CHOICES

AAEA Agricultural & Applied Economics Association

Volume 39. Quarter 3

Economic Impacts of Climate Change on the Agricultural Sector of the Colorado River Basin

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JEL Classifications: Q1, Q15, Q18, Q25
Keywords: Climate change, crop production, Colorado River Basin

In the Western United States, including the Colorado River Basin (CRB), climate change is characterized by increased temperature and other climatic variations that include a heightened frequency and severity of droughts (Barnett et al., 2008). Warming in the CRB has led to increased evaporation, reduction in total snowpack, changes in the timing of snowmelt, and a significant decrease in water runoff. These phenomena exemplify the aridification affecting the CRB region (Bass et al., 2023; Overpeck and Udall, 2020). It is crucial to differentiate between droughts and aridification. While drought refers to a temporary period of arid conditions, aridification denotes a transition toward a consistently water-scarce environment over a prolonged period. The risk of experiencing long, intense, and frequent drought periods, including multidecadal drought events, escalates with climate change. Besides aridification and droughts, climate change increases the likelihood of extreme events such as intense heatwaves, short and intense periods of dry and wet conditions, and widespread wildfires (McCoy et al., 2022).

In the CRB, rising temperatures are anticipated to reduce water availability by 6%–30% and increase the persistence of droughts up to 20 times more than historical records (Bedri and Piechota, 2022). Elevated temperatures increase reservoir evaporation and escalate water requirements for irrigation and municipal use due to increased agricultural and outdoor demand in urban areas. The impact of climate change on crop yield is uncertain. Although higher CO_2 concentrations and temperatures could increase crop yields for some crops, they may intensify crop water stress. However, climate change is expected to increase crop production failure chances in some areas of the CRB.

This article assesses the economic impact of reduced water availability for irrigating cropland across irrigation districts in the CRB region within the United States. The agricultural sector is the dominant water user in the Colorado River, with irrigation withdrawals accounting for 85% of the total withdrawal (Maupin et al., 2018; Crespo et al., 2023; Mullane, 2023). Water is used for irrigation of 2.2 million acres across the seven CRB states. To simulate the effects of climate change, we assume reductions of 10%, 20%, and 30% compared to baseline conditions, representing mild, severe, and extreme climate change scenarios, respectively. The analysis determines crop patterns and water allocations by irrigation districts that maximize the net income of crop production.[1] The marginal value of water for each district in the CRB reflects the significant impact that produces the scarcity of water.

The net income of crop production is quantified using a quadratic function in relation to the cropland area. The model incorporates constraints on the availability of water, land, and irrigation technology (flood, sprinkler, or drip). Water requirements for irrigation are set per unit of land and vary according to crop type, irrigation technology, and irrigation district. Crop yields diminish with additional land use, reflecting the fact that the most productive lands are cultivated first and produce the highest net income. The unitary cost of production and the unitary price of crops are constant, and they remain unaffected by changes in production. Further details of the model and parameters are available in Crespo et al. (2023).

Baseline Conditions in the CRB

Under baseline conditions, cropland distribution is the average between 2008 and 2021 of the observed acreage irrigated in the CRB In this study, crop production includes only the irrigation area inside the CRB and the acreage irrigated

[1] Net income is calculated as revenue minus production costs, including water costs, and excluding land rent.

Table 1. Cropland, Water Applied, Revenue, Cost, and Net Income in the CRB for the Baseline Scenario

	Cropland (1,000 acres)	Water Applied (1,000 acre-feet)	Revenue (million $)	Non-Water Costs (million $)	Water Costs (million $)	Net Income (million $)
Arizona	803	2,996	2,342	1,558	296	489
California	529	1,743	2,125	1,358	190	576
Colorado	469	1,655	900	492	188	220
Nevada	3	7	4	2	1	1
New Mexico	42	130	77	45	12	20
Utah	190	583	319	182	62	75
Wyoming	166	423	211	140	35	35
Basin	2,199	7,539	5,976	3,778	783	1,415

Note: The values include the production from irrigated land within the basin and from irrigated land in Southern California.
Source: Crespo et al. (2023).

by the All-American Canal;[2] otherwise, trans-basin uses of CRB water for agriculture were not considered. The baseline scenario includes 40 irrigation districts in the seven states that maximize the net income from the production of 39 various crops using three distinct irrigation technologies.

