Economic Analysis of the 2014 Drought for California Agriculture

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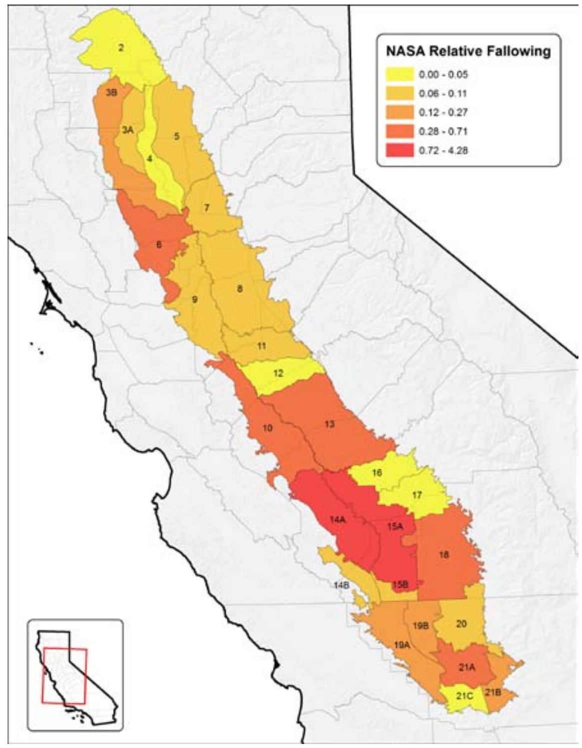

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Executive Summary

California is enduring its third driest year on record as agricultural, urban and environmental demands for water are at an all-time high. This report presents an assessment of the economic impacts of the 2014 drought on crop production, livestock and dairies using a suite of models.

This analysis extends the preliminary estimates of the Central Valley drought impacts released May 19, 2014 (Howitt *et al.* 2014) to include:

- Broadened coverage of the Statewide Agricultural Production Model (SWAP) to include major agricultural areas on California's central and south coasts and inland farms of the Imperial, Coachella and Palo Verde valleys,
- Updated SWAP agricultural production and economic impact estimates for the Central Valley using the most current data available,
- Estimated Central Valley impacts if the drought persists through 2015 and 2016, including economic effects and the impact of increasing groundwater depletion and pumping depths using the California Department of Water Resources' (DWR) C2VSIM model,
- Estimated fallowing of cropland due to drought using the SWAP model,
- Estimated losses to dairies and livestock using a supply elasticity approach based on pasture losses and feed crop prices, and
- Comments on the preliminary draft from various state agencies.

The study finds that the 2014 drought will result in a 6.6 million acre-foot reduction in surface water available to agriculture. This loss of surface water will be partially replaced by increasing groundwater pumping by 5 million acre-feet.

The resulting net water shortage of 1.6 million acre-feet will cause losses of $810 million in crop revenue and $203 million in dairy and other livestock value, plus additional groundwater pumping costs of $454 million. These direct costs to agriculture total $1.5 billion. The total statewide economic cost of the 2014 drought is $2.2 billion, with a total loss of 17,100 seasonal and part-time jobs. Table ES-1 summarizes the key findings of the study.

Table ES-1. 2014 Drought and California Agriculture Summary

Drought impact	Loss quantity
Water supply	
Surface water reduction	6.6 million acre-feet
Groundwater pumping increase	5 million acre-feet
Net water shortage	1.6 million acre-feet
Statewide costs	
Crop revenue loss	$810 million
Additional pumping cost	$454 million
Livestock and dairy revenue loss	$203 million
Total direct losses	**1.5 billion**
Total economic cost	**$2.2 billion**
Total job losses	**17,100**

Approximately 60% of the fallowed cropland, 70% of the statewide crop revenue losses and most of the dairy losses are likely to occur in the San Joaquin Valley. Most crop fallowing is expected for lower-value irrigated pasture and annual crops such as corn and dry beans.

Farms along the coast have access to groundwater and Southern California agriculture largely relies on Colorado River water supplies, which are less affected by this drought. Consequently, these areas are not expected to be significantly affected by the 2014 drought, with estimated direct crop revenue losses and increased groundwater pumping costs of $10 million and $6.3 million, respectively.

Statistically, 2015 is likely to be another dry year in California – regardless of El Niño conditions. Continued drought in 2015 and 2016 would lead to additional overdraft of aquifers and lower groundwater levels, thereby escalating pumping costs, land subsidence and drying up of wells. Additional dry years in 2015 and 2016 would cost Central Valley crop farming an estimated total of $1 billion a year.

These results highlight California agriculture's economic resilience and vulnerabilities to drought. They also underscore California's heavy reliance on groundwater to cope with droughts. Without replenishing groundwater in wet years, water tables fall and both reduce regional pumping capacity and increase pumping energy costs – ultimately threatening the viability of higher value permanent crops in some areas.

The 2014 drought has magnified our need to better understand two major mechanisms used to respond to drought in California: groundwater management and water markets. While our aggregate measures of groundwater depth over time and space are often good, our estimates of regional groundwater use are poor.

This lack of groundwater pumping information precludes most forms of regional groundwater management. Water markets are operating in a largely informal manner with reports of extremely high prices being paid throughout the Central Valley – prices at least three times those seen in the 2009 drought. However, the absence of a central clearinghouse for water trade information prevents normal market information on current prices and quantities from being available to buyers and sellers, which complicates coordination of water movement.

The following conclusions arise from this analysis:

- The 2014 drought is responsible for the greatest absolute reduction in water availability for California agriculture ever seen, given the high agricultural demands and the low streamflows and reservoir levels. Surface water availability is expected to be reduced by about one-third.
- Groundwater availability and use is the key to agricultural prosperity in the 2014 drought and future droughts. This year, groundwater may replace as much as 75% or 5 million acre-feet of the roughly 6.6 million acre-foot loss of available surface water. This would raise groundwater's share of agricultural water supply in California from 31% to 53%. Failure to replenish groundwater in wet years will continue to reduce groundwater availability to sustain agriculture – particularly more profitable permanent crops – during California's frequent droughts.
- Statistically, the drought is likely to continue through 2015 – regardless of El Niño conditions. If the drought continues for two additional years, groundwater substitution will remain the primary response to surface water shortage, with decreases in groundwater pumping capabilities and increasing costs due to declining water levels. A continued drought also increases the vulnerability of agriculture, as urban users with largely adequate supplies in 2014 will likely buy water from agricultural areas.
- Net water shortages for agriculture in this year's drought most severely affect the Central Valley with at least 410,000 acres lost to fallowing, $800 million in lost farm revenues and $447 million in additional pumping costs. These effects are most severe in the Tulare Basin. Dairy and

livestock losses from reduced pasture availability and higher costs of hay and silage add $200 million in agricultural revenue losses.

- Coastal and Southern California farm regions are less affected by the 2014 drought, with approximately 19,000 acres fallowed, $10.1 million in lost revenue and $6.3 million in additional pumping costs.
- State and regional policymakers concerned with drought should pay special attention to (1) groundwater reliability, (2) the ability of state and county governments to provide technical and organizational assistance to rural communities and (3) facilitating voluntary water trades between willing parties, including the defining of a standard environmental impact report for water transfers that can be assessed and approved prior to droughts. These policies would give local governments the ability to reduce the impacts of droughts to rural and agricultural areas and economies susceptible to water scarcity.

Introduction

The California Department of Food and Agriculture and the University of California, Davis, jointly funded the UC Davis Center for Watershed Sciences to estimate economic impacts of the current drought on California agriculture.

In conducting this work, the UC Davis Center for Watershed Sciences has collaborated with ERA Economics for updating and using the SWAP model of agricultural production in California, the California Department of Water Resources (DWR) to account for groundwater table depth interactions with the SWAP model, NASA for remote sensing estimates of fallowing, and the University of California's Agricultural Issues Center to estimate effects on dairies and livestock.

Drought water shortage conditions were developed in consultation with the Drought Task Force, DWR and local water providers.

This analysis builds on the preliminary estimates of Central Valley agricultural drought impacts report of May 19, 2014 (Howitt *et al.* 2014). New features include:

- Broadened coverage of the Statewide Agricultural Production Model (SWAP) to include selected major agricultural areas in California's central and south coasts and inland farms of the Imperial, Coachella and Palo Verde valleys,
- Updated SWAP agricultural production and economic impact estimates for the Central Valley using the most current data available,
- Estimated Central Valley impacts if the drought persists through 2015 and 2016, including economic effects and the impact of increasing groundwater depletion and pumping depths using DWR's C2VSIM model,
- Estimated fallowing of cropland using two remote-sensing methods and SWAP modeling,
- Estimated losses to dairies and livestock using a supply elasticity approach based on pasture availability and feed crop prices, and
- Comments on the preliminary draft from various state agencies.

