

EBS 243
TERM PROJECT
CALIFORNIA'S AGRICULTURAL 'VIRTUAL' WATER TRADE BALANCE
FINAL REPORT

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ABSTRACT

This paper explores the balance of California's agriculture-related, virtual imports and exports of water over the past fifteen years in order to establish trends and examine the implications for relying heavily on international trade for an agricultural water balance. The narrative that farmers in California need water to produce crops for state or national consumption is investigated, and geopolitical consequences are discussed, including how this balance affects California's water management in times of drought, economic hardship and strained international relations. Notable experts have dismissed the utility of virtual water considerations (Lund, 2014), and this paper covers multiple perspectives on the virtual water discourse.

INTRODUCTION

With increasing global trade, the water balance in a state or region can no longer be thought of purely in watershed-limited spatial terms. Some of the crops California farmers produce using water sourced from the state's natural supply are then exported to other countries. While these exports are taxed, a large share of the profits are directed to the grower of these crops, and not evenly redistributed to California residents and the environment that help subsidize the farmer's water supply. The water used to produce these exported crops can be thought of as a sink, or loss, to the state's hydrological balance. These 'virtual' water exports have become an increasing concern in the past couple decades as California's agriculture has turned to high-value, water intensive crops such as almonds and pistachios. However, California also imports water indirectly, or 'virtually', through agricultural products (as well as textiles, electronics and other goods). Considered in the balance, California is a net importer of virtual water. As noted by the Pacific Institute (Fulton, 2014), these imports tallied 44 million acre-feet (MAF) in 2014, or more than all unimpaired flow in California's natural waterways. While consideration of the water demand related to every import and export product can become laborious and speculative, water demand related to agricultural products is more easily estimated. By quantifying the agricultural virtual water balance, we can isolate this part of the overall debate around California's international water trade.

Agriculture is the primary consumer of California's non-environmental water supply, using an estimated 80% of human uses (Hanak and Mount, 2019). The agricultural sector is also a massive economic engine for the state, generating approximately \$50 billion in annual revenue and providing at least 400,000 jobs (James, 2022). Additionally, agriculture comprises 13% of the California's export revenue (USTR, 2018).

Into this context, this paper applies the concept of virtual water. While similar concepts related to water footprint and crop efficiency have been academically and practically discussed in earlier decades, the concept of virtual water was introduced in 1993 by the geographer J.A. Allan, who specifically related the quantity to trade relations, imagining it as a method by which global water imbalances could be rectified. Hypothetically, water-rich countries could produce more water-intense products, and trade these to water-

scarce countries, thus becoming net exporters of virtual water. Inversely, water-scarce countries would produce less water-intensive crops and be net importers of virtual water. However, although an ideal situation, contemporary global trade markets do not function as such, and water-scarce countries such as India produce some of the most water-intensive crops in the world.

More recently, this concept has been applied in academia and journalism in the context of California's fierce water supply debate. Numerous (somewhat alarmist) articles have been written which decry California 'sending' millions of gallons of water to China, Japan, Europe and other destinations during drought conditions in which other water uses in the state are constrained. These articles paint a picture of agricultural interests demanding food for crops that will end up on the tables of Californians and other Americans and deserve water allocations from taxpayer-subsidized water conveyance projects, while in reality their products are exported abroad, resulting in only indirect economic gains via the profits realized by the growers. While this concept of virtual water has gained a foothold in these policy debates, critics of the idea exist as well. Although many criticisms of the virtual water concept have to do with philosophical differences or semantic nuance, a few consistent threads can be summarized as follows. Skeptics of the concept reinforce that virtual water is not, in fact, real water, and should not be treated or discussed as such. They warn that virtual water calculations can be misleading metrics that do not account for site-specific conditions, or that the consideration of virtual inputs to products and services would extend to nearly everything, quickly complicating the utility of the analysis.

