Title

Understanding the Potential Impacts of Changes in Colorado River Water Supply on Southern California Users

Author

Guetz, Sami

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Understanding the Potential Impacts of Changes in Colorado River Water Supply on Southern California Users

Sami Guetz
Master of Advanced Studies in Climate Science and Policy
Scripps Institution of Oceanography
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Signature has been redacted for privacy purposes.

John Fleck, University of New Mexico

Signature has been redacted for privacy purposes.

Keiko Mertz, *Friends of the River*

Signature has been redacted for privacy purposes.

Tom Corringham, Scripps Institution of Oceanography

Signature has been redacted for privacy purposes.

Dan Cayan, Scripps Institution of Oceanography
Committee Chair

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I. ABSTRACT

Climate change and over-allocation of the Colorado River have resulted in difficult negotiations amongst the seven states (Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming) that rely on the river. The Lower Basin and Federal Government recently came to an agreement (May 2023) for voluntary users to conserve water in trade for financial compensation, resulting in an estimated 3 million acre-feet (MAF) of total conserved water by the end of 2026. Southern California imports more water from the Colorado River than any other user. The majority (80%) of California's 4.4 MAF allotment from the Colorado River is used to irrigate the region's $11.6 billion agriculture industry, and only 20% is used for municipal water. This study examines the annual consumptive use of the four largest importers of Colorado River water in California from 1964 – 2021 to identify extreme variations and understand the effect that precipitation plays in those variations. This study also focuses on the time period of 2002 – 2003, in which Southern California's imports were reduced by 1 MAF due to the Quantification Settlement Agreement (QSA), as a proxy to understand what major cuts in imports will mean to California's agriculture industry today. The study finds that local precipitation had a negative moderate-strong correlation with consumptive use prior to the 2003 QSA in three of the water districts, but a negative weak correlation following the 2003 QSA in all but one district. Reductions from the QSA were widespread but unevenly distributed; Metropolitan Water District decreased its consumptive use by nearly 50% (~0.5 MAF) while Imperial Irrigation District, the largest user of Colorado River water, decreased by less than 6% (0.2 MAF). Irrigated crop acreage (ICA) of all crops decreased by <1% between 2002 and 2003, with the largest decrease in alfalfa at 51,000 acres. Irrigated crop acreage of all crops increased, on average, in the years following the 2003 QSA, even though consumptive use decreased >12%; the ICA of alfalfa had an overall decrease of ~4% while common produce crops increased by ~3%. Similarly, the total water consumed water by alfalfa decreased >13% in the years following the QSA, while the consumptive use of common produce increased nearly 3%. Overall, alfalfa accounted for ~30% of the total irrigated crop acreage and ~44% of total water consumed within the water districts.

II. MOTIVATION

The Colorado River is a critical resource to the West, providing water supply to nearly 30 million people and irrigating over 3 million acres of farmland in Arizona, California, Colorado, New Mexico, Nevada, Utah, Wyoming and Mexico (Barnett & Pierce, 2009). Widely considered one of the most regulated water bodies in the world, the Colorado River is ruled by series of policies and compacts that make up the 'Law of the River' which encompasses decisions made more than a century ago, beginning with the Colorado River Compact (CRC) of 1922. The CRC allotments were based on flows from an anomalously wet two decades in the early 1900's and resulted in 16 million acre-feet (MAF) of water allotted annually – a quantity that exceeds actual annual supply by 0.4 – 2.9 MAF (*Management of the Colorado River: Water Allocations, Drought, and the Federal Role,* 2023). This overallocation paired with rapid expansion of cities in Southern California and Arizona has led to an imbalance of supply and demand from the Colorado River. Southern California is allotted 4.4 MAF – more water than any other user – on which it relies heavily to support is nearly 24 million inhabitants and $1 trillion economy (*Public Policy Institute of California,* 2018 and *Vergati & Sumner,* 2012). California's allocation is not only the largest, but the most senior under the 'Law of the River', meaning that California is the last to take cuts in times of shortage.

Climate change has altered the political and physical landscape in the West, and the future of the Colorado River, and everyone who relies on it, deeply depend on a restructuring of allocations across users and an existential shift in how water is perceived in the West. Southern California's senior water rights to the Colorado River have, in part, enabled the state to become the top producer of food in the U.S. The productivity of Southern California's agriculture industry, however, does not need to be tethered to its current water imports; users in Southern California are capable of adapting to dramatic cuts in imports, as seen in the 2002 – 2003 time period under the Quantification Settlement Agreement (QSA). This study focuses on the large cuts that came as a result of the QSA in 2003 and the effects those cuts had on agricultural production and value, particularly of alfalfa.

III. BACKGROUND

a. Hydrology of the Colorado River

The Colorado River begins in the Rocky Mountains of northcentral Colorado and flows 1,450 miles through the southwestern U.S. to the Gulf of Mexico (U.S. Bureau of Reclamation, 2012). Annual flows in the Colorado River are extremely variable, ranging from a record low in of 3.9 MAF in 1934 to 22.2 MAF in 1984 (Rajagopalan et al., 2009). Annual flow fluctuations are due to variation in precipitation in the Upper Basin; 70% of the annual flow originates from the snowpack in the Rocky Mountain headwaters (Xiao & Lettenmaier, 2021). The Colorado River Basin occupies approximately 250,000 miles (U.S. Bureau of Reclamation, 2012) and is divided into the Upper and Lower Basins at Lees Ferry, Arizona.

The hydrology and landscape of the Lower Basin has been severely altered to provide water to urban areas such as Phoenix and Los Angeles, as well as provide irrigation for agriculture in the arid landscape of Southern California. Southern California's agriculture industry is responsible for 80% of the region's consumptive water use, facilitated by a series of aqueducts and canals that siphon water 242-miles across the Mojave Desert from the Colorado River Basin (Cantor et al 2022 and *ASCE Library,* 2007).

b. Climate Change and Drought in the Western U.S.

The 2000-2021 period was the driest 22-year period since at least 800 CE as a result of anthropogenic climate change (Williams et al., 2022). The decrease in precipitation and increase in temperatures has caused a 20% decline in annual streamflow in the Upper Colorado River Basin (Hoerling et al., 2019). The effects of overuse and climate change are seen dramatically in the major reservoirs, Lake Mead and Lake Powell, which have historically provided critical storage (they have a combined storage capacity of 60 MAF) during prolonged periods of drought but reached critically low levels in 2022 (Rajagopalan et al., 2009). *Figure 1* shows the storage of Lake Mead and Lake Powell over time, and the recent decline in storage between the reservoirs.

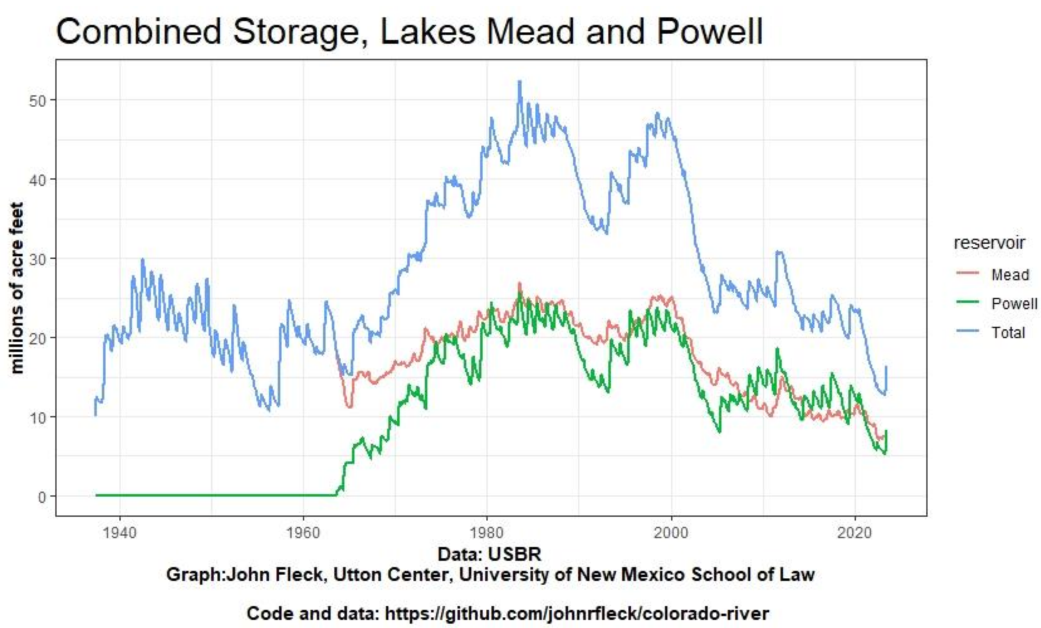

Figure 1*. Combined storage of Lake Mead and Lake Powell, provided by of John Fleck.*

c. Law of the River

The Colorado River is governed by a series of policies and agreements over a century old, bound up in what is commonly referred to as 'Law of the River'. The laws and policies that dictate Colorado River allocations are extensive. For this project, it is necessary to understand the following core policies:

The Colorado River Compact (1922) divided the Colorado River Basin into the Upper Basin (Colorado, New Mexico, Utah, and Wyoming) and Lower Basin (Arizona, California, Nevada) and allotted 7.5 million acre-feet (MAF) annually to each basin and 1.5 MAF to Mexico, for a total annual allocation of 16 MAF (*Colorado River Compact*, 1922) (*Figure 2)*.

The Boulder Canyon Project (1928) apportioned the Lower Basin's allotment of 7.5 MAF to Arizona (2.8 MAF), California (4.4 MAF), and Nevada (0.3 MAF) (*Boulder Canyon Project Act*, 1928) (*Figure 2)*.

The Colorado River Basin Project Act (1968) authorized construction of the Central Arizona Project[1] and made Arizona's allotment subordinate to California's in times of shortage (*Colorado River Basin Project Act,* 1968).

The Quantification Settlement Agreement (2003) came in response to California consistently using more than its entitlement of 4.4 MAF; the agreement confirmed an allotment of 3.1 MAF to Imperial Irrigation District (IID), 0.3 MAF to Coachella Valley Water District (CVWD), established transfers from IID to San Diego County Water Authority, Metropolitan Water District of Southern California, and CVWD in the amounts of 0.2 MAF, 0.1 MAF, and 0.1 MAF, respectively (*Quantification Settlement Agreement,* 2003).

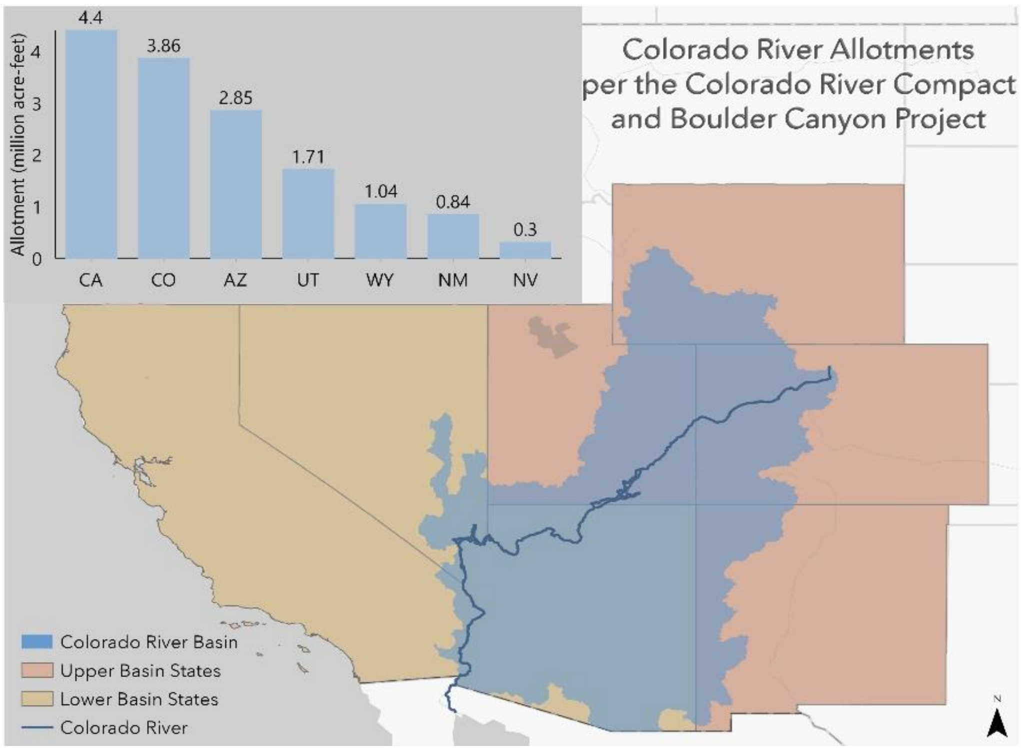

Figure 2*. Colorado River Allotments between the Upper and Lower Basin states. Map created in GIS*.

c. California Water Governance

Water rights in California are based on the "first in time, first in right" legal doctrine of prior appropriation which grants seniority of older rights over more recently obtained rights. Senior water rights are more secure than junior rights in times of shortage; junior water rights are subject to curtailment during drought (Grantham and Viers, 2014). Under this legal framework, supply to junior water users is curtailed entirely before senior users must spare even a drop. The governance structure of prior appropriation disincentivizes senior rights holders to conserve water due to the "use it or lose it" clause which means that water rights can be reduced if not used to their full extent (Lustgarten, 2015). Irrigation districts in Southern California hold senior rights to 3.85 MAF of water from the Colorado River (*Public Policy Institute of California,* 2018). This study provides analysis of all major users with a focus on Imperial Irrigation District.

d. Major Water Users in Southern California

Imperial Irrigation District (IID): Located in Imperial County, California, IID has more than 471,000 acres of irrigable land and relies solely on the Colorado River for irrigation (*Imperial Irrigation District,* 2020). Water from the Colorado is diverted below the Imperial Diversion Dam to the All-American Canal which takes water west along the border with Mexico to Imperial Irrigation District (IID). Imperial Valley is the largest user of water from the Colorado River, with "present perfected" rights (IID's deliveries are satisfied first in time of shortage) to 3.1 MAF of water annually (*Imperial Irrigation District,* 2020) (*Figure 3)*.

