Economic Impacts of the 2020–22 Drought on California Agriculture

Prepared for: The California Department of Food and Agriculture

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Executive Summary

California just ended its third consecutive year of drought, resulting in the driest three-year period in the instrumental record. Multi-year deficits in precipitation in the state's usually wetter northern regions have been compounded by increased crop evaporative demands, leading to water scarcity impacts to agriculture across the state.

Although 2020 was a dry year, water reserves stored during the wetter years of 2017 and 2019 greatly diminished drought impacts during that year. The water outlook changed rapidly in 2021—the third driest water year on record with the highest evaporative demand. The northern regions of the state—including the Sacramento Valley, the Scott and Shasta valleys, the Pit River valleys (northern intermountain valleys), and the Russian River—faced unusually dry conditions. Drought emergency conditions in 2021 were proclaimed first in the Russian River, Scott River and Shasta River basins, which faced subsequent curtailments. Water curtailments were extended to the Sacramento Valley later in the season. Water for local agriculture, ecosystems, exports, and water quality protection in the Sacramento-San Joaquin Delta were compromised by low water reserves.

Atmospheric rivers in October and December 2021 provided temporary drought relief for a portion of the state, but record low precipitation from January-September allowed for extreme drought conditions to reign into the 2022 water year. To overcome persistent precipitation deficits and below-average storage in major reservoirs, the state again implemented water rights curtailments and low water deliveries from the State Water Project. The US Bureau of Reclamation announced reduced Central Valley Project deliveries—including unprecedented cutbacks to senior contractors in the Sacramento Valley—and local agencies implemented cutbacks as a first tier of drought response measures. Compared with the 2021 water year, however, 2022 brought less severe water cutbacks in the San Joaquin Valley.

This report provides estimates of the economic impacts to agriculture for first three years of the current drought, which began in 2020. We use a combination of climate, hydrologic, agricultural and economic models, supplemented by informal surveys of irrigation districts and remote sensing data. The study includes nearly 88% of the 8.7 million acres of irrigated crop area in the state (LandIQ, 2019) excluding idle land. Our preliminary analysis for 2020–21 (Medellín-Azuara et al. 2022), focused on the Central Valley, and also examined the Russian River basin (North Coast), and northern intermountain valleys in Siskiyou, Shasta, and Modoc counties. Here, we expanded our spatial coverage to include the Central Coast, South Coast, and Colorado River.

Considering the magnitude of the hydrological drought—with the driest three-year period on record—impacts on California agriculture have varied widely by region and relative severity with respect to pre-drought conditions. In some areas, agriculture and its downstream sectors constitute a significant proportion of regional income and employment. While the local drought impacts have been significant for many communities in the Sacramento Valley and the northern intermountain valleys, the statewide economic impacts on farm income have been softened considerably by farm adaptations: increased groundwater pumping, water trading to reduce fallowing of crops with higher per acre returns, and crop insurance payments for some crops.

Surface water deliveries were reduced by nearly 43% in the Central Valley as a whole in both 2021 and 2022. Compared to 2019, statewide irrigated crops dropped by 563,000 acres in 2021 (7.4% of the total acreage covered in the study) and by 752,000 acres in 2022 (nearly 10%). The statewide direct economic impact from crop revenue losses totaled $1.3 billion in 2021 (3.5%), and $1.7 billion in 2022 (4.3%). The corresponding effects on regional value added –or GDP – were $810 million in 2021 and nearly $1.2 billion in 2022[1]. Neither year saw significant gross revenue losses in beef and dairies, in part because of high prices, yet increased production costs caused substantial loss in net revenue.

Downstream effects such as higher costs and lower feed crop availability for beef and dairies, as well as reduced crop production for food processing, also merit attention. Strong commodity prices for beef and dairy products buoyed their production during 2021 and 2022 despite reduced profits from higher cost of feed crops in California, and potentially reduced availability of imported feed from the Colorado River basin and other western states.

Food processing sectors saw shortages in supply of some crops, such as tomatoes and rice and other field crops, reducing output. Gross revenue losses in processing (which include purchases of agricultural products) were $2.4 billion (5.4%) for 2021 and $3.5 billion for 2022 in the Central Valley. Given the high share of purchased inputs in these activities, estimates of value added provide a better indication of their effects on regional economic activity. Value added from processing declined by roughly $590 million (5.8%) in 2021 and $845 million (8.3%) in 2022, significantly adding to the total economic impact of the drought. Such losses highlight the interconnections between local agriculture and food processing, which relies on sufficient supplies to operate at positive financial margins. Further investigation can help refine more direct impacts of drought on food and beverage processing.

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[1] Value added represents the contribution from a sector to the region's gross domestic product (GDP). It includes profits, compensation and taxes, and excludes the purchases of production inputs from other sectors.

TABLE ES-1. ESTIMATED DROUGHT IMPACTS ON CALIFORNIA AGRICULTURAL REGIONS IN THE STUDY DURING 2021 AND 2022.

Measure	Baseline (2019)	2021 Drought Impact		2022 Drought Impact	
Surface water (taf/yr)*	**13,869**	**-5,966**	**-43.0%**	**-5,895**	**-42.5%**
Sacramento	5,316	-1,454	-27.4%	-2,613	-49.2%
San Joaquin	3,820	-1,228	-32.1%	-1,228	-32.1%
Tulare	4,734	-3,283	-69.4%	-2,055	-43.4%
Groundwater (taf/yr)*	**12,286**	**4,140**	**33.7%**	**3,330**	**27.1%**
Sacramento	1,692	691	40.8%	1,100	65.0%
San Joaquin	2,260	1,015	44.9%	981	43.4%
Tulare	4,194	2,434	58.0%	1,249	29.8%
Total supplies (taf/yr)*	**20,189**	**-1,826**	**-9.0%**	**-2,565**	**-12.7%**
Sacramento	7,008	-764	-10.9%	-1,512	-21.6%
San Joaquin	6,080	-213	-3.5%	-247	-4.1%
Tulare	8,927	-849	-9.5%	-806	-9.0%
Irrigated area (1000 acres)	**7,618**	**-563**	**-7.4%**	**-752**	**-9.9%**
Increased pumping costs ($ million)*	**N/A**	**-184**	**N/A**	**-123**	**N/A**
Total gross revenues ($ million)	**82,250**	**-3,730**	**-4.5%**	**-5,190**	**-6.3%**
Crops	37,500	-1,320	-3.5%	-1,720	-4.6%
Processing industries	44,750	-2,410	-5.4%	-3,470	-7.8%
Total value added ($ million)	**34,170**	**-1,400**	**-4.1%**	**-2,015**	**-5.9%**
Crops	24,050	-810	-3.4%	-1,170	-4.9%
Processing industries	10,120	-590	-5.8%	-845	-8.3%
Total employment	**515,700**	**-14,740**	**-2.9%**	**-19,420**	**-3.8%**
Crops	425,000	-9,880	-2.3%	-12,050	-2.8%
Processing industries	90,700	-4,860	-5.4%	-7,370	-8.1%

*Indicates measures only including Central Valley impacts.

At the regional scale, the Sacramento Valley has faced the worst multi-year drought in decades, and the northern intermountain valleys saw important reductions due to curtailments and limited groundwater pumping, with impacts on feed crops, and downstream effects on higher costs for beef and dairies. Cutbacks and yield losses in Russian River basin irrigated lands came at a higher cost per unit of land and water compared to other regions, given the predominance of vines and orchards. The San Joaquin Valley also faced significant economic losses, but unlike the Sacramento Valley, conditions were better in 2022 than in 2021. Finally, the impact on the Central Coast and Southern agricultural regions was low compared to the Central Valley. The Central Coast faced some heat waves that caused yield losses particularly in 2022. Most agricultural idling in 2022 for the areas supplied by the Colorado River was due to existing long-term water transfer agreements between agricultural areas and coastal communities that were executed at higher levels during this drought.

For the Central Valley as a whole (including the Sacramento, San Joaquin, and Tulare Lake basins), surface water shortages were similar in both years (6 maf in 2021 and 5.9 maf in 2022), but the worsening conditions in the Sacramento Valley in 2022 drove a net water shortage increase (1.8 maf in 2021, and 2.6 maf in 2022), reflecting this region's more limited capacity to pump additional groundwater to make up for reduced surface deliveries. Compared to 2019, land idling in the Central Valley was estimated at 524,000 and 695,000 acres for 2021 and 2022 respectively. Incremental idling in all other regions was nearly 40,000 acres in 2021 and 55,200 acres in 2022, and concentrated mainly in the northern intermountain regions and the areas supplied by the Colorado River.

Our review suggests some efforts that could help improve adaptation to future droughts. Fostering increased flexibility to trade water could further reduce the impacts of drought on local economic activity and employment. Programs that pay farmers to reduce irrigation water use can also be used to augment available water for the environment and water quality control during dry years. Assessing where infrastructure improvements could facilitate more groundwater recharge during wet years will be essential in many farming regions. Safety net programs could reduce the vulnerability of local communities when agricultural workers lose employment from crops idling. And programs to mitigate dry wells and avoid groundwater level declines near drinking water wells could protect drinking water supplies while enabling farmers to pump more groundwater—and maintain crop production—during droughts.

All economic assessments of drought, including this one, have inherent uncertainty. Nonetheless, even approximate results help us quantify and understand the range of drought impacts to California's agricultural sector. Ongoing efforts to validate modeled outcomes will help assess model performance, fine-tune underlying assumptions, and incorporate more definitive observational data. Yet it is clear that California's agricultural sector continues to learn from and innovate during droughts. Continued adaptations will be essential to face future climate extremes with increased resilience.

Introduction

Multi-year droughts have always occurred in California and may have become even more severe in recent decades. The state just ended the driest three-year period on record, causing noticeable increases in idle agricultural land due to water delivery shortages. Low storage in reservoirs reduced surface water deliveries which were partially mitigated by increased groundwater pumping, causing several thousand domestic wells to go dry due to declining groundwater levels.

