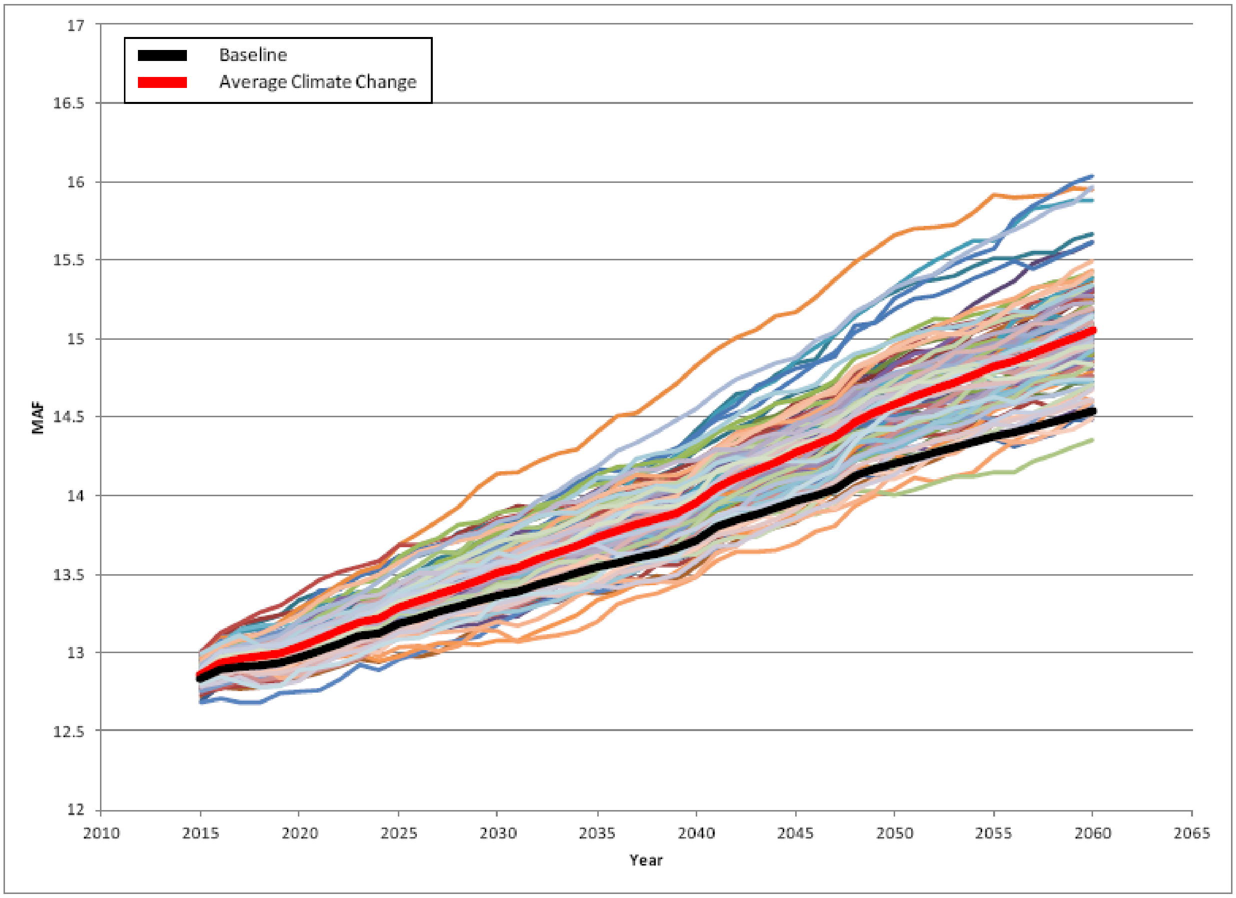

Figure 2: Regional climate model-driven demand forecasts (US Bureau of Reclamation, 2012).

