Water-Indexed Benefits and Impacts of California Almonds (California Water Footprint)

Project No.: **15-WATER6-Shilling**

Project Leader: Fraser Shilling
Department of Environmental Science and Policy
UC Davis
One Shields Ave.
Davis, CA 95616
530.752.7859
fmshilling@ucdavis.edu;

Project Cooperators and Personnel:
Dr. Julian Fulton, CSU Sacramento, Department of Environmental Studies
Michael Norton, Ph.D. Candidate, Geography Graduate Group

Objectives:

- Calculate an accurate water footprint for California almonds, using the most recent statewide data and where possible, local or regional research products to inform data-use, such as actual crop evapotranspiration values.
- Compare almond water footprint to economic benefits gained from almond production and sales.
- Carry out a more detailed analysis of the water footprint of almonds compared to food value components and total food value.
- Analyze the effects of variation in evapo-transpiration rates (ETo and ETc) geographically, temporally, by variety, and with physiological status.
- Compare the water footprint to other types of footprint (e.g., ecological, energy/carbon) and life cycle analysis in order to identify production and management actions that could contribute to reducing water impacts and increasing efficiency.

Interpretive Summary:

The domestic and international media have recently started focusing on the water footprint of California almonds and have related the water footprint to water use and the drought. The water footprint is an index of the complete use of and impacts to water systems. It is the sum of water impacts from production of a good or service used by people. It is typically expressed per unit production, per region, or per capita. Besides the problem of perception that California almonds have a large water footprint, there is the additional problem that the water footprint estimate quoted in the press may not be not accurate. We found that the California-almond water footprint is ~20% smaller than previously estimated and reported and has been gradually improving over time. Finally, the many nutritional and economic benefits that almond production and almonds provide are lost in a water footprint calculation that report volume of water per unit weight of almonds. We found that almond production provides a large economic and employment benefit to California, several times greater than the income from selling the almonds themselves. Almonds are also replete with protein, healthy fats, fiber, vitamins and

micronutrients. We found that when water footprint is expressed relative to nutritional benefits, then almonds go from having one of the largest water footprint (per unit weight) to being more in the middle of the range for different foods. There is no requirement that water footprint be only expressed in terms of volume per unit weight. Other denominators, such as economic benefit, protein (g), or total food benefit are likely to provide a better representation of the benefits of almonds relative to the water footprint and help consumers, water regulators, and growers all make more informed decisions.

Materials and Methods:

The concept of a water footprint (WF) is intended to capture the amount of water consumptively used in the production of goods and services. A water footprint includes the concept of "embedded," "embodied," or "virtual" water, meaning that the total water footprint of a product includes all water used throughout the production chain. When market demands result in products being traded between regions, these flows are referred to as virtual water imports or exports. For example, a virtual water export occurs when California exports almonds, while virtual water imports occur when California imports corn grain. Analyzed across multiple agricultural products and industrial sectors, water footprint assessments can provide information about water demands within or between economies and regions.

We calculated California's almond water footprint for years 2004-2014 following methods presented in Hoekstra et al. (2011) and using locally available data sources. Almond production data by county were obtained from the Almond Almanac 2014 (ABC 2014). Almond acreage data by county were obtained from the National Agricultural Statistics Service (USDA-NASS 2015). Consumptive blue and green water use factors were obtained from the California Department of Water Resources' Cal-SIMETAW model (Orang et al. 2013). For grey water footprint calculations, estimated nitrogen application and uptake rates were obtained from Brown (2016) and local governing standards were taken from CSWRCB (2010).

We then compared the water footprint to the economic benefits (GDP and jobs) and nutritional benefits (e.g., protein) of almonds production and consumption. We could not compare economic benefits of almond production to other crops because of the lack of detailed analyses for these other crops. For nutritional benefits, we did compare among crops using FDA values for these benefits as the basis for comparison.

Results and Discussion:

Over the 2004-2014 period, the average water footprint of one pound of raw California almond kernels was 610 gallons' blue water, 87 gallons' green water, and 464 gallons' grey water. The **text box** below shows how these figures were calculated.