[1] The Central Arizona Project is a 336-mile diversion canal designed to provide water to nearly one million people in Arizona (*Central Arizona Project,* 2000).

Coachella Valley Water District (CVWD): Located in Riverside County, California, two-thirds of its farmland is irrigated by Colorado River water via the Coachella Canal, a branch of the All-American Canal. The Coachella Canal supplies CVWD with 0.28 MAF of water from the Colorado River annually (*Coachella Valley Water District,* 2023) (*Figures 3 and 4)*.

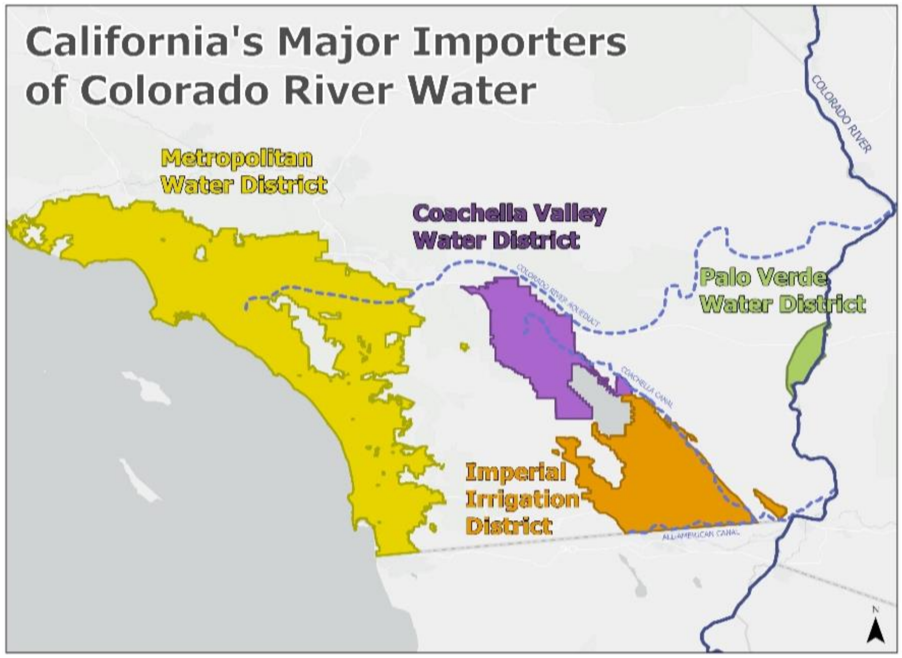

Figure 3. *Water districts in Southern California that import water from the Colorado River.*

Palo Verde Irrigation District (PVID): Located in Riverside and Imperial Counties in California, PVID contains more than 131,000 acres of irrigable land for which it relies 100% on the Colorado River (*Palo Verde Irrigation District, 2023)* (*Figures 3 and 4)*.

Metropolitan Water District of Southern California (MWD): MWD delivers water to San Bernardino County, Los Angeles County, San Diego County, Ventura County, and Orange County via the Colorado River Aqueduct. MWD has multiple sources of water, including the Colorado River (25%), State Water Project (30%), and stormwater and wastewater recycling, groundwater, and desalination (45%) (*Metropolitan Water District,* 2023). MWD also has large storage capacity that it can rely on in in years of drought. (*Figures 3 and 4)*.

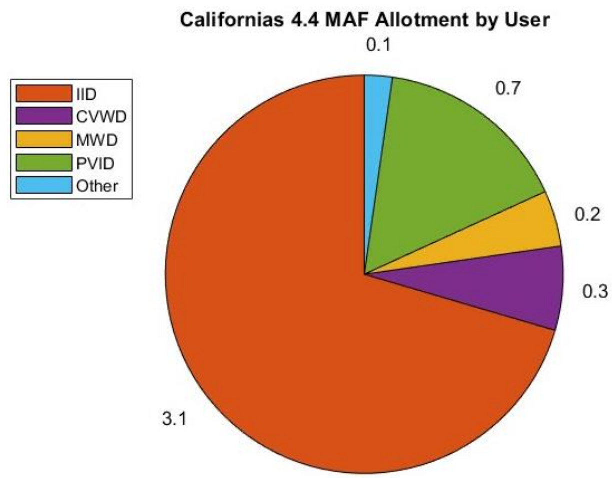

Figure 4*. California's 4.4 MAF allotment broken down by user.*

e. Current Setting

The impacts of climate change paired with overallocation, and overuse have led to a reckoning for the states that rely on the Colorado River. In August 2021 the U.S. Secretary of the Interior declared a Tier 1 shortage, a designation that requires a tiered set of cuts per the Drought Contingency Plan (U.S. Congress, 2019). The Federal Government asked the seven states at the end of the 2022 summer and again in the fall to reach an agreement for further cuts, but the states never reached a consensus. All states – with the exception of California – reached an agreement. In May 2023, the Lower Basin States released a letter of agreement to conserve a total of at least 3 MAF by the end of 2026 (Buschatzke et al, 2023). The *Lower Basin Plan* achieves conservation through federal compensation under the Inflation Reduction Act. The *Lower Basin Plan* received significant media coverage for being a “breakthrough deal” that will “keep the Colorado River from going dry” in a time of serious water shortage in the West (Flavelle, 2023). The agreement, however, falls short of actual reductions needed in the Lower Basin to achieve long-term water security. Further, it poses a risk to the future of the users that rely on Colorado River Basin. Most importantly, the *Lower Basin Plan* lacks essential detail on which districts, or even which states, will be responsible for the cuts. However, due to the breakdown of the Lower Basin allotments (Arizona 2.8 MAF, California 4.4 MAF, and Nevada 0.3 MAF), it can be assumed that many of the compensated cuts will go to California water districts, specifically Imperial Irrigation District, due to its unmatched allocation of 3.1 MAF which equates to 70% of California’s total, and 20% of total Colorado River allotments within the U.S.

IV. METHODOLOGY

This study aims to understand the potential impact of the Lower Basin Plan (released in May 2023) by focusing on the following questions: (1) Does local precipitation (County) or seasonal precipitation in the Upper Basin have an effect on deliveries?, (2) How are variations in consumptive use (i.e. deliveries) reflected in agricultural production (applied water, irrigated crop acreage, and total water consumed)?, and (3) What is the effect of fallowed land in Imperial Valley? The previous questions are analyzed as 'Pre-QSA', all years prior to 2003, and 'Post-QSA', all years following 2003, due to the large variability that occurred between 2002 and 2003 by the QSA. This research employs quantitative analysis of observational timeseries data through MatLab R2022a and ArcGIS Pro.

a. Deliveries

Annual consumptive use was gathered and organized in Excel (provided by J. Fleck) for Imperial Irrigation District (IID), Metropolitan Water District of Southern California (MWD), Coachella Valley Water District (CVWD), and Palo Verde Irrigation District (PVID) from the U.S. Bureau of Reclamation (USBR) Annual Water Accounting Reports from 1964 –2021 (U.S. Department of the Interior, 1964-2021). Consumptive use is the amount of water delivered to a district and not returned; the value is the same as the amount of water imported, or delivered, to a user from the Colorado River and used completely. Consumptive use was analyzed annually before and after the 2003 QSA to understand the long-term impact that major cuts had on individual districts. Two years were analyzed individually, 2002 and 2003, and then were compared to understand the immediate effect of the QSA. The difference between the average values during the 'Pre-QSA' and 'Post-QSA' time periods, and difference between the respective values for 2002 and 2003 were then used to find the change in deliveries as a value and a percent. The long-term change in deliveries was represented by the change from the 'Pre-QSA' to 'Post-QSA', and the immediate effect was represented by the change from 2002 to 2003.

Table 1*. Datasets used for annual delivery analysis.*

Dataset Used	Purpose	Source
Fleck_lower_basin_data.xlsx	Annual consumptive use 1964-2021 for IID, MWD, CVWD, PVID	John Fleck, complied from USBR Annual Accounting Reports (https://www.usbr.gov/lc/region/g4000/wtracct.html)

b. Precipitation Correlation

The correlations between annual exports of Colorado River water to Southern California and both (1) precipitation in the Upper Basin, and (2) local precipitation in Southern California were analyzed for IID, MWD, CVWD, PVID, and Total. The observational timeseries for the seasonal precipitation in the Upper Basin of the Colorado River was based on the average Utah ClimDiv 7 and Colorado ClimDiv 2 (provided by J. Mumford, derived from NOAA Clim Div 2 and ClimDiv 7 data), the two NOAA ClimDivs that comprise the majority of the Upper Colorado River Basin. The dataset provides precipitation in millimeters in 3-month increments (September – November, December – February, March – May, June – August) for each year. Most of the annual flow (70% - Xiao & Lettenmaier, 2021) originates from snowpack in the Rocky Mountains, so precipitation was aggregated for the months of December – May and named 'Upper Basin Seasonal Precipitation'. All precipitation values were converted from millimeters to inches.

Total annual precipitation for Imperial County, Riverside County, San Bernardino County, Orange County, San Diego County, Los Angeles County, and Ventura County for the time period of 1964 – 2021 were derived from PRISM datasets using an online interactive tool to analyze county-wide time-series. Annual precipitation was averaged between Imperial and Riverside counties for the correlation with PVID annual deliveries. Annual precipitation data was aggregated for Orange County, San Diego County, Los Angeles County, and Ventura County for the correlation with MWD annual deliveries due to the large area and variable landscape that MWD covers.

Correlations were calculated from 1964 – 2002 ('Pre-QSA') and 2003 – 2021 ('Post-QSA') contemporaneously ('no lag') and on a 'four-year-lag' for IID, MWD, CVWD, PVID, and Total. The 'four-year lag' correlation aggregated four years of precipitation totals and correlated the total to the subsequent year's delivery value (i.e. the total precipitation from 2000 – 2003 correlated with 2004 delivery). The purpose of the 'four-year-lag' correlation was to understand the effect that precipitation in previous years has on deliveries. For example, the ‘four-year-lag’ examined if four continuous years of drought lead to a significant decrease in deliveries. The ‘four-year-lag’ and ‘no lag’ correlations were kept independent by not including the contemporaneous year in the ‘four-year-lag’ correlation.