Table 1 presents crop acreage, water, revenue, cost, and net income of crop production by state for the baseline scenario. Crop production in California, Arizona, and Colorado captures 90% of the net income of water use by using 85% of the water applied on 80% of the irrigated acres. This shows that the net income per acre and net income per unit of water used is greater in California, Arizona, and Colorado than in Utah, Wyoming, New Mexico, and Nevada. In particular, California generates nearly double the economic value per acre-foot of water relative to other states, and net income per acre shows similar results. Arizona has the second-highest economic net income generated per acre and per unit of water used. In general, the Lower Basin states produce greater net income per unit of water used for agriculture than the Upper Basin states. Crop pattern differences explain the net income differences; trees and vegetables are more profitable than field crops.

Regarding crops grown in the CRB region, alfalfa and hay predominate in the basin's crop patterns, accounting for 66% of the irrigated area. Generally, the crop pattern is heavily focused on four crops: alfalfa, hay, cotton, and wheat. These crops collectively comprise 90% of the irrigated area (as indicated by red points in Figure 1). Although these crops cover a vast area, their net income constitutes approximately 50% of the total net income from agriculture. Detailed results at the irrigation district level are available in Crespo et al. (2023)

Climate Change and Water Allocations

Climate change projections consider different paths of greenhouse gas emissions, called Representative Concentration Pathway (RCP). The RCP 4.5 describes an intermediate scenario, and the RCP 8.5 describes a scenario in which emissions continue to rise. Streamflow is sensitive to variations in precipitation and temperature. Multiple projections of precipitation and temperature under concentration paths conform to the projections of streamflow in the basin. Lukas and Payton (2020) estimate streamflow changes at Lees Ferry for 2041–2070 relative to the 1971–2000 period with the projections of precipitation change and temperature of 64 scenarios of climate change. The majority of the scenarios project reductions of streamflow, and only scenarios with a 5% increase in precipitation compensate for the increase in temperature. However, the likelihood of a scenario in which the streamflow is sustained is low. The sensitivity of the flow to variations in precipitation is measured as the percentage variation of streamflow when precipitation varies. Streamflow varies between 2% and 3% for each variation of precipitations (Udall and Overpeck, 2017). A combination of increased temperatures over 4ºF (2.2ºC) and a reduction in precipitation of between 5% and 15% are associated with a reduction in runoff of over 20%. Other studies estimate the reduction of streamflow at between 6% and 31% (Woodhouse et al., 2021). Climate change projections provide an ensemble of results that range between increments in streamflow to extreme reductions of streamflow. The range of values is based on the consensus of those projections. Reductions in

[2] The economic net income of CRB water use for agriculture, as reported in this article, is a conservative estimate. We only account for irrigated areas within the CRB's physical boundaries and those irrigated by the All-American Canal. Consequently, this analysis excludes portions of Utah, Wyoming, New Mexico, and Nevada outside the CRB irrigated with CRB water. Water use from the CRB in these areas, regarded as inter-basin transfers, is not included in our study. Additional details of the model can be found in Crespo et al. (2023).

water availability are expressed as average values, misrepresenting droughts and wet periods. Taking into account those scenarios of climate reductions in water availability, this article examines three reductions of water availability due to climate change. Mild, severe, and extreme scenarios of climate change are analyzed by reducing water available in the agricultural sector by 10%, 20%, and 30% with respect to the baseline conditions. Reductions in water availability by 10% and 20% occur in both the RCP 4.5 and RCP 8.5 scenarios, and a reduction in water availability by 30% occurs in the RCP 8.5 scenario (Lukas and Payton, 2020). Fixing reductions in water availability is a simple way to simulate climate change and its impacts, as used in other articles (Baccour, Ward, and Albiac, 2022; Connor et al., 2012). Reductions in water availability are proportional and shared equally among all irrigation districts. Each irrigation district adjusts its crop distribution to maximize net income given the water restrictions. This outcome is equivalent to minimizing net income losses due to water scarcity at the irrigation district level. Crops are fully irrigated, and deficit irrigation is not permitted. The amount of water applied is fixed by the acreage of land, and there is no substitutability between land and water. Because of this, and because the relationship between production factors and net income is quadratic, the response to water scarcity is a reduction in cropland of all crops. The intensity of this reduction is determined by the relative value of each crop compared to the others. Since the baseline conditions represents the maximum, crop area in the baseline represents the maximum extension possible. Other adaptations in water management, such as increasing the availability of advanced irrigation systems, are not allowed in this model since they require assumptions on crop production yields.