Results are presented by crop group and region, with estimated impacts to crop acreage, employment, revenues and regional income. These results are from the integrated modeling framework developed for this project. The framework includes the widely used SWAP model linked with the IMPLAN model of regional economic and employment impacts, and the C2VSim groundwater-surface water simulation model.

Given the heavy reliance on groundwater to mitigate the 2014 drought, and the statistical likelihood that 2015 and 2016 will be dry years (Lund and Mount 2014), we evaluate the economic impacts of an extended drought (using less severe 2009 water delivery conditions). We summarize the drought-impact estimates for 2014 and for an extended, but less severe drought though 2015 and 2016.

The report is structured as follows:

- Water availability estimates
- Estimates of crop production and agricultural economic impacts for the Central and Salinas valleys and farm regions of Southern California
- Economic and production estimates for dairies and livestock
- Comparison of three estimates of 2014 fallowing because of the drought
- Study limitations and extensions
- Conclusions and policy recommendations
- Appendix detailing study methods, data and assumptions

Water Supply Availability

California is enduring its third driest year in 106 years of recordkeeping as agricultural, urban and environmental demands for water are at an all-time high.

Drought Curtailments from Water Agencies and Waterboard Emergency Regulations

On Jan.17, 2014, Governor Brown declared a drought emergency, triggering emergency regulations to protect habitat in the Sacramento-San Joaquin Delta and allowing a range of additional state actions. Since then, the State Water Resources Control Board has curtailed diversions for various water-right holders and some environmental flow requirements. Major state, federal and local water projects have also reduced water allocations, mostly to record lows.

Even today, the effects of water-right curtailments and reduced project releases for agriculture are not entirely clear. Many of them were anticipated in this year's irrigation district allocations to farmers. Here, we use the results of a survey of allocation reductions from irrigation districts to represent all water allocation and right curtailments.

Water Supply Availability and Groundwater Pumping

Table 1 summarizes the estimated reductions in water availability by year and region. The 2014 drought has decreased surface water availability by 6.6 million acre-feet relative to an average water year. Less severe drought conditions in 2015 and 2016 could be expected to reduce surface water availability by approximately 6 million acre-feet a year.

Table 1. Change in Surface Water by Region Relative to an Average Year (in millions of acre-feet a year)

Region	**Surface water use change**		
	2014	2015	2016
Sacramento Valley, Delta and East of Delta	-1.8	-2.3	-2.3
San Joaquin Valley	-1.8	-1.4	-1.4
Tulare Lake Basin	-3.0	-2.3	-2.3
Central Valley subtotal	**-6.5**	**-6.0**	**-6.0**
Central Coast	0.0		
South Coast	0.1		
South Inland	0.0		
Statewide	**-6.6**		

Note: 2015 and 2016 analysis was limited to the Central Valley.
Any differences in totals are due to rounding error.

In normal years, agricultural water use in the areas modelled by the SWAP model is about 26 million acre-feet (maf), with 18 maf from surface water and 8 maf from groundwater. For 2014, this water use is estimated to be reduced by about 1.5 maf. A 6.6 maf drought-related reduction in surface water availability amounts to a 36% reduction in surface water availability for agriculture, or a 25% reduction compared with total normal agricultural water use.

The proportion of irrigation water from wells is expected to jump from 31% to 53% this year. (The figures account for an estimated 1.5 maf reduction in total agricultural water use.) This amounts to a 62% increase in groundwater pumping.

The ability to increase groundwater pumping as a substitute for decreased surface water supplies is critically important to California's ability to cope with drought. Increased groundwater extraction, beyond diminished recharge during droughts, decreases groundwater levels, reduces groundwater quality and increases land subsidence (sinking). As groundwater levels drop, the costs to extract groundwater increase. In some areas, water levels can drop below the installed capacity of existing wells, causing wells to go dry and reducing groundwater pumping capacity for subsequent drought years.

This study estimates the increase in pumping cost and loss of well capacity due to declining water levels. The percentage of wells likely to go dry was estimated using statistical regression analysis of the distribution of existing well depth, which was estimated from well logs for each SWAP model region.

In areas with no alternative water supply, groundwater levels begin to drop below installed well depths, which increasingly forces growers to fallow fields. In areas with deeper wells, growers still have access to groundwater but must pay more in energy costs to extract it. In some areas it may not be profitable to irrigate standard crops and growers would adjust crop rotations or fallow fields.

Table 2 summarizes the estimated groundwater replacement and additional groundwater pumping cost in each year. Growers are expected to pump an additional 5 million acre-feet to partially offset surface water reductions, at a direct cost of $454 million. Drought in 2015 in 2016 would likely prompt additional pumping of 5 million acre-feet and 4.9 million acre-feet, respectively, at a cost of $438 million and $459 million.

The additional pumping in 2014 will drop water levels from a few feet to tens of feet, causing some grower to lose their wells and others paying more to pump from them. Come 2016, pumping costs increase by an additional 5%, primarily because of falling water tables. Our statistical analysis of the well depth finds a small percentage of wells going dry in each subsequent drought year.

Table 2. Additional Groundwater Use and Cost by Region Relative to an Average Year

	Additional use (maf/yr)			**Additional cost ($million/yr)**		
	2014	2015	2016	2014	2015	2016
Sacramento Valley, Delta and East of Delta	0.9	1.6	1.6	35.4	63.2	65.5
San Joaquin Valley	1.5	1.2	1.2	71.9	63.2	68.7
Tulare Basin	2.6	2.2	2.2	340.3	312.5	324.8
Central Valley subtotal	**5.0**	**5.0**	**5.0**	**447.6**	**438.9***	**459.1**
Central Coast	0.0	NA	NA	0.3		
South Coast	0.1	NA	NA	0.0		
Colorado River region	0.0	NA	NA	6.0		
Statewide	**5.1**	**5.0**	**5.0**	**453.9**		

Notes: 2015 and 2016 analyses were restricted to the Central Valley, where groundwater information is more available.

* Reduction in pumping cost for 2015 comes from a shift in pumping to areas of the Central Valley with higher groundwater tables.

Regional Crop Production and Economic Impacts of the Drought

The economic impacts of drought have been aggregated into six areas: (1) Sacramento Valley, Delta and East of the Delta, (2) San Joaquin Valley South of the Delta, (3) Tulare Lake Basin, (4) Salinas and Santa Maria valleys on the Central Coast, (5) South Coast and (6) inland agriculture in the Imperial, Coachella and Palo Verde valleys.

Crop types were aggregated from the standard 20 crop groups in the SWAP model to four groups compatible with the IMPLAN macroeconomic model: (1) cotton, grain and oilseed, (2) vegetables and non-tree fruit, (3) tree fruit and nut and (4) feed and other crops.

Table 3 and Figure 1 summarize changes in irrigated acreage by region for 2014 - 2016. The SWAP model estimates the response of growers to drought, including the decision to fallow land.

In the Central Valley, high-value crops including vegetables, non-tree fruits and permanent crops represent less than 13% of total fallowing as growers direct scarce water to the highest value use. Most of the crop fallowing is estimated to be feed and other annual crops. This pattern is repeated across years, fallowing in the valley declines from 408,000 acres in 2014 to 243,000 acres by 2016. The coastal areas and Southern California have access to surface and groundwater and are not expected to fallow significant acreage.