Table 2. *Datasets used for precipitation correlation analysis.*

Dataset Used	Purpose	Source
UpperCO_Seasonal_Precip.xlsx	Seasonal precipitation in the Upper Basin of the Colorado River	Compiled by Joshua Mumford, sourced from UT ClimDiv 7, CO ClimDiv 2 (NOAA)
Imperial_County.xlsx, LA_County.xlsx, Orange_County.xlsx, Riverside_County.xlsx, SanBern_County,xlsx, SanDeigo_County.xlsx	Total annual local precipitation for 1964 - 2021	https://prism.oregonstate.edu/explorer/

c. Applied Water, Irrigated Crop Acreage, Total Water, and Crop Value

Water balance data from 1998 – 2015 for the Southern California region (provided by T. Corringham, derived from California’s Department of Water Resources Water Plan Water Balance Data) were used to analyze the applied water (AW), irrigated crop acreage (ICA), and total consumed water (AWICA) for twenty different crops per year sorted by county and DAU (detailed analysis unit – a way of breaking down hydrologic areas, typically by county). Respective DAUs for IID, CVWD, and PVID were identified in ArcGIS Pro using a DAU shapefile from the State of California’s GIS Portal (*Figure 5*). Although some of the districts are in more than one DAU, the DAU that is associated with the majority of the district was used for simplicity. MWD was not analyzed due to the complexity of limiting DAU areas to agricultural areas within the MWD jurisdiction (a largely urban region). AW was measured in acre-foot per acre and ICA was measured in thousands of acres.

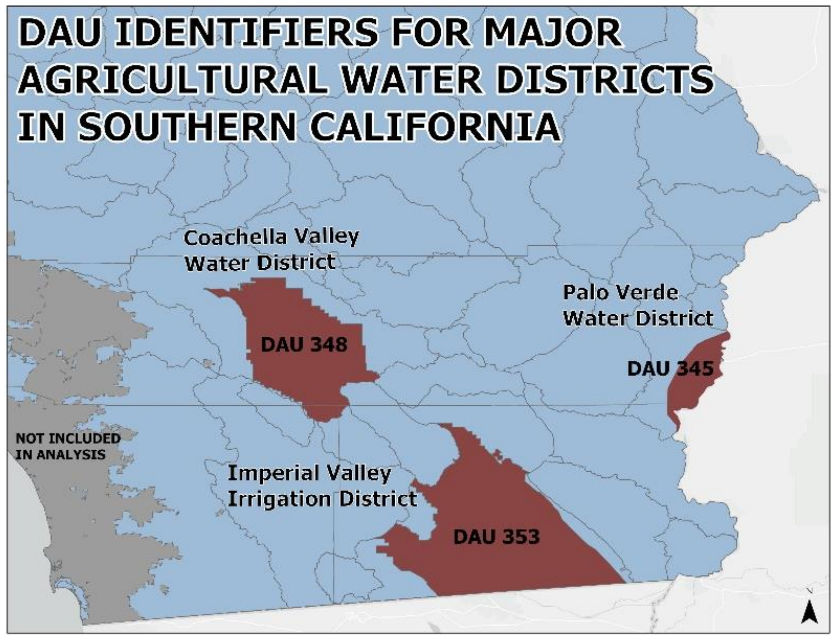

Figure 5*. A California DAU map and water district boundary map were used to identify which DAU's define each water district region.*

The weighted mean AW was calculated with:

$$Weighted\ mean\ AW = \frac{sum(AW\ x\ ICA)}{sum\ (ICA)}$$

AWICA was the factor of both variables in units of thousand-acre feet (TAF):

$$TW\ taf = AW\ (\frac{acre - foot}{acre})\ x\ \ ICA\ (thousand\ acres)$$

AWICA was the total water consumed by all crops. The analysis did not include all twenty crops and instead focused on: alfalfa, cotton, grain, pasture, other truck, and subtropical. The selected crops were identified through an initial analysis of identifying which crops had the highest ICA within the districts. Crops that had a low ICA were excluded from the analysis for simplicity. ‘Other truck’ crops included common produce such as lettuce, broccoli, and onions. The same analyses were done for AW, ICA, and TW. Each variable was analyzed per crop as a comparison from 2002 vs. 2003 to understand the direct impact of the QSA, and from 1998 – 2015 as a timeseries. The timeseries simply summed the data per year per crop and were plotted as values over time against annual deliveries for the corresponding water district. The data were also broken into two categories: 'Pre-QSA' defined data prior to 2003 and 'Post-QSA' defined data in 2003 and beyond. The annual average was then calculated for the 'Pre-QSA' and 'Post-QSA' data. The 'Average Pre-QSA' and 'Average Post-QSA' values were then compared to the 2002 vs. 2003 years to understand the effects that the QSA had immediately and on a longer timescale. A similar dataset containing crop values was used to analyze the annual production value of crops over time. This dataset (20230518_agprism, provided by Tom Corringham, derived from USDA NASS Agriculture Commissioners' Data) contained the same crops as the DWR data organized by county. The data was limited to Imperial and Riverside counties. Imperial County data were used compared to IID deliveries, and Riverside County data were compared to CVWD and PVID deliveries separately. The same analysis was done as for AW, ICA, and TW but for Real_Value_2020 which was a value (revenue) of the crop adjusted for inflation to 2020 USD. To understand the role that alfalfa played as a whole, TW for all crops across all districts was summed and used to calculate the average percent of TW that is used on alfalfa before and after the QSA.

Table 3. *Datasets used for agriculture analysis.*

Dataset Used	Purpose	Source
DWR_Water_Balance_Agriculture_Data_1998-2015.xlsx	Applied water (AW), irrigated crop acreage (ICA), total water (TW)	Tom Corringham, derived from California's Department of Water Resources Water Plan Water Balance Data
20230518_agprism.xlsx	Real_Value_2020	Tom Corringham, derived from USDA NASS Agriculture Commissioner's Data

d. Imperial Irrigation District

Imperial Irrigation District's (IID) annual crop reports from 1989 – 2019 (provided by J. Fleck, derived from Imperial Irrigation District data) were analyzed for a more detailed understanding of how the QSA affected crop production and fallowed land in Imperial Valley. The same methodology that was used in the previous section was used on irrigated land, fallowed land, alfalfa, lettuce, broccoli, and onions. The original dataset included monthly crop totals in the units of acres. The monthly data was averaged over each year to get average annual acreage of crops – this was done because the data is not 'harvested crops' so the mean value was taken to avoid counting crop acres more than once. The data was then divided into 'Pre-QSA' (1989 – 2202) and 'Post-QSA' (2003-2019). The average values for each time period were then taken to compare the difference in crop production, on average, before and after the QSA. The average values were then compared to crop acreage in 2002 and 2003 to understand the immediate impact on crop production by the QSA.

Table 4. *Datasets and sources for Imperial Irrigation District crop production analysis.*

Dataset Used	Purpose	Source
IID_CropAC_Report_2019_09.xlsx	Irrigatable land, fallowed land, alfalfa, onion, lettuce, broccoli	John Fleck, information request from IID https://www.iid.com/water/agriculture-customers/water-and-crop-news

V. RESULTS

a. Deliveries

Annual delivery data were plotted for the time period 1964 – 2021 for Imperial Irrigation District (IID), Metropolitan Water District (MWD), Coachella Valley Water District (CVWD), Palo Verde Irrigation District (PVID), Other, and Total (*Figure 6*). The timeseries showed a decrease in deliveries that occurred because of the QSA. Prior to the QSA, California imported an average of 0.57 MAF more than its allotted amount of 4.4 MAF. The timeseries also showed which users dominated the water imports from the Colorado River within California: IID imported more than half of California's total allocated amount of water, followed by MWD. 'Other' users made up only a small percentage of the water imported from the Colorado River.

The QSA resulted in an immediate decrease in deliveries to Southern California totaling 0.96 MAF between 2002 and 2003. MWD was responsible for making the largest cut of 0.56 MAF (approximately 45% of their previous year's delivery), followed by IID at 0.17 MAF. Notably, the 0.17 MAF was less than a 6% cut, compared to PVID's comparable 0.16 MAF cut, nearly 30% of its 2002 amount. There were differences in cuts made immediately following the QSA and the average cuts made over time in the period after the QSA was implemented; MWD still made the most cuts on average, at a more reasonable but still impressive 22% from 2003-2021 compared to 1964-2021 averages. IID's average cuts increased only slightly with time to 7% following the 2003 QSA (*Table 5*).

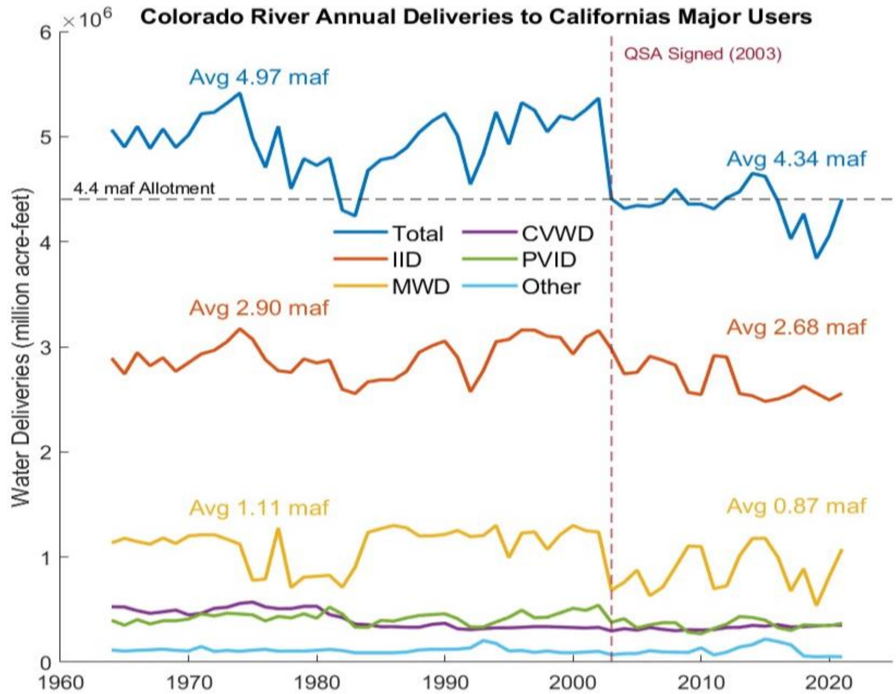

Figure 6. *Timeseries of Colorado River deliveries to Southern California's major users, including Imperial Irrigation District (IID), Metropolitan Water District (MWD), Coachella Valley Water District (CVWD), Palo Verde Irrigation District (PVID), Other and Total.*

Table 5*. Summary of annual deliveries as average values before and after the QSA, and in 2002 and 2003.*

	Changes in CO River Imports over time, as a result of the QSA				Changes in CO River imports as an immediate result of the QSA			
	Pre-QSA Average (maf)	Post-QSA Average (maf)	Difference (maf)	Difference (%)	2002 Delivery (maf)	2003 Delivery (maf)	Difference (maf)	Difference (%)
MWD	1.11	0.87	0.25	-22.1	1.24	0.68	0.56	- 44.8
PVID	0.42	0.36	0.07	-16.2	0.54	0.38	0.16	- 29.8
IID	2.90	2.68	0.22	-7.1	3.15	2.98	0.17	- 5.5
CVWD	0.42	0.33	0.09	-21.5	0.33	0.30	0.03	- 10.4
Other	0.11	0.11	0.01	-5.3	0.10	0.07	0.03	- 31.6
Total	4.97	4.34	0.63	-12.8	5.37	4.41	0.96	- 17.8

b. Precipitation Correlation

There was a clear inverse relationship between precipitation and deliveries prior to the QSA, where low local precipitation within each respective County coincided with higher deliveries. This correlation appeared to decrease following the QSA in 2003 (*Figure 7*). PVID and IID had the strongest inverse correlations between local precipitation and deliveries prior to the QSA at -0.56 and -0.68, respectively, with 99.99% confidence, meaning more precipitation in each County resulted in less annual deliveries. MWD had an inverse correlation between both local and Upper Basin precipitation and deliveries prior to the QSA, at -0.42 and -0.43, respectively, with 99.9% confidence, meaning more precipitation in the Upper Basin resulted in less annual deliveries. Only CVWD showed a correlation between precipitation (Upper Basin) and deliveries following the QSA, with a correlation of -0.42 at 99.9% confidence, meaning more precipitation in the Upper Basin resulted in less annual deliveries (*Table 6*).