Climate change has been occurring since the 1980s; as a result, the current water availability and requirements reflect the emerging effects of climate change. The Colorado Basin has managed to meet water demand during the first quarter of the century due to the water stored in reservoirs. However, given the current conditions of change and water management, it is challenging to imagine that water scarcity conditions can be alleviated with reserves, without a buffer of water that allows for storage.

Climate Change Impacts at the Basin Level

Table 2 shows the net income and cropland at the basin level for the scenarios of reductions in water availability. The results show that the reductions in water availability have a small impact on the total net income in the basin. Indeed, a decrease in water availability by 30% results in an estimated economic loss of $69 million annually, which constitutes about 5% of the net income in the baseline scenario. losses in net income are not directly proportional to the reductions in water. This means that as water scarcity increases, the losses in net income also increase significantly, suggesting that the water system has a certain level of adaptability to water scarcity. Once this threshold is surpassed, however, losses in net income escalate rapidly. This is consistent with the principle of diminishing returns, where the first croplands to be fallowed are those with lower productivity. The result does not include second-order impacts on the economy of the region.

Under extreme water scarcity, the reduction in water availability implies the fallowing of 606,000 acres of irrigated land, which is 28% of the cropland in the baseline (Table 2). Land reduction is lower than the reduction of water availability, indicating that crops intense in water use and lower economic value are fallowed first—the average net income per remaining acre increases by up to 30%.

Cropping Pattern Changes

Figure 1 illustrates several aspects of the crop's representation and the impact of extreme climate change. The red points represent the crop's prevalence under baseline conditions, expressed as the percentage of total basin acreage occupied by the crop. The green triangles depict the impact of extreme climate change on each crop, showing the percentage reduction in irrigated acreage compared to baseline conditions. Last, the blue squares indicate the proportion of the total acreage reduction attributable to the reduction in crop acreage. Each of these elements provides a different perspective

Table 2. Irrigation Cropland and Net Income by Water Availability and Policy Scenarios

