Economic Analysis of the 2016 California Drought on Agriculture

A report for the California Department of Food and Agriculture

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Davis, California, August 15, 2016

Economic Impacts of the 2016 California Drought for Agriculture
Executive Summary

California's agriculture and extensive water supply system have been challenged by recent years of drought. After four years of severely dry conditions, a wetter 2016 winter and spring helped California partially recover surface water storage and increased recharge to some aquifers. Nevertheless, statewide storage in reservoirs remains below historical average and groundwater remains in substantial overdraft in many areas.

Table ES - 1: Summary of agricultural impacts of the 2016 California drought

Description	Impact	Base year levels	Percent change
Surface water shortage (million acre-ft)	2.6	18.0	-14%
Groundwater replacement (m acre-ft)	1.9	8.4	23%
Net water shortage (million acre-ft)	0.7	26.4	-2.6%
Drought-related idle land (acres)	78,780	1.2 million*	6.6%
Crop revenue losses ($)	$247 million	$37 billion	0.6%
Dairy and livestock revenue losses ($)	Minor	$12.4 billion	NA
Costs of additional pumping ($)	$303 million	$780 million	38.8%
Direct costs of drought ($)	$550 million	NA	NA
Total economic impact ($)	**$603 million**	NA	NA
Direct drought job losses (farm seasonal)	1,815	200,000[#]	0.9%
Total job losses from drought	**4,700**	NA	NA

* NASA-ARC 2015 estimate of normal Central Valley idle land.

[#] Total agricultural employment is about 412,000, of which 200,000 is farm production.

Following methods in previous drought assessments (Howitt et al. 2014, 2015), we employ primary information from surveys of major irrigation districts on water delivery expectations, public announcements of federal and state water contract allocations, local water projects, access to groundwater, and anticipated water market transfers. These data describing water supply conditions are inputs to the SWAP model, which estimates changes in statewide cropping patterns, farm revenues, and production costs in response to the drought. Impacts to dairies and livestock are estimated using sector statistics and trends. A region-wide impact analysis of employment, value added, and gross output also was conducted. Table ES-1 above summarizes estimated impacts of drought on California agriculture for 2016.

Agriculture in California remains strong, with moderate growth in value, and in some cases employment, despite four years of dry conditions. In 2016, several agricultural regions face water supply shortages due to streamflow temperature, endangered species regulations, and salinity control requirements. In these regions we estimate an increase in crop fallowing, reduced revenues, and employment, especially in areas without access to groundwater. The findings of our 2016 drought impact analysis can be summarized as:

1. In 2016, persistent drought conditions will likely result in surface water supply losses of about 2.6 MAF, of which 1.9 MAF will be replaced with additional groundwater pumping. As in previous dry years, groundwater reserves are critical for managing drought. Overall drought effects are much milder than in 2014 or 2015. Drought effects to agriculture in 2016 were driven largely by low water availability south of the Delta and restrictions on ability to move water across the Delta.
2. Crop fallowing as a result of water shortage is estimated to be approximately 80 thousand acres relative to average water supply conditions, representing just below 1 percent of all irrigated area in California. About 90 percent of land fallowed due to drought is in the Central Valley south of the Delta.
3. We estimate the 2016 drought results in $247 million loss of farm-gate revenues and 1,815 full and part time jobs statewide. As in previous drought years, losses are concentrated in the Central Valley south of the Delta.
4. When the spillover effects to other sectors of the economy are considered, we estimate total output value losses of $600 million and 4,700 full and part time jobs statewide due to drought in agriculture. Despite the drought, overall agricultural value and employment grew statewide during recent drought years due to several factors including favorable global prices l for some crops.
5. High dairy prices in 2014 were followed by higher forage costs and lower milk prices in 2015 and 2016. Forage costs have since decreased due to wetter conditions. The dairy sector is more vulnerable to market conditions than drought.
6. Some areas, including highway corridors in the Central Valley, have increased risk of dust exposure due to agricultural fallowing in drought.
7. Groundwater continues to be the buffer water supply during drought. However, analysis of well completion reports and groundwater depth monitoring data in the Tulare region indicate well maintenance and replacement costs could increase as water levels fall below critical points in well screens. From 2012 to 2015 an increase of $1.7 per acre-foot per year in pumping costs is likely to have occurred.
8. A diversified and global California economy also has dampened the adverse effects of recent water shortages in agriculture. Losses from water cutbacks to irrigated areas, revenue losses, and statewide impacts have been large, but economic losses have been much less severe than water cutbacks statewide.

Suggested Citation:
Medellin-Azuara, J., MacEwan, D., Howitt, Richard E., Medellín-Azuara, Sumner, D.A. Lund, J.R. (2016). Economic Analysis of the 2016 California Drought on Agriculture. Center for Watershed Sciences, UC Davis. Davis, CA, 17 pp.

Introduction

Persistent dry conditions over the past few years have put California's irrigated agriculture under severe water stress. Improved precipitation during the winter and spring of 2016, and favorable market conditions, among other factors, have improved prospects for agriculture in 2016. However, water supply restrictions for temperature, endangered species, and salinity management continue to challenge some farming regions.

We present an analysis of the economic impact of the 2016 drought on California's agriculture. The analysis relies on a suite of models and data to estimate responses to water scarcity. The Statewide Agricultural Production Model (SWAP, Howitt et al. 2012) is calibrated to average year water conditions and used to simulate the response of agriculture to changes in water availability. SWAP model output is linked to the IMPLAN input-output model and used to estimate changes in gross revenues, employment, and value added across all related sectors of the economy.

The report is structured as follows. First, we summarize 2016 water supply conditions for agriculture. Next, we present the results of an economic analysis of impacts to agriculture using the SWAP model, and impacts to ancillary industries using the IMPLAN model. We conclude with a discussion of policy implications, limitations, and future analyses. Several appendices provide further details on groundwater availability and cost, land fallowing, consumptive use, livestock and dairies, employment, and regional economic impacts.