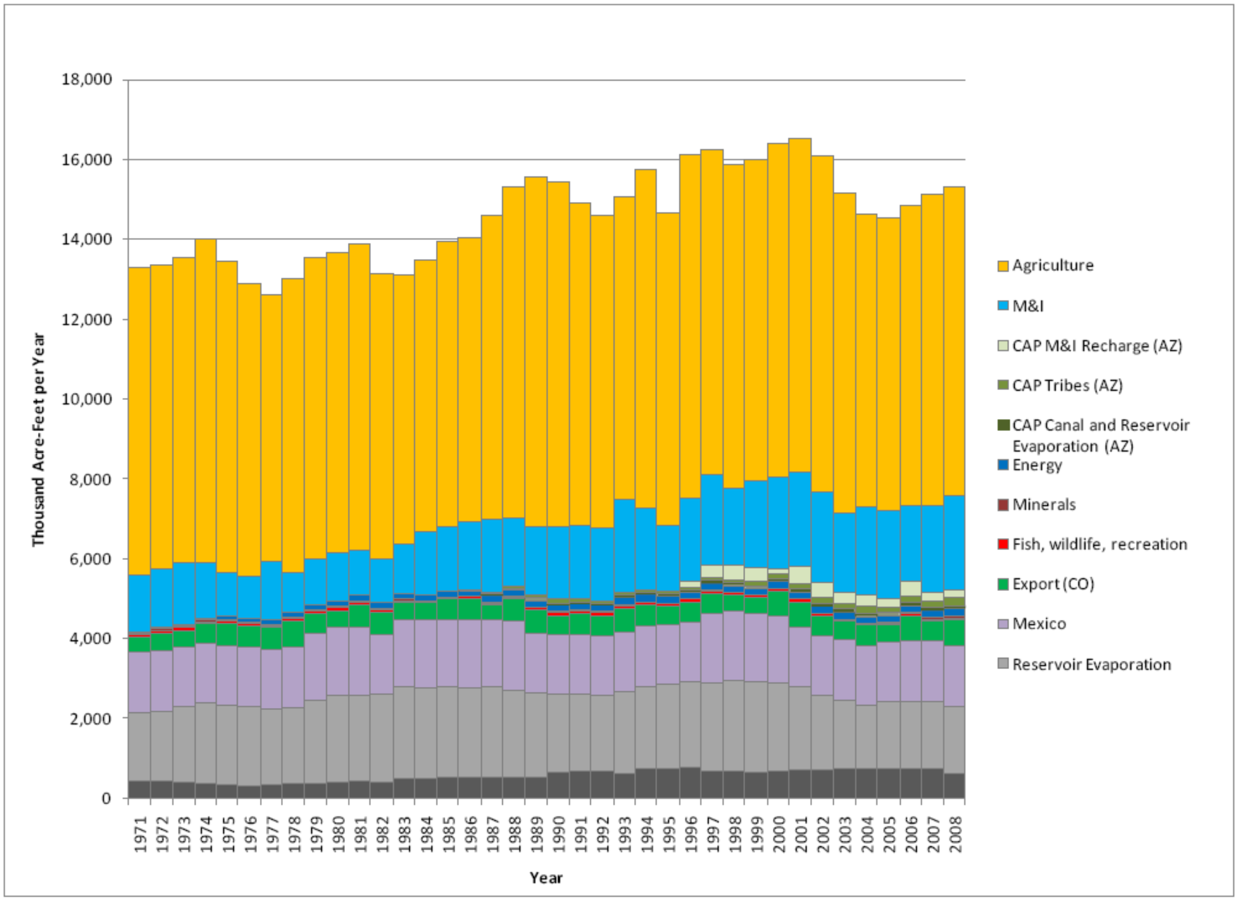

Figure 3: Consumptive use of Colorado River water by sector by year (US Bureau of Reclamation, 2012).