OBJECTIVES

With this background in mind, project research objectives include foremost investigating trends in virtual water export from California's agriculture sector over fifteen years (2004 – 2019). These trends will be compared with changes in overall agricultural water use – have virtual water export rates outpaced, remained constant, or decreased as related in total water use? The virtual water associated with the export of specific crop categories is also a topic of research, and lastly, how do precipitation / water supply availability trends effect these export rates? The deliverables of this report include plots and tables of the past fifteen years showing agricultural water use as compared to virtual water exports, both as a single sum and separated by DWR-designated crop categories. Additionally, water intensity and crop export percentages of these crop categories are compared. The hypothesis here is that the amount of virtual water exported has increased even if the percentage of total crops exported has not increased, due to a changing, more water-intensive crop portfolio.

LITERATURE REVIEW

Fulton et al. (2012) note that a key difference should be clarified within the water footprint of all goods; all water used to produce a crop does not travel the same distance or have the same amount of human intervention. The categories used to differentiate water supply in Fulton, et al. (2012) are “green water” (precipitation or rainwater falling directly on a cropland), “blue water” (water allocated to cropland from other sources), and “graywater” (recycled water). The Fulton et al. 2012 study provides overall estimates for the total amount of virtual water associated with imported and exported goods and services in California, separated by water type (Figure 1).

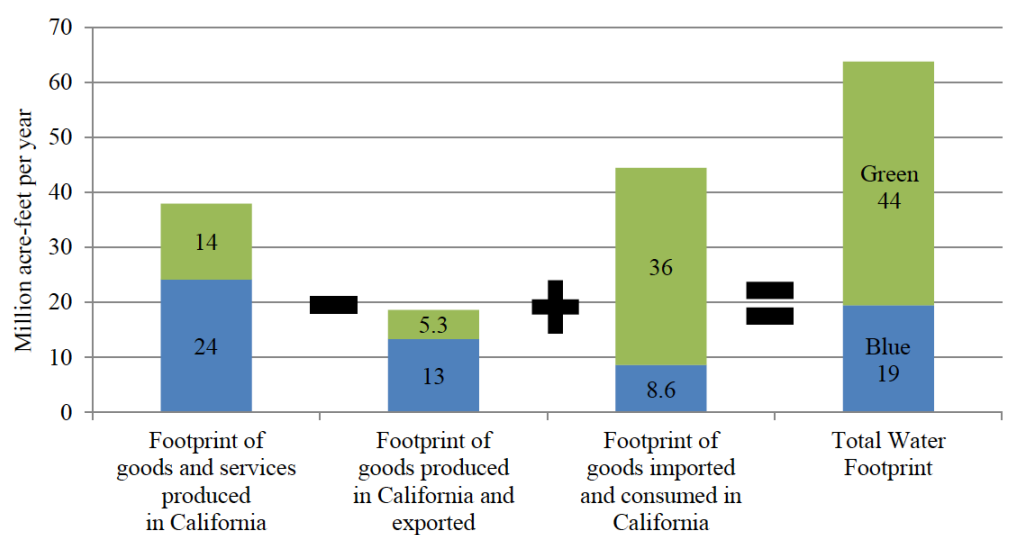


Figure 1. California’s Blue and Green Water Footprint, by Component. From Fulton et al., 2012.