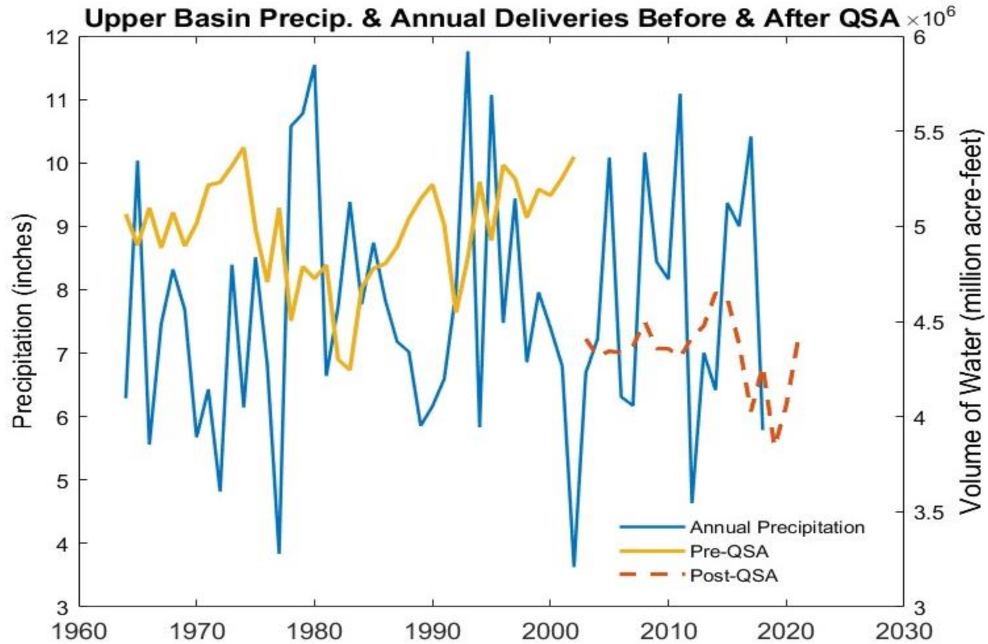

Figure 7. *Seasonal precipitation in the Upper Basin of the Colorado River compared to total annual deliveries to Southern California before and after the Quantification Settlement Agreement in 2003. The precipitation is based on Dec. to May in Utah and Colorado.*

Contemporaneous correlations between the observed average annual precipitation in the Upper Basin and annual deliveries to all of the districts (Total) were calculated and plotted for the years before (*Figure 8*) and after (*Figure 9*) the QSA in 2003; there is a clear decrease in the effect that precipitation had on deliveries following the QSA.

Table 6. *summary of correlation values between precipitation and annual deliveries.*

Region		No Lag		4-year LAG	
		Pre-QSA	Post-QSA	Pre-QSA	Post-QSA
IID	Upper Basin	-0.27	-0.21	-0.05	-0.24
	County	-0.68 p-value = 0.00	-0.28	-0.44 p-value = 0.008	-0.09
CVWD	Upper Basin	0.02	-0.21	0.18	0.29
	County	-0.02	-0.27	-0.28	0.11
PVID	Upper Basin	-0.36	-0.42 p-value = 0.073	0.01	-0.32
	County	-0.56 p-value = 0.00	-0.31	-0.24	-0.02
MWD	Upper Basin	-0.42 p-value = 0.008	0.11	-0.25	-0.06
	County	-0.43 p-value = 0.006	-0.2	-0.07	-0.21
Total	Upper Basin	-0.49 p-value = 0.002	-0.2	-0.14	-0.22

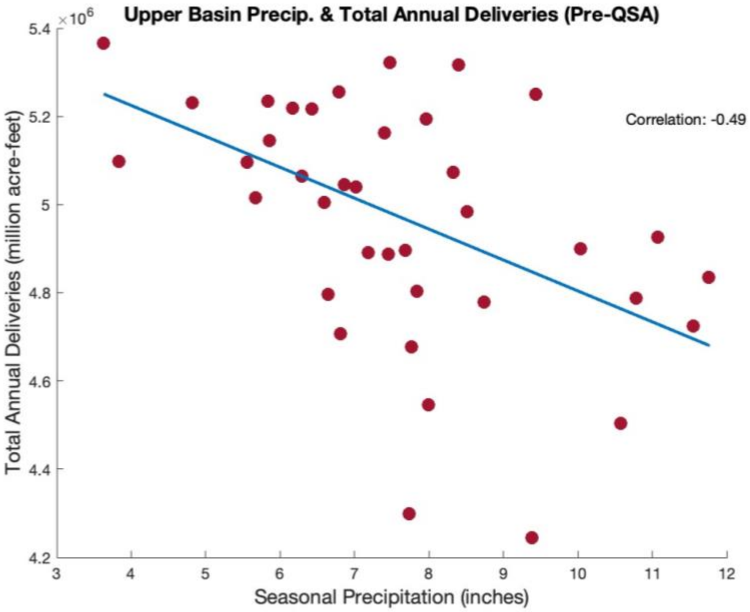

Figure 8. *Correlation between Upper Basin precipitation and total annual deliveries before the Quantification Settlement Agreement (QSA), no lag.*

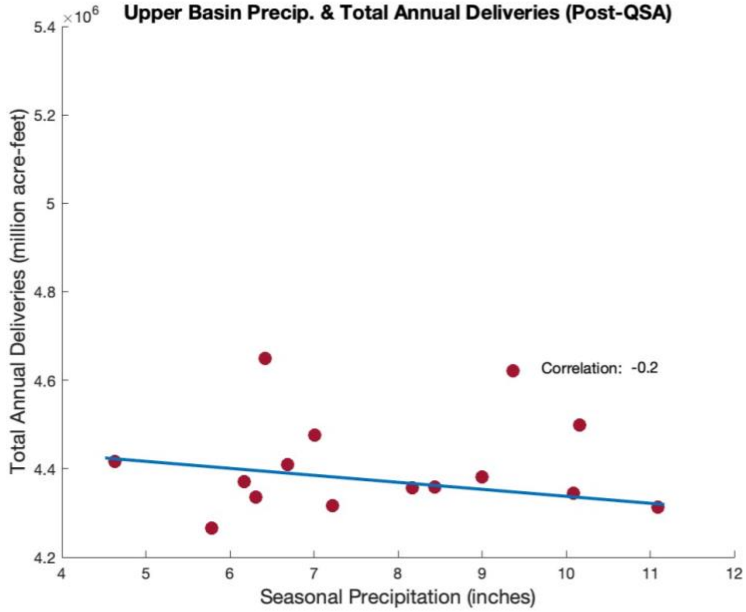

Figure 9. *Correlation between Upper Basin precipitation and total annual deliveries after the Quantification Settlement Agreement (QSA), no lag.*

The correlations between the observed average annual precipitation in Imperial County and annual deliveries to IID were plotted for the years before (*Figure 10*) and after (*Figure 11*) the QSA in 2003. Following the QSA, annual deliveries were significantly less affected by local annual precipitation.

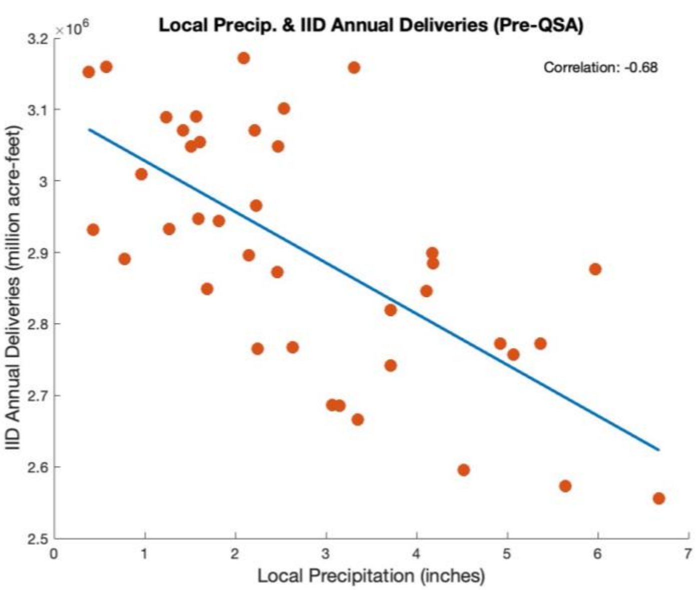

Figure 10. *Correlation between precipitation in Imperial County and annual deliveries to Imperial Irrigation District before the QSA, no lag.*

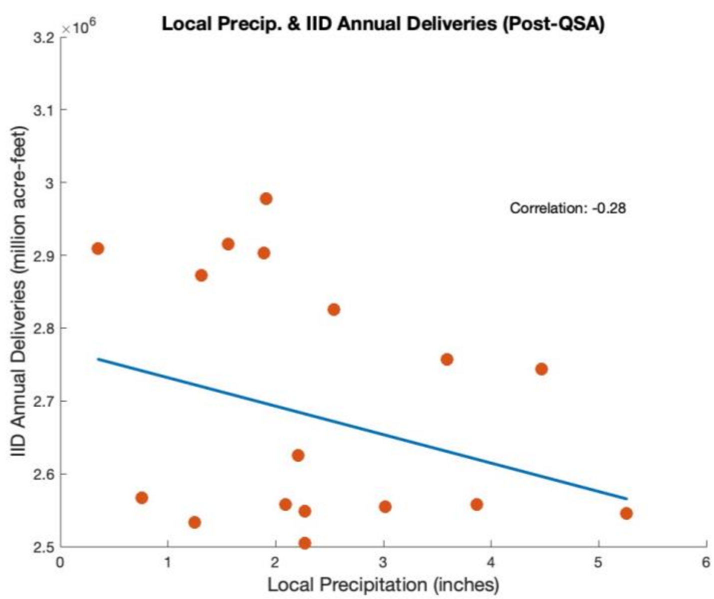

Figure 11. *Correlation between precipitation in Imperial County and annual deliveries to Imperial Irrigation District after the QSA, no lag.*

The correlations between the observed (and aggregated) annual precipitation in San Bernardino County, Los Angeles County, San Diego County, Ventura County, and Orange County and annual deliveries to MWD were plotted for the years before (*Figure 12*) and after (*Figure 13*) the QSA in 2003. Like the IID, the effect of precipitation in MWD's jurisdiction decreased on annual deliveries decreased.

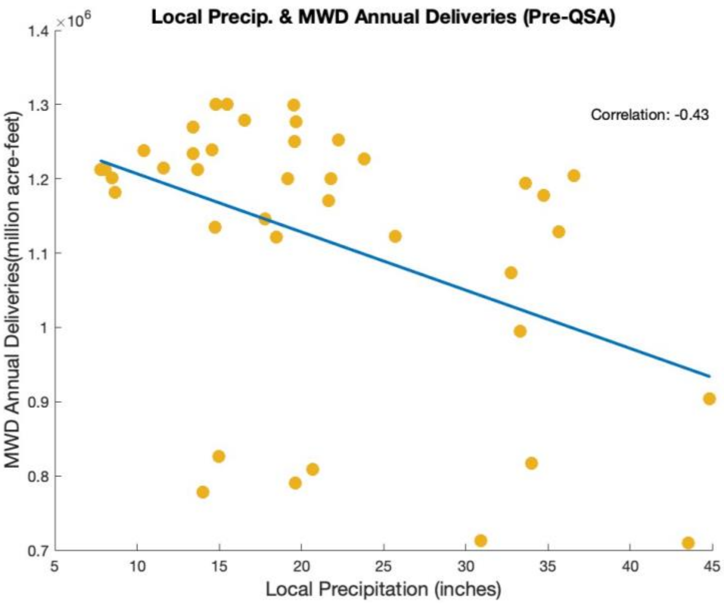

Figure 12. *Correlation between precipitation in MWD's jurisdiction and annual deliveries before the QSA, no lag.*

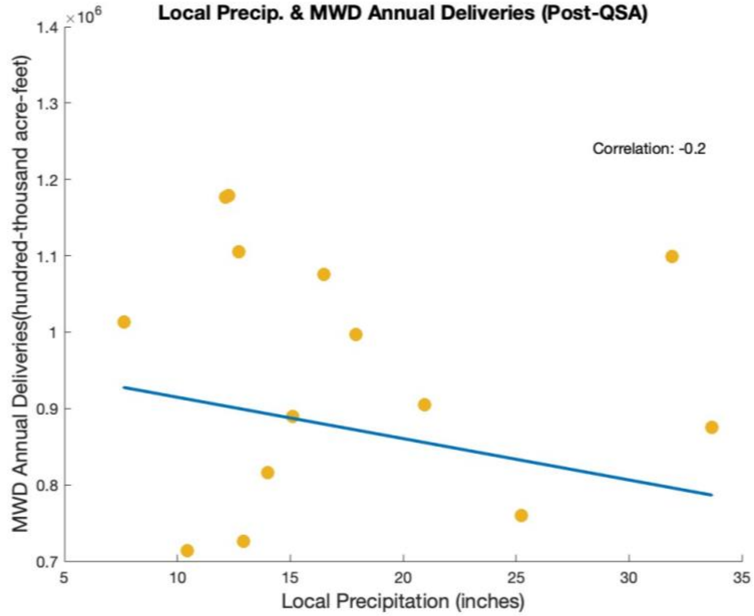

Figure 13. *Correlation between precipitation in MWD's jurisdiction and annual deliveries after the QSA, no lag.*

c. Agriculture

Annual crop data containing twenty different crops produced in the agriculture water districts (PVID, IID, and CVWD) were examined against total annual water deliveries between the three districts. Unsurprisingly, there was a strong positive correlation (Corr = 0.69, p-value = 0.0014) between total annual deliveries to the agriculture districts and total annual ICA, showing that the acreage of irrigated land increased in years when more water was delivered. This study focused on five crops: alfalfa, cotton, grain, subtropical, and other truck crops. These five crops were chosen as they were among the most abundantly grown crops in the region. 'Other truck' crops included lettuce, broccoli, and onions which were individually examined for IID later. The correlation between the selected five crops and annual deliveries to the agriculture districts was also strong (Corr = 0.71, p-value = 0.0011). The slight increase in correlation verified these crops were affected by changes in deliveries. There was a clear decrease in ICA that occurred at the time of the QSA, but it was unclear which crops were most responsible for the correlation. The relationship between total annual deliveries and ICA of the respective crops were examined separately. Only weak relationships were found; however, alfalfa displayed the most significant (inverse) relationship (Corr = -0.36, p-value = 0.1402).