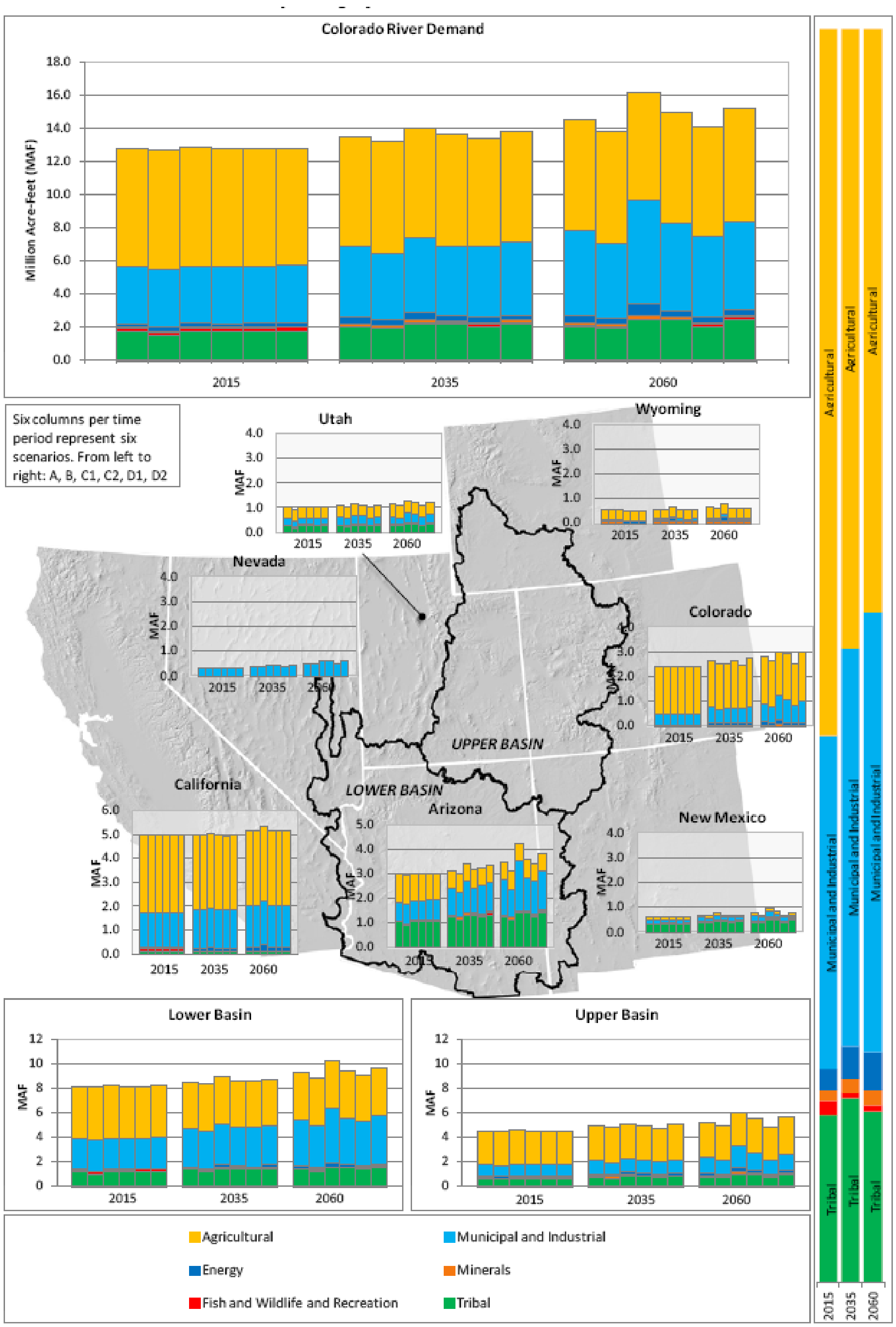

Figure 4: Consumptive use of Colorado River water by state, sector, development scenario (bars within years), and year (US Bureau of Reclamation, 2012).

2 Why is the Colorado Basin in shortage?

From a market perspective, if we consider the supply of water fixed (that is, unadjustable by the market) then the only variables that can move are demand and price. One can imagine the neophyte economist proudly proclaiming that the water shortage could be fixed by simply increasing the price of water until supply and demand are in equilibrium. And in some sense, this is true. If water were able to be priced on an open market, many farming regions in the southwest would become unprofitable and promptly be evacuated, sparing water for "higher value" uses. But there are many reasons why we might not want water to be allocated based on market mechanisms. On principle, it seems wrong to commodify an essential component of life, and pragmatically, we might not want to dislocate southwest farmers and culture by making irrigation water more expensive than market prices for food support.