Water Supply Conditions

A wetter 2016 winter and spring substantially increased the surface water reserves in Northern California. Although water availability conditions are much improved since 2015, reservoir storage remains significantly less than historical averages, and there is increased pressure to manage environmental flows. In addition, groundwater elevations in the southern Central Valley are unlikely to have substantially recovered. For these reasons the economic impact of drought to agriculture should be substantially less in 2016 than in 2014 or 2015, although some regions continue to face declining groundwater elevations and reduced surface water deliveries.

Water allocations for agricultural contractors in 2016 are generally higher than in 2014 or 2015. Central Valley Project (CVP) Sacramento River Settlement and San Joaquin River Exchange Contractors are allocated 100 percent of their contract supply, as are CVP agricultural water service contractors north of the Delta. CVP agricultural water service contractors south of the Delta, primarily on the west-side of the San Joaquin Valley are currently allocated only 5 percent of contract supply. Friant Division contractors on the east-side of the San Joaquin Valley are allocated 75 percent of Class 1 supply. As of May, the State Water Project (SWP) contract allocation is set at 60 percent. A major limit on CVP and SWP water project deliveries has been limited ability to move water from the wetter Sacramento Valley across the Sacramento-San

Joaquin Delta to southern and western areas of California. Balanced against higher allocations from the SWP and CVP are concerns from many districts, particularly in the Sacramento Valley, over potential curtailments to manage water temperature for fish.

To assess the water supply outlook for agricultural irrigation, water managers at 40 districts in the Sacramento and San Joaquin Valleys were surveyed. District staff reported a better water supply outlook in the 2016 water year than in 2014 or 2015. In addition to higher contract allocations, districts were again able to rely on groundwater banking, carryover surface storage, and within-district transfers to limit the impacts of water shortage this year. Most districts expect to supply their growers with close to full irrigation demand, with any supplemental irrigation being met by groundwater pumping. A summary of the water supply conditions for 2016 is provided in Table 1, which shows net water shortages of nearly 680 thousand acre-feet statewide, mostly in the southern Central Valley (Figure 1).

Table 1. Estimated Change in Water Availability and Use, 2016 drought (thousand acre-feet)

Region	Surface Water	Groundwater	Net Delivery Shortage
Sacramento River, Delta and East of Delta	-145	30	-115
San Joaquin River	-545	440	-100
Tulare Lake	-1,920	1,460	-460
Central Coast	0.0	-2.9	-2.9
South Coast	0.0	-0.6	-0.6
South Inland	0.1	-0.4	-0.2
Total	**-2,610**	**1,930**	**-680**

Despite 100 percent allocations, Sacramento Valley settlement and service contractors report water supply reliability issues due to operational restrictions on Shasta Reservoir to maintain cool temperatures for salmon eggs. These districts report that the low level of the Sacramento River has at times made it infeasible to divert water from the river, as districts seek to prevent pump cavitation. These issues may be more severe for diverters further south and for individual farmers with only one point of diversion. To continue to provide water throughout the irrigation season some districts may supply groundwater from district-owned wells, at a higher cost than river water. Operational constraints due to fisheries management were also cited in the San

Joaquin Valley. Kings River operators report challenges managing water quality in the watershed scarred by the devastation of the Rough Fire in 2015.

Water transfers in 2016 are limited due to capacity constraints on Delta exports, mostly regarding environmental reverse flow limits on Old and Middle rivers within the Delta. Demand for water transfers remains high as San Joaquin Valley CVP contractors only received a 5 percent allocation and most districts seek to restore reserves following several drought years. Depressed rice prices at the time of planting enticed many rice farmers to consider land idling to supply water transfers. Despite the abundance of willing buyers and willing sellers, no districts reported through-Delta transfers and only a few reported intra-basin transfers in 2016.