Table 3. Changes in Irrigated Crop Areas by Region and Crop Group (in thousands of acres)

2014 Statewide					
	Cotton, grain and oilseed	Feed and other crops	Fruit and nut trees	Vegetables and non-tree fruit	Total
Sacramento Valley, Delta and East of Delta	-54	-83	-9	-4	-151
San Joaquin Valley	-76	-39	-8	-3	-125
Tulare Basin	-81	-24	-24	-4	-133
Central Valley subtotal	*-211*	*-147*	*-41*	*-10*	*-409*
Central Coast	0	-3	0	0	-3
South Coast	-5	-8	0	0	-13
Colorado River region	-0.16	-3	0	-0.1	-4
Total	**-216**	**-160**	**-41**	**-10**	**-428**
2015 Central Valley					
Sacramento Valley, Delta and East of Delta	-52	-97	-7	-3	-159
San Joaquin Valley	-17	-32	-4	-0.5	-54
Tulare Basin	-7	-5	-15	-0.5	-27
Total	**-77**	**-133**	**-26**	**-4**	**-240**
2016 Central Valley					
Sacramento Valley, Delta and East of Delta	-52	-97	-5	-3	-157
San Joaquin Valley	-17	-32	-4	-0.4	-54
Tulare Basin	-13	-8	-10	-1	-32
Total	**-82**	**-137**	**-20**	**-4**	**-243**

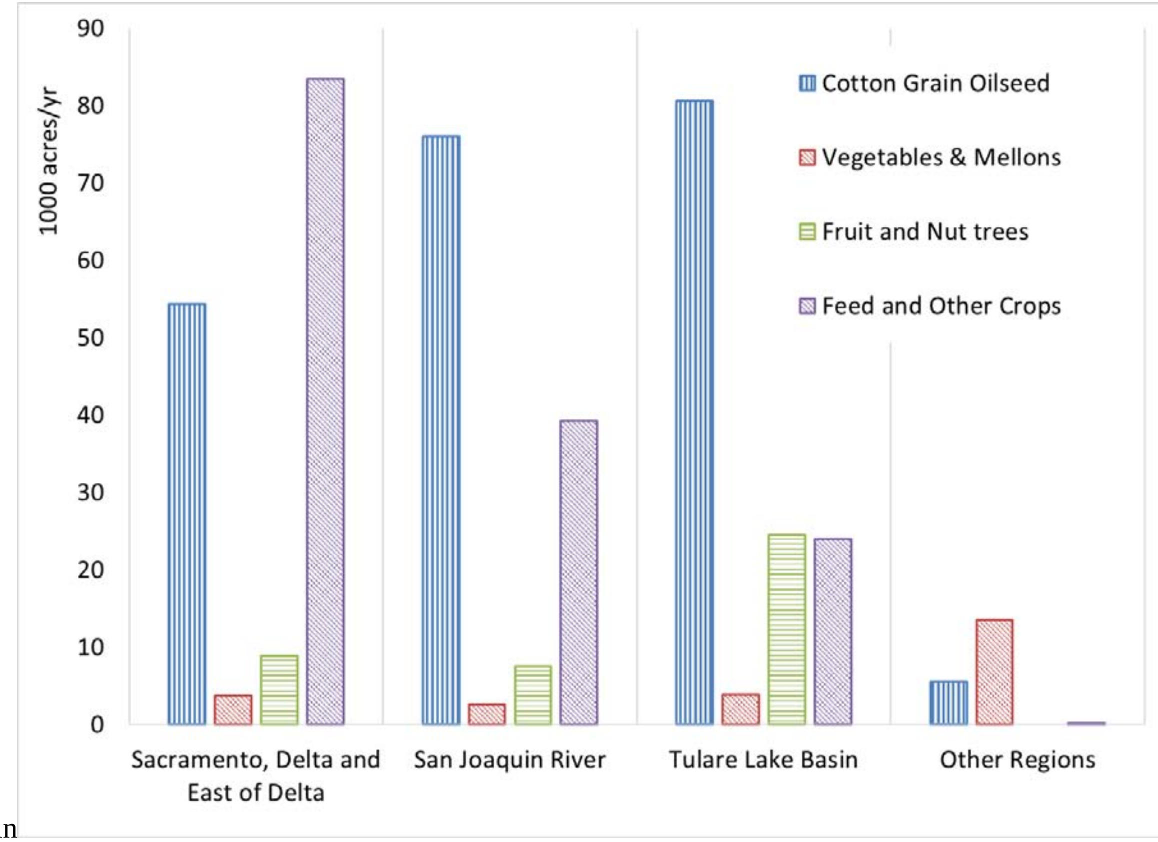

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Figure 1. Crop acreage reductions in 2014 drought, Central Valley regions

Drought Effects on Gross Crop Revenues

Table 4 and Figure 2 summarize the estimated change in gross crop revenues because of drought. For the Central Valley, the 2014 drought costs approximately $800 million. Approximately 70% of these losses occur south of the Sacramento-San Joaquin Delta largely because of the severe cutbacks in Delta exports, which provide much of the region's water supply. A similar pattern can be seen if the drought persists through 2015 and 2016, with somewhat increased surface water deliveries. An additional $10 million in gross crop revenue losses is expected in the coastal areas and inland Southern California.

Table 4. Changes in Crop Revenues by Area and Crop Group (in millions of dollars, 2014 values)

2014 drought					
	Cotton, grain and oilseed	Feed and other crops	Fruit and nut trees	Vegetables and non-tree fruit	Total
Sacramento Valley, Delta and East of Delta	-76.8	-76.8	-52.7	-13.2	-219.4
San Joaquin Valley	-105.7	-42.6	-46.3	-12.7	-207.3
Tulare Basin	-123.8	-51.2	-179.0	-19.5	-373.4
Central Valley subtotal	-306.3	-170.5	-277.9	-45.4	-800.1
Central Coast	0.0	-0.7	0.0	0.0	-0.7
South Coast	-2.7	-5.9	0.0	0.0	-8.5
Colorado River region	-0.1	0.8	0.1	-1.7	-0.9
Statewide	-309.2	-176.3	-277.8	-47.1	-810.3
2015 drought					
	Cotton, Grain and oilseed	Feed and other crops	Fruit and nut trees	Vegetables and non-tree fruit	Total
Sacramento Valley, Delta and East of Delta	-76	-80	-43	-10	-209
San Joaquin Valley	-25	-25	-27	-2	-79
Tulare Basin	-11	-9	-100	-3	-123
Central Valley	-112	-114	-170	-15	-411
2016 drought					
	Cotton, grain and oilseed	Feed and other crops	Fruit and Nut trees	Vegetables and non-tree fruit	Total
Sacramento Valley, Delta and East of Delta	-76	-80	-31	-10	-197
San Joaquin Valley	-24	-25	-27	-2	-78
Tulare Basin	-19	-13	-70	-5	-108
Central Valley	-120	-118	-128	-17	-383

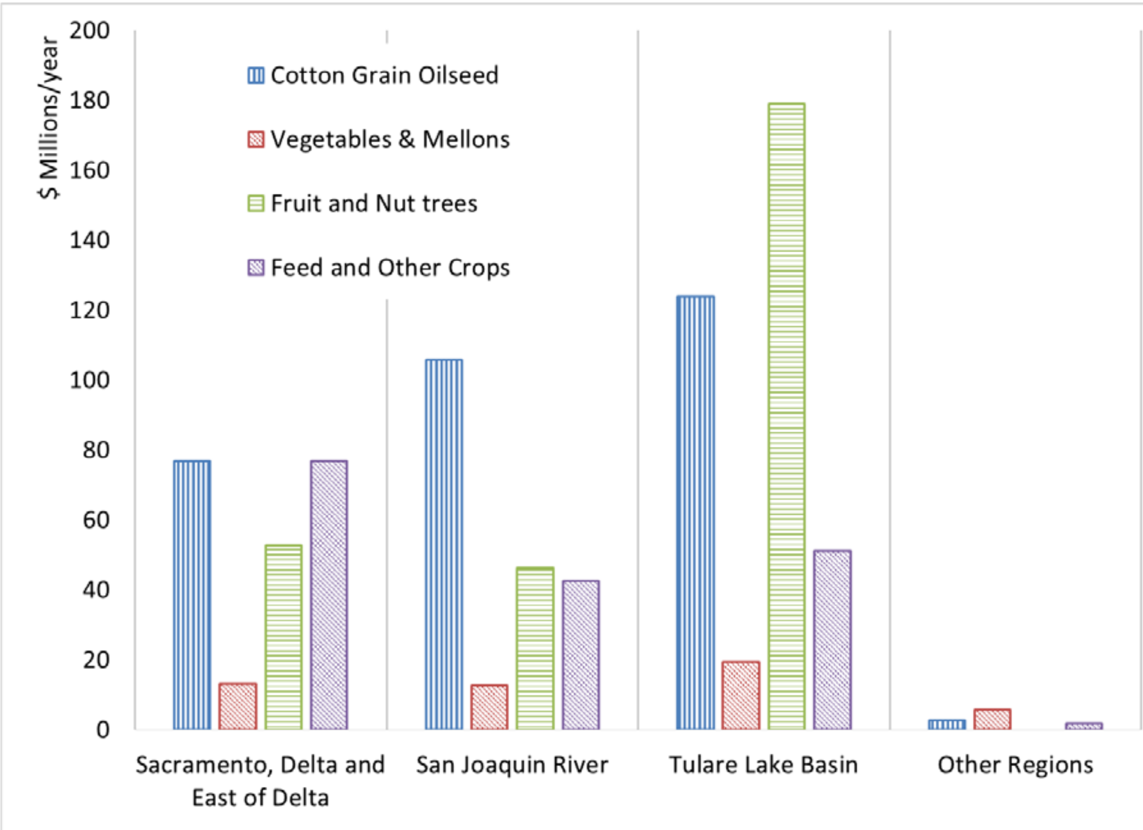

Figure 2. Crop revenue reductions for 2014 drought, Central Valley regions

Drought Effects on Commodity Prices

The SWAP model includes crop demand functions for world market crops and those crops in which California has a large enough share of the relevant market to face downward sloping demands. Almonds and pistachios, some subtropical and citrus crops as well as vegetables and non-tree fruits are included under this last set of commodities. Model runs indicate some price increases for forage and field crops in response to the decreased production during the drought. However, these price changes do little to compensate for losses from fallowing, lower yields (from hay crops) and increased pumping costs. The exception may be the total market for alfalfa where higher California prices may offset some of the higher costs of irrigation and lower alfalfa yields.