Market mechanisms aside, there are other reasons why water use in the Basin is greater than it might optimally be. Public utilities are profit oriented, and the motivations that stem from that don't necessarily align with public interest. For example, water utilities might develop additional water resources before they are truly needed to claim prior appropriation rights, to demonstrate additional capacity for growth, or to augment their administrative footprint and associated power (Chesnutt and Beecher, 1998).

Additionally, water utilities face strong pressure to maintain continuous supply during times of drought. If, during non-drought periods, users are very efficient, there is little slack in the system to absorb shortage. This phenomenon is known as demand hardening, and it represents a significant force preventing utilities from promoting conservation and efficiency (Howe and Goemans, 2007). A case study in Aurora, Colorado by Kenney et al. (2008) illustrates: In the 2000-2005 drought, heavy water users dramatically decreased their usage, but the lowest volume users had few options to cut use, and so their use changed little during the drought (Figure 5). If, before the drought, all users had been as efficient as the low-level users, the system would likely not have been able to cope with the reduced supply.

Another factor working against water utilities promoting conservation is the throughput incentive. Similar to any business, utilities make money by selling more of their product; however, when most of a product's costs are wrapped up in the manufacture of a product, the marginal gains from each additional sale are relatively constant. For water utilities, however, the vast majority of costs are fixed (i.e., independent of volume delivered; e.g., infrastructure, administration), so the marginal profit on each unit of water sold is increasing. This is what led to the adoption of decreasing block-rate pricing structures, wherein users pay less for each additional unit of water.

There are several reasons why water utilities' motives do not align with conservation interests. Therefore, policies aimed at water conservation will need to be implemented at higher levels of government than water utilities (Chesnutt and Beecher, 1998).