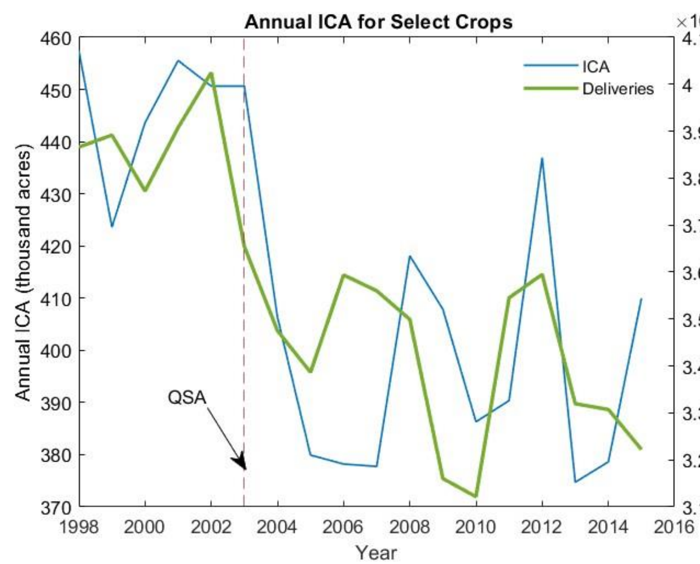

Figure 14. *Relationship between total annual deliveries to IID, PVID, and CVWD and total annual irrigated crop acreage (ICA).*

d. Agriculture – Applied Water (AW)

Annual AW for the selected crops within each agriculture district was examined against annual deliveries. The sharp decrease in deliveries from 2002 to 2003, as seen in *Figure 6*, was highlighted when zoomed in to the individual districts. Alfalfa consumed the most AW in all three districts (*Figures 15, 16,* and *17*).

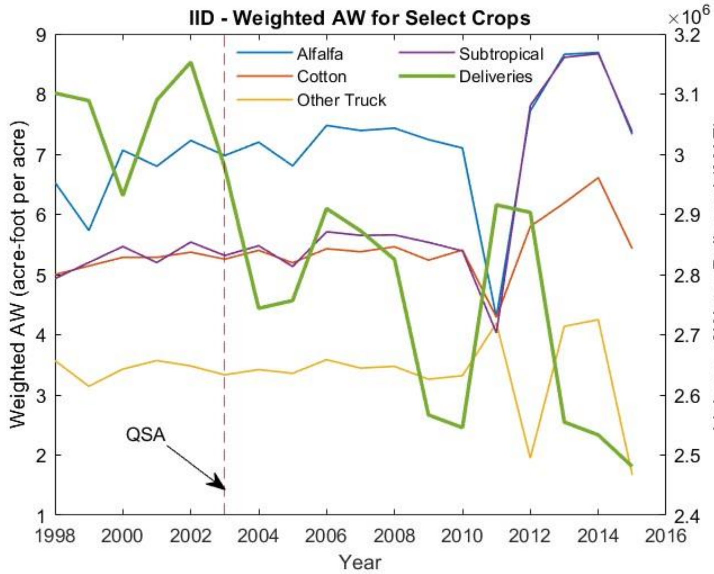

Figure 15. *Weighted applied water (AW) for select crops in Imperial Irrigation District (IID).*

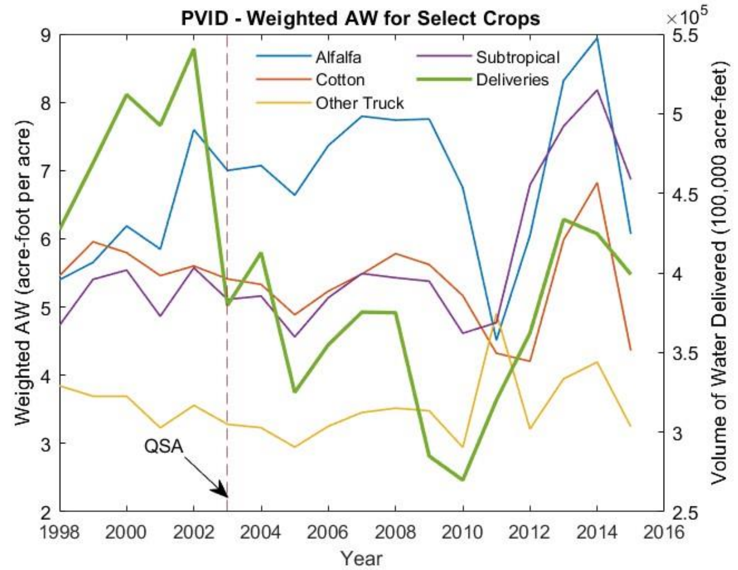

Figure 16. *Weighted applied water (AW) for select crops in Palo Verde Irrigation District (PVID).*

The amount of AW decreased for all crops from 2002 to 2003, with relatively even decreases across all crops (*Figure 18*). Subtropical had the largest decrease in AW from 2002 to 2003 but increased over the long-term following the QSA. Alfalfa had the largest long-term increase in water of >10%. Overall, the five selected crops (25% of 'All Crops') made up approximately 35% of all AW. Alfalfa made up 27% of the AW out of the selected crops, and > 9% out all crops before the QSA, and increased to >29% and 10% following the QSA, respectively. Common produce crops (other truck), accounted for only 5% of the AW consumed by all crops (*Table 7*).

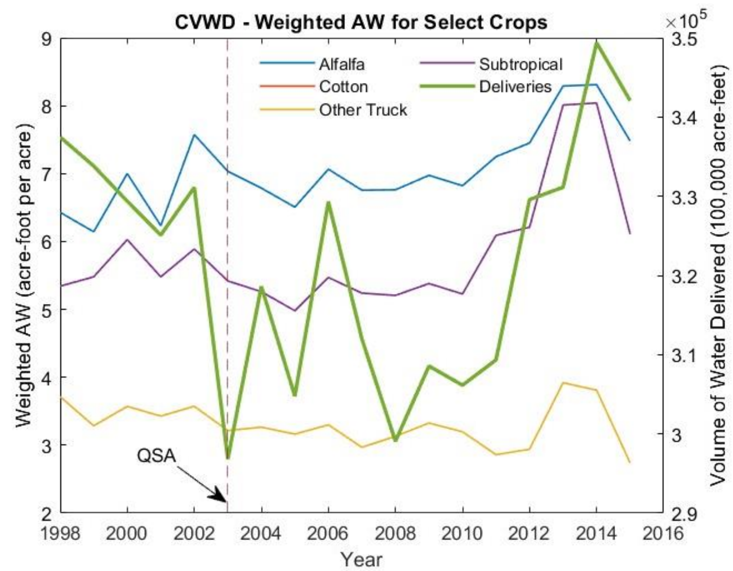

Figure 17. *Weighted applied water (AW) for select crops in Coachella Valley Water District (CVWD).*

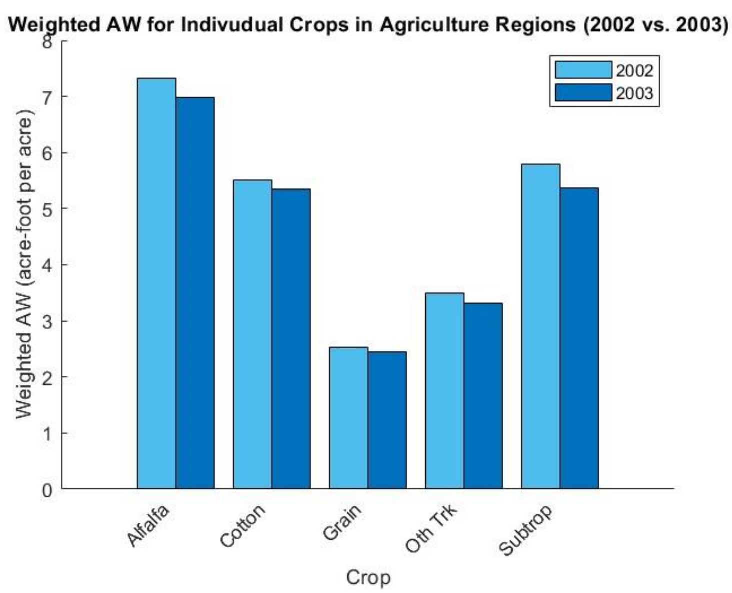

Figure 18. *Weighted applied water (AW) for select crops in all districts in 2002 and 2003.*

e. Agriculture – Irrigated Crop Acreage[2] (ICA)

Alfalfa accounted for the highest ICA in IID and PVID and had an obvious decline following the 2003 QSA (*Figures 19* and *20*). In CVWD, however, alfalfa only accounted for a small amount of ICA and did not appear to be affected by the QSA (*Figure 21)*.

Aggregated among all the districts, alfalfa had the highest irrigated crop acreage (ICA) at approximately 244,000 acres in 2002, followed by common produce crops at ~99,500 acres. The ICA of alfalfa decreased by 21% (51,300 acres) from 2002 to 2003, and other truck only decreased by 6.8% (*Table 8*). The ICA of cotton increased by nearly 60% from 2002 to 2004 (*Table 8*), even though AW showed a decrease of ~3% (*Table 7*).