Drought Effects on Dairies

Dairies and other livestock comprised 30% or $12.4 billion of California's total agricultural commodity value in 2012. Dairy industry revenue totaled $6.9 billion while revenue from cattle and calves totaled $3.3 billion (CDFA 2014).

More than 65% of dairy production cost is for feed. Alfalfa hay alone is about 20% of feed costs and silage adds another 10% to the bill. Alfalfa hay prices have increased 40% since January 2014. Most feed concentrates are made of corn, soymeal and other grains from the Midwest. Corn and other grain and oilseed prices have declined in the past year. Higher local feed costs have increased the total production cost for dairy by about 12%. Dairy production can adjust monthly, but supply response to temporary disruptions tends to be small. Yu and Sumner (2014) suggest a short run supply elasticity with respect to feed prices of about -0.1 for milk production. All else equal, we would expect dairy production to be reduced by 1.2%. However, the price of milk and cattle has increased substantially since 2012, and are currently at historic highs. With higher than normal milk revenue to feed cost margins in 2014, we expect somewhat less short term supply response to higher forage costs for dairies.

Our middle range estimate for the reduction in dairy output is 1.5% relative to an average year, leading to a reduction of $104 million in statewide direct impacts.

Drought Effects on Livestock

The beef cattle industry in California includes cow-calf, feeder cattle and stocker and feedlot operations, with cow-calf and feedlots accounting for the largest proportion of sales in this sector with $3.1 billion in gross sales. Cattle are often marketed several times over their life so gross sales includes those intermediate transactions. The poultry industry, including eggs, broilers and turkeys, is significant but less likely to be affected by drought because poultry eat mostly on concentrate feeds from out of state. Sheep and hogs account for a very small share of California agricultural value.

Impacts of the California drought on cattle are moderated by three factors. First, California has a small share of the national beef herd. From this, about 2 million calves are 6% of the national total, whereas cattle on feed (steers and heifers) are 4%. California faces national prices for cattle and conditions here have little impact on the national supply situation. Second, feed concentrates for cattle are largely from out of state, prices rose after the 2012 Midwest drought, but have declined and are back to 2009 prices in 2014. Dry roughage (alfalfa hay) prices are high, but hay is a small proportion of the total costs for the beef industry. Third, the economic cycle for the sector is at a stage of low cattle numbers and high prices, so producers have seen larger profits in the past two years and 2014 prices are at historic highs.

The impact of the California drought has been mainly through effects on pasture. Pasture, including irrigated pasture, is the most important source of feed for the pre-feedlot segment of the industry. The California drought, especially the lack of rain in the winter of 2013-2014 reduced pasture quality and the number of cattle per acre substantially during the crucial winter and spring period of calving and raising of feeder cattle on pasture. This lack of feed caused sales of calves and some cows out of the state. Furthermore, irrigated pasture mostly used for beef cattle will face higher pressure from other crops needing water during drought, thus cattle numbers have some additional pressure to decline. The drought also has increased alfalfa hay prices, so feeding in confined feedlots became more expensive. We expect 3% or more in revenue losses for the sector in 2014 due to lack of pasture and $100 million reduction in statewide gross revenues.

Drought Effects on Groundwater Use and Cost

Increased costs of groundwater will be significant. For 2014, replacing about 5 million acre-feet of surface water with groundwater will cost $447 million dollars in the Central Valley and about $6.3 million elsewhere in the state. By 2016, the additional cost could increase to nearly $460 million for the Central Valley.

Since we do not see a significant change in commodity prices, we define this cost as a loss in net revenues for the farmer. From a statewide perspective, the cost of increased electricity can be considered as a transfer from the farming sector to the power generation sector. About 89% of increased pumping costs occur south of the Delta, where only 40% of the power generation capacity occurs. Some of the additional expenditures on energy may return to the Central Valley economy. Some additional direct jobs in the power generating sector will depend on the structure of the power industry.

Statewide Total Economic Impacts

Gross revenue losses from the SWAP model and of the effects on dairy and livestock revenues are linked to the IMPLAN input-output model. The model takes direct changes in sector output (gross sales or revenues) and provides detailed information on direct, indirect and induced effects from the economic event (drought) by tracing expense on other economic sectors and households as employment, labor income, value added, and sector output.

In this section, we present a summary of IMPLAN results by year and commodity type.

Employment has been adjusted to account for both part-time and full-time employment. Labor income represents both wages from employees and proprietor income. Value added is the difference between total sector output (gross revenues) and the non-labor business expenses. Changes in value added can be used as a measure of the agricultural sector's gross domestic product and is a measure of economic activity in a region (Medellin-Azuara *et al.* 2012).

Direct effects show the first round effects of an economic change. Indirect effects are the estimated losses from all other sectors associated with agricultural crop production. The induced effects trace household expenses from both households employed in crop farming and households receiving income from related sectors of the economy. The sum of the direct, indirect and induced effects is called the total or multiplier effect.

Economic Impacts by Year and Region

Tables 5 and 6 summarize the economic impacts from crop farming, increased groundwater pumping, and livestock and dairies for the entire Central Valley and central coast and Southern California agriculture. Table 5 summarizes the 2014 drought effects and Table 6 summarizes the 2015 and 2016 drought.

For a 1.5% loss in the dairy industry and 3% loss for the cattle industry, direct revenue losses of about $203 million could be expected statewide. When the multiplier effects are included, the overall reduction in revenue is $442 million and approximately 1,615 seasonal and full-time jobs statewide.

Statewide economic impacts for the 2014 drought total an $2.2 billion in lost revenue and 17,100 jobs lost.

Table 5. Economic Impacts of the 2014 Drought ($ in millions*)

Impact type	Employment	Labor income ($)	Value added ($)	Output ($)
Central Valley crops				
Direct Effect	-6,722	-274.5	-310.5	-800.1
Total Effect	-15,183	-581.2	-894.6	-1,728.9
Crops in Salinas Valley, inland and coastal Southern California				
Direct Effect	-200	-5	-5	-10
Total Effect	-297	-13	-10	-23
Statewide livestock and dairies				
Direct Effect	-582	-19.8	-67.4	-202.5
Total Effect	-1,615	-71.7	-164.1	-441.9
Statewide economic impacts				
Direct Effect	-7,504	-299	-383	-1,013
Total Effect	-17,095	-666	-1,069	-2,194

*Denomination corrected from earlier version

Table 6. Economic Impacts of a 2015 and 2016 Drought in the Central Valley ($ in millions*)

Impact Type	Employment	Labor income ($)	Value added ($)	Output ($)
2015 drought				
Direct Effect	-3,158	-146.9	-167.3	-408.7
Total Effect	-8,495	-349.0	-551.1	-1,016.8
2016 drought				
Direct Effect	-2,965	-129.2	-147.1	-378.4
Total Effect	-8,047	-323.8	-519.8	-969.6

*Denomination clarified from earlier version

Summary of Total Economic Impacts

Table 7 summarizes the total economic impact of the drought and compares the estimated losses with the magnitude in an average water year from previous sections.