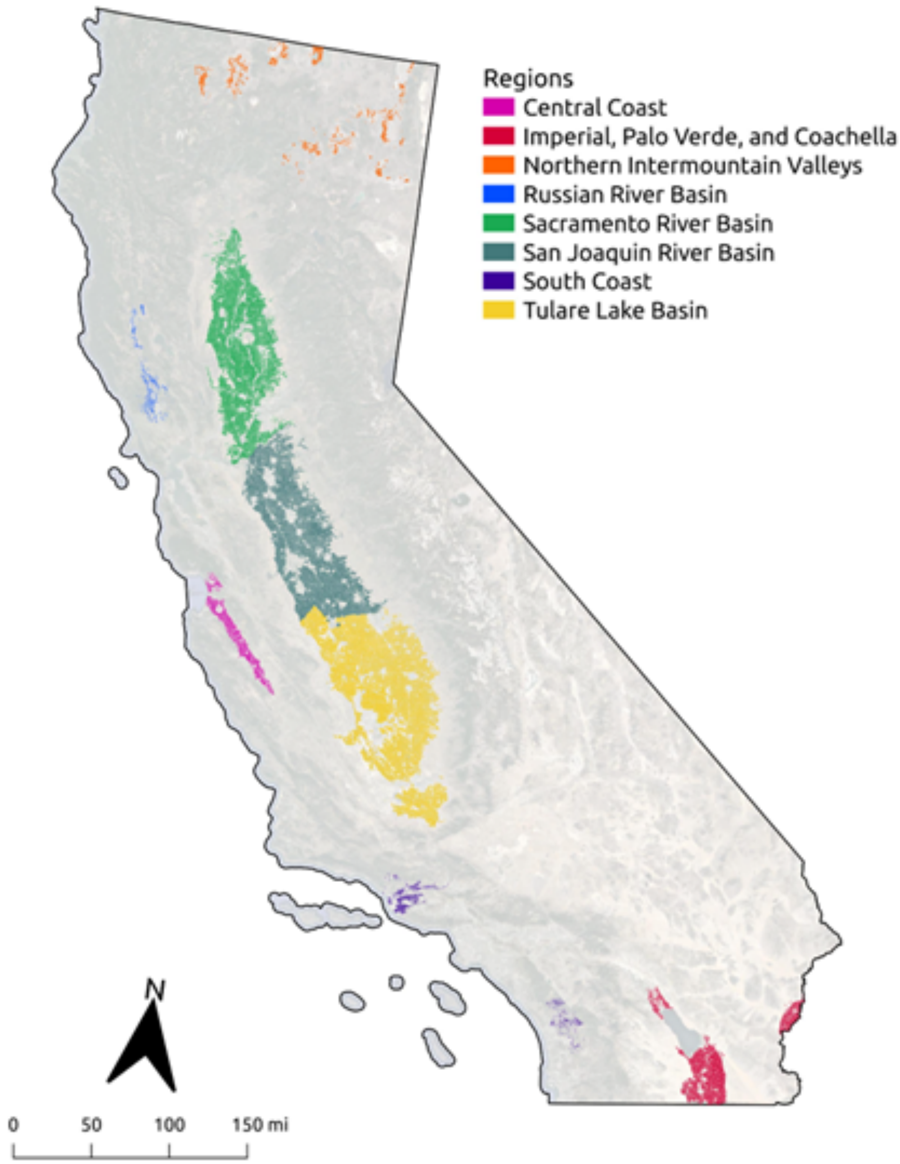

FIGURE 1. COVERAGE OF THE AGRICULTURAL REGIONS IN THE STUDY.

This report presents estimates of changes from the current drought period (2020–22) in water supply, land idling, gross value and employment in California agriculture compared to 2019 pre-drought conditions. We combined hydro-economic models, remote sensing data on evapotranspiration, announced and reported surface water deliveries and curtailments, and informal surveys with various stakeholders in estimating the aforementioned changes. We focus on a selection of regions including the Central Valley, the Northern Intermountain Regions in Siskiyou, Shasta and Modoc counties, the Russian River Basin, Central and South Coast, and the Imperial Valley (covering 87% of the irrigated area in the state) shown in Figure 1. We present estimates of 2021 and 2022 drought impacts, and provide insight to identify vulnerable agricultural areas and communities for which drought impacts seem higher.

In addition to drought, lingering effects of the COVID-19 pandemic, inflationary pressures (especially for food and energy), disruptions in the food supply chain, global price changes, and other factors influenced crop choices for California growers. Strong commodity prices for animal products not only increased demand for irrigated feed crops including alfalfa, silage corn and irrigated pasture, but also increased their cost due to a higher opportunity cost of water. A 20-year drought in the Colorado River Basin—where at least 70% of the irrigated area is in feed crops—further increased price pressure on feed crops. Meanwhile, low tree nut prices reduced interest in expanding acreage for those crops. Record high prices for processing tomatoes, in part because of reduced acreage in 2021, motivated farmers to plant moderate acreage, some of which suffered from late season heat wave crop damage in 2022 (Western Farm Press, 2022). But by far the largest single change was crop idling for rice in the Sacramento Valley, which saw a reduction of about 270,000 acres relative to recent historic acreages of roughly 550,000 acres. Opportunistic removals of aging almond trees totaled roughly 40 thousand acres in 2021 and about 55 thousand acres in 2022[1]. In the northern areas of the state that rely on groundwater, our initial findings for 2022 suggest reductions in crop yields and irrigated areas of forage crops such as alfalfa, grain and pasture crops.

In the following sections we first describe climate characteristics of the 2020–22 drought, then we review the water supply conditions in the Central Valley and other areas, and lastly, we estimate statewide incremental idled land during 2021 and 2022. Economic impacts of the drought on irrigated agriculture are presented with an added section downstream sectors such as beef and dairy, and food and beverage processing. Finally, we discuss potential limitations of this study, and present the main conclusions and insights for managing droughts.

Climate Summary

Three consecutive hot-dry water years of 2020, 2021, and 2022 resulted in chronic severe drought for much of California. This three year period has been the driest three-year period in the instrumental record (1895–present, see Figure 2). To compound water resource challenges, temperatures were approximately 3°F above 20th century averages during this period, contributing to reduced snowpack and increased evaporative demand.

Statewide precipitation during water-year 2020 was 68% of 20th century averages, followed by an abysmally dry water-year 2021 that only brought the state half of its average precipitation and was the third driest in over 125 years of records. Both 2020 and 2021 years also were accompanied by temperatures that were well above 20th century averages, which contributed to 3 to 5 inches of additional evaporative demand annually relative to late 20th century averages.

The 2022 water year featured early season optimism for drought relief due to an atmospheric river in October that broke all-time precipitation records to Sacramento and surrounding locations, and a series of storms in December that both boosted reservoir levels and snowpack levels. In fact, snowpack in the Sierra Nevada was well above typical values by the start of the calendar year. This was then followed by the driest January-September on record. In many locations, snowpack levels peaked in January, rather than their typical March-April time frames, due to the relentless dry spell during the latter half of winter. Summer conditions in 2022 were not as hot and dry across the state as in 2021. An active monsoon brought occasional rainfall and a more moist air mass reduced evaporative demand. Despite the lackluster precipitation during January-September, water year 2022 precipitation was 71% of the 20th century average, making it the 19th driest water year since 1895.

While several numerical metrics such as the water year precipitation, the Palmer Drought Severity Index, and others depict drought conditions at the end of the 2022 water year as less severe than they were one year prior, the culmination of three very dry to extreme dry years is notable. With 63% of average precipitation over the cumulative three-year period, the state has collectively lost out on over a year's worth of precipitation.

Hot-dry droughts such as the 2020–22 drought and the 2012–16 drought have required us to rethink how droughts are quantified (Figure 3). Efforts to incorporate the demand side of drought, to complement the precipitation or supply side, are needed as anomalously high demand can tax soil and vegetative moisture, potentially increase irrigation requirements, and allow for the deterioration of drought conditions due to a larger gap between water supply and water demand. Water-year 2022 had the seventh highest evaporative demand values for the state since 1980, ultimately resulting in quantitatively similar water conditions as in the 2020 water year, when precipitation was lower. Complementary to the record setting 3-year precipitation deficit during 2020–22, we find that water-year evaporative demand over the past three years is the highest in the analysis record (1980–present), approximately 1″ higher than during the 2012–14 period (Figure 3).

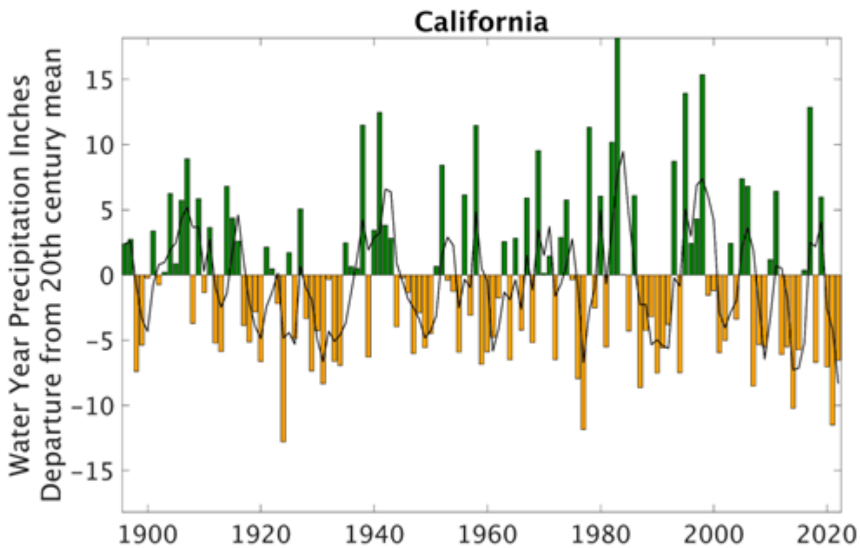

FIGURE 2. STATEWIDE WATER YEAR (OCT-SEP) PRECIPITATION ANOMALIES EXPRESSED AS A DEPARTURE FROM THE 20TH CENTURY AVERAGE. WATER YEAR 2022 WAS THE 19TH DRIEST IN THE PERIOD OF RECORD (SINCE 1895). THE BLACK LINE DENOTES THE THREE-YEAR TRAILING AVERAGE SHOWING THAT WATER YEARS 2020–22 WERE THE DRIEST THREE CONSECUTIVE YEARS IN THE INSTRUMENTAL RECORD.