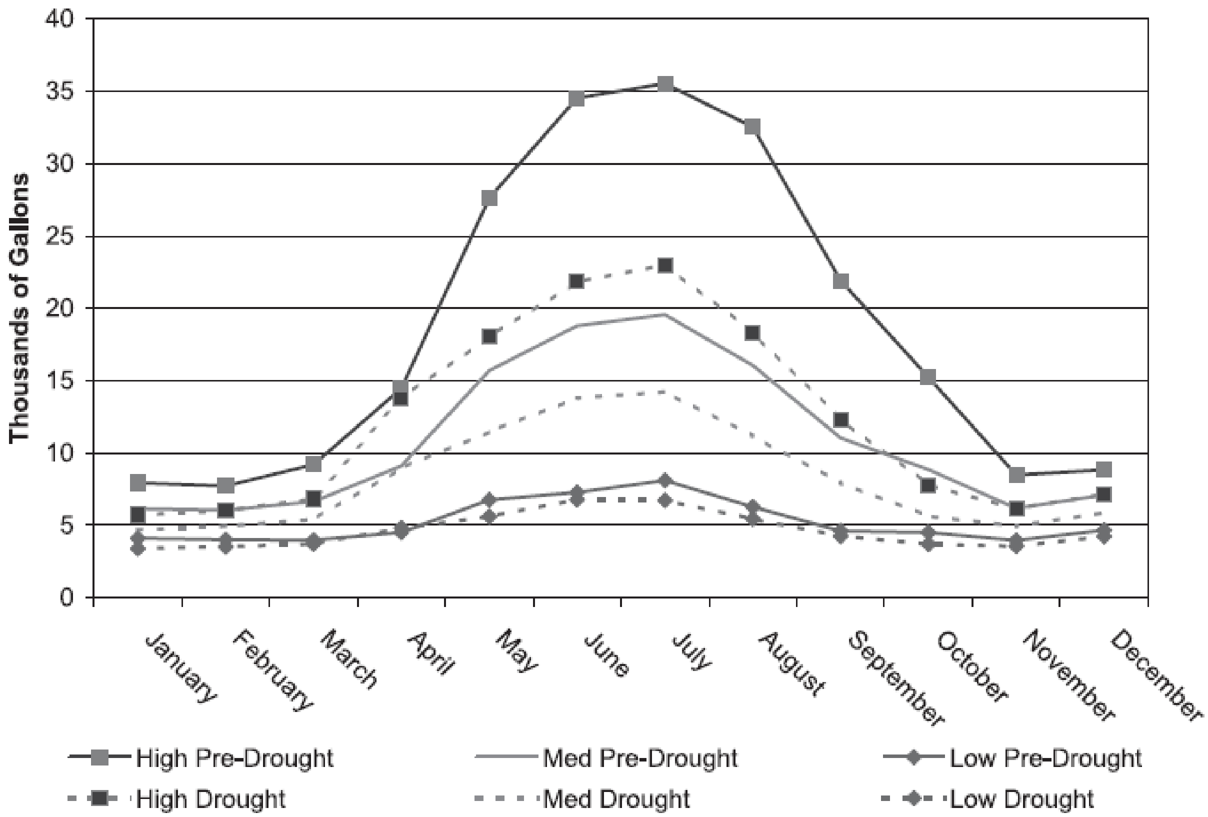

Figure 5: Reduction in water use by residents' water use class in Aurora, Colorado during drought (Kenney et al., 2008).

3 Water conservation can increase water use

It is not the case that a liter of water saved is a liter of water gained. Water serves consumptive and non-consumptive uses, and conservation of mass ensures that non-consumptively used water remains in the system. In irrigation, water applied in excess of evapotranspiration (ET) must either infiltrate groundwater (and irrigation is an important source of aquifer recharge in many regions (Scanlon et al., 2006)) or return to surface water flows from which it can (quality concerns aside) be used again. An important—but often ignored—consequence of this is that increasing agricultural water use efficiency can lead to increased consumptive water use. This is a consequence of farmers irrigating more acres or thirstier crops with efficient measures in place (holding gross use constant). Ward and Pulido-Velazquez (2008) is a fascinating, provocative study that shows through hydroeconomic modeling that subsidizing agricultural water efficiency can perversely increase total consumptive water use.

This fact is often ignored, even in relatively sophisticated treatments of water management and policy. For example, Richter et al. (2013) write that "Agricultural water conservation holds considerable promise as a source of future water supply for cities... [I]t may be possible to *increase farm productivity* – important to global food security – through the use of more efficient irrigation technologies, due to more precise water and fertilizer application, *while avoiding increases in water consumption* (see for example IWMI, 2007; Dunn et al., 2010; Dixon et al., 2011)" (emphasis added). Of the three citations they cite in support of this idea, one is a purely economic model with no treatment of return flows (Dixon et al, 2011), one is a description of trials on a single piece of land (Dunn et al., 2010), and the last cautions against exactly this type of reasoning: "Water productivity gains are often difficult to realize, and there are misconceptions about the scope for increasing physical water productivity ... There is greater reason to be optimistic about increasing economic water productivity ... by switching to higher value agricultural uses" (Molden, 2007). Water management and policy must consider integrated hydrology if it is to have any chance of dealing successfully with the immense challenges that need to be confronted in the coming decades.

Not only are return flows from agriculture significant from a systems management perspective, they are also important ecologically. Carrillo-Guerrero et al. (2013) point out in a hydroeconomic modeling study that agricultural irrigation "inefficiencies" are critical for some ecosystems. Recognizing this, they suggest, may help water management move from a more confrontational to cooperative mode.

> [The assumption] that higher efficiencies in agriculture per se would make more water available to sustain the Colorado River delta wetlands, may not be valid as higher efficiency may mean the reduction in the "operational releases" and "excess flows" discharged into the floodplain and the reduction of water applied to croplands. The net effect of these efficiency improvements in water use may actually mean less water available for wetlands... [The] assumption that agriculture and environmental uses are mutually exclusive competitors is not true for the

> Colorado River delta marshes, as these important habitat types have developed thanks to agricultural return flows. Acknowledgment of the Mexicali Agricultural Valley as an integral part of the delta ecosystem might be the required change in the water management-wetland restoration paradigm. (Carrillo-Guerrero et al. 2013)

4 With all that water, what's being grown where for how much?

Figure 6 shows irrigated acreage in the predominant crops grown in the Basin by state. It is immediately apparent that most irrigated area in the Basin is growing food for livestock. Unfortunately for the River, alfalfa is by far the thirstiest crop around (Figure 7). Alfalfa is not remotely the most profitable crop on a per-acre or per-acre-foot basis (Figure 8; Hanak et al., 2011; Mayberry, 2000; Medellín-Azuara et al., 2012); however, as a nitrogen-fixing legume, it may produce well in poor soils where other crops preform poorly. Alternative, lower water use crops that are suitable for such areas should be investiaged and those that are found profitable should be aggressively promoted by outreach specialists in places like the Imperial Valley of Southern California.