As seen in this figure and discussed in the introduction, there is a total net import of virtual water in the state. However, there is a net loss of blue water (24 MAF to 19 MAF), with a net increase in green water (33 MAF). Additionally, while some have pointed to this net increase of virtual water supplies as a reason to not be concerned with the entire concept (Lund, 2014), the measures are related but not co-dependent. This zero-sum conceptual approach implies that agricultural commodities are traded for one another on the global market. It is decidedly not so, and exporting less ‘virtual water’ through agricultural commodities would not somehow preclude the continuing import of other crops. While Lund (2014) also notes that the idea of virtual water could easily be expanded to include nearly everything, since at some level all people, goods and services rely on some amount of direct or indirect water input, agriculture accounts for 80% of California’s water usage. Not only is it of chief concern within the state’s water supplies, but there is a more direct relationship between crop growth and water usage than there is with, for instance, the production of clothing or of a skilled service such as aerospace engineering. Agricultural water demand can be directly changed by altering crop portfolios. Recent trends have exhibited consolidating farming companies, with intensifying crops of higher value and higher water use, such as almonds and alfalfa (Arax, 2019). While imported virtual water is accessible to much of the state’s population through the sale of goods, the benefits from exported virtual water often end up in the control of few farmowners, while state taxpayers are often saddled with the burden of infrastructure repair and maintenance, for which the vast system of canals, pumps, and aqueducts are largely established to supplant the state’s agricultural industry. This is yet another reason to isolate the agricultural component of the virtual water balance.

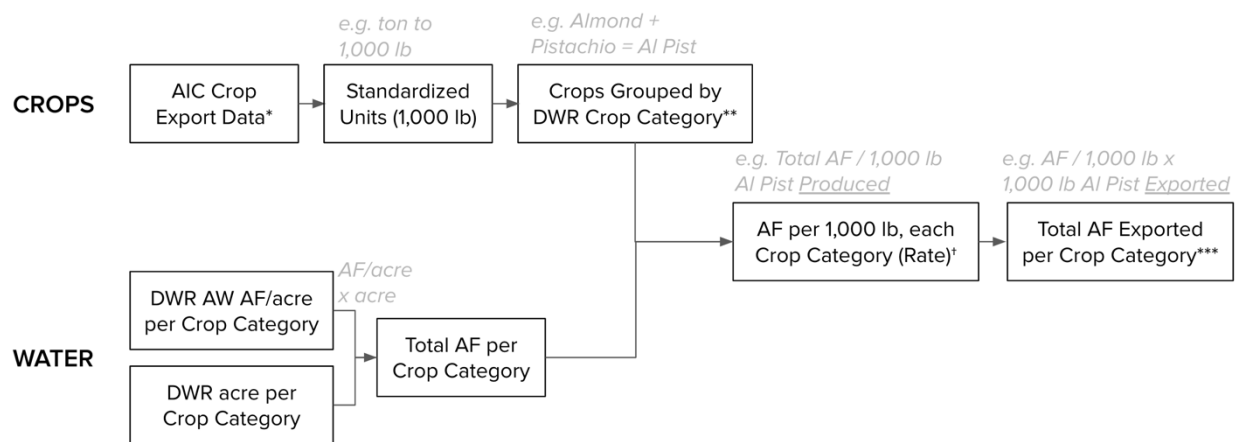
The study further divides the amount of imported and exported water by commodity type. However, primarily because accurate data is difficult to obtain, the study does not specify from which specific

counties or landowners in California these commodities are being exported. As discussed later, this is an important component of considering the state’s virtual water footprint. The division of water resources in California is well known, with some regions exhibiting a water demand much greater than their natural supply, creating a deficit that is satisfied only by importing water through expansive state and federal diversion projects, or through the overdrafting of critical groundwater aquifers.

In some areas, foreign companies importing produced crops have adopted a more direct method: they have purchased farmland in California (and other southwestern states), grown the agricultural commodities themselves using state-allocated water, and exported these products themselves. Although the ripple effects of foreign investment within California are numerous, several southwestern states are concerned that this process results in a more direct, and less ‘virtual’, export of their state’s water supplies (Kruzman, 2021a, Kruzman 2021b).

METHODS

A single dataset of virtually exported water of California’s agricultural sector does not exist; rather, export data is available for select crops from the UC Davis California Agricultural Issues Lab for at least 90% of exported products, and agricultural water use estimates are available from the state Department of Water Resources. However, the units and crop categories contained within these two databases do not always overlap. The general methodology for deriving an annual applied water (AW) estimate for crop exports is shown below in Figure 2. In general, it consists of applying the rate of water use per acre to all acres associated with a certain crop to get the total water use per a single crop, then applying that amount to the total amount of crop produced, and multiplying by the fraction of the crop that was exported to result in the total amount of water virtually exported.