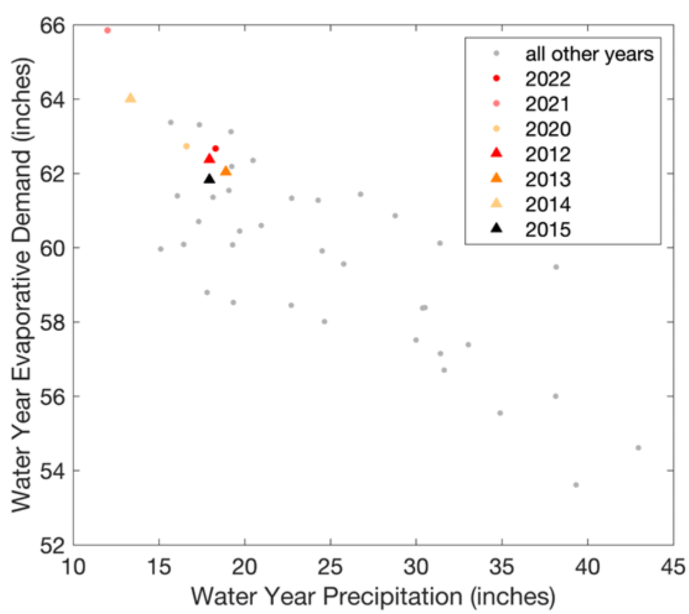

FIGURE 3: SCATTERPLOT OF WATER YEAR PRECIPITATION AND EVAPORATIVE DEMAND FOR CALIFORNIA DURING 1980–2022.

Water Supply Conditions

Surface water availability in the Central Valley

After the wet years of 2017 and 2019, California endured three successive dry years, causing major problems for the state's agriculture, cities, small communities, and the environment. Figure 4 shows water storage conditions in major Central Valley reservoirs over the past five years. In the spring of 2019, Central Valley reservoirs were nearly full. Precipitation shortfalls in 2020 started to reduce water stored in reservoirs, especially in the Sacramento Valley, and by 2021 water year reservoir levels fell to drought levels. Reservoir levels in the Sacramento River in the spring and summer of 2021 were lower than at any time in the recent decades, although reservoir releases and inflows to the Delta from the Sacramento Valley remained similar to 2015. Both Tulare Lake and the San Joaquin River reservoirs had very low levels, although not as extreme as in the Sacramento River basin. The 2021 October and December rains were more bountiful in the San Joaquin River and especially in the Tulare Lake Basin, making reservoir storage conditions better in the spring of 2022 (the start of the irrigation season) than in 2021. Conversely, in the Sacramento River the critical conditions in reservoir levels persisted in 2022, only recovering slightly during the summer from exceptional cuts in reservoir releases and water deliveries.

Figure 5 shows releases from the major reservoirs during the irrigation season (May through September), highlighting how reservoir managers reacted. Releases in 2021 were similar to 2015 in the Sacramento River basin, in the San Joaquin River basin releases were higher than in 2014 but lower than in 2013. And in the Tulare Lake basin, reservoir releases were higher than in 2015 but lower than in 2014.

In 2022, Sacramento River releases continued to decline, but inflows to the Delta increased compared to 2021, resulting in decreased water supply availability for irrigation. In the San Joaquin Valley, deliveries were similar to the previous year, while in the Tulare Basin region, the improvement in reservoir conditions made reservoir managers increase releases above levels in 2013.

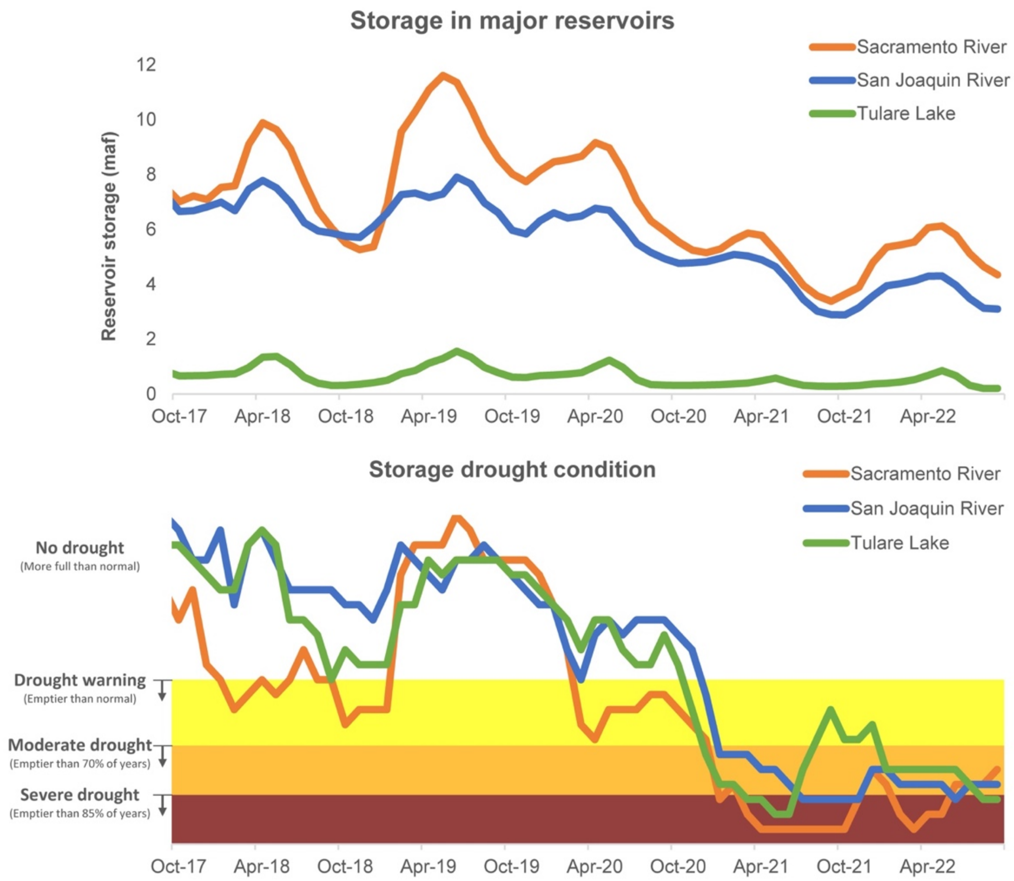

FIGURE 4. STORAGE AND RESERVOIR DROUGHT CONDITION IN MAJOR CENTRAL VALLEY RESERVOIRS BY HYDROLOGIC REGION (DROUGHT CONDITION IS THE MONTHLY PERCENTILE OF TOTAL STORAGE COMPARED TO THE 2000–22 PERIOD).

In summary, the Sacramento Valley has seen in these three years the worst drought in recent history. Water supplies in 2021 were similar to 2015 (the worst year of the 2012–16 drought) with slightly higher reservoir releases and slightly lower Delta inflows; water curtailments came late in the season despite unprecedentedly low storage conditions in the spring of 2021 (Gartrell et al., 2022). In 2022 reservoir releases were lower and water curtailments came early in the year, increasing Delta inflows during the irrigation season and resulting in all-time low water supplies in the Sacramento Valley. For the San Joaquin Valley, the situation has been less critical, and the drought has reduced deliveries during 2021 and 2022 to levels comparable to the early years of the 2012–16 drought, but not as much as in 2015. For the Tulare Lake region, 2021 was more severe—worse than 2014 but better than 2015—while the situation in 2022 improved and surface deliveries were higher than in 2013.

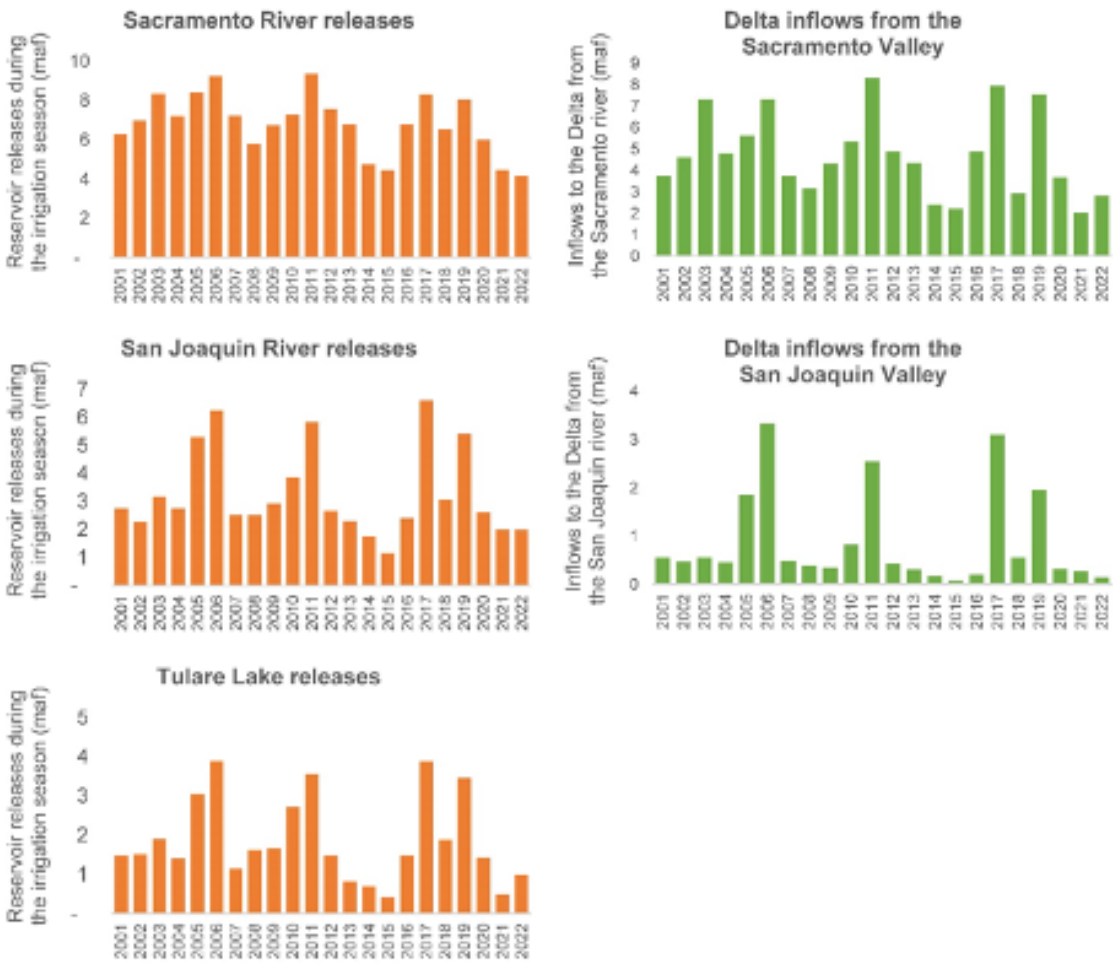

FIGURE 5. MAJOR RESERVOIR RELEASES AND DELTA INFLOW CONTRIBUTIONS BY BASIN.