Table 7. 2014 Drought and California Agriculture Summary

Drought impact	Loss quantity	Average year	Percent loss
Crop production			
Water Use	6.6 maf	26 maf	25%
Net shortage after increased groundwater pumping	1.5 maf	26 maf	6%
Fallowed irrigated land	428,000 acres		
Crop revenue loss	$810 million	$35 billion	2.3%
Revenue lost plus additional pumping cost ($454 million)	$1.26 billion	n/a	
Economic loss	$1.75 billion	n/a	
Direct crop production job losses (seasonal and full-time)	6,920	170,000	4.0%
Direct, indirect and induced job losses	15,480	n/a	
Dairy and livestock production			
Direct revenue losses	$203 million	$12.4 billion	1.6%
Total revenue losses	$442 million	n/a	
Direct crop production job losses (seasonal and full-time)	580	29,000	2%
Direct, indirect and induced job losses	1,615	n/a.	
State agriculture totals, 2014			
Revenue loss	$1.0 billion	$45 billion	2.2%
Revenue lost plus additional costs ($454 million)	$1.5 billion	n/a	
State agricultural economic loss	$2.2 billion		
Direct crop production and livestock job losses (seasonal and full time)	7,500	200,000	3.8%
Direct, indirect and induced job losses (seasonal and full-time)	17,100	n/a	

Comparison with the 2009 Drought

Our analysis of the socioeconomic impacts of the 2014 drought finds that impacts are likely to be significantly higher than those in 2009 (Howitt *et al.* 2011). The 2009 drought resulted in estimated total losses of 7,500 jobs and 270,000 acres fallowed. In contrast, the 2014 drought is estimated to cause 17,100 jobs lost and 428,000 acres fallowed. The most significant difference between the 2009 and 2014 drought is that CVP and SWP contracted water is significantly lower. In addition, Friant Division contractors are projected to receive no deliveries and many local surface water supplies on the east side of the valley are reduced because of decreased Sierra snowpack. The combined socioeconomic effects of the 2014 drought are up to 50 percent more severe than in 2009.

Estimates of Agricultural Fallowing

We estimated fallowing attributable to the 2014 drought using the SWAP model. The model results can be cross-checked with inferences from USDA crop acreage surveys and estimates based on remote-sensing data. The USDA surveys and remote-sensing methods can identify the total change in irrigated acreage. But they cannot estimate the proportion of that change attributable to the 2014 drought without more detailed statistical analysis to control for other factors that affect fallowing. As such, these surveys and remote-sensing data should be viewed as an estimate of the total idle agricultural land, not fallowing attributable to the drought.

On June 30, USDA published its estimates of crop acres for selected crops in California. We do not use this information for our projected losses for California irrigated crops for two reasons. First, the USDA y collects only information for what they define as "principal" crops (based on national acreage), which account for only half of the state's irrigated acreage. Second, the USDA measurement of the winter wheat crop in California includes dryland wheat and partially irrigated winter wheat. These caveats aside, the USDA data are consistent with our estimates for the crops covered.

Remotely sensed estimates of idle cropland were generated by a NASA-USDA-USGS team working with DWR. They used the time series of Normalized Difference Vegetative Index (NDVI) data – collected by four NASA and USGS satellites and composited every eight days – to generate separate estimates of idle cropland for the winter and summer growing seasons.

Their preliminary 2014 idle-acreage estimates for summer (compared with 2011) are thought to be high, perhaps by as much as 50%, mainly because of delays in planting. Those delays resulted in a much higher percentage of acreage appearing to be bare or having scant vegetative cover in June. In fact, field validation surveys show those fields had just been planted or were being prepared for planting.

NASA expects that estimates for summer in early August (using satellite data through July 31) will have much lower uncertainty. In addition, new remote sensing based estimates of idle acreage available from the USDA National Agricultural Statistics Service will also be incorporated into the analysis.

A similar approach was employed by UC Davis, using both NDVI and the near infrared reflectance on surface for three Landsat 7 and 8 Row Paths in the Central Valley, excluding some portion of Shasta County, the Delta and southern Kern County in late May and early June 2012-2014. We also find high uncertainties associated with a late start in the growing season. Preliminary estimates indicate at least 295,000 acres of idle agricultural land for the San Joaquin Valley and the Tulare Basin in late May.

Table 8 shows the range of idle cropland estimates from SWAP and NASA.

Table 8. Estimates of Idle Irrigated Cropland for 2014 in the Central Valley (in thousands of acres)

Region	**SWAP 2014-2012**	**NASA 2014-2011**	**Range**
Sacramento Valley	151	130-260	151-260
San Joaquin Valley	125	115-230	125-230
Tulare Lake	133	380-760	133-760
Central Valley total	409	645-1,290	409-1,290

Notes: The SWAP model estimated fallowed acreage due to 2014 drought.
NASA's estimated idle acreage is the total idle land due to all factors including drought.

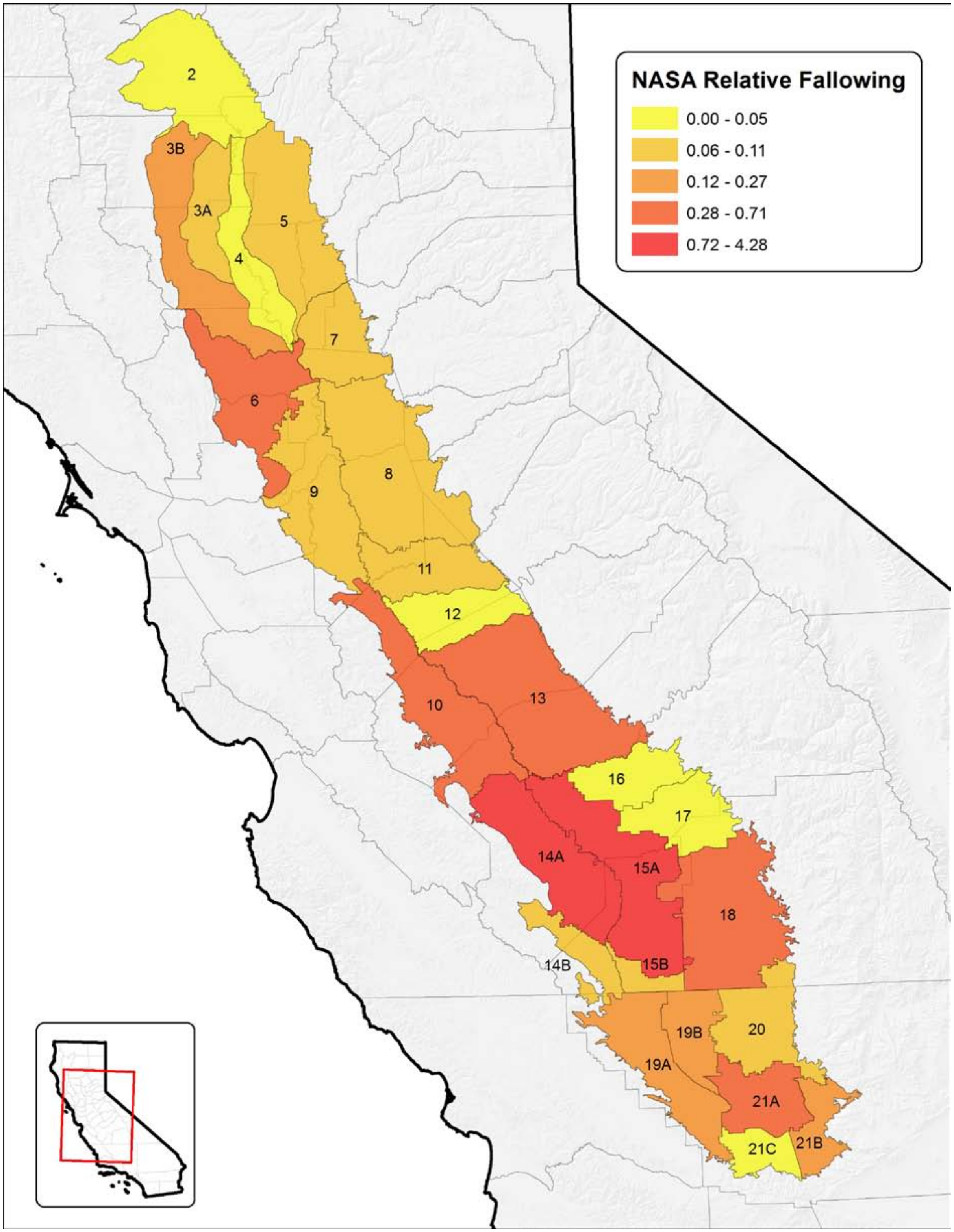

Figure 3. Difference in Idle Central Valley cropland between 2014 and 2011, relative to the total agricultural land in each region. Prepared by authors using information from the Satellite Mapping consortium project of DWR, NASA Ames Research, CSU-Monterrey Bay, USGS and the USDA.