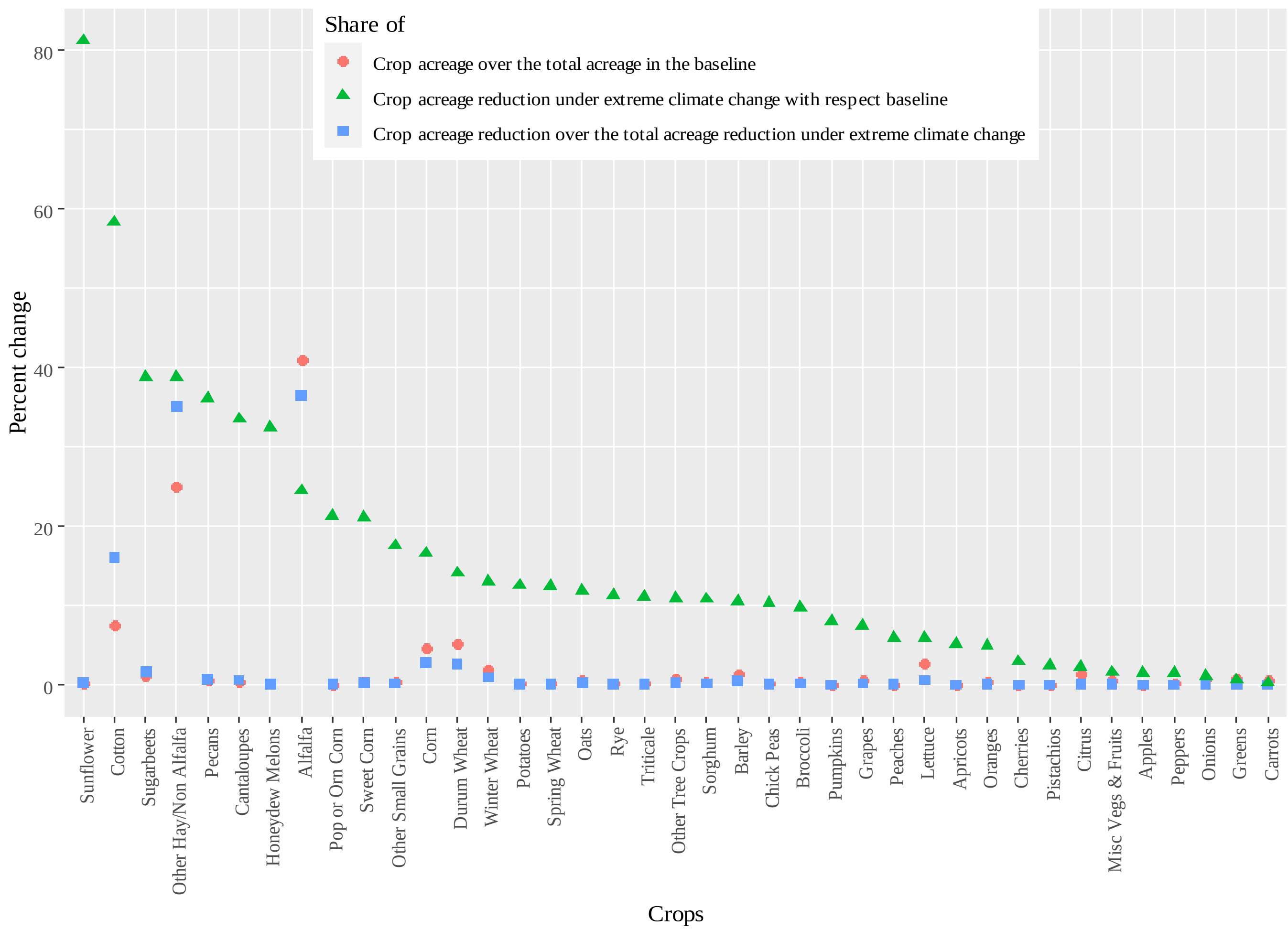
Water availability reduction (%)	Water availability reduction (1,000 acre-feet)	Net income (million $)	Reduction of net income from baseline scenario (million $)	Reduction of net income over baseline (%)	Cropland (1,000 acres)	Reduction of cropland from baseline (1,000 acres)	Reduction of cropland over baseline (%)
Baseline		1,415			2,200		
10	754	1,408	8	1	1,998	202	9
20	1,508	1,385	30	2	1,796	404	18
30	2,262	1,347	69	5	1,594	606	28

on the crop's role and the effects of climate change. For instance, the sunflower acreage experiences a significant reduction of over 80% compared to the baseline conditions, as indicated by the green triangle in Figure 1. This demonstrates that climate change has a substantial impact on sunflower production. However, the blue square in Figure 1 shows that the proportion of the total acreage reduction attributable to sunflowers is small. This is because, as the red points in Figure 1 indicate, sunflowers occupy a small portion of the total acreage under baseline conditions.

Under extreme water restrictions (30% reduction of water availability), 31 of the 39 crops suffered net income losses lower than 5% compared to the baseline scenario. These crops represent a small share of the total cropland area in the basin, less than 10% of the total area of the baseline conditions (red points in Figure 1). Alfalfa, hay, cotton, and wheat accounted for a large share of the basin (red points in Figure 1), and consequently, these crops suffer the impact of water reductions, accounting for 90% (blue squares in Figure 1) of the acreage reduction (545,000 acres). The acreage of alfalfa and hay decreased intensely, given the magnitude of these crops over the total (red points and blue squares in Figure 1). However, other crops with a lower share of the total acreage experienced a relatively large impact, such as sunflower and cotton (green triangles in Figure 1). Under extreme water reduction, alfalfa fallowing is about 25%, and the irrigated area of hay reduces by around 38% with respect to the baseline (green triangle in Figure 1). Despite the significant reduction in acreage of alfalfa and hay, the net income losses from crop production are small, around 6% for alfalfa and 15% for hay, relative to the net income from the baseline scenario.