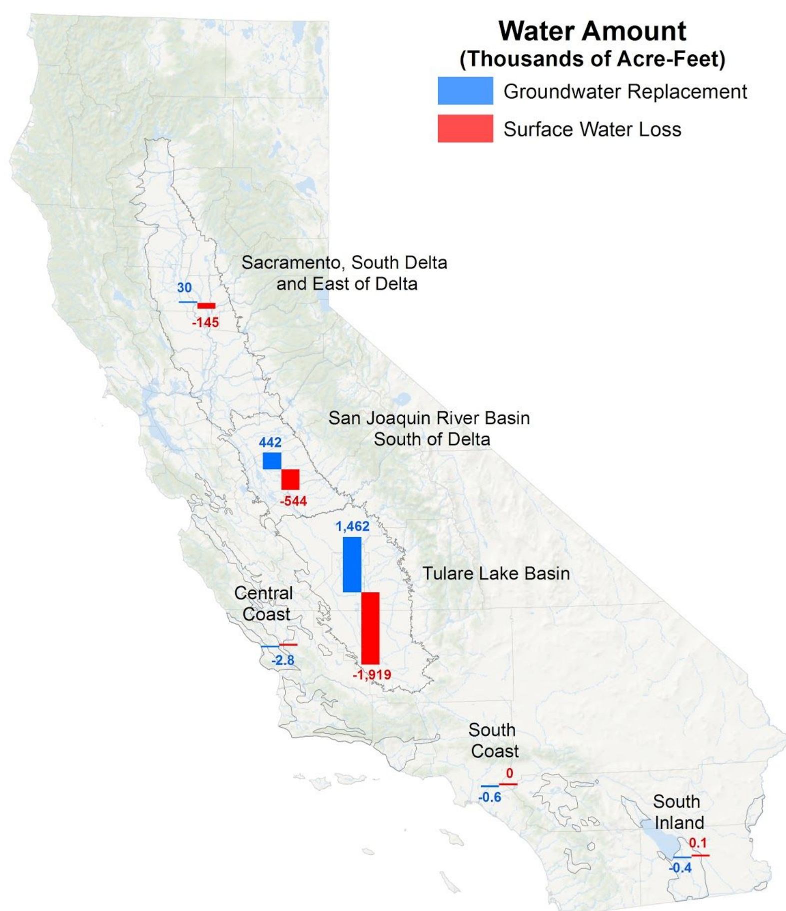

Figure 1: Change in water supply conditions

Many districts noted that dry soil profiles, resulting from extended drought, may reduce runoff even in areas where precipitation was above average. In addition, conveyance losses have increased annually for many districts during the drought and this year is no exception. One district reported that less than 60 percent of the water it sent from its reservoir to its landowners within the district was actually received by the landowners, due to conveyances losses in the river and in unlined canals to depleted aquifers. Both of these surface water losses help recharge groundwater supplies, which have been drawn down in many areas to offset reduced surface water supplies.

One phenomenon widely reported during California's ongoing drought is continued new plantings of permanent crops. For example, from 2010 to 2015, non-bearing almond acreage increased from 85,000 acres to 220,000 acres (USDA Plantings Report). Cropping decisions are based on a number of factors in addition to water supplies, including crop prices, market access, soil type, and climate. In the short-term, transitioning from most crops to tree crops results in a water savings. Immature tree crops use an average of less than 2 acre-feet of water annually in their first three years. Assuming the crops they replaced use 3 acre-feet of water annually, water savings from non-bearing almond, pistachio, and walnut trees in 2015 amounted to over 400,000 acre-feet. Such water "savings" might be unavailable in future drought years with larger areas of bearing perennial crops.

Drought Impacts

Irrigated area

Water conditions information compiled was employed as an input for the SWAP model to estimate changes in irrigated areas and gross revenues. About 79 thousand acres of land are estimated to be fallowed due to drought in 2016 (Table 2). Most of the fallowed cropland is on the west-side of the Tulare Lake Basin, where surface water shortage is most severe.

Table 2. Estimated Change in Irrigated Crop Acreage from Drought, 2016 (1000 acres)

Region	Vegetables	Orchards and Vines	Feed Crops	Other Field	Grain	Total
Sacramento River, Delta & East of Delta	0.1	0.1	-0.9	0.1	0.7	0
San Joaquin River	0.2	-0.1	-0.6	0.2	0.3	0
Tulare Lake	-12	-1.6	-15	-33	-16	-77
Central Coast	-0.4	0	-0.1	-1.3	-0.4	-2
South Coast	0	0	0	0	0	0
South Inland	0	0	0.1	-0.1	0	0
Total	**-12**	**-1.5**	**-16**	**-34**	**-15.5**	**-78**

Most fallowing is concentrated in the Tulare Lake Basin. Improved surface water supply in the Sacramento Valley, and limited ability to transfer water through the Delta, have reduced fallowing in this area. Minimal drought fallowing is expected for areas outside of the southern Central Valley.

Crop Revenues

Revenue losses for crops due to drought in 2016 are estimated at $223 million dollars. These losses are concentrated in the Tulare Lake Basin Table 3.

Table 3. Estimated Change in Crop Revenues due to Drought, 2016 (millions of dollars)

Region	Vegetables	Orchards and Vines	Feed Crops	Other Field	Grain	Total
Sacramento River, Delta and East of Delta	-0.4	-1.6	-1.8	-0.1	-3.4	-7.3
San Joaquin River	-0.1	-7.7	-2.9	-1.1	-19	-13.8
Tulare Lake	-62.0	-35.2	-39.7	-54.8	-30.9	-222.8
Central Coast	-3.1	-0.2	-0.1	0.9	-0.2	-2.8
South Coast	-0.1	-0.1	0.0	-0.1	-0.0	-0.2
South Inland	-0.1	-0.1	0.1	-0.0	0.0	-0.2
Total	-65.8	-44.9	-44.5	-55.2	-36.4	-246.8

In addition to the agricultural crop revenue losses, increased pumping costs to make up for surface water shortages are estimated at $303 million. More than 80 percent of the increased pumping cost ($250 million) is in the Tulare Lake Basin. Another 15 percent is in the San Joaquin River Basin. Appendix A shows a case study for change in groundwater levels and costs for drought depletion of groundwater using well completion reports and level monitoring data for the basin.

Dairies and Livestock

We examined the potential effect of drought on the dairies and livestock sectors. Market conditions (feed costs and milk prices) have a more significant impact on the dairy and cow-calf industries than drought. The direct effects from drought in 2016 on these industries are not significant. However, if milk and cattle prices rebound suddenly, the industries may be hampered by the continuing low acreage of hay and silage, and continued reductions in irrigated pasture area.

Dairies are approximately 15 percent of agricultural revenue in California. The dairy industry is also the major customer for hay and silage that are about 1.5 million irrigated acres statewide. Thus the economic situation and outlook for the dairy industry is important for understanding lingering agricultural impacts of drought in California.

The main issue for the global dairy industry since the beginning of 2015 has been a long period of extremely low milk prices, especially following record high prices in 2014. Low milk prices have been particularly hard on the California dairy industry where number of milk cows was about 2.4 percent lower and milk production was about 3.4 percent lower in 2015 relative to 2015. Through April 2016 California milk production is down another 4 percent relative to the same period in 2015. California is the only state of the top 8 in the United States to have lower milk production so far in 2016 than in 2015. As the price of milk has risen and fallen, so have alfalfa hay prices in the dairy region of the San Joaquin Valley. Hay prices reached a peak in 2014 with drought and high milk prices and fell about 20 percent with the decline in milk prices in 2015. Hay price has fallen again by another 20 percent to extremely low prices in June 2016 caused by low dairy demand and more irrigation water availability.