* AIC Crop Export Data includes only 57 principal commodities (account for >90% state's production)

** Agreement between AIC crops and DWR crop categories not always present (e.g. eggs, turkey not included)

† Average AF / 1,000 lb rate applied to years 2014-2019, where no DWR AW data is available

*** Total AF Exported does not include crops for which export data is not available (e.g. safflower)

Figure 2. Agricultural Virtual Water Export Methodology

RESULTS

Results are shown below, following the methodology outlined above. Figure 3 compares overall total agricultural water use with virtual water exports. Table 1 and Figure 4 show the percentage of overall agricultural water use that these virtual exports account for, and Figure 4 also compares this proportion to the proportion of agricultural products exported.

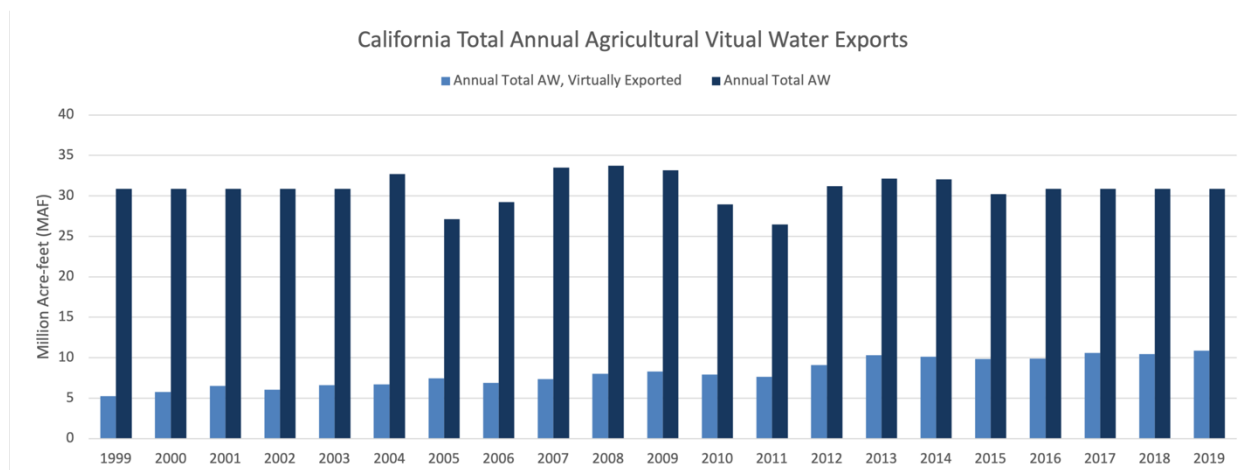


Figure 3. California Total Annual Agricultural Virtual Water Exports

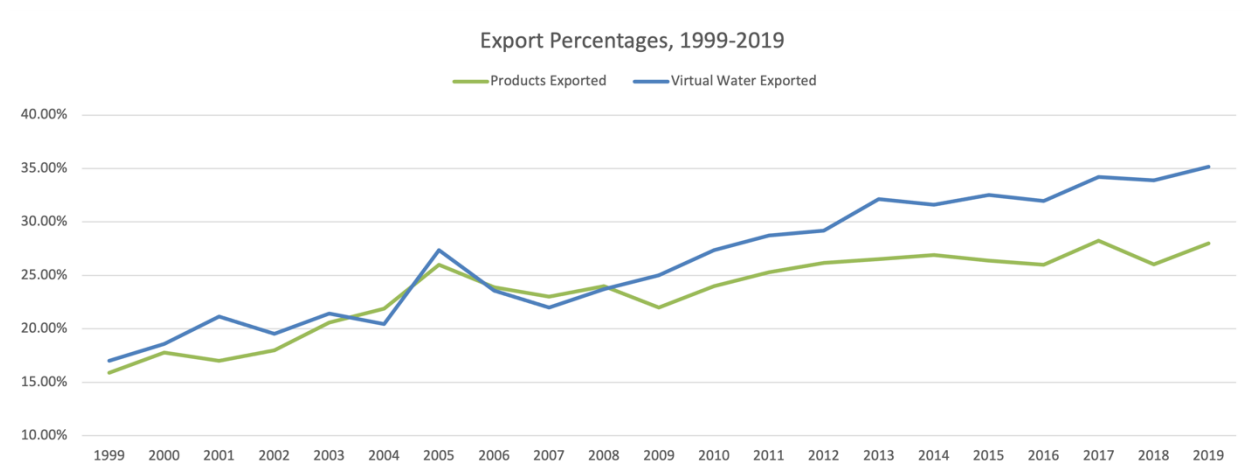


Figure 4. Export Percentages, 1999-2019

Table 1. Percentage of Agricultural Water Exported, 2004-2019

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Virtual Ag. AW (MAF)	5.3	5.7	6.5	6.0	6.6	6.7	7.4	6.9	7.4	8.0	8.3
Ag. AW Export (%)	17.0	18.6	21.1	19.5	21.4	20.4	27.4	23.6	22.0	23.7	25.0

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Virtual Ag. AW (MAF)	8.3	7.9	7.6	9.1	10.3	10.1	9.8	9.7	10.4	10.3	10.7
Ag. AW Export (%)	25.0	27.4	28.7	29.2	32.1	31.6	32.5	31.5	33.7	33.3	34.6

A few trends can be seen from the figures above. For one, the amount of total annual agricultural applied water fluctuates between years but is relatively constant around 30 MAF. However, the amount of virtually exported water increases significantly, from 6.7 MAF in 2004 to 10.7 MAF in 2019. These amounts account for 20.4% and 34.6% of the total agricultural AW of a given year – an average annual increase of 0.88%. This could imply that agricultural exports are increasing in general, which they are, as shown in Figure 4. However, this rate of increase (from approximately 22% in 2004 to 28% in 2019, a rate of 0.38%) is far outpaced by the increased rate of virtual water exports.

Examining the change in specific crops can help explain this trend. Figure 5 shows overall agricultural water use in MAF per crop category, and Figure 6 shows the amount of water that has been virtually exported per crop category. Table 2 also shows the percentages of these crops categories associated with each figure.