Fruit and nut crops are very profitable and many are less water intensive than other crops. However, they hurt system resilience because orchards cannot be followed. Where a field of wheat can be followed during a drought, a stand of trees must receive adequate water to survive. Thus the ongoing transition to tree crops may be akin to the demand hardening observed in cities undergoing significant conservation measures.

Acres (1000s)											
Crop	AZ	CA	CO	NV	NM	UT	WY	US Total	Mexico	CRB Total	% total
Total Forage	307	289	332	17	37	124	208	1,315	79[a]	1,394[a]	41%
Alfalfa hay	257	181	157	-	29	104	55	783	79	863	26%
Other tame hay	28	97	119	-	0.2	10	21	285	-	275	8%
Pasture	53	2	263	8	15	153	131	628	23	651	19%
Wheat	86	43	41	-	-	0.1	-	169	250	420	12%
Vegetables[b]	138	96	4	-	11	0.1	-	250	30	280	8%
Cotton	171	22	-	-	-	-	-	193	60	253	8%
subtotal	754	452	641	25	64	277	339	2,555	443	3,077	89%
Total Irrigated	876	504	697	25	99	322	342	2,868	499	3,367	

Figure 6: Irrigated acerage by crop and state (Cohen et al., 2013).

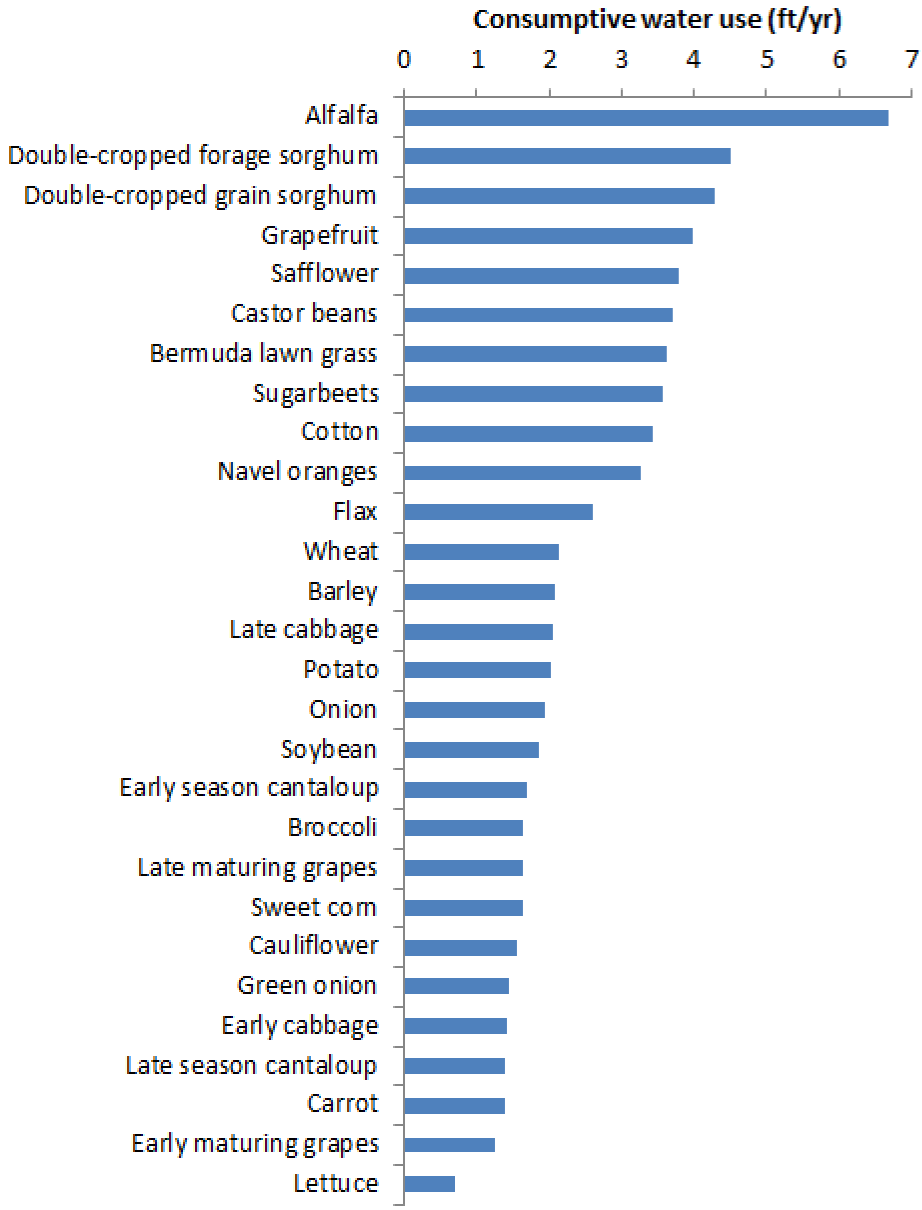

Figure 7: Consumptive water use of the most common crops grown in the Southwest US (data from Erie et al., 1982).

Crops	Gross water (%)	Net water (%)	Gross revenues (%)	Irrigated acres (%)	Gross revenues/ gross water ($/af)	Gross revenues/ net water ($/af)
Irrigated pasture	12	11	0.4	9	31	47
Rice	10	9	2	6	127	223
Corn	7	7	1	7	176	258
Alfalfa	18	18	4	12	200	287
Cotton	7	8	3	7	416	551
Other field crops	8	8	3	13	375	573
Fruits and nuts	27	29	44	30	1,401	1,875
Truck farming and horticulture	10	10	42	16	3,724	5,363

Figure 8: Profitability of various crops (in California). Note the right-most column is revenue per unit of water consumed. From Hanak et al. (2011).

5 Studying farmer behavior

Medellín-Azuara et al. (2012) used a hydroeconomic model to estimate the effect on income and jobs of a 75% increase in the cost of water or 25% forced reduction in use among Southern California farmers. The results are, I think, striking for showing how resilient semi-desert agriculture is to water conservation interventions. They estimate a 75% increase in water cost would directly lead to 1,200 jobs lost and $250 million less productivity. Unfortunately, they don't present the volume of water saved by such a policy, nor do they discuss gains from its alternative uses. It is important to