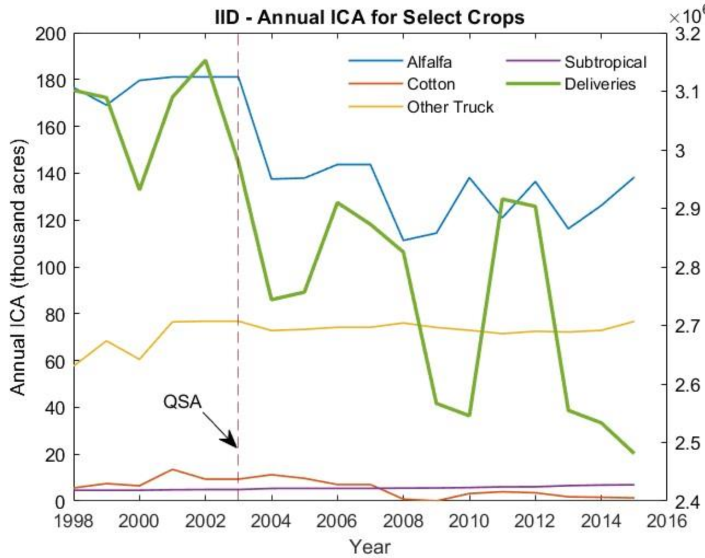

Figure 19. *Annual irrigated crop acreage (ICA) in Imperial Irrigation District (IID).*

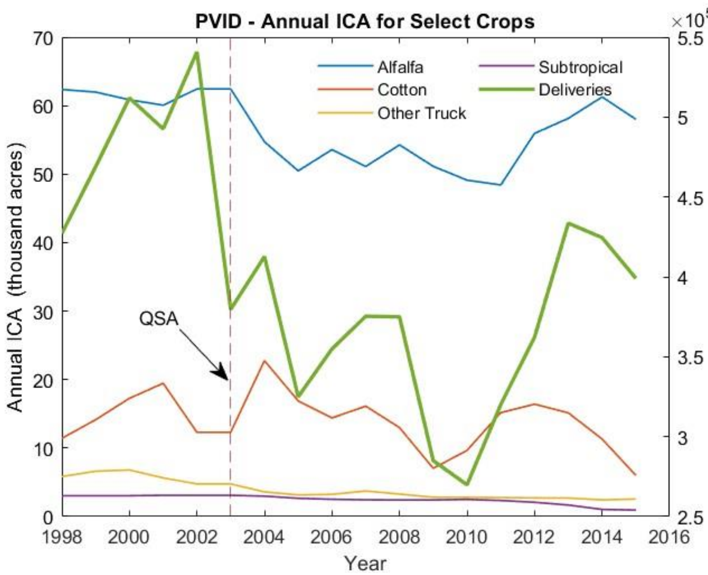

Figure 20. *Annual irrigated crop acreage (ICA) in Palo Verde Irrigation District (PVID).*

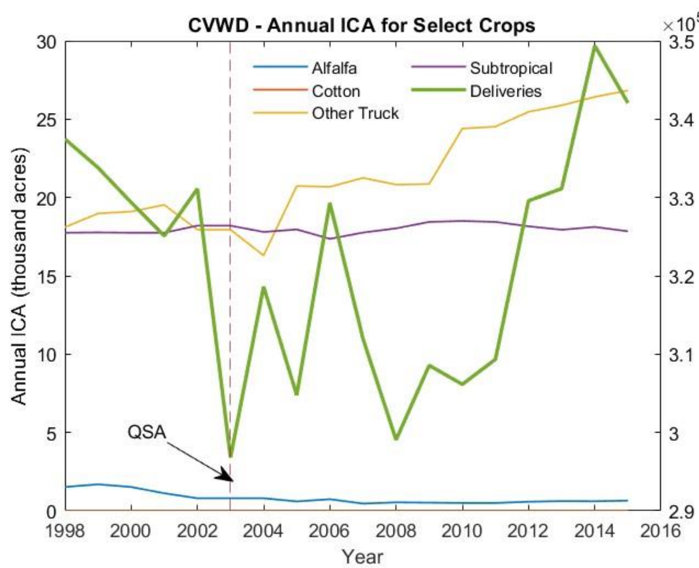

Figure 21. *Annual irrigated crop acreage (ICA) in Coachella Valley Water District (CVWD).*

Table 7. *Applied water (AW) for crops aggregated for IID, PVID, and CVWD.*

Crop	Pre-QSA Avg. AW (acre-foot per acre)	Post-QSA Avg. AW (acre-foot per acre)	Difference Avg. AW (acre-foot per acre)	Percent Change (%)	AW 2002 (acre-foot per acre)	AW 2003 (acre-foot per acre)	Difference AW (acre-foot per acre)	Percent Change (%)
Alfalfa	6.5	7.2	0.7	10.2%	7.3	7.0	-0.3	-4.6%
Cotton	5.5	5.3	-0.22	-3.3%	5.5	5.3	-0.2	-2.9%
Grain	2.5	2.6	0.1	3.8%	2.5	2.4	-0.2	-3.3%
Other Truck	3.5	3.3	-0.2	-4.3%	5.8	3.3	-0.2	-5.4%
Subtropical	5.5	6.0	0.4	7.7%	3.5	5.4	-0.4	-7.3%
Select Crops Total	23.6	24.4	0.9	3.6%	24.6	23.6	-1.2	-4.8%
All Crops Total	68.8	70.4	1.6	2.4%	71.4	64.7	-6.7	-9.4%

[2] The data for ICA in 2002 and 2003 were the same, so 2004 was used in this analysis.

Alfalfa saw a long-term decrease in the years following the 2003 QSA of 21%, or 51,000 acres (*Table 8*), even though the AW of alfalfa increased more than 10%, signifying alfalfa water use may have become less efficient (*Table 7*). Overall, alfalfa accounted for more than 50% of ICA out of the selected crops before the 2003 QSA and decreased by only 3% to 47% of the total following the QSA. Among all crops, alfalfa accounted for 36% before and 31% before and after the QSA, respectively (*Table 8*). Common produce (other truck), however, increased from 14% of all crops before the 2003 QSA, to 16% after (*Table 8*).

Table 8. *Irrigated crop acreage (ICA) for crops aggregated for IID, PVID, and CVWD.*

Crop	Pre-QSA Avg. ICA (thousand acres)	Post-QSA Avg. ICA (thousand acres)	Average Avg. ICA (thousand acres)	Percent Change (%)	ICA 2002 (thousand acres)	ICA 2004 (thousand acres)	Difference (thousand acres)	Percent Change (%)
Alfalfa	240.4	189.4	-51.0	-21.2%	244.3	193.0	-51.3	-21.0%
% of All Crop Total	35.5%	30.7%						
Cotton	23.4	18.2	-5.2	-22.1%	21.6	34.0	12.4	57.1%
Grain	64.2	66.5	2.3	3.6%	59.0	60.5	1.5	2.6%
Other Truck	92.6	99.4	6.8	7.4%	99.5	92.7	-6.8	-6.8%
% of All Crop Total	13.7%	16.1%						
Subtropical	25.6	26.1	0.5	2.0%	26.2	26.2	0.0	-0.2%
Select Crops Total	446.2	399.7	-46.5	-10.4%	450.6	450.6	0.0	0.0%
All Crops Total	675.3	616.0	59.4	8.8%	614.6	614.2	-0.3	-0.1%

f. Agriculture – Total Water Used (AWICA)

The AWICA used on alfalfa closely mirrored delivery trends in IID, decreasing significantly with deliveries following the 2003 QSA, while grain, other truck, and subtropical crops stayed relatively constant (*Figure 22*). The AWICA consumed by alfalfa also closely mirrored delivery trends in PVID (*Figure 23*). In CVWD there did not appear to be a significant relationship between delivery and AWICA trends, especially in the 2002-2003 period (*Figure 24*).

All crops experienced a decrease in AWICA from 2002 to 2003, with the largest percent decrease on subtropical crops (~7%) and the smallest percent decrease on cotton (< 3%). By value, however, alfalfa crops saw the largest overall decrease in TW of 83 TAF (thousand acre-feet) from 2002 to 2003, which accounted for nearly 70% of the decrease in AWICA for selected crops, and 54% of all crops (*Table 9*). Alfalfa also had the largest decrease over the long-term following the 2003 QSA of 208 TAF; cotton had the largest decrease by percent at a 25% decrease (*Table 9*).

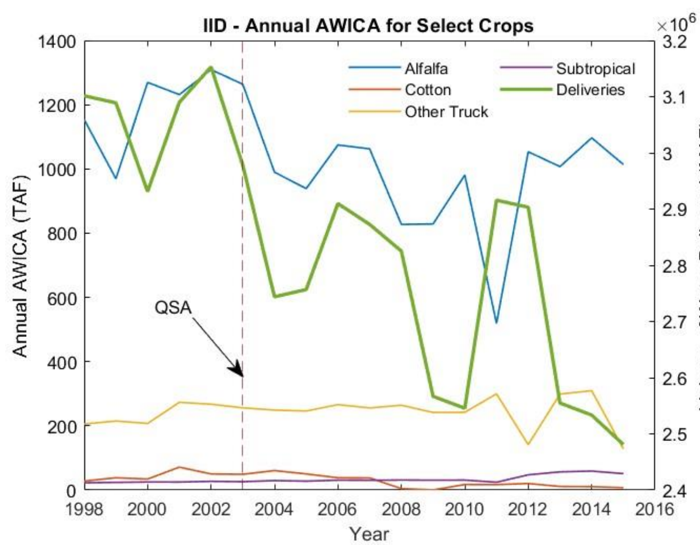

Figure 22. *Annual total consumed water (AWICA) in Imperial Irrigation District (IID).*

Overall, alfalfa consumed significantly more water (AWICA) than the other crops and had a higher ICA in two out of three districts.

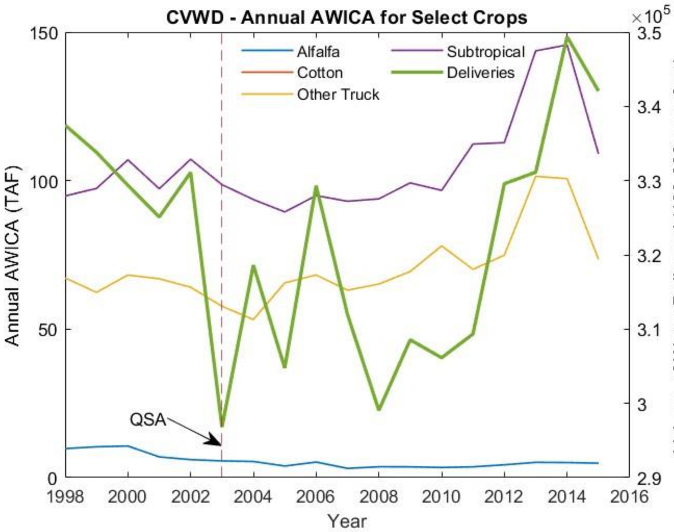

Figure 23. *Annual total consumed water (AWICA) in Palo Verde Irrigation District (PVID).*

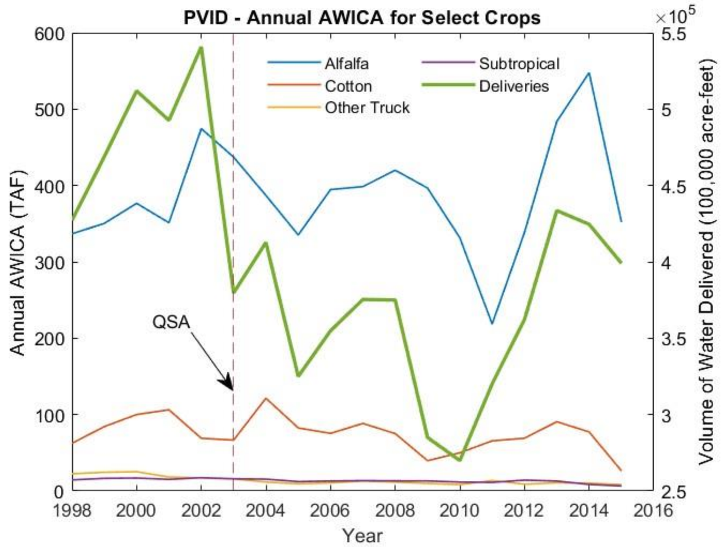

Figure 24. *Annual total consumed water (AWICA) in Coachella Valley Water District (CVWD).*

Table 7. *Total applied water in average annual before and after the QSA, and in 2002 and 2003.*

Crop	Pre-QSA Avg. AWICA (TAF)	Post-QSA Avg. AWICA (TAF)	Difference Avg. AWICA (TAF)	Percent Change (%)	AWICA 2002 (TAF)	AWICA 2003 (TAF)	AWICA Difference (TAF)	Percent Change (%)
Alfalfa	1,573.3	1,365.7	-207.6	-13.2%	1,789.5	1,706.5	-83.0	-4.6%
% of All Crop Total	48%	43.5%						
Cotton	128.8	96.3	-32.5	-25.2%	119.1	115.6	-3.4	-2.9%
Grain	162.3	175.7	13.5	8.3%	148.8	143.9	-4.9	-3.3%
Other Truck	320.9	329.3	8.3	2.6%	348.3	329.3	-19.0	-5.5%
% of All Crop Total	9.8%	10.5%						
Subtropical	141.5	155.4	13.9	9.8%	151.6	140.5	-11.1	-7.3%
Select Crops Total	2,326.7	2,122.4	-204.3	-8.8%	2,557.2	2,435.9	-121.3	-4.7%
All Crops Total	3,265.1	3,132.5	-132.6	-4.1%	3,169.0	3,015.6	-153.4	-4.8%

g. Agriculture – Real Value 2020

Other truck crops had the highest value, expressed as total revenue, in 2002 and 2003 for Imperial and Riverside counties (*Figures 25* and *26*). Subtropical crops were the most valuable crop produced in Riverside County until the early 2000's, but other truck crops became the most valuable and stayed the most valuable since (*Figure 26*). Alfalfa was the second lowest revenue crop, followed by grain crops, in Riverside County. Other truck crops had the highest revenue for all years in Imperial County, followed by alfalfa crops (*Figure* 25).