Estimating the reduction in overall Central Valley water supplies

The state of surface supplies is only part of the story, as farmers pump more groundwater to respond to surface shortages. But the ability to pump differs across the three hydrologic regions, with a North-to-South gradient in surface supply reliability that is mirrored by differences in pumping capacity. The Sacramento basin has less variability in surface supplies and less need to increase pumping in dry years (and hence fewer wells). The San Joaquin and especially the Tulare Lake basin have greater variability in surface supplies, and much more pumping capacity. Figure 6 shows the overall supplies (from surface and groundwater source) in the three regions, showing the greater variability of surface and groundwater sources from North to South.

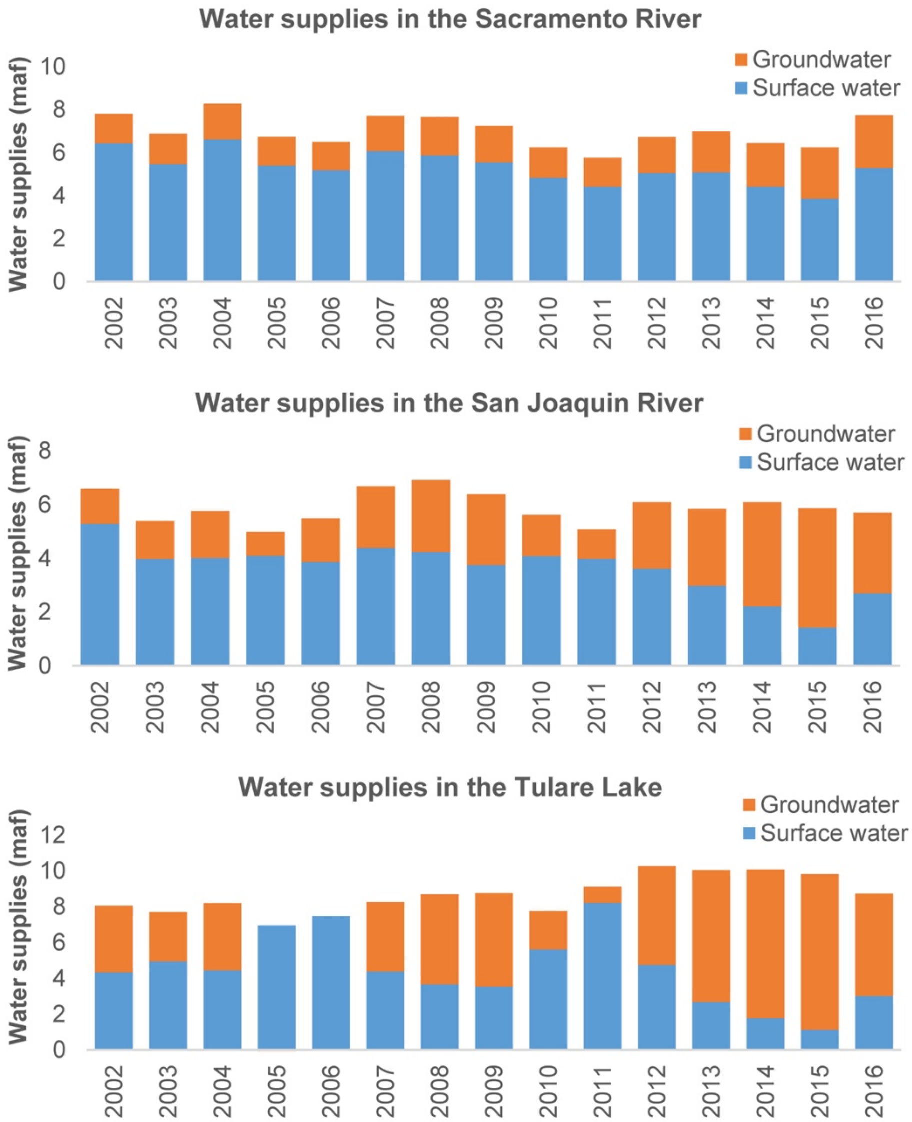

FIGURE 6. WATER SUPPLY BY SOURCE IN THE THREE CENTRAL VALLEY BASINS. SOURCE: DWR CALIFORNIA WATER PLAN WATER BALANCE DATA.

Using historical 2002–16 water balance data from the California Water Plan datasets, measurements of surface storage conditions and deliveries from the California Data Exchange Center (CDEC) for the 2000-2022 period, historical 2000–22 deliveries data from State Water Project (SWP) and Central Valley Project (CVP) reports, water right curtailments for 2021 and 2022 from the State Water Resources Control Board (SWRCB), and supplemental remote sensing data from evapotranspiration, we estimate reductions in overall water supplies in the three Central Valley regions (more details in Appendix A).

First, we estimate conditions for surface and groundwater supplies for the three Central Valley hydrologic regions for 2019. These conditions are representative of wetter years with more active cropland and less idle land, where farmers are less constrained by water supplies. Table 1 shows the total base supplies by hydrologic region.

TABLE 1. WATER DELIVERIES TO AGRICULTURE IN THOUSAND ACRE FOOT PER YEAR (TAF/YR). SOURCE: AUTHORS CALCULATIONS USING THE CALIFORNIA WATER PLAN UPDATE DATASETS.

	Baseline conditions - 2019 (taf/yr)		
Hydrologic region	**Surface deliveries**	**Groundwater pumping**	**Total supplies**
Sacramento River	5,316	1,692	7,008
San Joaquin River	3,820	2,260	6,080
Tulare Lake	4,734	4,194	8,927
Central Valley Total	**13,870**	**8,146**	**22,015**

Then, we use measured data from storage conditions, irrigation season deliveries from reservoirs, and inflows to the Delta to estimate 2021 and 2022 surface supplies assuming that farm deliveries from surface reservoirs are similar to years in the historical record with comparable conditions. Finally, we estimate incremental groundwater pumping to offset reduced surface deliveries. We use a similar approach, using data from the historical water balance, but adjusting pumping with complementary evapotranspiration data from remote sensing. The results of 2021 and 2022 appear in Tables 2 and 3 below (for details see Appendix A).

TABLE 2. ESTIMATED ANNUAL WATER SUPPLIES IN THOUSAND ACRE-FOOT PER YEAR (TAF/YR) FOR 2021.

	Estimated supplies for 2021 (taf/yr)			**Shortage compared to 2019 (taf/yr)**
Hydrologic region	**Surface deliveries**	**Groundwater pumping**	**Total supplies**	
Sacramento River	3,861 (-27%)	2,383 (+41%)	6,244 (-11%)	764 (-11%)
San Joaquin River	2,592 (-32%)	3,275 (+45%)	5,867 (-4%)	213 (-4%)
Tulare Lake	1,450 (-69%)	6,628 (+58%)	8,078 (-10%)	849 (-10%)

TABLE 3. ESTIMATED ANNUAL WATER SUPPLIES IN THOUSAND ACRE-FOOT PER YEAR (TAF/YR) FOR 2022.

	Estimated supplies for 2022 (taf/yr)			Shortage compared to 2019 (taf/yr)
Hydrologic region	**Surface deliveries**	**Groundwater pumping**	**Total supplies**	
Sacramento River	2,703 (-49%)	2,793 (+65%)	5,495 (-22%)	1,512 (-22%)
San Joaquin River	2,592 (-32%)	3,241 (+43%)	5,833 (-4%)	247 (-4%)
Tulare Lake	2,679 (-43%)	5,443 (+30%)	8,122 (-9%)	806 (-9%)

The results for the Central Valley show a similar reduction in surface supplies in 2021 (6 maf) and 2022 (5.9 maf). But the spatial distribution was very different, with shortages in 2022 much more concentrated in the Sacramento Valley, and less severe drought conditions in the Tulare Basin. Given the lower pumping capacity of the Sacramento Valley, the final net shortage in 2022 was higher (2.6 maf in 2022 versus 1.8 maf in 2021), with most of this shortage affecting the Sacramento Valley.

Incremental Idle Land During Drought

Every year, some irrigated agricultural lands in California are idled for a variety of reasons including agronomic rotations, water shortage, and business decisions to balance production costs, crop revenues and opportunities for idling and selling water. We consider 2019 as our agricultural baseline. This wet year directly preceded the three consecutive dry years of 2020–22, and therefore represents the most recent pre-drought agricultural mosaic. Our economic impacts estimations consider the effects of incremental land idling between the 2019 baseline and the two most recent dry years (2021 and 2022).

Using remote sensing data and an algorithm developed for this study (see Appendix C for details), we assess incremental idle land in 2021 and 2022 compared to 2019 (Table 4). We estimated 563,000 acres of idle land in 2021 relative to 2019, of which 524,000 acres in the Central Valley and 39,000 acres in other regions included in this study. For 2022, we estimated 752,000 acres of idle land relative to 2019, including 696,000 in the Central Valley, 32,000 acres in the northern intermountain regions, 3,000 acres in coastal areas, and 21,000 acres in the Colorado River Region. The Sacramento River Basin had high drought-related idling in 2021 and 2022 for a variety of reasons including historically low surface water deliveries, water transfers from rice and other field crop farming to other activities outside the basin (including supplies for coastal urban areas and for higher value commodities in the San Joaquin Valley), and a less developed groundwater pumping infrastructure than in the San Joaquin Valley.

Closely behind the Sacramento Valley in idle land is the Tulare Lake Basin, which regularly idles land during droughts and experienced an increase in idle land of about a quarter million acres in both 2021 and 2022 compared to 2019. While deliveries of project water from CVP and SWP were relatively low, higher reservoir releases in some locations, imports from the north, and increased pumping due to a more robust groundwater supply infrastructure reduced estimated idle land relative to the 2012–16 drought for the San Joaquin Valley at large (Lund et al., 2018). In the San Joaquin River region—comprising portions of San Joaquin, Stanislaus, Merced and Madera counties—water supplies to agriculture were less restricted, resulting in only minor increases in idled land. We estimated some scattered idle land in the west side of the basin and in Madera County, adding up to roughly 65,000 acres basin-wide in 2022, a 10,000-acre increase compared to 2021.

TABLE 4. SUMMARY OF DROUGHT-RELATED IDLED LAND IN 2021 AND 2022 COMPARED TO 2019 BASELINE CONDITIONS. SOURCE: AUTHORS' ESTIMATES.