Text box: calculation of average water footprint values for California almonds

$$Blue\ water = \frac{4.3\ acre-feet/acre}{1.2\ tons_{kernels}/acre} \times \frac{1\ ton}{2{,}000\ lbs} \times \frac{325{,}851\ gallons}{1\ acre-feet} = 610\ \frac{gallons}{lb_{kernels}}$$

$$Green\ water = \frac{0.6\ acre-feet/acre}{1.2\ tons_{kernels}/acre} \times \frac{1\ ton}{2{,}000\ lbs} \times \frac{325{,}851\ gallons}{1\ acre-feet} = 87\ \frac{gallons}{lb_{kernels}}$$

$$Grey\ water = \frac{3.2\ acre-feet/acre}{1.2\ tons_{kernels}/acre} \times \frac{1\ ton}{2{,}000\ lbs} \times \frac{325{,}851\ gallons}{1\ acre-feet} = 464\ \frac{gallons}{lb_{kernels}}$$

Using global-level data, Mokone and Hoekstra (2011a) estimated that the water footprint of California almonds was 482 gallons' blue water, 278 gallons' green water, and 795 gallons' grey water. Thus, our calculations show a lower overall water footprint, but with key differences between the types of water: less green and grey water, but higher blue water. This likely reflects the resolution of data available to construct a global dataset and the particular dependence on irrigation in California's agricultural sector.

Across the time period that we considered, the water footprint of California almonds has changed significantly. **Figure 1** shows that the overall water footprint has decreased by about 28%, including reductions in blue, green and grey water uses.

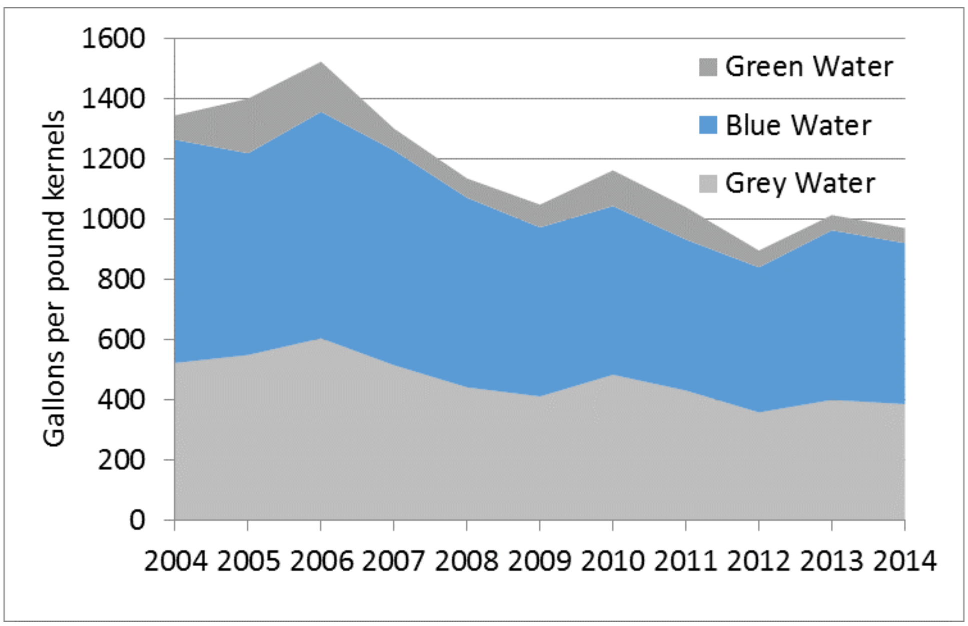

Figure 1. Temporal variation in the water footprint of California almonds

Water footprints among almond-growing regions across California vary greatly, nearly threefold according to our analysis. **Figure 2** shows the water footprint of almond production in California's fourteen largest almond growing counties. Over the eleven-year period analyzed, Sutter and Tehama counties had the highest average total (green, blue and grey) almond water footprints, at 1,887 and 1,853 gallons per pound, respectively. Kings and Fresno counties had the lowest, at 665 and 863 gallons per pounds, respectively.