The collapse in global dairy prices have been more important than drought to dairy production in California in recent years. But a large decline in hay prices and an increase in silage production in 2016 is welcome for an industry struggling with low revenues.

The California cattle industry also has potential for large influence from drought. The cattle industry has two broad segments; the grazing industry that includes cow-calf and feeder cattle operations and the feedlot segment that finishes feeder steers and heifers to slaughter weight with intense feeding of grain.The pasture-based grazing segment was severely affected by poor pasture conditions during the 2014 and 2015 drought years and by lower water availability.

The cattle feedlot segment buys grains and oilseeds from outside California and these markets are little affected by California drought. Feedlots also use California produced hay and the lower prices in 2016 are a welcome relief relative to drought years on 2014 and 2015. California feedlots also compete in national markets for feeder cattle as inputs and fed cattle as their output. Market prices for fed cattle are down by almost 20 percent and almost 40 percent for feeder cattle allowing for wider margins for the feedlot cattle business.

The cow-calf and feeder cattle segments of the cattle industry are important in California and have benefited from better pasture conditions in 2016. Unfortunately with low market prices for feeder cattle the industry cannot profit from feeding calves and yearling cattle longer. For this segment of the industry the drought that destroyed pastures in 2014 occurred at worst time and low prices now limit recovery.

Impact on Employment and the Region's Economy

We use the SWAP economic model to estimate direct revenue impacts from changes in irrigated areas due shortage in water supply and increasing pumping costs. These direct costs serve as the basis to calculate spillover effects on employment, sector output, and value added using the IMPLAN model. Table 4 below summarizes direct and total economic impact by region in 2016 due to drought. Appendix F provides more disaggregate results by region.

Table 4. Summary of 2016 Economic Impacts of Drought to California's Agriculture

Direct Impacts			
Region	**Employment (Jobs)**	**Value Added ($Million)**	**Output ($ Million)**
Central Valley	-1,785	-177	-244
Other Areas	-31	-2	-3
Statewide	-1,815	-180	-247
Total Impacts			
Region	**Employment (Jobs)**	**Value Added ($Million)**	**Output ($ Million)**
Central Valley	-4,645	-382	-597
Other Areas	-58	-5	-7
Statewide	-4,702	-387	-603

Direct impacts occur from crop revenue losses due to drought-related fallowing and cropping pattern adjustments. When spillover effects from goods and service demands from agriculture and households in the region are factored in, the direct effects are magnified. The total effects section of Table 4 captures such impacts.

Our analysis estimates that 1,785 direct full and part time jobs are lost due to the 2016 drought (Table 4 and Figure 2), with minor additional job losses in other areas. Gross sales (output) losses on the order of $247 million statewide result from changes in irrigated areas involving fallowing and cropping pattern shiftings. Value added, representing the contribution to California GDP, is estimated to fall by $180 million statewide. Total impacts are estimated to be 4,700 full and part time jobs, $604 million in sector output losses, and $387 million in decreased value added. This includes increased pumping costs which may reduce farming profits. Figure 2 summarizes these impacts.

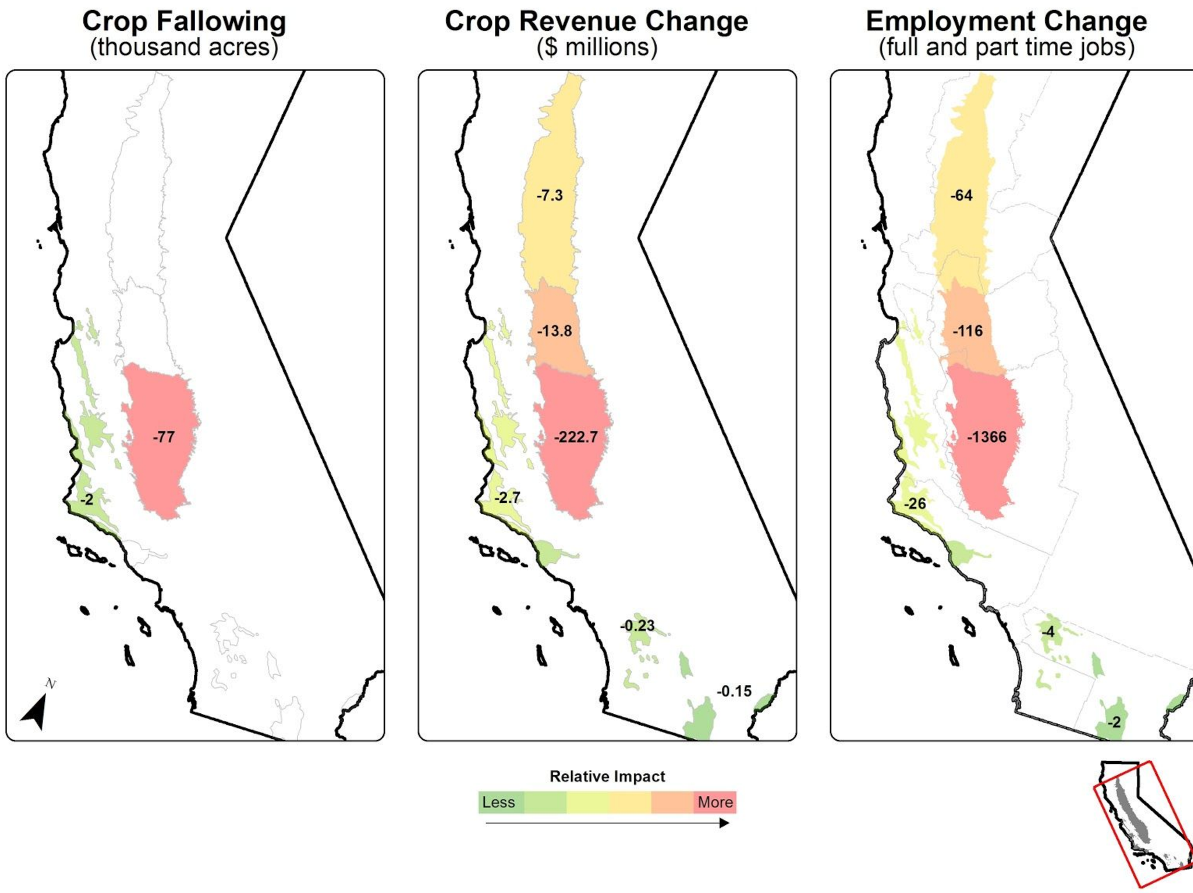

Figure 2. Summary of regional impacts of the 2016 drought to California agriculture

Other Impacts

We examined the impacts of drought on changing groundwater levels (Appendix A), idle land areas (Appendix B), consumptive water use (Appendix C), employment (Appendix D), and potential for dust (Appendix E). These effects are summarized here.