The revenue of alfalfa and pasture crops dropped significantly from 2002 to 2003 (27% and 38%, respectively). Other truck crops decreased by a lesser amount of 19% but totaled a revenue loss of $187 million due to the high value of the crops.

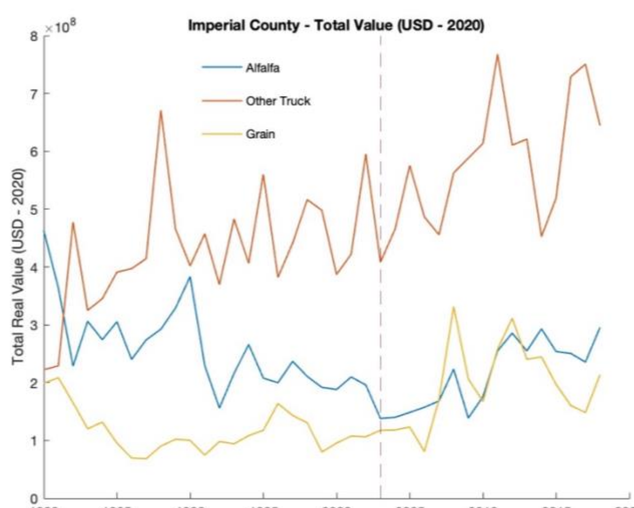

Figure 25. *Total revenue (2020 USD) for alfalfa, other truck, and grain crops in Imperial County.*

On average, cotton crops had the largest percent decrease in revenue of 60%, or $51 million, following the 2003 QSA. Other truck crops increased 47% in value, equating to $321 million. The largest revenue loss came from subtropical crops at an average of $98 million following the 2003 QSA. Grain and other truck were the only crops to have an increased average value following the QSA; grain doubled in value (*Table 10).*

The total value of all crops in Imperial and Riverside counties was an average of $2.3 billion for the years before the QSA, and an average of $2.4 billion for the years following the QSA; although deliveries decreased in both counties, the agriculture industry increased in value by $100 million. The value of alfalfa crops, however, decreased by $44 million. Before the QSA, alfalfa crops accounted for 12% of the total revenue between Imperial and Riverside counties and fell to 9% following the 2003 QSA (*Table 11*).

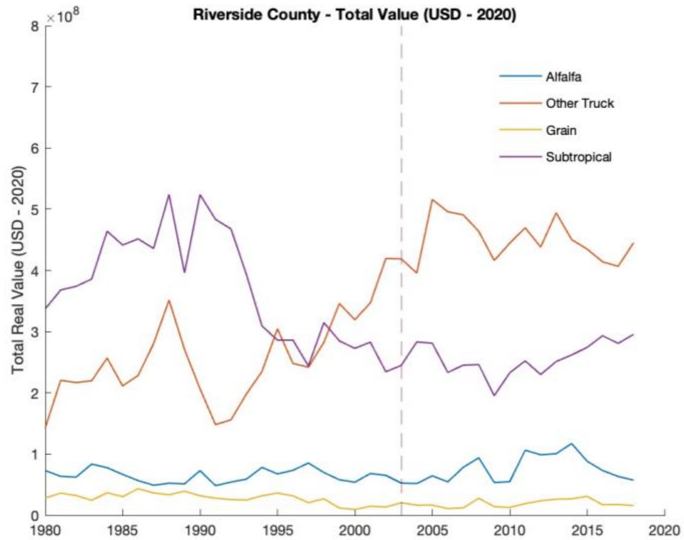

Figure 26. *Total revenue (2020 USD) for alfalfa, other truck, grain, and subtropical crops in Riverside County.*

Table 10. *Value of crops aggregated for Imperial and Riverside counties, adjusted for 2020 inflation.*

Crop	**Pre-QSA Avg. Value (USD – 2020)**	**Post-QSA Avg. Value (USD – 2020)**	**Difference Avg. Value (USD – 2020)**	**Percent Change (%)**	**Value 2002 (USD – 2020)**	**Value 2003 (USD – 2020)**	**Value Difference (USD – 2020)**	**Percent Change (%)**
Alfalfa	324,287,832	280,537,452	-43,750,381	-13	261,052,010	190,593,437	-70,458,573	-27
% of All Crop Total	12%	9%						
Cotton	84,891,549	33,574,197	-51,317,352	-60	31,301,131	32,275,866	+974,735	+3
Grain	144,335,108	217,346,885	+73,011,777	+51	119,862,998	138,019,920	+18,156,922	+15
Other Truck	683,019,603	1,004,225,332	+321,205,729	+47	1,014,731,704	827,090,388	-187,641,316	-19
% of All Crop Total	30%	42%						
Subtropical	411,024,942	312,437,665	-98,587,277	-24	309,978,008	292,672,503	-17,305,505	-6
Select Crops Total	1,647,599,034	1,848,121,531	+200,562,497	+12	1,736,925,851	1,480,652,114	-256,273,737	-15
All Crops Total	2,300,000,000	2,400,000,000	+100,000,000	+4	2,320,000,000	2,050,000,000	-270,000,000	-11

Table 11. *Percentage of alfalfa value before and after the QSA compared to total.*

	'Pre-QSA' Avg. Value (USD)	**'Post-QSA' Avg. Value (USD)**
Alfalfa	324 million	280 million
Total	2.3 billion	2.4 billion
% of Total	12%	9%

Other truck crops were the most valuable and increased from an average of $683 million to an average of $1 billion after the QSA. Overall, other truck crops account for 42% of total agriculture revenue in Imperial and Riverside counties (*Table 12*).

Table 12. Percentage of other truck crops value before and after the QSA compared to total.

	'Pre-QSA' Avg. Value (USD)	**'Post-QSA' Avg. Value (USD)**
Other Truck	683 million	1.0 billion
Total	2.3 billion	2.4 billion
% of Total	30%	42%

h. Imperial Irrigation District Crop Production

IID crop production was analyzed in depth due to the district large allotment of water from the Colorado River (3.1 MAF). The production of alfalfa was compared to specific (lettuce, broccoli, and onion) crops within the 'other truck' category that was previously analyzed. Alfalfa crops were produced significantly more than lettuce, broccoli, or onions in IID (*Figure 27*). The production of lettuce, broccoli, and onions did not appear to vary much over between 2002 and 2003; lettuce and broccoli increased following the 2003 QSA (*Figure* 28).

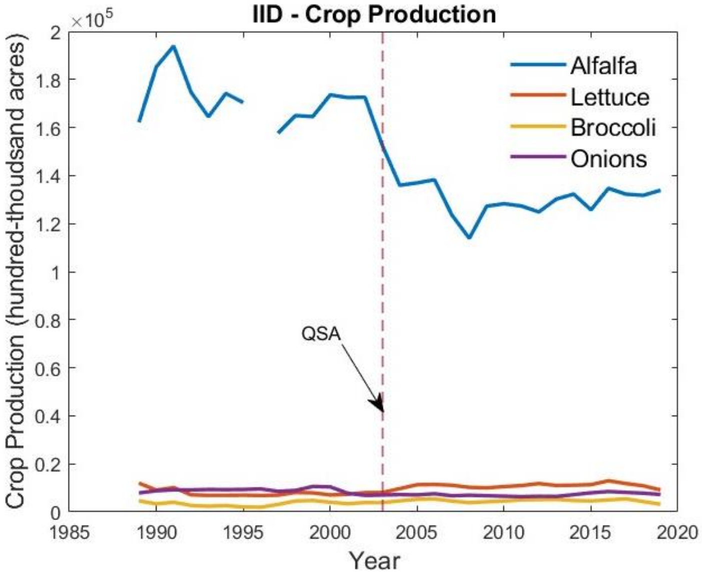

Figure 27. *Crop production of alfalfa, lettuce, broccoli, and onion in Imperial Irrigation District (IID).*

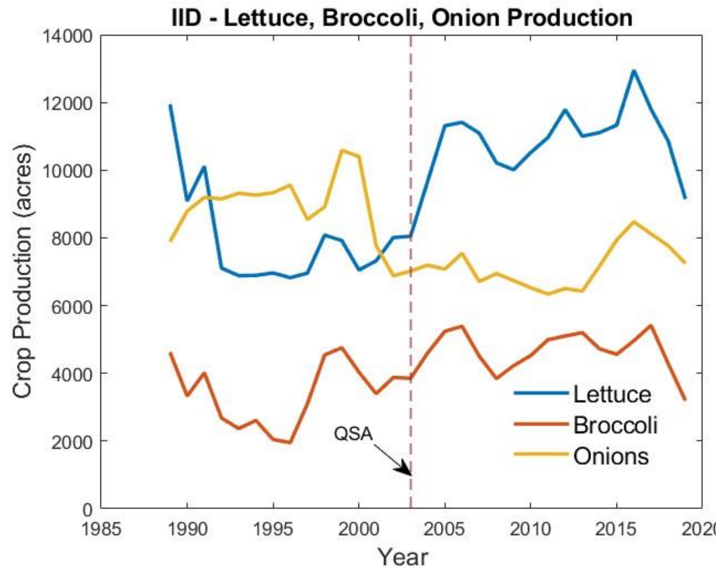

Figure 28. *Crop production of lettuce, broccoli, and onion in Imperial Irrigation District (IID).*

Table 13. *Imperial Irrigation District annual crop production of alfalfa, lettuce, broccoli, and onions.*

Crop	Pre-QSA (ac)	Post-QSA (ac)	Difference (ac)	Percent Change (%)	2002 (ac)	2003 (ac)	Difference (ac)	Percent Change (%)
Alfalfa	171,603	131,148	-40,455	-24	172,623	152,503	-20,120	-12
Lettuce	7,940	10,778	+2,838	+36	8,009	8,048	39	+0.5
Broccoli	3,380	4,624	+1,244	+37	3,876	6,880	3,003	+78
Onion	8,970	7,160	-1,810	-20	3,851	7,020	3,168	+82

Broccoli and onions increased 78% and 82%, respectively, between 2002 and 2003 while lettuce increased by < 1%. Alfalfa decreased by 12%, which equated to more than 20,000 acres of production from 2002 to 2003. On average, alfalfa and onion production decreased by 24 and 20%, respectively, following the 2003 QSA. Alfalfa production decreased by 40,000 acres, compared to the decrease in onion production of 1,800 acres. Lettuce and broccoli production increased by 2,800 and 1,200 acres, respectively (*Table 13*).

Table 14. *Imperial Irrigation District annual irrigated and fallowed land.*

Land Use	Pre-QSA (ac)	Post-QSA (ac)	Difference (ac)	Percent Change (%)	2002 (ac)	2003 (ac)	Difference (ac)	Percent Change (%)
Irrigated	404,115	367,131	-36,984	-9	420,038	403,767	-16,270	-4
Fallowed	18,905	22,008	+3,103	+16	22,752	25,251	2,499	+11

The amount of irrigated land decreased by 4% between 2002 and 2003, and continued to decrease to a total of 9% on average following the 2003 QSA. Fallowed land increased 11% from 2002 to 2003, and on average by 16.5% following the 2003 QSA (*Table 14* and *Figure 29*).

i. Results: Key Points

- Southern California saw a total decrease in deliveries of 0.96 MAF (18%) during the time period 2002 and 2003; MWD took the largest cut of 0.56 MAF and IID took the smallest cut by percent (>6%).
- Lower Colorado River water imports were associated with higher local precipitation before the 2003 QSA, but the two were not associated following the 2003 QSA.
- Alfalfa consumed the most applied water, within all three irrigation districts.
- The AWICA of alfalfa changed directly with deliveries in IID and PVID but not CVWD.
- “Other truck” crops had the highest revenue in Imperial County.
- Alfalfa production is significantly higher than the production of lettuce, broccoli, and onions in IID.
- The production of lettuce, broccoli, and onions increased between 2002 and 2003 while alfalfa production decreased in IID.
- Irrigated land decreased from 2002 to 2003 and fallowed land increased from 2002 to 2003.
- Total annual agriculture revenue in the study area increased by an average of approximately $100 million during the study period, even though annual water imports from the Colorado River decreased by nearly 13% over the same time period.