Some Public Policy Implications

The effects of such a severe drought on California's large agricultural economy would be much greater without two resources: 1) extensive groundwater availability and 2) the availability of water markets to re-distribute water to crops with the highest economic value while compensating selling farmers. The safeguarding and development of these two resources are essential for mitigating economic effects of the drought continuing, as well as future droughts. We suggest six areas of public and technical policy improvements which could enhance California's ability to deal with future droughts.

1. Groundwater management. Currently California is the only western state without state groundwater rights regulations or measurements on major groundwater use. A first step to local groundwater management, as opposed to groundwater regulation, is to measure pumping. Currently, two groundwater policy bills under consideration in California, and the key role of groundwater in drought provides incentives for more management of groundwater, to help assure groundwater support for crops in drought conditions.

2. Water Trade Environmental Impact Reports (EIRs). Water trading is another key to successful drought management. Many water trades induce adverse environmental impacts, so EIRs are needed for water trades. However, it is equally important that environmental considerations are not used as a trade blocking device by those who oppose trades for other reasons. This happened to several proposed water trades during the 2009 drought. A policy solution is to define a generic EIR for water transfers that can be assessed prior to a drought. If the pre-drought EIR is approved then the transfer can proceed, with any later damages adjudicated through a legal system after the fact. This policy change would lower the costs of water transfers, and provide greater predictability and flexibility during drought.

3. A Water Trade Clearing House (or ISO). The surface water distribution system in California is an interdependent network of individually run canals, reservoirs, and rivers. Coordinated operating agreements and contracts exist among some agencies, but moving water efficiently under drought conditions could be improved. California's water system has parallels to the electricity grid system before its reorganization. Today, California's electric power is routed and dispatched with a market and prices managed by an Independent System Operator (ISO). A similar water ISO might operate to improve adaptability and responsiveness (Hanak et al 2011). It would take significant federal and state level political impetus to implement a similar system for water, but it remains a promising policy innovation.

4. Linking Groundwater and Economic models. Groundwater's importance has been emphasized, but the motivation for groundwater use is economic, while the costs are determined by hydrogeology. Modeling outcomes for different groundwater (and larger water system) management actions requires close coupling of groundwater and larger water supply system models with economic models of water use. Alternative approaches for such modeling need to be tested and evaluated.

5. Remote Sensing of Water Use. This study demonstrated the promise and limitations of remote sensing estimates of land fallowing. Remotely sensed land and water use data should be able to provide a real time cross-check of the water supply-based estimates of land fallowing and economic outcomes. In the 2009 drought it was only long after the drought that definitive estimates of fallowed land were available. Remotely sensed estimates potentially offer an information system that can be used for management during the drought period. An impartial inter-agency consortium should be established to develop and evaluate alternative remotely sensed water use measures.

6. Water Data Management. The spatial and temporal resolution of remotely sensed water information promises to generate a tsunami of data. Alternative systems of structuring, managing, and accessing this data should be researched and tested before the wave arrives. Several emerging protocols exist for water data management, for example Hydro-platform that can form the basis of data management tests.

Limitations and Extensions

Results from the SWAP model are fundamentally driven by the estimates of water availability detailed above. Of necessity, these estimates were made from surveys of irrigation districts, announced CVP and SWP contract deliveries, and groundwater pumping estimates from the California Department of Water Resources. All of these sources of information have associated errors which should diminish as the drought develops and more information becomes available.

Crop prices used were based on 2013 price levels which have been influenced by other non-drought related effects. Therefore, to identify the effect of drought on crop prices we have held other factors constant and thus show relatively small drought-related price changes.

The aggregate regional impacts mask significant variability in regional impacts. Several east-side communities are facing a severe risk of losing access to minimum water supplies with consequent effects on local economies. Some communities will be affected by the loss of agricultural production and other communities will be affected by the loss of farm jobs.

We have made every attempt to be clear about the data, methods and assumptions underlying this analysis, but are mindful that we are dealing with a complex economic system that is driven by an evolving water shortage and market forces.

Over the course of this project we have identified several broad and important areas for future research:

- The need for better integration of economic models such as SWAP with groundwater models such as C2VSim. We believe that an integrated hydrologic and economic modeling framework would be a valuable tool for a long-term agricultural economy that relies on groundwater.
- We are aware that the two main avenues for drought response, namely groundwater and water markets, require timely data and information. We see measurement of water use and transparency in transactions as essential prerequisites to an efficient market allocation of water resources.
- We see a strong potential in remotely sensed estimates of land and water use as a cost-effective and timely source of information.
- The water use and remote sensing data available so far, as of the end of June, remains early in this agricultural irrigation season. When data becomes available on cropping and field idling after and later in this irrigation season, there will be a better basis for both estimating the agricultural impacts of the drought and improving our methods for remote sensing and modeling impact estimation, management and policy analysis.

Conclusions and Policy Recommendations

The following conclusions arise from this analysis.

- The 2014 drought is responsible for the greatest absolute reduction to water availability for agriculture ever seen, given the high agricultural demands and low streamflows and reservoir levels. Surface water availability is expected to be reduced by about one-third.
- Groundwater availability and use is the key to agricultural prosperity in the 2014 drought and future droughts. This year, groundwater may replace as much as 75 percent or 5 million acre-feet of the roughly 6.6 million acre-foot loss of available surface water. This would raise groundwater's share of agricultural water supply in California from 31% to 53%. Failure to replenish groundwater in wet years will continue to reduce groundwater availability to sustain agriculture – particularly more profitable permanent crops – during California's frequent droughts.
- Statistically, the drought is likely to continue through 2015 – regardless of El Niño conditions. If the drought continues for two additional years, groundwater substitution will remain the primary response to surface water shortage, with decreases in groundwater pumping capabilities and increasing costs due to declining water levels. A continued drought also increases the vulnerability of agriculture, as urban users with largely adequate supplies in 2014 would likely buy water from agricultural areas.
- Net water shortages for agriculture in this year's drought most severely affect the Central Valley with at least 410,000 acres lost to fallowing, $800 million in lost farm revenues and $447 million in additional pumping costs. These effects are most severe in the Tulare Basin. Dairy and livestock losses from reduced pasture availability and higher costs of hay and silage add about 200 million the agricultural revenue losses.
- Coastal and Southern California regions are less affected by the 2014 drought, with approximately 19,150 acres fallowed, $10.1 million dollars in lost revenues and $6.3 million in additional pumping costs.
- State and regional policymakers concerned with drought should pay special attention to (1) groundwater reliability, (2) the ability of state and county governments to provide technical and organization assistance to rural communities, and (3) facilitating voluntary water trades between willing parties, including defining a standard environmental impact report for water transfers that can be assessed and approved prior to droughts. These policies would give local governments the ability to reduce the impacts of droughts to rural and agricultural areas and economies susceptible to water scarcity.

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Appendix on Methods

This section summarizes the methods used to estimate the economic impacts of the 2014 drought and extended drought in 2015 and 2016. We provide a summary of the drought water shortage conditions and a brief description of the SWAP model. We discuss how we linked the SWAP model to other hydrologic models and the IMPLAN model.

Agricultural Areas Covered

This study examined agriculture in California's Central Valley, Salinas Valley, Santa Maria, Ventura, Metropolitan, San Diego, Imperial, Palo Verde and Coachella areas. These areas together cover over 90% of all irrigated crop area in California (9.4 million acres statewide in 2010). Figure A-1 illustrates the locations of these major agricultural areas, represented in the SWAP model. A more detailed definition of all SWAP regions is provided in Table A-1.