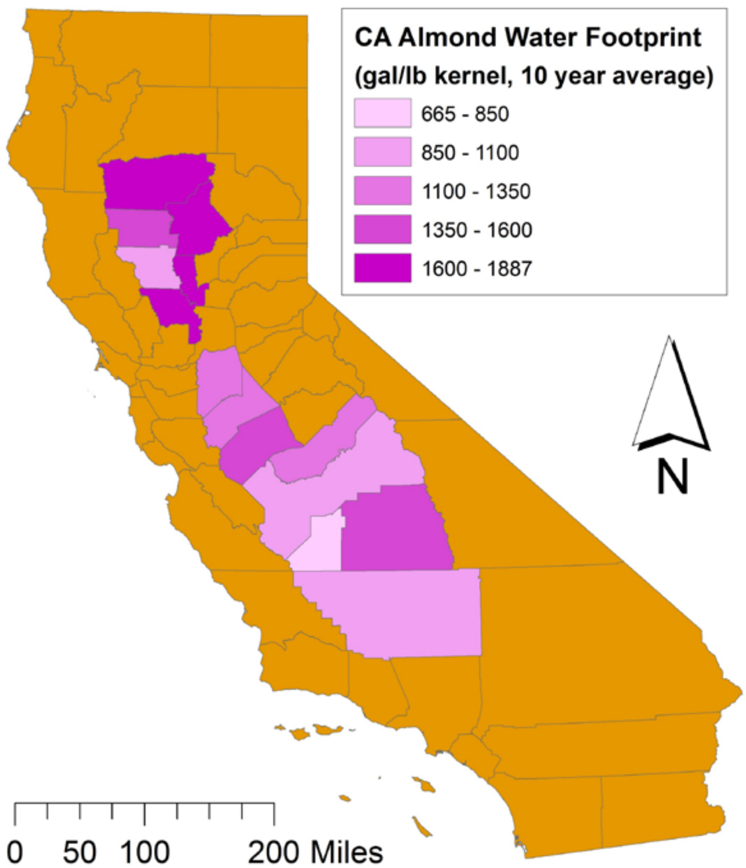

Figure 2. Regional variation in the water footprint of California almonds

This variation may seem counterintuitive when one thinks about the growing conditions in the northern counties being milder than in the hotter, drier southern counties. Indeed, as **Figure 3** indicates, evapotranspiration of applied water (ETaw) rates in parts of the southern counties range from one to two feet greater than in northern counties. Nevertheless, the hotter, drier conditions in the southern counties help make almond crop yields so much greater that they outweigh the effect of higher ETaw values on the overall water footprint.