Region	Baseline 2019 irrigated area (1000 acres)	2021 increased idle land compared to 2019 (1,000 acres)	2022 increased idle land compared to 2019 (1,000 acres)
Central Valley Total	**6,415**	**524**	**696**
Sacramento River	1,727	203	381
San Joaquin River	1,944	55	65
Tulare Lake Basin	2,745	266	249
Northern Intermountain	268	27	32
Coastal	415	2	3
Colorado River	519	10	21
All Regions	**7,618**	**563**	**752**

Outside of the Central Valley, we used remote sensing changes in evapotranspiration, interviews and other local conditions data across years to approximate drought-related idled land (Appendix C). The northern intermountain basins, which largely grow feed crops, also had some increased idle and/or lower crop production compared to pre-drought conditions. Decreases in productivity were roughly the same for 2021 and 2022 compared to 2019. Given the two-decade long drought in the Colorado River basin states, what might seem to be low levels of land idling may have deeper impacts for the local livestock sector, which relies on lower costs from local feed crops to be profitable.

Coastal agriculture, comprising the Russian River, Central Coast and, South Coast regions, hosts higher value commodities and had little incremental idling in both dry years compared to 2019. Nevertheless, even small yield losses in grapes, berries, and specialty vegetables can have relatively high economic impacts due their labor intensity, higher gross revenue per acre, and higher value added in downstream sectors.

Colorado River agricultural regions are not well connected to the Central Valley hydrologic regions which experienced the most water shortages in the current drought. With the exception of groundwater pumping in Coachella, deliveries of water to irrigated agriculture in Coachella, Imperial and Palo Verde are largely from California's allocations of Colorado River. This river's supply is also allocated to six other states and Mexico, and the basin is experiencing severe shortages. Thus far no cutbacks have been imposed on California given its seniority in water rights, but this is unlikely to continue as agreements on water cutbacks across states progress for the 2022–23 water year. Whereas most increased fallowing in the region to date may be attributable to long-term transfer agreements between agricultural and urban users within California, additional cooperative solutions to reduce irrigation water use may be on the horizon to address these longer-term challenges in the river basin.

Tables 5 and 6 and Figure 7 summarize the distribution of land idling by crop category. The majority of idled land in the Central Valley was for annual field and grain crops (especially Sacramento Valley rice and cotton in the Tulare basin), although there was also some early removal of trees and vines. Idling in the Russian River basin (North Coast) was also concentrated in feed crops, but some orchards and vines had below average yields. Central Coast farming did not experience much idling but did experience below average yields for berries and specialty vegetables.

TABLE 5. SUMMARY OF INCREMENTAL IDLED LAND (IN THOUSAND ACRES) IN 2021 COMPARED TO 2019 BASELINE CONDITIONS BY CROP GROUP. SOURCE: AUTHOR'S ESTIMATES.

Region	Alfalfa and Pasture	Corn	Other Field and Grain	Trees and Vine	Vegetable and other Fruit	Total
Central Valley	**47**	**82**	**278**	**68**	**49**	**524**
Sacramento	17	13	146	12	16	203
San Joaquin River	12	10	13	17	3	55
Tulare Lake	18	59	119	40	30	266
Northern Intermountain	15	-	12	-	-	27
Coastal	1	-	1	-	-	2
Colorado River	6	2	1	-	1	10
All Regions	**69**	**84**	**292**	**68**	**50**	**563**

TABLE 6. SUMMARY OF INCREMENTAL IDLED LAND (IN THOUSAND ACRES) IN 2022 COMPARED TO 2019 BASELINE CONDITIONS BY CROP GROUP. SOURCE: AUTHOR'S ESTIMATES.

Region	Alfalfa and Pasture	Corn	Other Field and Grain	Trees and Vine	Vegetable and other Fruit	Total
Central Valley	**33**	**87**	**445**	**72**	**58**	**695**
Sacramento	9	21	309	15	26	381
San Joaquin River	8	13	21	19	4	65
Tulare Lake	16	53	115	38	28	249
Northern Intermountain	20	-	12	-	-	32
Coastal	2	-	1	-	-	3
Colorado River	16	2	2	-	1	21
All Regions	**71**	**89**	**460**	**73**	**59**	**752**

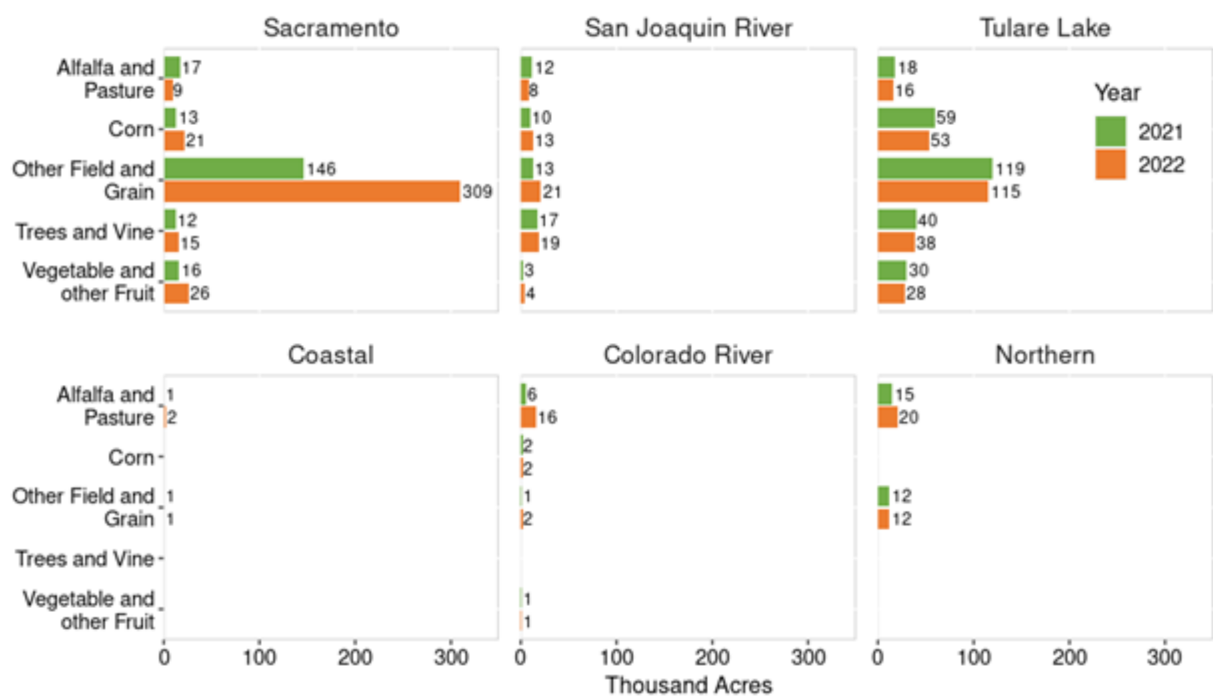

FIGURE 7. INCREMENTAL IDLE LAND IN 2021 AND 2022 BY CROP GROUP WITH RESPECT TO 2019.

Figure 8 shows the spatial distribution of idle land in the Central Valley for 2021 and 2022 using the results from the evapotranspiration analysis with SSEBop data (Appendix C) and the Statewide Crop Mapping from Land IQ 2019, available at DWRs website[2]. The spatial distribution of idle land changed between 2021 and 2022. During 2022 the largest rice production regions of the state (Sutter, Colusa and Glenn counties) were the most affected, increasing the idle rice from 123 thousand acres in 2021 to 267 thousand acres in 2022[2]. For the San Joaquin Valley, the increase in fallowing between 2019 and 2022 was concentrated in the western part of the region.

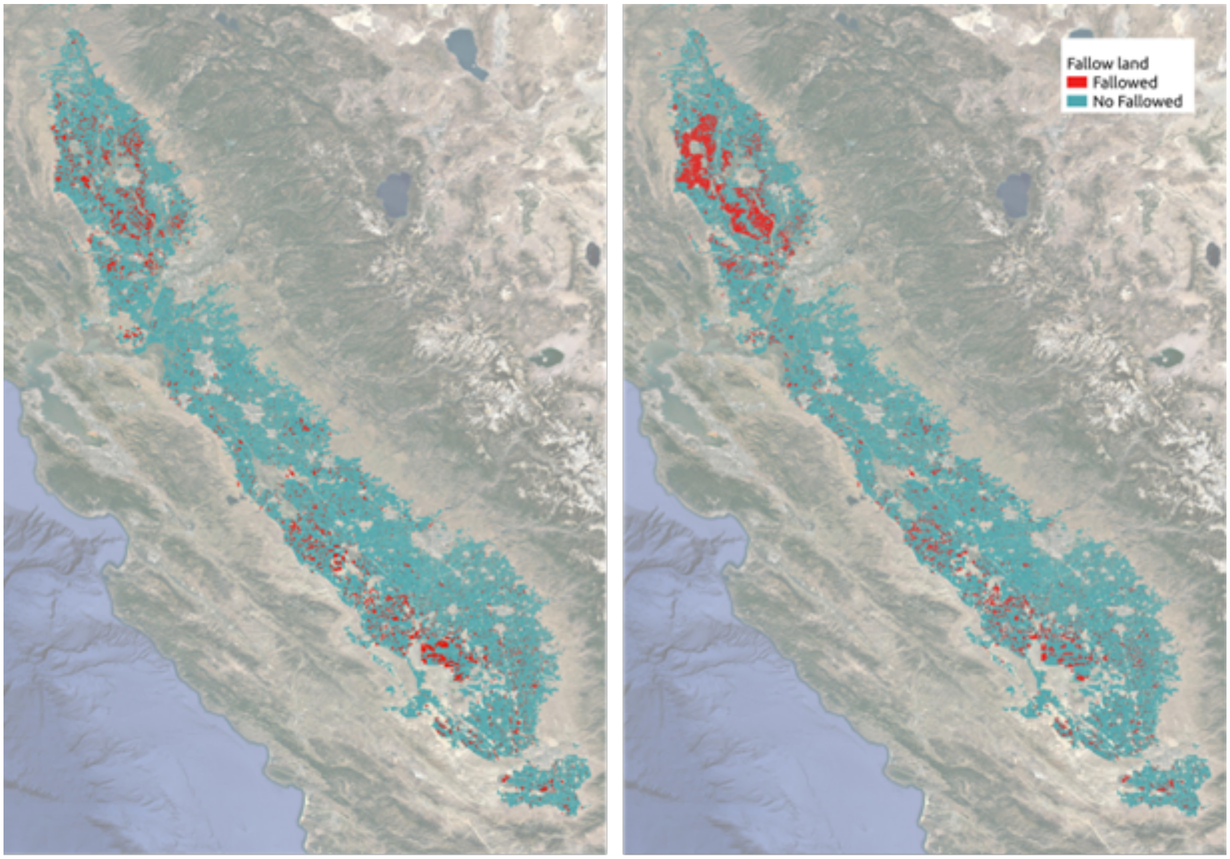

FIGURE 8. MAPPING OF IDLE LAND FOR 2021 (LEFT) AND 2022 (RIGHT) COMPARED TO THE 2019 BASELINE YEAR FOR THE CENTRAL VALLEY. RED COLOR REPRESENTS FIELDS CLASSIFIED AS FALLOWED AND TEAL FIELDS CLASSIFIED AS NOT FALLOWED. SOURCE: AUTHOR CALCULATIONS BASED ON SSEBOP ACTUAL EVAPOTRANSPIRATION (APPENDIX C).