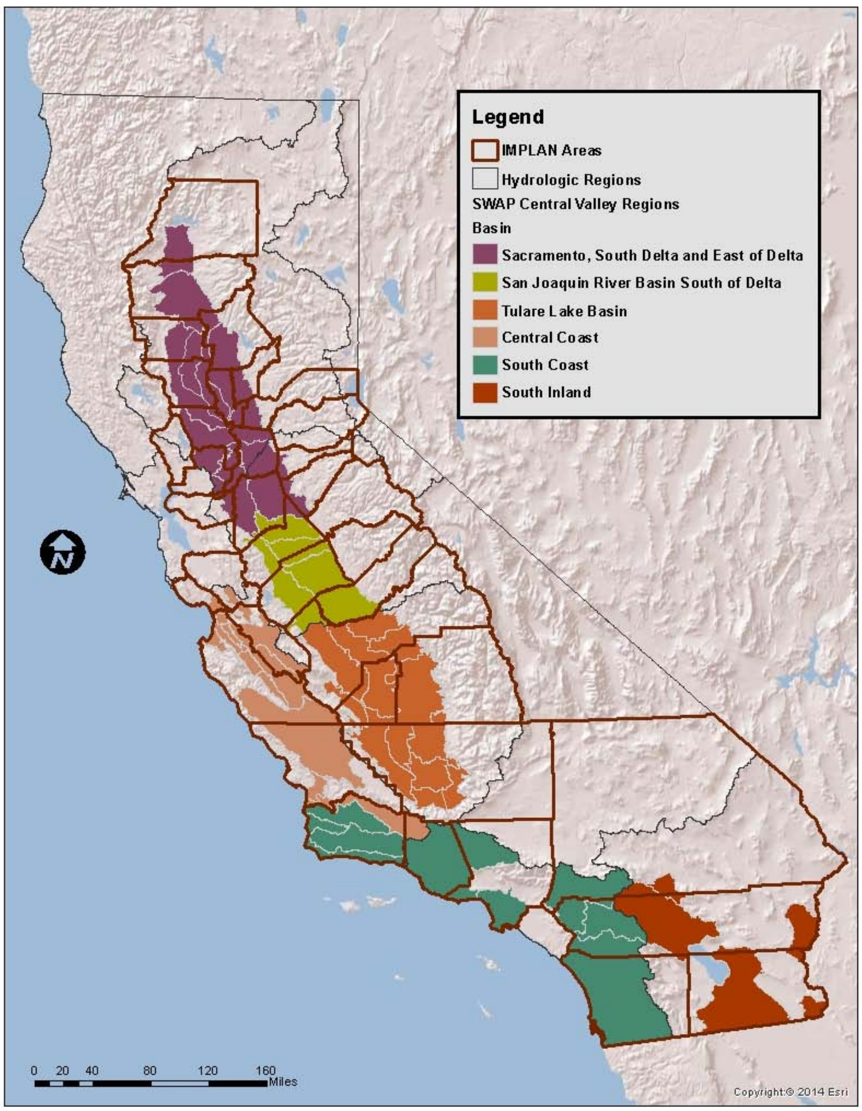

Figure A-1. Coverage SWAP Model for the drought study.

Table A-1. SWAP regions definitions and example districts or agricultural areas.

SWAP Region	Region definition and example districts	Drought Study Region
1	Bella Vista WD, and miscellaneous Sacramento River water users	Sacramento, Delta and East of Delta
2	Tehama, and miscellaneous Sacramento River water users	
3a	Glenn Colusa ID	
3b	Tehama Colusa Canal Service Area.	
4	Princeton‐Codora‐Glenn ID, and miscellaneous Sacramento River water users	
5	Feather River Region	
6	Yolo and Solano Counties.	
7	Sacramento County north of American River	
8	Sacramento County south of American River and San Joaquin County	
9	Delta Regions	
10	Delta Mendota Canal	San Joaquin River
11	Stanislaus River area	
12	Turlock ID	
13	Merced I.D., Madera ID, Chowchilla WD, and Gravely Ford	
14a	Westlands WD	Tulare Lake Basin
14b	Local and groundwater	
15a	Tulare Lake Bed	
15b	Dudley Ridge WD and Devils Den (Castaic Lake)	
16	Eastern Fresno County	
17	Friant‐Kern Canal, Hills Valley ID, Tri‐Valley WD, and Orange Cove	
18	County of Fresno area	
19a	Kern County SWP Service Area	
19b	Semitropic W.S.D SWP Service Area	
20	Friant-Kern Canal. Shafter-Wasco, and South San Joaquin ID	
21a	Cross Valley Canal and Friant-Kern Canal	
21b	Arvin Edison WD	
21c	Wheeler Ridge-Maricopa	
22	Santa Clara and San Benito County	Central Coast
23	Salinas Valley	
24	San Luis Obispo and Santa Maria	
25	Santa Barbara area	South Coast
26	Ventura County	
27	Metropolitan Water District Service area, excluding San Diego and Ventura County areas	
28	Coachella Valley	South Inland
29	Blythe / Desert areas	
30	San Diego	
31	Imperial Valley	
32	Yuma	

Statewide Agricultural Production Model (SWAP)

The SWAP model was the central modeling framework used to estimate drought impacts on crop production, costs, and revenues. A comprehensive description of the SWAP can be found in Howitt *et al.* (2012). The SWAP model is a statewide economic model of agricultural production, calibrated to a recent base year of land and water use conditions. The SWAP model includes 27 areas in the Central Valley and10 additional regions covering the coast and Southern California. Twenty crop groups are included in the base dataset, and crop production cost information, agricultural prices and yields and estimates of applied water are compiled from various sources, including the USDA NASS County Agricultural Commissioner's Annual Crop Reports, UC Cooperative Extension Cost and Return Studies, and California Department of Water Resources water budget data. The SWAP model has a portfolio of water sources including groundwater, contract water, and local diversions that are used depending on the relative cost of the sources and local water availability levels. Constraints on crop stress (under irrigation), permanent crops, and water transfers also have been imposed in the model. The SWAP model is also able to estimate yield changes and intensive margin adjustment, agricultural land use conversion, and changes in crop prices.

In a base SWAP model run, input use and cropping decisions calibrate within 1% to a base dataset. In policy analysis with SWAP, various parameters can be changed, such as water availability by sources, reductions in the available agricultural land, input factor use prices and crop yields. We typically estimate a “no action” or “existing conditions” alternative and then compare the “policy” drought alternative to the estimated baseline. In this way the SWAP model results are can be interpreted as changes from an average year.

The base data in the SWAP model was updated to 2010 using the latest available information on irrigated crop areas and applied water from the California Department of Water Resources (DWR). Table A-2 summarizes irrigated crop area in the base SWAP model dataset.

Table A-2. Base irrigated crop areas in the SWAP model. (1000 acres).

Region	Cotton, Grain and oilseed	Feed and other Crops	Fruit and Nut Trees	Vegetables and non-tree fruit	Total
Sacramento	1,027	364	672	180	2,243
San Joaquin	579	251	608	181	1,620
Tulare Lake	1,106	352	1,289	327	3,073
Central Coast	23	3	114	459	598
South Coast	40	8	146	106	300
South Inland	194	261	45	140	641
Statewide	2,968	1,240	2,874	1,393	8,474

Hydrologic and Groundwater Replacement Conditions

The SWAP model uses 2010 as the base for water use in agriculture across the state. According to the Water Year Hydrologic Classification Indices published by DWR[1], 2010 was a below normal year for the Sacramento Valley and an above normal year for the San Joaquin Valley. 2010 is the most recent data available for applied water data from DWR.

Drought in 2015 and 2016

Drought conditions in 2015 and 2016 were based on the 2009 drought. According to DWR’s statistics on water year types, there is a 29% chance that a critically dry year will be followed by another critically dry

[1] See: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST.

year (doubling the normal change of a critically dry year). The chance of a critically dry year does not seem to be affected substantially by El Niño conditions.

Water Availability for 2014

The drought impact analysis was based on expected Central Valley Project and State Water Project deliveries announced by the Bureau of Reclamation and California Department of Water Resources (DWR) on April 18, 2014. The project team surveyed major water districts in the Central Valley to determine expected shortages in local surface water supplies and the availability of carry-over storage. The short run ability to increase groundwater pumping was based on DWR's maximum groundwater pumping estimates for the years 2006-2010. We surveyed water districts along the coast and in Southern California. Most districts will continue to primarily use groundwater for agricultural irrigation. Surface water represents a small share of total water used along the coast and Southern California so the zero allocation from CVP and SWP in some areas will not substantially impact current irrigation practices. Colorado River surface water is expected to remain stable. Presently, Lake Powell, the largest Colorado River reservoir is at 44% of full capacity. Diamond Valley Lake in Hemet is at 70% of full capacity.

Groundwater Replacement

Groundwater has historically been the swing resource for droughts in California, particularly in most agricultural areas. Groundwater use during the 2014 drought will supplement for most surface water shortages in the Central Valley and elsewhere. The additional cost of groundwater itself reduces some crop production, typically for the least profitable crops.