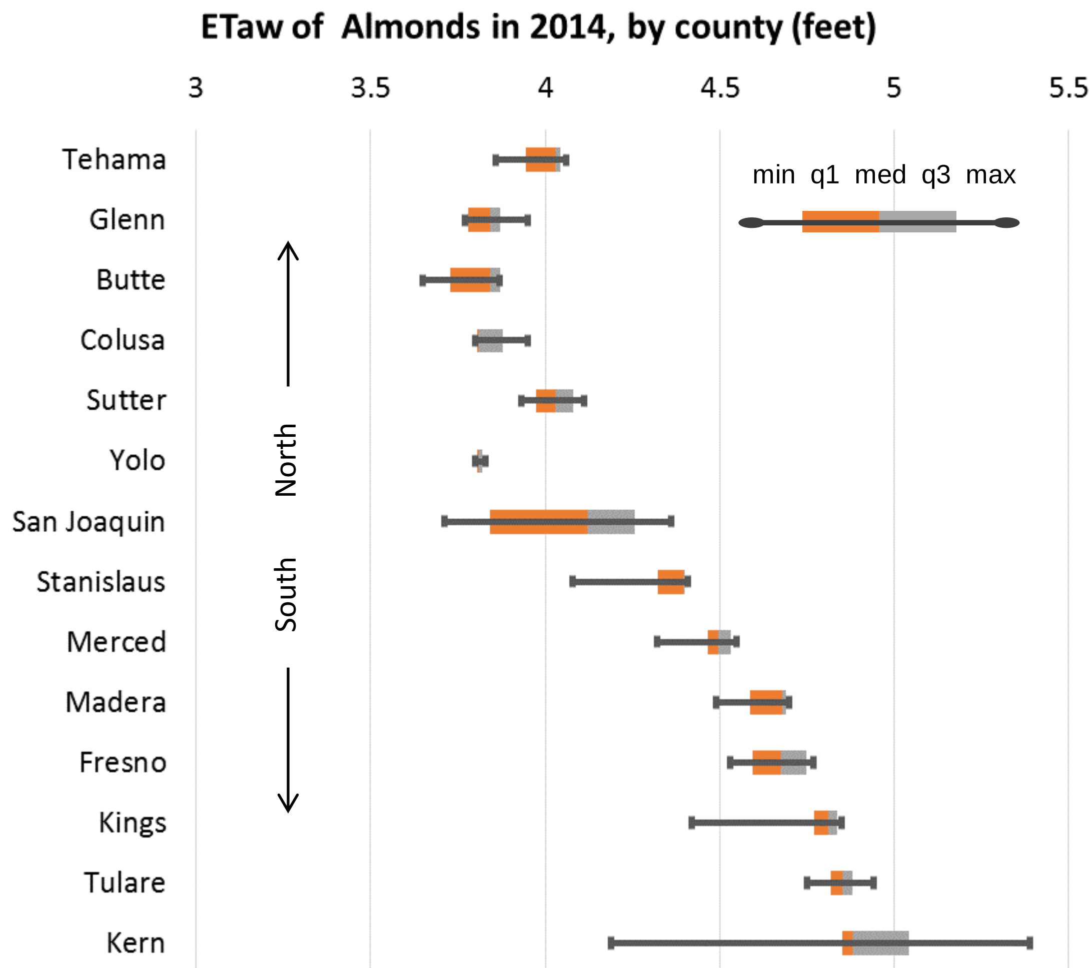

Figure 3. Variation in evapotranspiration of applied water (ETaw) rates for almond orchards among California counties

On-farm almond prices more than doubled from $1.45 in 2008 to $3.21 in 2014 (**Figure 4**). Over the years, there have been several previous spikes in the on-farm almond price (blue line) that also correspond with drops in total production (green columns). These spikes are consistent with the expectation that in years with low supply the market price of almonds would increase for those buyers still competing in the market. In recent years, however, the almond price has remained high by historical standards despite increasing production.

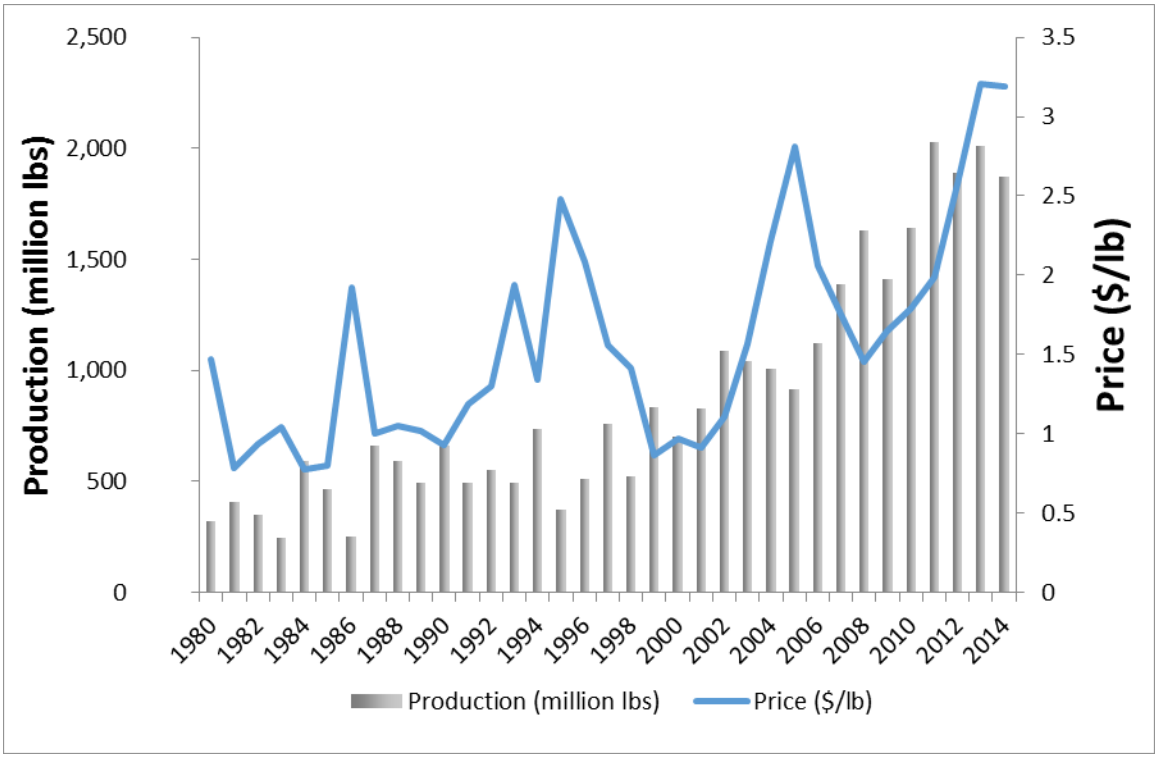

Figure 1. On-farm price and total production for years 1980-2014. Source: USDA-ERS (2015).