Economic Impacts

Irrigated Crops

Land idled in response to drought reduced crop growers' gross revenues. We estimated for the year 2022 about $1.7 billion in statewide crop revenue losses compared to 2019. The same comparison for 2021 yields $1.3 billion in statewide crop revenue losses (Tables 7 and 8, and

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[2] These results are consistent with the USDA FSA estimates of prevented planting, see Appendix D for more details.

Figure 9). Crop revenue losses in 2022 were similar for the Sacramento River and the Tulare Lake basin, roughly $659 million and $621 million respectively. Another $184 million were lost in the San Joaquin River basin. In the 2021 water year drought impacts were slightly higher in the Tulare Lake basin ($667 million), and still high, but less pronounced, in the Sacramento Valley, with $358 million in revenue losses.

TABLE 7. ESTIMATED CROP GROSS REVENUE LOSSES ($ MILLION) DUE TO DROUGHT FOR 2021 COMPARED TO 2019.

Region	Alfalfa and Pasture	Corn	Other Field and Grain	Trees and Vine	Vegetable and other Fruit	Total
Central Valley	**57**	**97**	**409**	**408**	**210**	**1,182 (-4%)**
Sacramento	15	11	228	51	53	358 (-8%)
San Joaquin River	14	13	25	91	13	157 (-2%)
Tulare Lake	27	74	156	267	144	667 (-4%)
Northern Intermountain	13	-	9	-	6	28 (-7%)
Coastal	1	-	0	26	45	73 (-1%)
Colorado River	8	11	2	10	10	40 (-2%)
All Regions	**79**	**108**	**420**	**444**	**271**	**1,323 (-4%)**

TABLE 8. ESTIMATED CROP GROSS REVENUE LOSSES ($MILLION) DUE TO DROUGHT FOR 2022 COMPARED TO 2019.

Region	Alfalfa and Pasture	Corn	Other Field and Grain	Trees and Vine	Vegetable and other Fruit	Total
Central Valley	**48**	**101**	**660**	**423**	**232**	**1,464 (-5%)**
Sacramento	10	19	482	65	81	659 (-15%)
San Joaquin River	12	15	33	107	17	184 (-2%)
Tulare Lake	26	66	145	251	134	621 (-4%)
Northern Intermountain	18	-	8	-	8	34 (-9%)
Coastal	1	-	-	39	91	131 (-2%)
Colorado River	20	13	3	19	36	91 (-5%)
All Regions	**87**	**114**	**671**	**481**	**367**	**1,720 (-5%)**

Outside of the Central Valley, the highest gross revenue losses came from some annual crops with high per acre revenue in the northern basins, along with reduced yields in non-tree fruits and vegetables and vines in coastal areas. Such losses add up to $256 million (roughly $115 million more than in 2021). In some areas like the Colorado River agricultural regions in Coachella, Imperial Valley and Palo Verde, idled land and shortages are related to past water transfer agreements, some of which get exercised more intensely during dry periods.

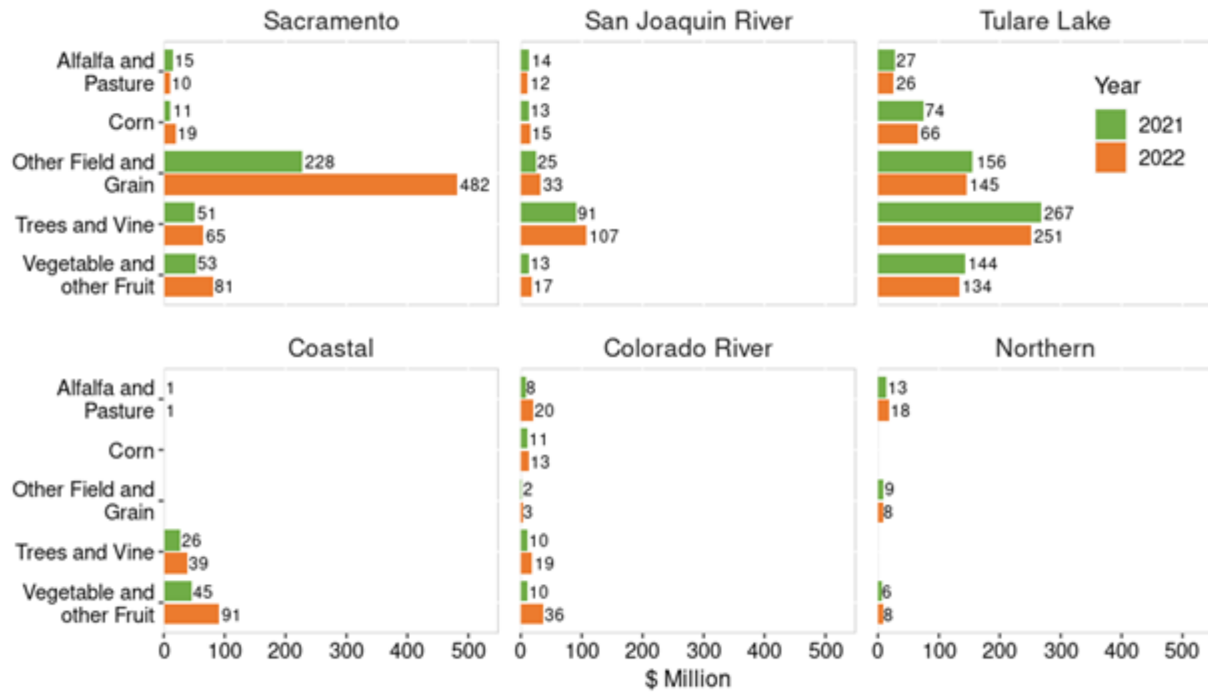

FIGURE 9. CROP GROSS REVENUE LOSSES (IN $MILLION/YEAR) DUE TO DROUGHT FOR 2021 AND 2022 COMPARED TO 2019.

Increased Groundwater Costs in the Central Valley

As in most past droughts surface water shortages are partially offset by additional groundwater pumping in places where infrastructure and legal regulations allow it. In the Central Valley, roughly 4,140 taf of additional groundwater pumping occurred in 2021, and 3,330 taf in 2022. We estimated increased pumping costs using the energy cost to lift water from median groundwater levels in the region (obtained from DWR Periodic Groundwater Level Measurements). The pumping augmentation cost in 2021 was $183.6 million, while the costs decreased in 2022 to $123.1 million (Table 9). Part of this cost could be offset by reduced surface water costs, but in many irrigation districts in California, surface water supplies are fixed costs based on land assessment.

The lower additional pumping costs in 2022 reflect the better surface water conditions in 2022 in the Tulare Lake basin, where groundwater levels are lower; the increase in pumping in the Sacramento Valley is less costly because of shallower groundwater depths.

TABLE 9. ESTIMATED INCREASE IN GROUNDWATER PUMPING COSTS IN THE CENTRAL VALLEY IN 2021 AND 2022 COMPARED TO 2019.

	Groundwater pumping augmentation (taf)		**Energy costs (million $)**	
Basin	**2021**	**2022**	**2021**	**2022**
Sacramento River	691	1,100	14.9	23.8
San Joaquin River	1,015	981	28.2	27.3
Tulare Lake Basin	2,434	1,249	140.4	72.1
Central Valley	**4,140**	**3,330**	**183.6**	**123.1**

The increase in groundwater extraction during droughts could result in at least two additional types of costs to growers that we haven't accounted for in our estimates:

- Increased capital costs for new wells: Increased groundwater pumping during drought cause significant declines in groundwater levels. Maintaining groundwater supplies can require deepening or drilling new wells to replace dry wells. On average, around 930 new agricultural wells are dug every year in California, but this number increases significantly during droughts. In 2021, 1,447 new agricultural wells were dug in the state, and as of October of 2022, 960 new wells were already built. While some of these wells are likely being installed to increase pumping capacity—for instance in places that had been relying on surface water deliveries—some are likely dug to replace wells that have gone dry. As a rough illustration of the costs of well drilling, the capital cost for all new irrigation wells in 2021 totals approximately $150 million. We will account for these costs in the final project report, when more data is available.
- Option value of groundwater: Option value refers to the value of not using a scarce natural resource (in this case groundwater) so that it might be available for use in the future. Under the Sustainable Groundwater Management Act, sustainability needs to be achieved by the early 2040s while avoiding significant and unreasonable impacts. Groundwater agencies (GSAs) have developed plans for ramping down groundwater use for overdrafted basins—including most sub-basins within the San Joaquin Valley. By increasing groundwater use during droughts, groundwater users may be incurring costs by reducing the amount of groundwater they will be able to extract in the future. We have preferred not to attempt to calculate this cost for two reasons. First, it is not clear that groundwater extractions today will limit groundwater extraction in the future in overdrafted basins. If agencies are able to avoid significant and unreasonable impacts, they could use a "soft landing" approach, ramping down average groundwater use until 2040. Second, some of the increased groundwater pumping is located in sub-basins that are not critically overdrafted (especially in the Sacramento Valley); in these areas, it may be possible to replenish aquifers during future wetter years without reducing pumping.

Beyond costs for the agricultural sector, declines in groundwater levels during droughts can cause other important socio-economic and environmental impacts—or externalities—that are not quantified here. One of the most significant impacts is to drinking water wells of small disadvantaged communities located in agricultural regions. Over the past two years, numerous small water systems have faced shortages and more than 2,000 domestic wells have gone dry. While some wells can go dry from lack of natural replenishment of groundwater basins during droughts, significant pumping by larger irrigation wells also cause these problems in some areas. Groundwater level declines also cause land subsidence—in some cases damaging infrastructure—and can reduce flows in streams and wetlands, resulting in environmental impacts.