Well operations

A pilot analysis using well completion completion reports and water depth data was done to investigate impacts of drought on well operations. A 27 square mile area in Tulare County, in a basin considered to be critically overdrafted and high priority under the SGMA, served as the test bed. The proof of concept employed information on well screen characteristics to build distributions of top, middle and bottom elevations of local well screens in the area (Figure 3). This information combined with historical water level depths approximate the change in pumping capacity in the region as some wells go dry during drought. This also provides estimates on how pumping costs for the remaining active wells increase due to declining water levels. A full description of the analysis is provided in Appendix A of this report.

Results highlight the potential of such well operations analysis to improve understanding of increasing costs and diminished capacity for pumping during drought. These costs are due to higher energy costs for increased lift, as well as costs for lowering pumps and rehabilitating or replacing wells. Study outcomes also provide the basis to estimate rates at which groundwater levels and pumping capacities may change due to continued overdraft particularly during major droughts. For the study region near the city of Tulare, increased average costs of $1.7 per acre-ft per year may have occurred during the 2012-2015 time period. Larger areas can make these modest increases significant for an irrigation district or basin. Further analysis will improve changing well screen depth distributions over time as more well data becomes available.

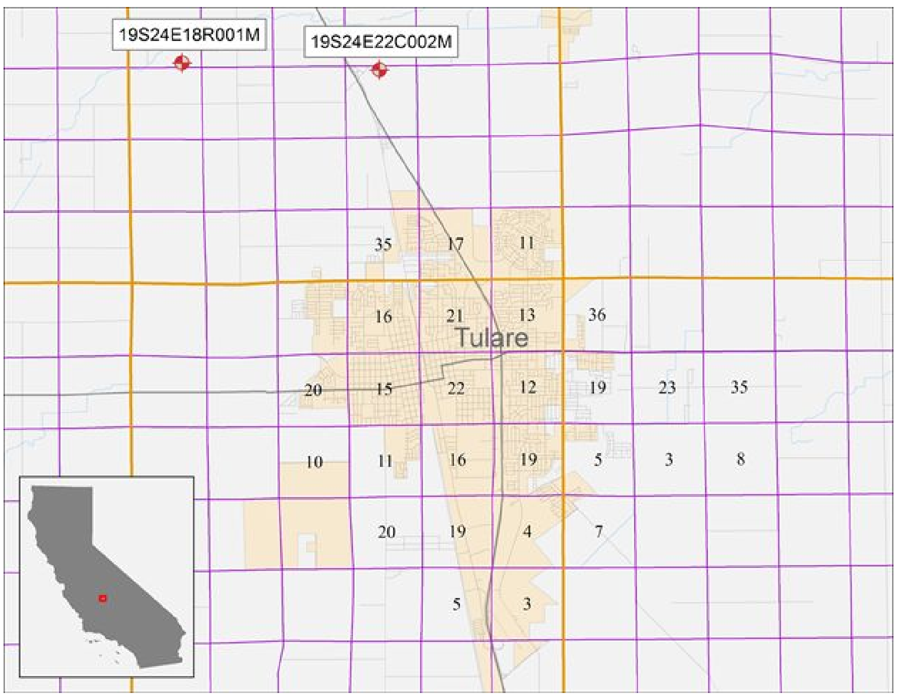

Figure 3. Map of Tulare, CA. Orange lines outline public land survey townships, purple lines outline individual sections within each township. The values within each section indicate the number of well completion reports within that square mile. The two red icons at the top of the figure indicate the locations of two wells for which groundwater hydrographs were constructed to represent high and low estimates of the water level variations.

Change in Idled Areas

Remote sensing data from Landsat imagery and published statistical information were used to assess idle land for 2011, 2014, and 2015. A method was developed at UC Davis to estimate greenness and wetness combined in agricultural crop areas in the Central Valley. This is detailed in Appendix B. Results indicate at least 400 thousand acres more were idled in 2015 than in 2011 (Figure 4). This total is less than the nearly 600 thousand acres of additional idle acres estimated by NASA for the same time period, although idling of most crop groups show agreement for the two methods. Some NASA non-specified crop categories have large difference in estimates. Further work on land fallowing during this year will examine these non-specified categories as the 2016 season unfolds. Idle land itself is not an indication of drought conditions, but by comparing wet and dry year idle land conditions it may provide a baseline to study drought adaptation. Change in irrigated areas from USDA statistics are provided in Appendix G.