Comparing the price received for the crop against the amount of water used is a good first step. However, the economic benefit to California from the almond industry also includes the processing and manufacturing sectors as well. In addition, not all of the benefit of the California almond industry can be described as value-added, which contributes to the state's Gross State Product. In the following table (**Table 1**), with employment and economic value statistics from Sumner et al. (2015), we estimate the economic value of each acre-foot of water use by the California almond industry in 2014.

Table 1. Economic and employment benefits of almond production.

Employment by CA Almond Industry, 2014	
Farm Employment	21,000
Indirect Employment	47,000
Processing and Manufacturing	36,000
Total	104,000
Total Value of Output	$21.5b
Economic Value Added	$11b
Water consumed, 2014	5,978k AF
Water consumed per job	57.48 AF
Economic output per AF	$3,596
Value Added per AF	$1,840

The total value of crops was compared to the corresponding water footprint, to facilitate comparison of crops with each other (**Figure 5**). Crops that are more valuable for each unit of water consumed are on the top left of the figure, and commodities that consume an outsize amount of water for their economic value appear on the bottom right of the figure. The majority of crops appear in the bottom left quadrant of the figure, as they neither consume large amounts of water nor receive high prices at market. The staple crops highlighted in gray at the bottom of the figure have a larger WF per ton than many other agricultural commodities, but do not receive high prices at market. The blue box on the upper left includes several fruits – blueberries, raspberries, cherries, and strawberries. These four products provide more value for each cubic meter of water footprint. There are three commodities in the upper right quadrant of the figure: almonds, walnuts, and beef. Each of these commodities command provides high value, but are also high risk according to their WFs. The value of almonds per ton is much higher than that of walnuts or beef.