Beef and Dairy Cattle

Drought affects California's livestock industry mainly through cost and availability of feed for the animals. The livestock industry relies on grains and oilseeds that are mostly shipped into the state, and on forage from rainfed and irrigated pasture, alfalfa and other hay, and corn and small grain silage grown mostly within California. By-product feeds, such as almond hulls, wine-grape pomace and other products from fruit, vegetable, and other food processing, are also a significant share of feed value, especially for the dairy industry.

The poultry and beef feedlot industries rely mainly on grains and oilseed feeds shipped into California and so face fewer challenges and smaller costs increases from droughts occurring within the state, including this most recent drought. We note, however, that grain and oilseed feeds shipped into California were also expensive in 2022.

In 2022, California's drought reduced forage availability substantially and raised costs for purchased forages for the cattle grazing industry, which brings billions of dollars of farm revenue to the California economy. Lack of rainfall on pastures in the coastal range and foothills of the Sierra Nevada range directly reduced beef cattle pasturage. Beef cattle from California sell into national and international markets where California supply conditions have little effect on product prices. With high expected prices for calves, beef cow numbers were up slightly in January 2022 compared to most prior years and up 8% compared to 2019.

In 2022, monthly national beef cattle prices were about 20% above prices for the same months in 2019 through 2020 (United States Department of Agriculture, ERS 2022). This pattern continued through August for calves, cull cows, and steers and heifers exceeding 500 pounds. Although forage costs and availability were a severe problem, cattle producers benefited from higher prices on cattle and calves sold in 2022. Net revenue was lower that it would otherwise have been and cattle production and supply might have been somewhat larger but for lower expected forage availability.

Dairy cows numbered 1.72 million in 2022, almost constant over the past four years. Milk production through August 2022 has been equal to the first 8 months of 2021, but up 3.6% compared to the first 8 months of 2019 (United States Department of Agriculture, 2022). This slight increase in milk production reflects the effect of drought in 2022 on forage costs. That is, California milk production and revenue would have been up by more, but for the very high production costs and prices of hay and silage.

Milk prices averaged about $26 per hundredweight in the first 8 months of 2022, and have been about 50% higher than in 2021 and 2019 and more than 60% higher than in 2018 (United States Department of Agriculture, 2022). (The pandemic year of 2020 had large payments that more than compensated for any declines in milk revenue.) Direct dairy farm revenue is very likely to exceed $8 billion in 2022, making it again the largest part of California agricultural revenue. These remarkably high milk prices would have been expected to raise cow numbers and milk production per cow substantially, but for increases in feed costs. Dairy employment is proportional to milk production, which has been roughly constant. But for the drought, dairy employment would likely have been slightly higher.

The impact of the drought in 2022 is clearly reflected in alfalfa hay quantity and prices. Very high milk prices would have been expected to raise hay and silage production in California if not for prevailing drought conditions. Instead, all hay acreage in 2022 was about the same as 2021 and 2020–about 15–20% lower than in 2017–19. For alfalfa hay in particular, 2022 acreage is about equal to 2021 and about 20% below the average of 2017–19. Corn that is not harvested for grain (mostly harvested as silage), which has recently been almost all corn planted in California, was only 350,000 acres in 2022, slightly below 2018–21 and equal to the low acreage reached in 2017 (United States Department of Agriculture, 2022).

The price of alfalfa hay reflects a drought-constrained supply in all the western states, and high milk prices increased willingness to pay higher prices for alfalfa. In the first 8 month of 2022 the price of premium alfalfa hay in California averaged $323 per ton, about 40% above the average price in the first 8 months of 2021, and about 50% higher than the average price for 2019 and 2020 (USDA, 2022). The high cost of alfalfa hay and limited supply of silage limited the expansion of California milk production in 2022 and the ability to take advantage of high milk prices that were caused mainly by factors outside California. As with our 2021 estimates, we do not attempt to approximate gross revenue losses caused by drought. For 2022, the increase in gross revenues due to high milk and cattle prices were mostly absorbed by the higher cost of feed crops.

Food Processing

Because most food processing employs crop and animal products as production inputs, its gross value of the sector is inclusive of purchases from agriculture. Here we provide an initial estimate of potential drought impacts to the food processing sector assuming the current proportion of Central Valley sourcing of crops and animal products to food and beverage processing in the Central Valley. We take approximate reductions in crop gross revenues as a proxy for decreased supply to food and beverage processing to obtain estimated impacts of drought in these downstream sectors. Also, we assume no changes in beef and dairy products. Food and beverage processing outside of the Central Valley was excluded from this analysis. Lastly, production of beef and dairy is assumed to be comparable to pre-drought conditions, hence no shortage of such inputs to food and beverage processing is expected, even though higher costs may pose some challenges.

Because processing has a high share of purchased inputs (including farm products already included in our estimates of crop losses), estimates of value added losses (central columns in Table 10) provide a better measure than revenue losses of the economic impacts of drought. Assuming the ratio of locally sourced crops to imports stays roughly constant, we estimate 2022 direct value added losses of $846 million, up from $589 million in 2021. The losses in 2022 were substantially higher in the Sacramento Valley ($549 million) than in the San Joaquin Valley ($298 million) (Table 10). Direct job losses in food and beverage processing in the Central Valley in 2022 are estimated at 7,366 jobs. Lastly, since these sectors are sourced from agriculture, we do not report the multiplier effects to avoid potential double counting of impacts. Nevertheless, other sectors that also supply production goods and services to food processing are potentially affected by a decrease in food processing activities.

TABLE 10. ESTIMATED IMPACT OF IDLED LAND IN 2022 AND 2021 ON FOOD AND BEVERAGE PROCESSING IN THE CENTRAL VALLEY. SOURCE: AUTHOR'S CALCULATIONS USING IMPLAN (2019).

	Employment (Jobs)		Value Added (Million $)		Gross Revenue (Million $)	
Basin	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
Sacramento Valley	2,499	4,794	294	549	1,172	2,223
San Joaquin Valley	2,357	2,572	295	298	1,237	1,244
Central Valley	**4,856**	**7,366**	**589**	**846**	**2,409**	**3,467**

In the Sacramento Valley, rice milling and some fruit and vegetable canning were likely affected the most. In the San Joaquin Valley, the impacts were more spread out across different processing activities, although processing of nuts and canned fruits seem the most affected by idled land. While these estimates provide reference points to identify drought vulnerabilities in processing in connection with idled land and animal production, other drivers including access to other production inputs (e.g., labor), volatility in demand, and disruptions in supply chains may play a more prominent role in food processing production decisions. Also, input-output models like IMPLAN assume fixed prices and ratios of production value to employment and value added, but these factors can change during higher inflation periods. The team continues to investigate the interlinkages between crop, animal products, and processing and their potential adaptations.

Regionwide Economic Impacts

In addition to the regional economic effects from drought and idled land on gross revenues (Tables 7 and 8 above) and food and beverage processing (Table 10), we also estimated the overall impacts on employment and value added for 2021 and 2022. Value added is similar to GDP—it measures an activity's contribution to total regional economic activity—the sum of wages, profits, returns to land, and taxes generated by the activity. We again used IMPLAN (2019). The largest economic effects of the drought were concentrated in the Central Valley, given its higher proportion of land in irrigated agriculture, and the higher variability in water supplies during droughts. Table 11 summarizes the direct economic impacts of crop idled land, increased pumping costs and food processing by region for 2021. Statewide total gross revenue losses are estimated at $3.9 billion. Overall direct employment losses are 14,728 full and part-time jobs, from which 9,882 were from reductions in crop production, and the remainder from food and beverage processing. Value added is estimated to have decreased by $1.4 billion.

Table 12 summarizes the overall economic impacts of direct economic impacts for crop idled land, increased pumping costs, and food processing by region for 2022. Statewide direct gross revenue losses are estimated at nearly $5.3 billion, including costs of idle land, increased pumping, and food processing. Employment losses, not including multiplier effects, total 19,418 full and part-time jobs. Value added is estimated to have decreased by $2 billion. Statewide economic impacts in 2022 were higher than in 2021, and the largest change from 2021 to 2022 was observed in the Sacramento Valley region, reflecting sharp increases in idled cropland.

TABLE 11. SUMMARY OF ECONOMIC IMPACTS OF THE 2021 DROUGHT IN CALIFORNIA AGRICULTURE AND PROCESSING SECTOR.

Impact	Sacramento Valley	San Joaquin Valley	Northern Inter-Mountain	Coastal	Colorado River	State
Crops						
Gross revenues ($M)	358	824	28	73	40	1,323
Employment (Jobs)	2,312	6,555	194	567	254	9,882
Value added ($M)	213	520	11	44	24	812
Pumping Costs ($M)	15	169	-	-	-	184
Processing						
Gross revenues ($M)	1,172	1,237	-	-	-	2,409
Employment (Jobs)	2,499	2,357	-	-	-	4,856
Value added ($M)	294	295	-	-	-	589
Total Direct Impacts						
Gross revenues ($M)	1,545	2,229	29	73	40	3,915
Employment (Jobs)	4,810	8,912	194	567	254	14,738
Value added ($M)	507	815	11	44	24	1,401

TABLE 12. SUMMARY OF ECONOMIC IMPACTS OF THE 2022 DROUGHT IN CALIFORNIA AGRICULTURE AND PROCESSING SECTOR.

Impact	Sacramento Valley	San Joaquin Valley	Northern Inter-Mountain	Coastal	Colorado River	State
Crops						
Gross revenues ($M)	659	805	33	131	91	1,720
Employment (Jobs)	3,698	6,478	263	1,019	591	12,049
Value added ($M)	438	588	15	78	54	1,172
Pumping Costs ($M)	24	99	-	-	-	123
Processing						
Gross revenues ($M)	2,223	1,244	-	-	-	3,467
Employment (Jobs)	4,794	2,572	-	-	-	7,366
Value added ($M)	549	298	-	-	-	846
Total Direct Impacts						
Gross revenues ($M)	2,906	2,148	33	131	91	5,309
Employment (Jobs)	8,492	9,049	263	1,019	591	19,414
Value added ($M)	987	885	15	78	54	2,018

Direct value added losses in 2022 agriculture represent roughly 4.9% crop value added ($24 billion). Value added from food and beverage processing in the Central Valley are $10 billion, thus losses in 2022 are about 8.3%. While such estimated impacts are not comprehensive, these provide a reference point for identifying areas more severely affected by drought. This includes places whose economy rely on agriculture and food industry and communities with limited access to off-farm employment which also lack a reliable water supply.