remember that agriculture pays far less for water than municipal and industrial users, so it seems likely that the net effect of such a policy might be an increase in regional economic production and employment. Of course, policymakers should be cognizant of considerations beyond economic markers, but economic studies of the effects of policy should consider gains as well as losses.

In a different vein of social scientific research, Baumgart-Getz et al. (2012) perform a meta-analysis of 26 studies of the drivers of US farmers' adoption of environmental best management practices (BMP). They find that more informed and more networked farmers are more likely to implement BMPs, suggesting an important role for outreach specialists and grower organizations in promoting environmental practices. However, they find no effect of farmer BMP adoption likelihood from being networked with university cooperative extension. This is at odds with other research (e.g., Lubell and Fulton, 2008), but if it holds, it suggests that extension specialists should rethink the way they interact with farmers, especially around environmental practices. Interestingly, Baumgart-Getz et al. (2012) find a strong, but highly variable, positive relationship between a farmers' concern for the quality of their crop and their adoption of BMPs. Outreach that connects quality concerns with environmental concerns may be especially effective.

6 Conclusions

The Colorado River is over-allocated and demand will almost certainly increasingly outpace supply in the coming decades. This water challenge is soluble, but it will require carefully crafted management policy and cooperation among disparate interests. Furthermore, there will be losers: Some interests will get less water than they want, and indeed, some irrigated farmland will likely be fallowed. Water utility policies must be brought into alignment with public conservation interests. Since utilities are highly regulated entities, this would seem to require more political will but less conflict negotiation than other challenges. The nuances of hydrology, ecology, and human behavior must be appreciated and incorporated into policy decisions. Those three systems are tightly coupled, and integrative science will play a critical role informing policymakers and managers.

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