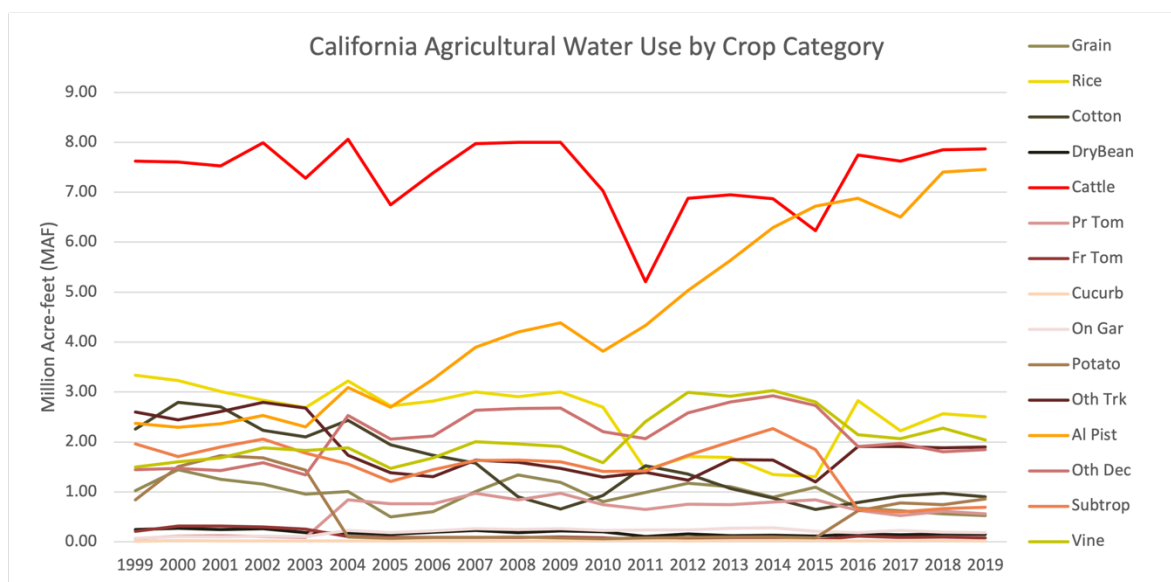


Figure 5. California Agricultural Water Use by Crop Category

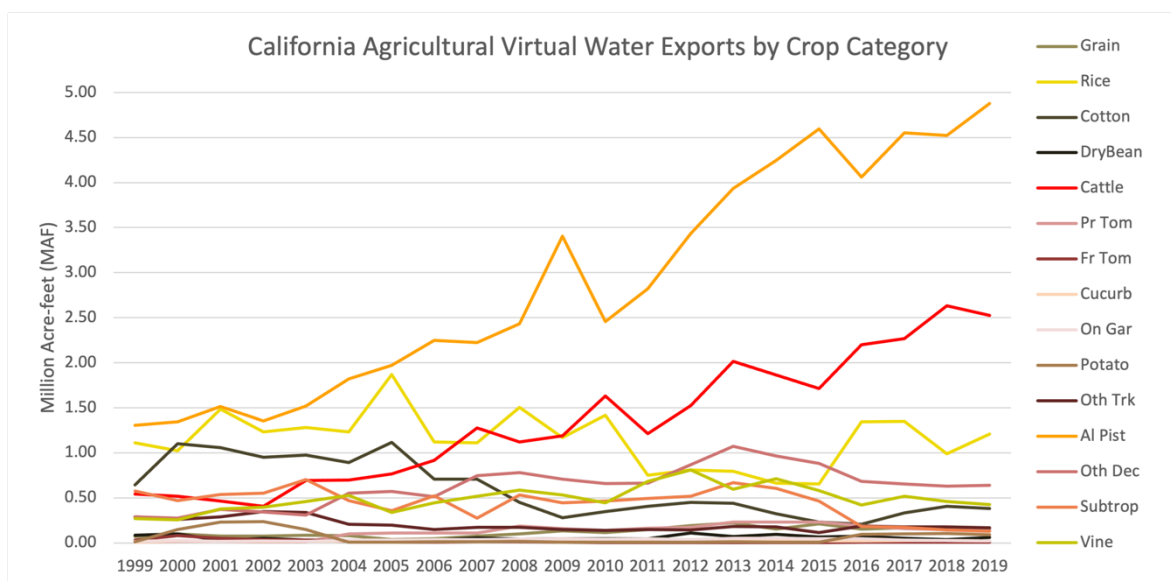


Figure 6. California Agricultural Virtual Water Exports by Crop Category

Table 2. Average Share of Applied Water (AW) by Crop Category, Total and Virtual Exports

Avg. Share of Applied Water (AW) by Crop Category, Total and Virtual Exports

	Grain	Rice	Cotton	DryBean	Cattle	Pr Tom	Fr Tom	Cucurb	On Gar	Potato	Oth Turk	Al Pist	Oth Dec	Subtrop	Vine
Percent of Total AW	2.85%	7.48%	3.92%	0.53%	23.09%	2.59%	0.22%	0.69%	0.78%	0.29%	4.74%	16.56%	7.83%	4.70%	7.22%
Percent of Exported AW	1.45%	10.13%	3.69%	0.57%	21.84%	1.83%	0.03%	0.19%	0.27%	0.11%	1.21%	45.97%	6.86%	1.62%	4.22%