Discussion of Drought Impact Estimates

Every drought brings renewed challenges to agriculture, communities, ecosystems and urban water systems in unprecedented ways, yet institutional learning stays and improves planning for future droughts (Lund et al., 2018). Diminished precipitation, snowpack, and water reserves are features common to all droughts, but their spatial and temporal distributions can vary widely across droughts. Recent droughts, including this current one, have brought higher temperatures and landscape evapotranspiration, further compounding water stresses. In this research, we characterize and quantify the response and economic effects of drought-related water scarcity on agricultural planting and water use decisions using the best available information on land and water use, and employing hydro-economic models (Harou et al. 2009) to estimate cropping patterns that maximize net farming returns in response to changes in water availability.

Agricultural adaptations to drought such as water trading, shifting cropping patterns, opportunistic land idling, and higher groundwater pumping are driven by a range of economic, social, and regulatory considerations. It is not always straightforward to determine the specific contributions of these various factors. We have also sought to capture how other factors—such as changes in crop prices and crop yields—have affected cropping decisions and economic outcomes. During the past two years multiple additional challenges have influenced the agricultural sector, such as inputs cost increases (e.g., fertilizers), increasing inflation, and lingering effects of the COVID-19 global pandemic such as labor shortages and supply chain disruptions. All of these challenges have likely influenced the economic outcomes for California agriculture, although sufficient data is not yet available to quantify their contributions.

Price and Yield Effects

Yield and price effects significantly drive economic losses from drought. From anecdotal information, some crops such as alfalfa, almonds, berries and tomatoes had decreased yields in some areas from heat and water stress. Disruptions in the supply chain, including export of California crops, may increase inventory and depress some crop prices as in the case of almonds (Sahagún, 2022) and walnuts (Chipman and Saraiva, 2022) this year. Expected agricultural commodity prices, a primary driver in planting decisions, are often part of a global market outlook beyond regional hydrologic conditions and local water supply challenges. Lastly, high prices for some field crops such as alfalfa or prime cotton varieties may incentivize cultivating these crops despite water scarcity and potential increases in the costs of production. Price effects in the 2021 and 2022 water years cause complications when comparing to the 2019 baseline, as prices are determined by market conditions, which can be impacted by production and demand trends. Additional information on yield considerations for perennials and specialty fruits and vegetables can be found in Appendix F.

Crop Year Baseline

In this study, we employed a 2019 land use and production economics baseline, as it provides a recent and consistent pre-drought point of reference. Compared to 2018, there were 141 thousand additional planted acres—the baseline we used in the preliminary report (Medellin-Azuara et al. 2022). Accounting for this difference in acreage between the 2018 and 2019 baselines, the 524,000 acres of fallowed land in 2021 compared to 2019 translates to 383,000 of acres fallowed compared to 2018, consistent with the estimated 385,000 fallowed acres for the Central Valley in our preliminary report. Most of the increased acreage between 2018 and 2019 was for lower value crop groups such as alfalfa, irrigated pasture, and grains, plus some young perennials. Hence, the estimated gross revenue impact difference between baselines is small—just $20 million. A more detailed discussion of baseline use is provided in Appendix B.

Crop Insurance and Water Transfers

The effect of the farmland registered in USDA programs for natural disasters, including drought conditions, raises some functional challenges for quantifying the economic impacts of drought. We used the USDA Farm Services Agency (FSA) crop reports (USDA-FSA,2022) to inform our estimates on idle land, reported under the prevented acreage category (see Appendix D for more information). Some crops enrolled under the USDA's Risk Management Agency crop insurance program have coverage for prevented planting benefits that pays a certain amount per acre, mainly for rice and cotton, when enrolled farms can document that it would not have been economic to plant because it was known at planting time that there would be a lack of available irrigation water to sustain the crop. Such insurance provides some economic relief to growers that have incurred pre-planting costs. For some growers the prevented-planting insurance benefit actually exceeds the potential profit of growing an alternative crop on the insured parcels. Furthermore, in some cases some irrigation water that might have been use growing rice, cotton, or other grain crops may be transferred to permanent crops or other crop that need irrigation every year. By some estimates, roughly 137 taf in water transfers in the Sacramento Valley were classified as crop-idling transfers in 2021 (Chaudhry, A., Personal communications, 2022 Oct. 25) with average prices of $575 per acre-foot (Lohdorff and Scalmanini Consulting Engineers, 2022). These transactions reduce the overall economic impact of drought by partially reducing gross revenue losses from idling. At the same time, water-importing crops may see a decline in net revenues due to water purchases, while even greater costs from otherwise higher idling are avoided.

Conclusions

The current 2020-2022 drought has once again highlighted the resilience of California's agriculture to climate extremes. At the same time, this drought has exposed some other vulnerabilities that need attention such as land idling hotspots, vulnerable communities and the need to replenish water to aquifers in future years to offset excess pumping during droughts. Some other conclusions arise from this work:

1. The three-year period that started in 2020 has been one of the driest and hottest periods in the state's instrumental record, with just 68% of the 20th century average precipitation. This low precipitation was accompanied by an additional 3–5 inches of evaporative demand annually from vegetation, which increased the gap between water availability and demands for agriculture, ecosystems and communities.
2. The compounding drought effects of the 2020 and 2021 water years worsened water supply conditions for the northern part of the state in 2022. Net water shortage for the Sacramento Valley doubled in 2022 (1.5 MAF) compared to 2021 (760 TAF). In contrast, some parts of the San Joaquin Valley saw slight improvements in water supply conditions. In contrast, shortages in the Russian River basin were less severe in 2022 than in the prior year.
3. Strategic short term land idling was the most common cropping decision adaptation in this drought, particularly for crops which are easily idled from a net return and investment standpoint. Taking 2019 as the most recent baseline before this drought, idle land in 2021 was roughly 563 thousand acres (of which 524 thousand in the Central Valley). Worsening conditions for the Sacramento Valley increased idle land by nearly 190 thousand acres in 2022, and overall idling for the regions analyzed in the study totaled 752 thousand acres (695 thousand in the Central Valley). Some crops such as rice, and other field and grain crops showed extensive idling. In some cases prevented planting insurance and revenues from water transfers provided some financial relief.
4. The reduction in crop acreage during drought causes gross farm revenue losses, which also affect the rest of the economy. Our initial estimates are crop revenue losses of $1.3

billion for 2021 and $1.7 billion for 2022 compared to 2019 conditions for all areas analyzed in the study. The largest proportion of such losses is in the Central Valley due to drought-idled land. Areas outside the Central Valley—including the Russian River and coastal areas—had some fallowing, yet yield losses in vines, and some vegetables due to dry and warm conditions were the main source of revenue losses. Additional energy costs from pumping were roughly $123 million in 2022, down from $183 million in 2021 due to higher surface water deliveries in the San Joaquin Valley in 2022.

5. Beef and dairy industries have benefited recently from high animal product commodity prices and higher than normal revenues. However, higher local forage costs caused by lack of irrigation water and higher water costs have reduced their ability to benefit fully from such higher product prices. Therefore, both beef and milk production has been lower than they would have been.
6. The food processing sector often receives less attention during droughts. Yet our initial estimates of the cascade effects of decreased production of some crops, highlight challenges to the sector in the Central Valley. Overall, value added losses of $845 million were estimated for 2022 in the Central Valley, with a decrease of nearly 7,400 jobs. Gross revenue losses for 2022 are higher ($3.5 billion), but these are a less useful measure of the impact to the regional economy given the high share of agricultural production inputs used in this sector, which are already accounted for in our estimates of the impacts of land idling.
7. The overall value added impact of the 2022 drought in California agriculture and food processing are estimated at $2 billion ($600 million higher than in 2021) and about 19,414 jobs (4,700 more than in 2021). While these estimates do not encapsulate all nuances in farming and processing decisions during droughts, they are nevertheless useful in identifying systemwide vulnerabilities due to water shortages and climatic factors as we prepare for future droughts.

Our analysis of adaptations during this drought point to some suggestions for continued improvements in water management during future droughts:

- Water trading across commodities and agricultural regions can substantially reduce the economic impacts of drought by allowing crops that generate higher net revenues, value added, and employment to remain in production . Facilitating the further development of water exchanges, with care to identify and address possible impacts for agricultural communities and ecosystems, can improve drought response (Ayres et al. 2021).
- In a similar vein, programs that pay water users to forego irrigation or employ other water conservation strategies during dry years (e.g. 2022 Delta Drought Response Pilot Program) may bring net water savings while protecting water quality and

environmental flows and in some cases helping wildlife habitat. Paying growers for idling in the Colorado River Basin states may also increase water storage in the basin's major reservoirs and help avoid more severe cutbacks.

- Assessing infrastructure needs and making appropriate improvements can help reduce the costs of future droughts. For instance, the lower pumping capacity that the Sacramento Valley has compared to the San Joaquin and Tulare Basins made this region more vulnerable in 2022. Considering SGMA requirements, future pumping must remain within sustainable levels, but the wetter Sacramento Valley could likely afford to pump more during dry years if adequate recharge programs are in place (Escriva-Bou et al. 2021). Increasing overall recharge capacity to take advantage of wetter years is also essential, and this will often require investments to improve water conveyance and to operate surface and groundwater storage facilities in greater coordination.
- Carefully designed crop insurance programs can provide economic relief for farmers when water is not available or heat and water stress affect crop yields. Prevented-planting crop insurance provisions have benefited some farmers of crops within the program during this drought.
- Many local communities within farming areas have also been impacted by the drought, but agricultural workers are generally not covered by unemployment insurance, and California currently lacks a robust safety net to assist them. It is crucial to identify and assist communities that rely on seasonal and permanent agricultural jobs that are vulnerable to drought.
- Additionally, some small communities whose drinking water access relies on shallow wells have reported lack of groundwater access during droughts. In the past two years 2,400 household wells (2,115 in the Central Valley) were reported as dry (DWR,2022). While the reduced natural replenishment of groundwater basins during droughts can cause groundwater levels to fall, this problem is exacerbated in some places by increased pumping from nearby agricultural wells. Groundwater sustainability agencies—the local agencies responsible for implementing SGMA—can reduce drinking water vulnerabilities by developing robust well mitigation programs and investing in groundwater recharge projects that help replenish groundwater near communities.
- Lastly, careful examination of the effectiveness of dry-year actions outlined in local groundwater sustainability plans can improve prospects for successful SGMA implementation, which will be key to long-term drought resilience.

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