Cotton acreage accounts for the third largest share, around 7% of the total cropland area in the baseline scenario (red points in Figure 1). Under severe water restrictions, cotton declines heavily in the amount of the irrigated area by 58% (green triangle in Figure 1). These

Figure 1. Percentage of Crop Acreage over the Total in the Baseline Scenario (Red Points), Percentage of Crop Acreage Reduction under Extreme Climate Change with Respect to the Acreage in the Baseline (Green Triangle), and Share of the Crop Reduction over the Total Reduction under Extreme Climate Change Conditions (Blue Square)



reductions in cotton production result in net income losses of 34% compared to the baseline scenario.

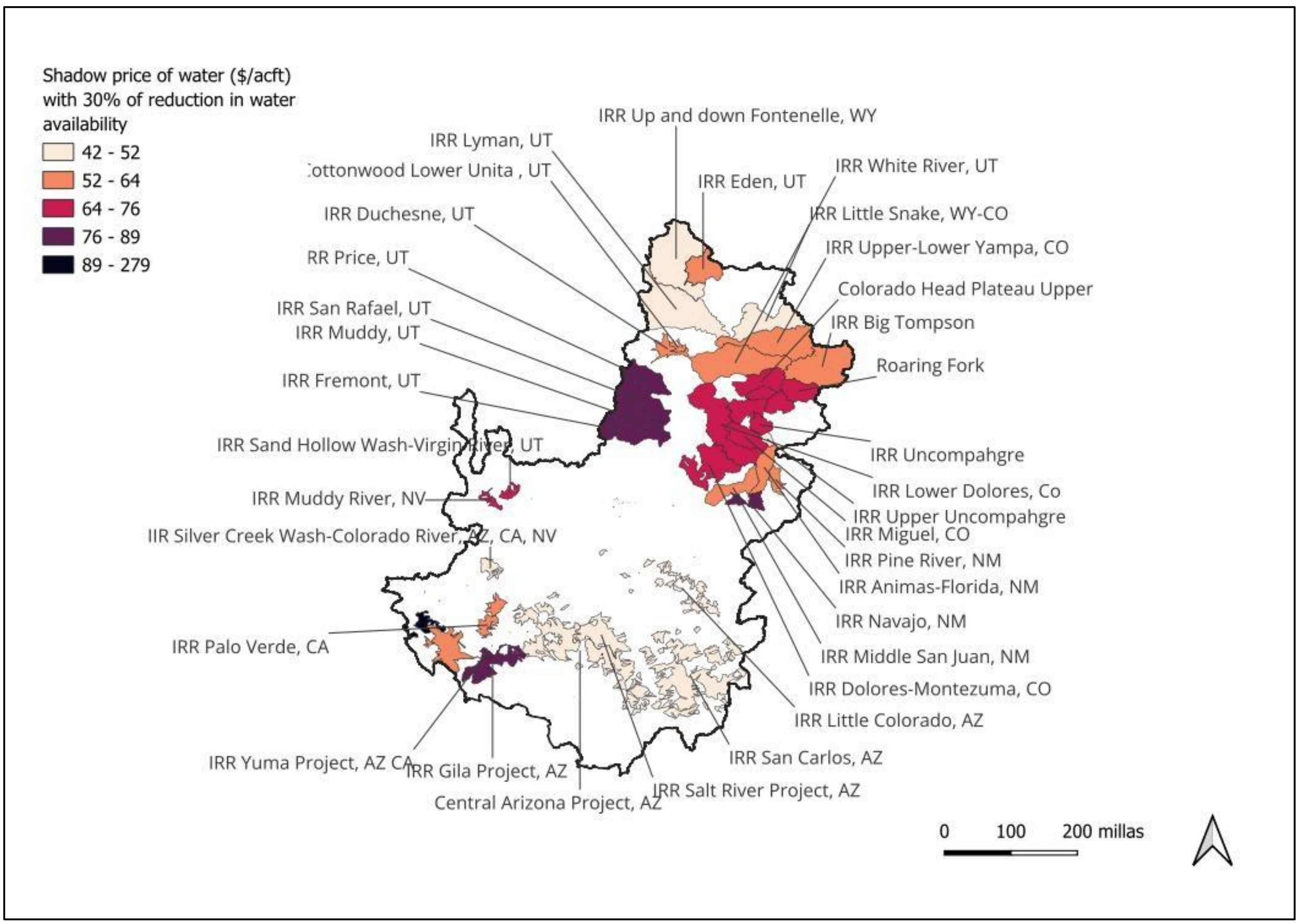
The net income of alfalfa, hay, and cotton crops decrease only slightly when the acreage is reduced significantly. This shows that a large portion of the acreage allocated to those crops is low in productivity, and net income is provided by a smaller portion of area with high productivity. Therefore, reductions in water availability affect irrigated areas with low productivity, and the area with high productivity continues to produce. In consequence, the average net income per acre of those crops increases more than the 50% with respect to the baseline conditions.