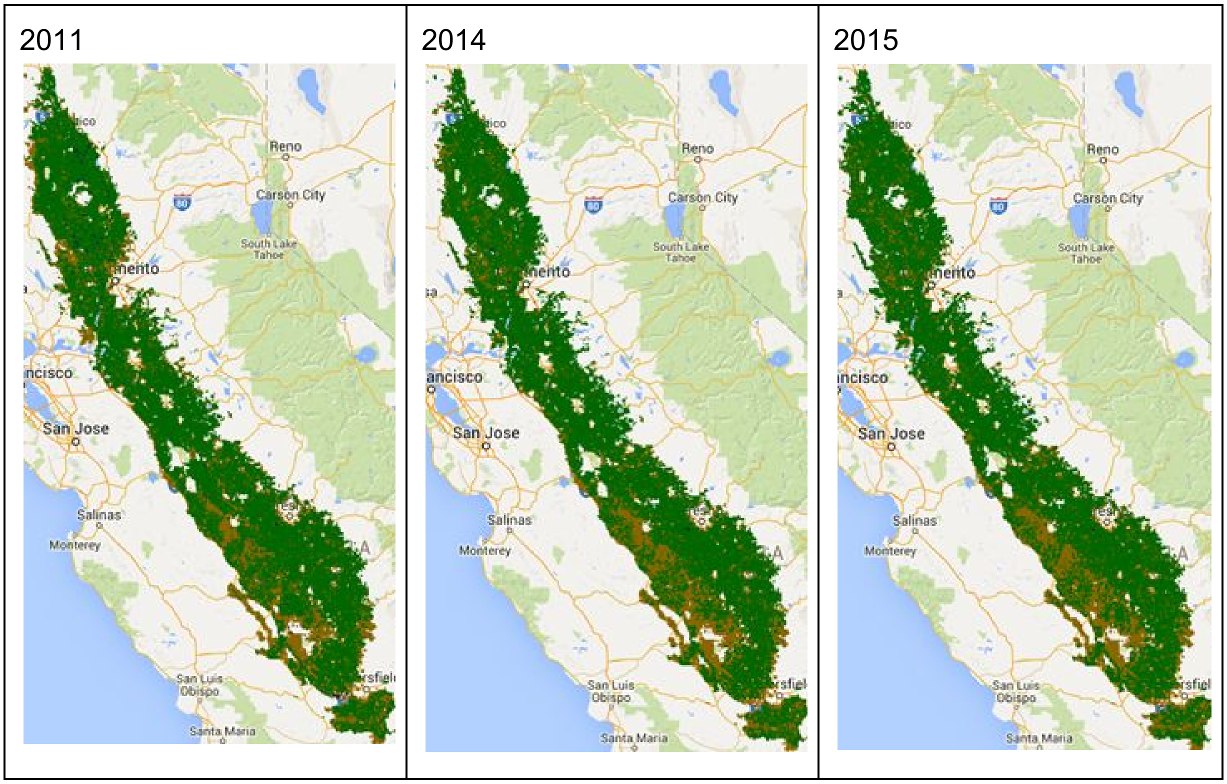

Figure 4: UCD Idled land maps for year 2011, 2014, and 2015.

Change in Crop Consumptive Use

Changes in consumptive water use in crops in Kern County were estimated using Landsat imagery and an energy balance evapotranspiration approach for 2011, 2014 and 2015. A full description of the methods and findings is shown in Appendix C. Results point to a decrease in consumptive use in some permanent crops groups, such as almonds, due to stress irrigation and planting of new orchards which temporarily consume less water; and a generalized increase in consumptive use for other crops. Annual crops show steady water use per unit area, but a decline in total irrigated area which results in reduced total water use for annual crops. These estimated changes in consumptive use are consistent with past drought study predictions for crop shifting and fallowing of annual crops due to drought (Howitt et al. 2014 and 2015).Understanding adaptations such as stress irrigation and planting of new orchards which employ less than full irrigation requirements, will help improve predictions on idle land and total water use during droughts.

Potential for Dust Issues Along Major Central Valley highways

Using NASA idle land information for 2015, the UC Davis team identified areas along the major Central Valley highways (interstate 5 and CA-99) that might be at risk of greater dust and visibility problems from idled land Between 2011 and 2015, an increase of 200 miles with more dust exposure due to land fallowing was identified (see Appendix E). The areas lie within a 500-meter buffer along the major two highway arteries. While this bottom-up approach provides a reasonable approximation to dust risks, further research employing statistical analysis and air monitoring data will improve understanding in the drought prone areas near the main highway systems.

Employment

Published agricultural labor data from the California Employment and Development Department suggests that agricultural employment growth was very small from 2013 to 2014, but grew during 2015. These statistics indicate that about 30,000 new agricultural jobs were added for a total of 441 thousand agricultural jobs statewide. Most employment growth was in the San Joaquin Valley and the Central Coast for fruits, nuts and vegetables. Strong prices, high demand for some labor-intensive commodities, and growth of agriculture as a whole may have supported more this apparent gain in agricultural employment for most areas, despite the drought. Further details are provided in Appendix D of this report.

In contrast, data from Department of Community Services and Development on the Drought Emergency Assistance Program (DEAP), suggests that assistance to unemployed or underemployed individuals are the largest in areas for which past drought studies predict most fallowing (Figure 5). From the $6.5 million in direct services provided by DEAP, 57 percent were given to farm-related workers who were considered under or unemployed in the San Joaquin River and the Tulare Lake basins. Some discrepancies between employment statistics, crop modeling predictions and drought assistance deployment are inevitable. In this case, we feel that the overall employment data reflect continued shifts to permanent crops during the drought, with higher employment per acre, as well as the higher variance in employment data.