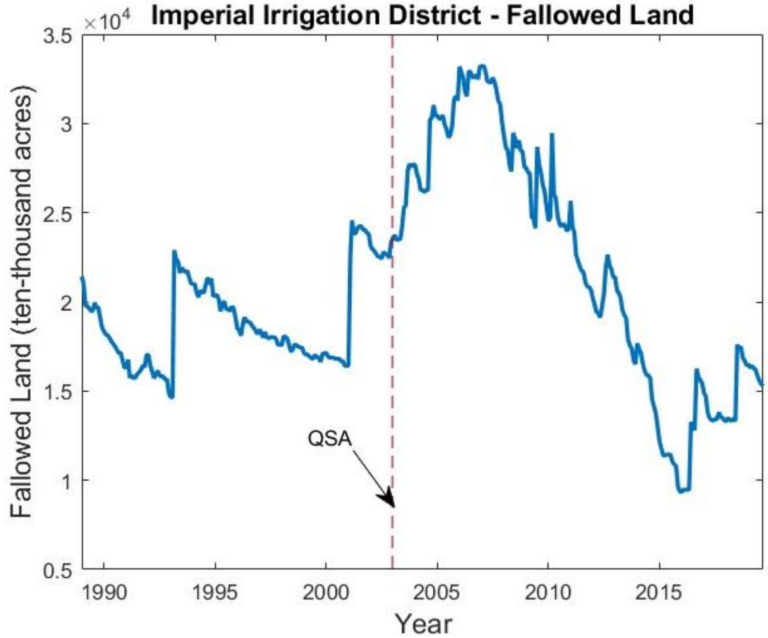

Figure 29. *Fallowed land in Imperial Irrigation District (IID).*

V. DISCUSSION

The data revealed that agriculture practice, along with Colorado River and California water governance, drive patterns in annual deliveries of Colorado River water. Three of the four major importers of water from the Colorado River in Southern California are agricultural districts (IID, PVID, and CVWD), while MWD is largely urban. At the time of the QSA in 2003, MWD was responsible for making the largest cuts due to their more junior rights compared to agricultural users; MWD was able to achieve a reduction of nearly 50% in consumptive use of Colorado River water, through previous planning efforts that helped them quickly call on other sources, such as the State Water Project, water stored in Lake Mead, and a land fallow agreement with PVID (Fleck, 2023). The land fallow agreement between MWD and PVID is observed in PVID’s decrease in deliveries from 2002 to 2003 (*Figure 6)*. IID made the second largest cut from 2002 to 2003 by value (0.17 MAF), albeit the smallest cut by percentage (> 6%) due to IID’s senior rights; the 0.17 MAF cut was likely the result of the land transfer agreement with San Diego County Water Authority (SDCWA) under the QSA, which established a 0.2 MAF transfer from IID to SDCWA (*Quantification Settlement Agreement,* 2003).

The data also revealed that prior to 2003, more annual local precipitation in a year meant less water imported to three of the four districts (IID, MWD, and PVID) (*Table 6*). Following the QSA, however, local precipitation had almost no effect on water deliveries (*Table 6*). The QSA came in response to the Federal Government demanding that California take only its 4.4 MAF of allotted water, whereas it had taken closer to 5.4 MAF for decades. The positive relationship between precipitation and imported likely are a result of California importing more than its allowance in dry years. Moreover, the lack of relationship between precipitation and deliveries following the QSA demonstrates the effect of the “use it or lose it” clause of Prior Appropriation, a doctrine that reduces water rights if not used to their full extent (Lustgarten, 2015). Overall, the lack of relationship between precipitation and consumptive use indicates the Colorado River as a system almost exclusively controlled by the policies by which it is governed.

The 2003 QSA significantly reduced total annual imports of Colorado River water to California. Each water district experienced a decrease in imports, and the scale of reduction within each district was reflected in crop production. Alfalfa accounted for the largest portion (~30%) of total irrigated crop acreage and had the largest decrease of 51,000 acres (21%) following the 2003 QSA (*Table 8*). Alfalfa also accounted for about 45% of total consumed water across all districts. Common produce crops ('other truck') accounted for only about 16% of total irrigated crop acreage and increased by nearly 7,000 acres following the QSA and accounted for only 10% of total consumed water across all districts (*Table 8*).

Together, the Imperial and Riverside counties had an increase in revenue of $100 million (*Tables 12* and *13*) even in the face of sustained water reductions (15%) after 2003 *(Table 5*). Somewhat surprisingly, alfalfa was the lowest value crop, accounting for just 9% of the total revenue within Imperial and Riverside counties (*Table 11*). In comparison, other truck crops constitute 42% of the revenue, but consume only 25% of the water that alfalfa consumes (*Table 12*). The production of other truck crops – specifically broccoli, lettuce, and onion – increased between 2002 and 2003 when IID's deliveries were reduced, while alfalfa production decreased (*Table 13*). The observed increase in production of high value crops during years of water reduction help the agriculture industry maintain revenue while using less water.

Not surprisingly, the amount of land fallowed during years of water reduction increases during years of water reduction. In IID, alfalfa was the only crop that decreased in acreage, indicating it was also the only crop to be fallowed. This observation verified that due to alfalfa's flexible nature (it can be fallowed one year and grown the next), water reductions to agriculture regions results in fallowed alfalfa fields (Cantor et al, 2022). Having the flexibility to fallow alfalfa fields during years of drought is beneficial for the agriculture industry. Given that alfalfa is such a water-intensive crop, however, it is important to understand the implications of growing such great quantities (*Figure 25* shows the scale at which alfalfa is grown compared to lettuce, broccoli, and onions).

VI. CONCLUSION & APPLICATION

I have examined the data available on annual water imports from the Colorado River and their effect on crop production within agricultural regions of Southern California. I have also conducted a comprehensive literature review regarding water allocations of water from the Colorado River to the four major importers in Southern California and implemented interviews with leading experts in California water policy and the Colorado River. Along with the facts previously concluded, combined with history and current events, I do not think the recent Lower Basin Plan (LBP) agreement (May 2023) is an adequate solution to the Colorado River water shortage. The agreements made under the LBP compensate landowners to conserve a total of 3 million acre-feet (MAF) of water by the end of 2026, largely funded by the Inflation Reduction Act (IRA) at an estimated $1.2 billion (Flavelle, 2023). As observed in the data, compensated reductions are very likely to come in the form of fallowed alfalfa fields, predominately in Imperial Irrigation District (IID). IID has rights to about 70% of California's total allotment from the Colorado River that are senior to other users, meaning the IID is not subject to reduction in years of shortage. Under this current policy structure, water shortage is met by paying landowners within IID to fallow fields to achieve water conservation.

It is important to reiterate that the global climate is rapidly changing; an increase in temperature and a decrease in precipitation will have the combined effect of decreased flow in the Colorado River and decreased water levels in the reservoirs. Climate change will result uncertain deliveries. Consequently, users will have to learn to adjust to diminished water imports. The LBP is not a viable solution to the crises because it does not account for the progression of climate change; paying landowners to fallow will become increasingly unsustainable as decreased water imports will increase the need to conserve water, which in-turn will increase the number of fields that need to be fallowed.

Additionally, the impact of paying the landowners for the next three years may have significant impact on Imperial County's unemployment rate, which is already among the lowest in the nation at 17.3% (Imperial County Economic Forecast, 2022). In Imperial County, the agriculture industry is the second largest employer, but its contribution is decreasing (*Figure 30*). Money from the IRA would have a more long-term effect if it was used to help landowners invest in transitioning alfalfa fields to solar farms. A common criticism of a proposal such as this draws the criticism of, 'farmers just want to farm' – but fallowed fields do not get farmed either. Furthermore, the compensated fallowing per the LBP is not limited to the next few years; the Colorado River supply will continue to decrease and therefore the amount of fallowed land is likely to increase. Although fallowed land may achieve water consumption reductions, approximately one-third of the alfalfa grown in California is exported (*California Farm Bureau,* 2023). By this estimate, nearly one-third of the water used to grow alfalfa is exported, which in Southern California could be up to 300,000 acre-feet of water annually (*Table 10*). Lastly, it is important to reiterate that the production of common produce, such as lettuce and broccoli, increased even when fields were fallowed, indicating that food production in Southern California is not completely coupled to the state maintaining its 4.4 MAF allotment of water from the Colorado River. The production of alfalfa, however, is largely coupled to Colorado River deliveries to the agricultural regions of Southern California. The alfalfa industry in the region, therefore, should be scrutinized as water supply diminishes in a changing climate.

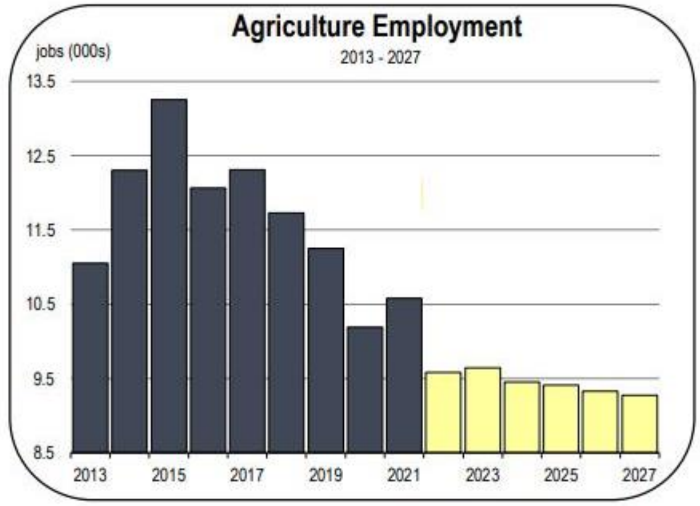

Figure 30. *Unemployment in Imperial County (Imperial County Economic Forecast, 2022).*

VII. RESOURCES

California Farm Bureau. (2023), Desert Farmers Defend Maligned Alfalfa Production, Ag Alert.

Cantor, A., Turley, B., Ross, C.C., & Glass, J. (2022) ,Changes to California Alfalfa Production and Perceptions during the 2011–2017 Drought, The Professional Geographer, 74:4, 628-641, DOI: 10.1080/00330124.2022.2075409

Barnett, T. P., and D. W. Pierce (2009), Sustainable water deliveries from the Colorado River in a changing climate, *Proc. Natl. Acad. Sci. U. S. A.*, 106, 7334– 7338, doi:10.1073/pnas.0812762106.

Boulder Canyon Project Act. (1928).

Buschatzke, T., Hamby, J.B., & Entsminger, J. (2023). Lower Basin Plan.

Coachella Valley Water District. (n.d.). Coachella Valley Water District. Retrieved from https://www.cvwd.org

Colorado River Compact. (1922).

Flavelle, C. (2023). Breakthrough Deal to Keep the Colorado River from Going Dry, For Now. The New York Times.

Grantham, T. E., and J. H. Viers. *2014. 100 Years of California's water rights system: Patterns, trends and uncertainty. Environmental Research Letters 9 (8):084012.doi: 10.1088/1748-9326/9/8/084012.*

Fleck, J. (2023). Personal Communication.

Hoerling, M. et al. (2019). Causes for the Century-Long Decline in Colorado River Flow. 32(23).

IID. (n.d.). Annual Reports. Imperial Irrigation District.

Lustgarten, A. 2015. *Use it or lose it: Across the West,exercising one's right to waste water. ProPublica, June 9.*

Matthes, J., and M. Kohring. 2008. The content analysis of media frames: Toward improving reliability and validity. Journal of Communication 58 (2):258–79. doi: 10.1111/j. 1460-2466.2008.00384.x

Public Policy Institute of California. (2018). California's Water: The Colorado River.

Rajagopalan, B., Nowak, K., Prairie, J., Hoerling, M., Harding, B., Barsugli, J., Ray, A., and Udall, B. (2009), Water supply risk on the Colorado River: Can management mitigate? *Water Resour. Res.*, 45, W08201, doi:10.1029/2008WR007652.

U.S. Congressional Research Service. (2023). Management of the Colorado River – Water Allocations, Drought, and the Federal Role.

U.S. Congress. (2019). Public Law No. 116-14. Retrieved from https://www.congress.gov/plaws/publ14/PLAW-116publ14.pdf

Vergati, J. A., & Sumner, D. A. (2012). Contributions of Agriculture to Employment and the Economy in Southern California. *Report. University of California Agricultural Issues Center, Davis, CA*.

Williams, A. P., Cook, B. I., & Smerdon, J. E. (2022). Rapid intensification of the emerging southwestern North American megadrought in 2020–2021. *Nature Climate Change*, *12*(3), 232-234.

Xiao, M., & Lettenmaier, D. P. (2021). Atmospheric rivers and snow accumulation in the Upper Colorado River basin. *Geophysical Research Letters*, *48*(16), e2021GL094265.