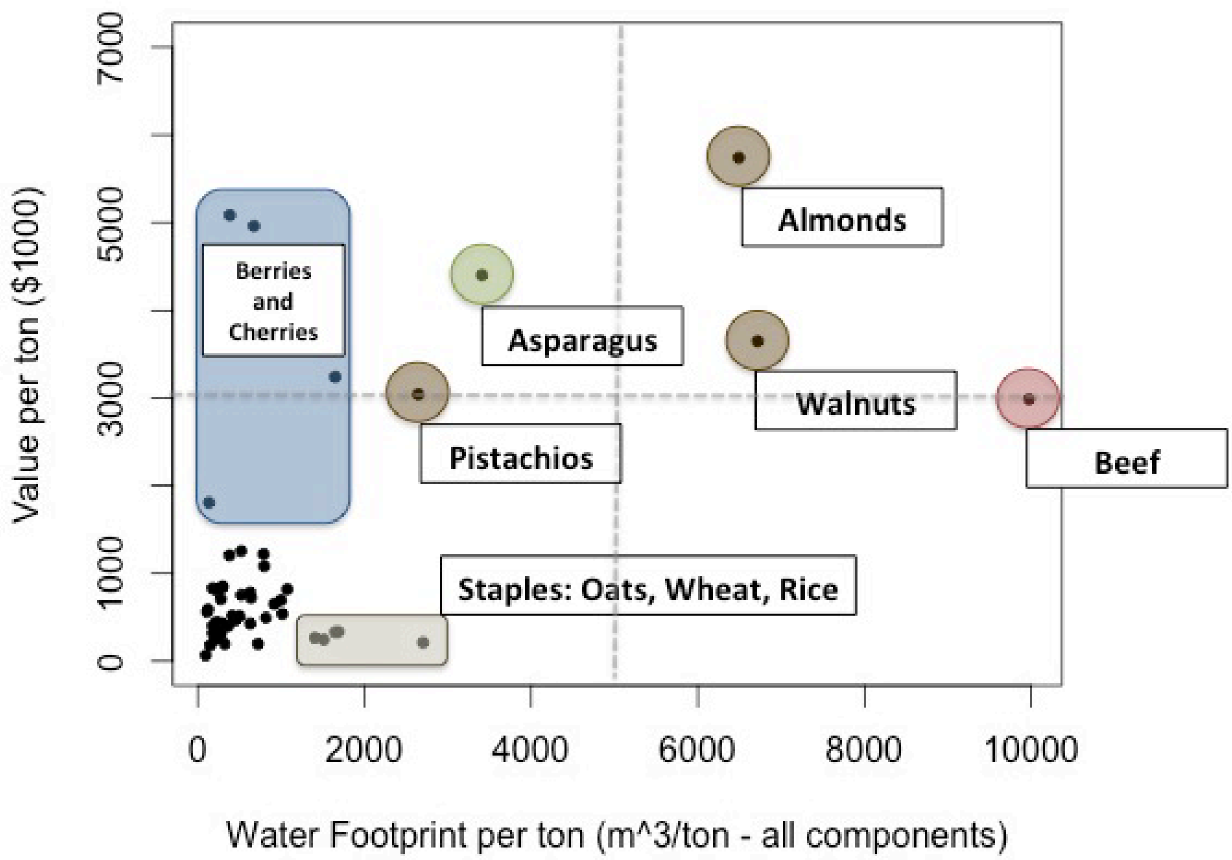

Figure 52. A comparison of WF values against the value of the crop per ton. Data source: USDA-NASS (2015) for agricultural statistics and Mekonnen and Koekstra (2010) for WF estimates.

The nutrient-rich foods (NRF) index was used to compare crops (**Figure 6**); the NRF is an index that rates foods based on their nutritional content (Fulgoni, Keast, and Drewnowski 2009). The NRF includes nine nutrients to encourage (protein, fiber, vitamins A, C & E, calcium, iron, magnesium, and potassium. The NRF also includes three nutrients to limit (saturated fat, added sugar, and sodium). As fresh fruits and vegetables are not significant sources of added sugar or sodium, they were omitted.

First, **Figure 6** shows the diverse nutritional profile of almonds in the nine nutrients that make up the NRF index. With the exceptions of vitamins, A & C, almonds rank at or near the top of all California crops in seven of the nine nutrients. Second, **Figure 6** shows that those nutritional benefits are gained at a cost, namely a water footprint that is one of the highest among California crops. This figure illustrates the tradeoffs that will need to be considered in order to achieve more efficient use of California water.

Using **Figure 6**, we can compare almonds to foods like beef, which is the rightmost point in each of the 10 plots. Beef is high in protein and iron, but does not have the diverse nutritional profile of almonds. In addition, beef also has a much higher water footprint for each 100 g of food produced. Likewise, there are some foods with lower water footprints that contain larger amounts of specific nutrients. Finding an effective method of growing crops that will provide a wide array of nutrients while still working within the finite amounts of water available in the state.