Spatial Distribution of the Impacts of Climate Change

Under extreme climate change, net income losses for irrigation districts represent between 1.6% and 8.6% of the net income of the baseline. In relative terms, five irrigation districts maintain net income losses below 5% of the net income of the baseline, which is the average net income losses for the basin. These irrigation districts are Palo Verde (California), Imperial (California), Gila (Arizona), Coachella (California), and Yuma (Arizona), which are able to mitigate the loss of net income because an important share of the net income of these irrigation districts results from the production of trees and vegetables. Adapting to climate change requires maintaining high-value crops with advanced irrigation technology in production and reducing intensely low-value crops such as alfalfa and hay. The irrigation districts highly specialized in field crops have insufficient capacity to change crop patterns and, consequently, to preserve net income.

Figure 2 shows the shadow price of water by irrigation district under extreme climate change, which ranges from $42 per acre-foot to $279 per acre-foot. The shadow price of water indicates the variation in net income for one additional acre-foot of water. The differences in the shadow price between the irrigation districts identify where the water is more valuable and

Figure 2. Shadow Price of Water ($/acre-feet) by Irrigation Districts with 30% Reduction in Water Availability



Note: Shadow price indicates the increment in the net income for one additional unit of water.

the cost of water scarcity. Also, the differences in shadow price show the direction of potential water interchanges.

Summary and Policy Implications

Climate change in the Colorado River Basin is expected to reduce water availability by 30% compared to the last century. The basin is facing water shortages resulting from the imbalance between water demand and supply. Those shortages are expected to increase as climate change imposes a reduction in water availability. This paper examines the impacts of climate change on the agricultural sector in the CRB. The results indicate that alfalfa, hay, and cotton support the reduction of water availability, given the large share of those crops in the total area. However, the impacts on the net income at the basin level, irrigation district, and crops are relatively small compared to the size of fallowed land. The adaptation strategy of irrigation districts to climate change relies on changing the cropping pattern by fallowing low-productivity crops to maintain high economic value, including high-productivity acreage covered by alfalfa and hay. The production of cotton suffers severely from water restrictions, and the impact on the net income for the sector is large.

The results indicate that irrigation districts have the capacity to adapt to water restrictions and maintain net income with the production of crops with high economic value. This result makes us reflect on the current efficiency of water use in the basin.

Declining water inflows and aridification will impose water restrictions that will probably result in permanent reductions of water allocations. The emerging conditions in the basin push for a revision of water management, which may include long-term strategies to face climate change. The results of this article are optimistic since alternative effects of climate change—such as an increase in evapotranspiration, variations of yields, and crop failure—are not considered. In addition, the analysis omits the temporal dimension of drought. This overlooks the fact that climate change increases the probability of experiencing long-lasting and intense drought conditions, thereby ignoring an important source of uncertainty. Risk management is essential to provide robustness to the water system. Therefore, a comprehensive analysis of those aspects of climate change is needed for the CRB.

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Acknowledgments: We are grateful for the support from the UC Riverside OASIS Internal Funding Award (OASIS-IFA), W4190 Multistate NIFA-USDA project, "Management and Policy Challenges in a Water-Scarce World," and The Giannini Foundation of Agricultural Economics.