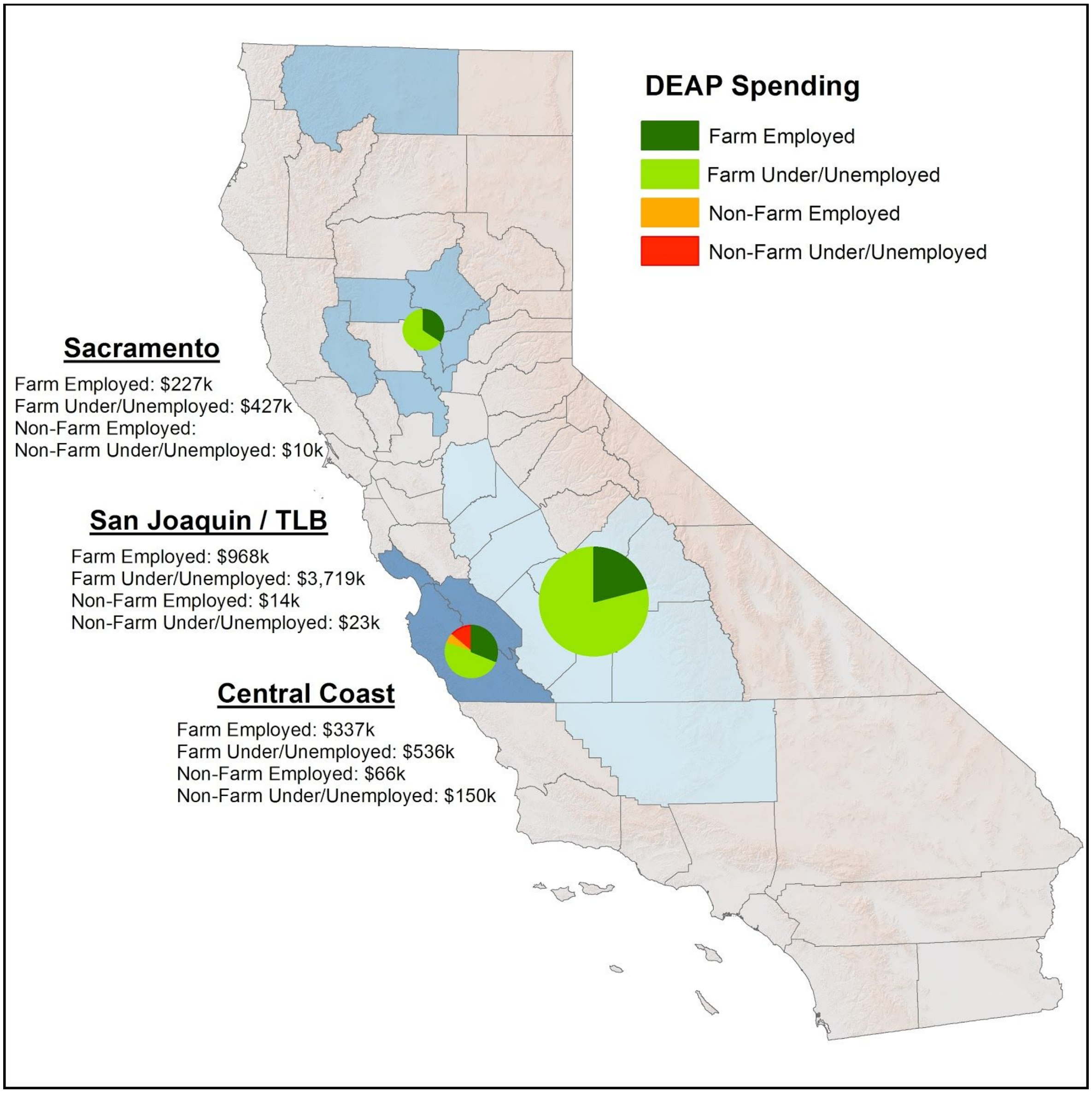

Figure 5. Distribution of financial assistance to households in selected areas of the Drought Emergency Assistance Program (DEAP) from August 2015 to June 2016. Farm category includes farm and farm-related workers. Some counties under the DEAP program are excluded to protect anonymity of recipients.

Policy Implications

Crises such as drought open opportunities to innovate. Learning from past droughts has improved ability to weather current droughts. Some opportunities to improve policy and water management are:

- *Flexibility in Water Allocation.* System-wide robustness to drought can be increased by expediting water transfers having low environmental impact. Post-analysis of recent droughts suggests that water exchanges between rice and other field crop farming in the

Sacramento Valley were crucial in avoiding more costly land idling. A similar approach can help supplement water for cities and support environmental streamflows. A clearinghouse for water exchanges could increase transparency and confidence in the system.

- *Water accounting.* Opportunities to improve water accounting information would help clarify management of water generally, and is especially needed for groundwater sustainability, water rights administration, environmental flows, and more active water markets (Escriva-Bou et al. 2016). An integrated approach led by state agencies using common and well documented data frameworks and repositories, will greatly improve transparency and reliability for drought management.
- *Remote Sensing Data.* While remote sensing and ground monitoring network data provide a great deal of information for estimating water use and idle land conditions, a comprehensive statewide land use survey program should be part of this bundle. This will improve models based on remotely sensed data, including estimates of consumptive use of groundwater, and understanding adaptation to drought.
- *Health of Agriculture.* Agriculture in California has again demonstrated robustness to drought and substantial adaptation capacity. Modest growth in value and employment during dry conditions is likely due to a portfolio approach involving crop mix, intensity in water use, use of carry-over storage, groundwater and water transfers on the management side. Favorable market conditions in a highly diversified California economy also play a role in agriculture's remarkable prosperity, only modestly diminished statewide by drought. Studying water management and policy gaps that could disrupt these adaptations while maintaining low environmental impacts may improve prospects of agriculture under climate change and other stressors.
- *Groundwater management.* Groundwater retains substantial ability to buffer effects of continued drought in much of California, despite 5 years of drought. Studying drought impacts reveals vulnerabilities in the water system specially for agriculture. Groundwater sustainability is a major vulnerability. An examination of possible economic effects on agriculture of the Sustainable Water Management Act will improve preparedness and reduce costs to the farm sector as deadlines for implementation approach.
- *Delta water supplies*. The major drought impacts to agriculture in 2016 arise primarily from reductions in the ability to supply agriculture with water from the Sacramento-San Joaquin Delta. In 2016, this reduction in Delta export capability was primarily due to endangered species restrictions on reverse flows in Old and Middle rivers in the southern Delta. The Delta and groundwater together are the incremental water supplies for agriculture, so demands on these two sources are tied closely.