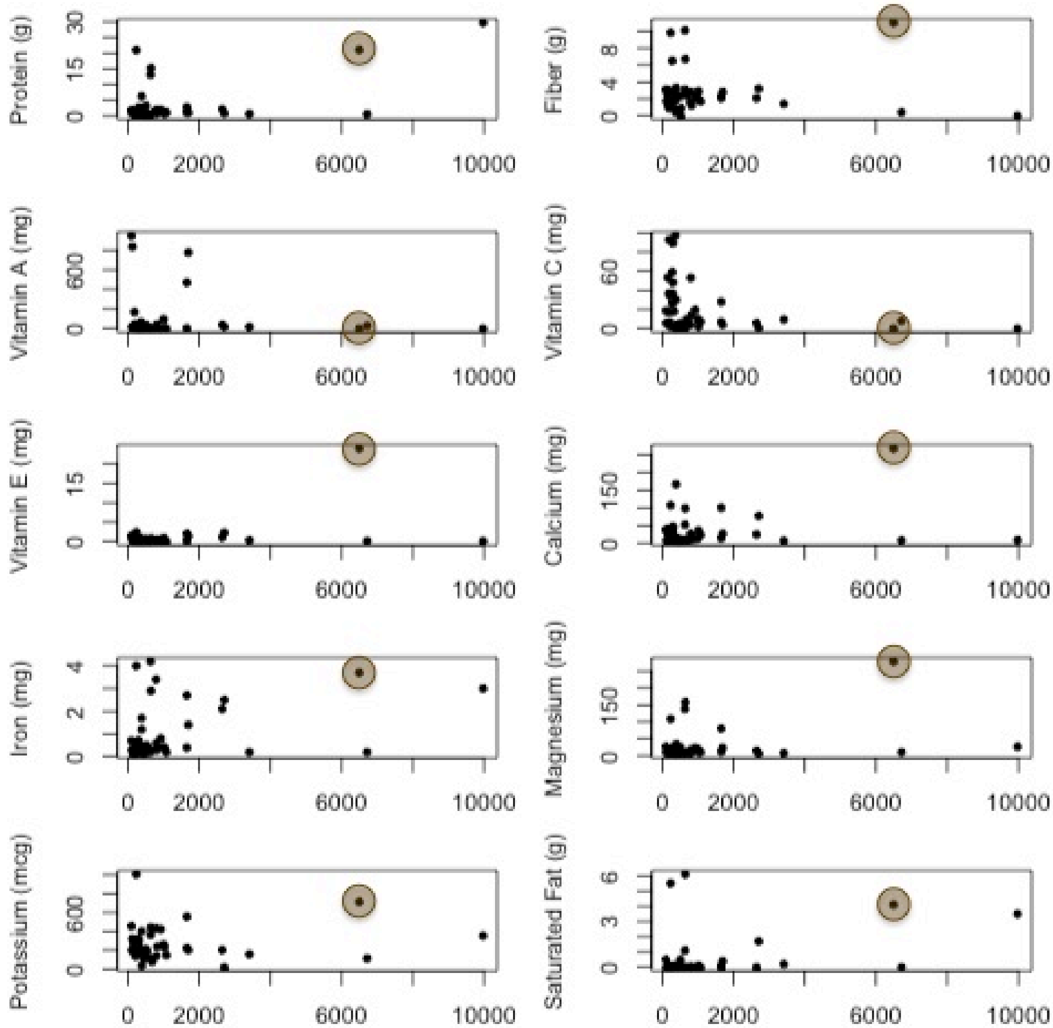

Figure 6. A comparison of WF (horizontal axis) against various nutrients for California crops. Almonds are highlighted by brown circles.

Although the study is not yet complete, we can draw the following conclusions:

- A revised almond water footprint of <1,000 gal/lb can be shared publicly, along with the comment that the value is declining over time.
- Almond water footprint is the lowest in the highly-productive San Joaquin Valley counties, which are also areas where there is the most pressure on local groundwater basins, with some in severe over-draft and decline.
- Almonds are one of the most economically valuable crops in CA and provide direct and indirect benefits to the CA economy.
- Almonds provide the highest or among the highest combined nutritional benefits of foods and when scaled to water footprint, are better than other high water footprint foods.

Research Effort Recent Publications:

A manuscript describing the research is in preparation.

References Cited:

ABC, Almond Board of California. 2014. *Almond Almanac 2014*.

Brown, Patrick. 2015. Personal Communication. UC Davis Department of Plant Sciences. Davis, CA

California State Water Resources Control Board (CSWRCB). 2010. *Groundwater Information Sheet – Nitrate*

Fulgoni VL 3rd[1], Keast DR, Drewnowski A. Development and validation of the nutrient-rich foods index: a tool to measure nutritional quality of foods. J Nutr. 2009 Aug;139(8):1549-54. doi: 10.3945/jn.108.101360

Hoekstra, AY, AK Chapagain, MM Aldaya, and MM Mekonnen. 2011. *The Water Footprint Assessment Manual: Setting the Global Standard*. London: Earthscan.

Mekonnen, M. M., and A. Y. Hoekstra. "The green, blue and grey water footprint of farm animals and animal products." (2010)

Mekonnen, Mesfin M., and Arjen Y. Hoekstra. "The green, blue and grey water footprint of crops and derived crop products." *Hydrology and Earth System Sciences* 15.5 (2011a): 1577-1600

Orang, Morteza N, Richard L Snyder, Geng Shu, Quinn J Hart, Sara Sarreshteh, Matthias Falk, Dylan Beaudette, Scott Hayes, and Simon Eching. 2013. "California Simulation of Evapotranspiration of Applied Water and Agricultural Energy Use in California." *Journal of Integrative Agriculture* 12 (8). Central Iron and Steel Research Institute: 1371–88. doi:10.1016/S2095-3119(13)60742-X

Sumner, D., Matthews, W.A., Medellin-Azuara, J., Bradley, A. 2015. "The Economic Impacts of the California Almond Industry." University of California Agricultural Issues Center.

USDA-NASS. 2015. "California Agricultural Statistics 2013 Crop Year." USDA National Agricultural Statistics Service, Pacific Regional Office, California