Central Valley

To assess groundwater availability for 2015 and 2016 in the extended drought years, we conducted a set of sequential runs using C2VSim, the California Department of Water Resources groundwater model (Brush *et al.* 2013). In this sequence, initial levels in the SWAP model provided surface water deliveries and pumping quantities for 2014 to C2VSim. Then C2VSIim estimated changes in the water table depths for 2015. SWAP used changes in the groundwater table elevations from C2VSim to estimate loss in pumping capacity by region and pumping costs for year 2015. Surface water deliveries for the 2015 drought were used in the SWAP model. The resulting cropping patterns for 2015 then provided C2VSim information on applied water and pumping during the year so C2VSim could estimate the new groundwater table levels for 2016. The percent change in groundwater levels for 2016 from C2VSim were then used to estimate the last year of the synthetic drought's cropping patterns with SWAP.

We believe that substantial new well drilling is unlikely to have a widespread effect for an extended drought. Although this lack of new pumping capacity is less realistic if the drought continues, we are analyzing a worst case in which pumping capacity depends on the resulting water table depths and local well pump screen depth distributions.

Central Coast and Southern California

Coastal and Southern California agriculture are less likely to experience severe surface water curtailments due to the relative decoupling of these regions from the 2014 drought. However, if the drought continues in 2015 and 2016, the depletion of water stored for urban uses in Southern California might impose some pressure over other uses, increasing opportunity costs of water in the region and resulting in greater water shortages for agricultural users (in some cases compensated for by water sales to urban areas).

Region-wide Economic Impacts using IMPLAN

Input-Output models allow tracing expenses in a region's economy after an economic event has occurred. One of the most widely used input-output models is Impact Analysis for Planning Model (IMPLAN) developed by the Minnesota IMPLAN Group (MIG) Inc. The model was originally used by the US Forest Service to conduct economic impact analyses on forestry but more recently has been adopted by academics, agencies and consultants to estimate region-wide economic effects of exogenous changes in a region of interest.

We used job estimates from the California Employment and Development Department (EDD) to adjust farm employment and convert to full time equivalents in an intermediate step. Results presented in the report for employment are seasonal and full time jobs. Personal communication with agricultural labor (Phillip Martin) and estimates form literature Martin and Taylor (2013) indicate that for every full time equivalent job there are about two full time and part-time jobs per year in California. IMPLAN's built in sector output (gross revenues) for various agricultural commodity groups were also compared to SWAP's gross revenues by large crop group. We characterized the six SWAP aggregate regions (Figure A-1) in IMPLAN by aggregating the corresponding county groups as shown in Table A-3. Interaction between SWAP and IMPLAN is shown in Figure A-2.

Table A-3. Drought regions and corresponding IMPLAN county group models.

IMPLAN Regions	**Counties**
Sacramento River	Amador ,Butte , Calaveras, Colusa ,Contra Costa,El Dorado, Glenn , Placer ,Sacramento, Shasta, Solano,Tehama, Sutter, Yolo and Yuba
San Joaquin River	Madera, Mariposa, Merced, San Joaquin, Stanislaus, Tuolumne
Tulare Lake Basin	Fresno, Kings, Tulare, and Kern Counties
Central Coast	Monterrey, Santa Clara, San Benito, San Luis Obispo
South Coast	Ventura, Los Angeles, San Diego, Santa Barbara
Inland Southern California	Imperial and Riverside

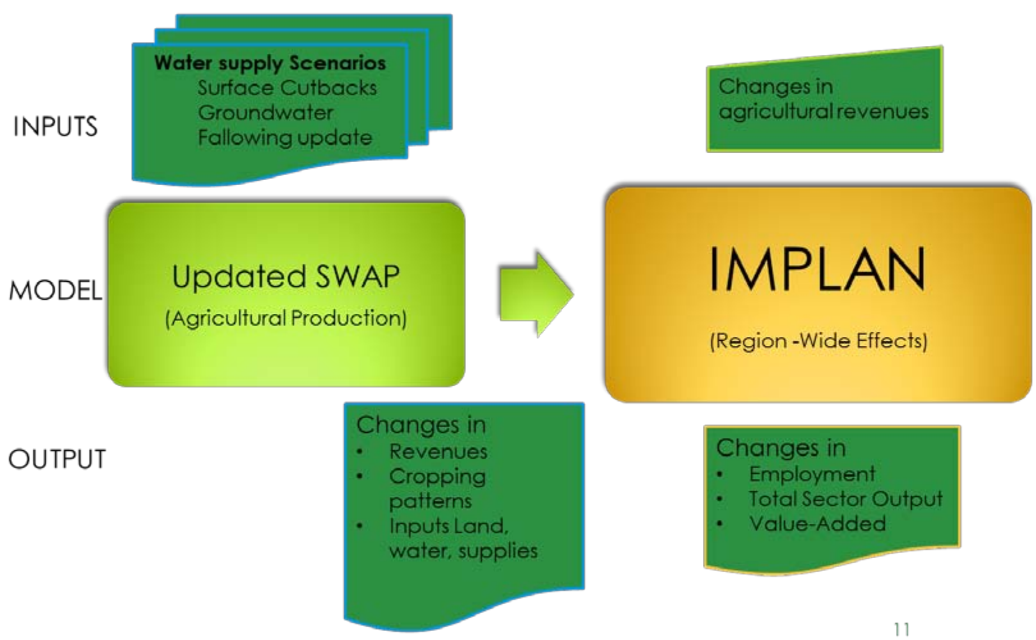

Figure A-2. Interaction of SWAP and IMPLAN modeling with inputs and results.

Use of satellite information

A preliminary analysis of fallowing using the Normalized Difference Vegetation Index (NDVI) available reflectance on surface spectral bands was conducted for three satellite images in the Central Valley including the Sacramento Valley, the San Joaquin Valley and the Tulare Lake Basins (Figure A-3). Landsat 8 and Landsat 7 images from May 2012 to May 2014, and for early June for the case of the Sacramento Valley were used, it was found that for the San Joaquin Valley and the Tulare Lake basin at least 295,000 acres are idle in 2014 with respect to 2012. Idle agricultural land estimates for the Sacramento Valley are still under development as images later in the season would improve estimates.

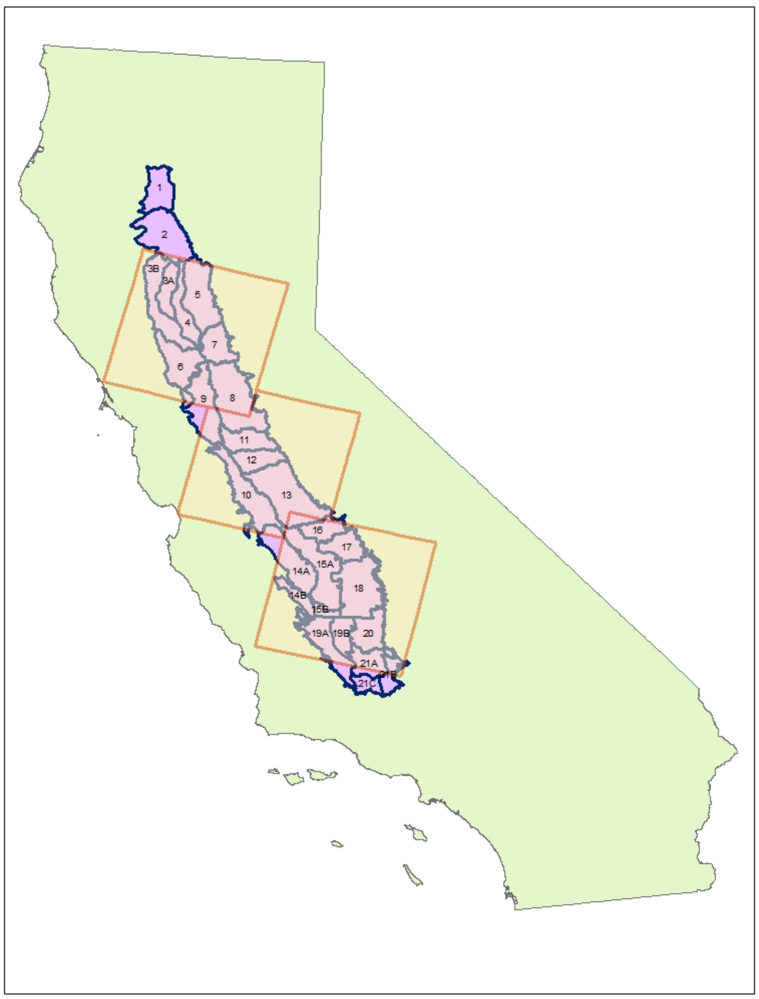

Figure A-3. Analyzed Landsat rows and paths for idle land from 2012 to 2014.