Limitations and Extensions

Limitations from this work arise from various sources including data, models and assumptions. Some of these have been discussed in Howitt et al. (2015). Yet presented results and insights provide useful information to improve understanding of droughts and consequences, and long term water management in the state. We provide a set of limitations and extensions to consider for current work and future iterations of this analysis.

- *Groundwater data and models*. Information on wells, groundwater levels, rates of extraction and recharge are becoming available via well completion reports, simulation models (C2VSim, CVHM), and water depth monitoring data. Yet uncertainties remain about the potential distribution of groundwater capacity and how this changes over time. The approach employed here for an area in Tulare provides a starting point to improve understanding of interacting aspects of groundwater pumping costs and capacities at a basin scale over time. Insights from the approach include rates at which pumping and surface water conditions change water level depths, pumping costs and well rehabilitating or replacement costs. Prospects for groundwater pumping capacity can help improve cost estimates from models like SWAP. Extension to the approach include time-varying well screen-depth distributions and larger area coverages, which will be useful for longer term drought studies and regional SGMA analyses
- *Water availability.* Every year by April, there is usually a good estimate for statewide surface water reserves. However, water supply conditions change constantly over the course of the irrigation season. Estimates from surveys to irrigation water district and published announcements, and access to groundwater provide a starting point. Yet installation of new wells, dry wells, increased contract water deliveries and water transfers will change prospects for water availability during the season. Better repositories for these elements will improve predictions of drought effects.
- *Impact analysis.* Crop revenue losses and increased pumping costs largely drive primary (direct) economic impacts of drought to agriculture including employment, gross sales (output) and value added. Underlying assumptions from using input-output models like IMPLAN rely on a snapshot of the region's economy and existing interactions. This cascades into the estimated multiplier effects as well. In reality, adaptations in factor use intensity, price adjustments and other compensating mechanisms can reduce impacts of drought on the state's economy. Future work using models which characterize these relationships could improve drought-related economic impact impacts.
- *Employment*. Agricultural labor impact estimation presents tremendous challenges given the large seasonal and market-driven fluctuations in supply and demand, geographies of commodity, uncertainties in the use of contract labor, and the high proportion of undocumented labor. Even finely diced agricultural labor data by commodity, region and season often puzzles researchers. Nevertheless, data from the state's Drought Emergency Assistance Program (DEAP) confirms that the density in farm-related labor force that received assistance coincides with the density of predicted job losses in our economic analysis. A more thorough investigation of farm employment including its mobility, use of contract labor by commodity group and region and proportion of undocumented labor force will improve future predictions of employment impacts under drought.
- *Remote sensing information.* Satellite imagery combined with ground level monitoring data and reasonably recent land use information provide a cost-effective way of learning

about consumptive water use, idle land, and adaptation to drought among other things. Yet lag time between satellite pases, resolution and other uncertainties often pose hurdles to the analyst. Recent regulation easing the way to use of drone technology may help overcome some of these issues and improve future analyses.

Conclusions

In spite of the study limitations and further work, some insights arise from the present analyses:

1. In 2016, persistent drought conditions will likely result in surface water supply losses of about 2.6 MAF, of which 1.9 MAF will be replaced with additional groundwater pumping. As in previous dry years, groundwater reserves are critical for managing drought. Drought effects to agriculture in 2016 were driven largely by low water availability south of the Delta and restrictions on ability to move water across the Delta.
2. Crop fallowing as a result of water shortage is estimated to equal approximately 80 thousand acres relative to average water supply conditions, representing just below 1 percent of all irrigated area in California. About 90 percent of land fallowed due to drought is in the Central Valley south of the Delta.
3. We estimate the 2016 drought results in $247 million loss of farm-gate revenues and 1,815 full and part time jobs statewide. As in previous drought years, losses are concentrated in the Central Valley south of the Delta.
4. When the spillover effects to other sectors of the economy are considered, we estimate total output value losses of $600 million and 4,700 full and part time jobs statewide due to drought. Despite the drought, overall agricultural value and employment grew statewide during recent drought years due to a range of factors including favorable market conditions for some crops.
5. High dairy prices in 2014 were followed by higher forage costs and lower milk prices in 2015 and 2016. Forage costs have since decreased due to wetter conditions. The dairy sector is more vulnerable to market conditions than drought.
6. Some areas including highway corridors in the Central Valley have increased risk of dust exposure.
7. Groundwater continues to be the buffer resource during drought. However, analysis of well completion reports and groundwater depth monitoring data in the Tulare region indicate well maintenance and replacement costs could be significant as water levels approach critical points in well screens. Some of these costs may accumulate as deferred maintenance. From 2012 to 2015 an increase of $1.7 per acre-foot per year in pumping costs is likely to have occurred.
8. A diversified and global California economy has dampened the adverse effects of recent water shortages in agriculture. Losses from water cutbacks to irrigated areas, revenue losses, and statewide impacts have been large, but economic losses have not been as severe as water cutbacks statewide.

Acknowledgements

Authors are thankful for funding provided by the California Department of Food and Agriculture and the Center for Watershed Sciences through a generous donation from the SD Bechtel Jr. Foundation. This work owes a great deal of effort to research, modeling, data and management support from the following people and organizations:

Center for Watershed Sciences
Barbara Bellieu,Cathryn Lawrence, Nicholas Santos, and George Scheer

California Department of Water Resources
Can Dogrul, Charles Brush, and Tariq Kadir

California Department of Community Services and Development
Sylmia Britt and Michael Small

California Employment and Development Department
Muhammad Akhtar, Brandon Hooker, Paul Wessen, and Spencer Wong

California Department of Food and Agriculture
Joshua Eddy, Amrith Gunasekara, Jennifer Lester Moffitt, and Carol Tate

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