Several key points emerge from these figures. Although there are numerous crop categories clustered towards the lower end of these plots, significant quantities of water are associated with a few of the top crop exports. In overall water usage, cattle, which contains both ‘alfalfa’ and ‘pasture’ water use designations, has averaged the most water use between 2004 and 2019, 7.13 MAF. Combined almond and pistachio production has averaged the second-most during this time period, 5.11 MAF, but has increased substantially during this time, so that by 2019, their water use (7.50 MAF) has surpassed that of cattle (7.26 MAF). Vines, Rice and Other Deciduous crop categories are also notable users of overall agricultural water, consuming over 2.00 MAF in 2019. These same five crop categories are the highest exporters of virtual water as well, as shown in Figure 6, although the magnitudes are not the same. In this category, the water associated with the production of almonds and pistachios is exported at a higher rate than cattle for all fifteen years of data analysis, with nearly 5 MAF exported in 2019. Table 2 shows the average share of AW from each of these crop categories for both overall and exported water quantities. Notably, almonds and pistachios constitute only 16.56% of the overall agricultural water use, but account for nearly 46% of the virtually exported water.

To further investigate the water demand and export trends of each DWR-defined crop category, water intensity of each crop, defined here in terms of acre-feet of water used per 1,000 lb of commodity production, are plotted in Figure 7 and paired with the percentage of each crop category that is exported, seen in Figure 8.

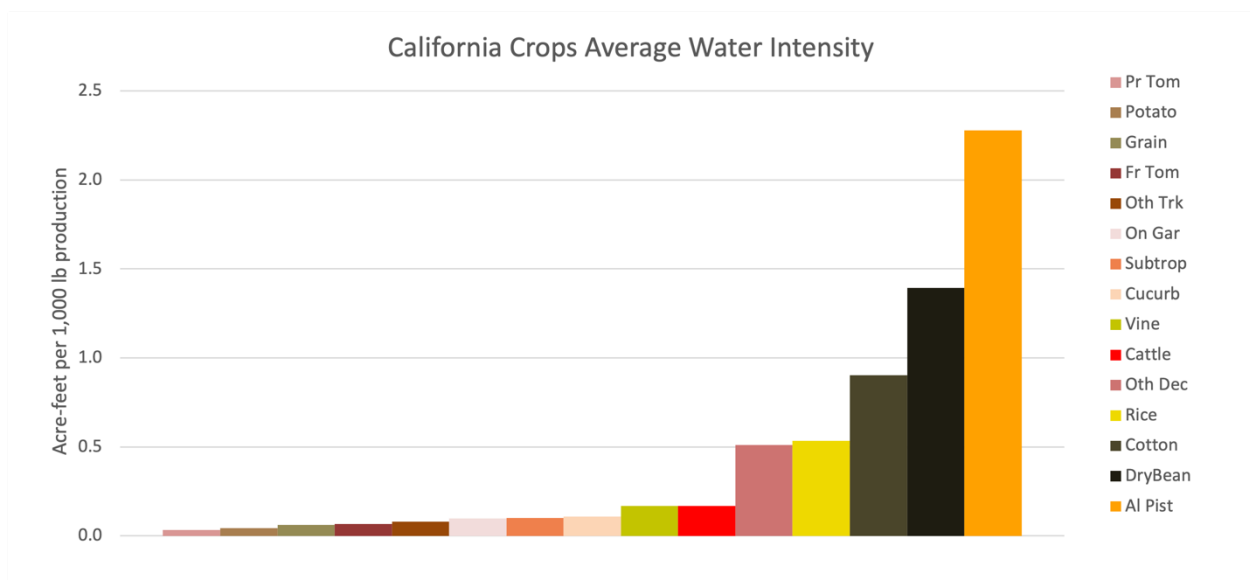


Figure 7. California Crops Average Water Intensity

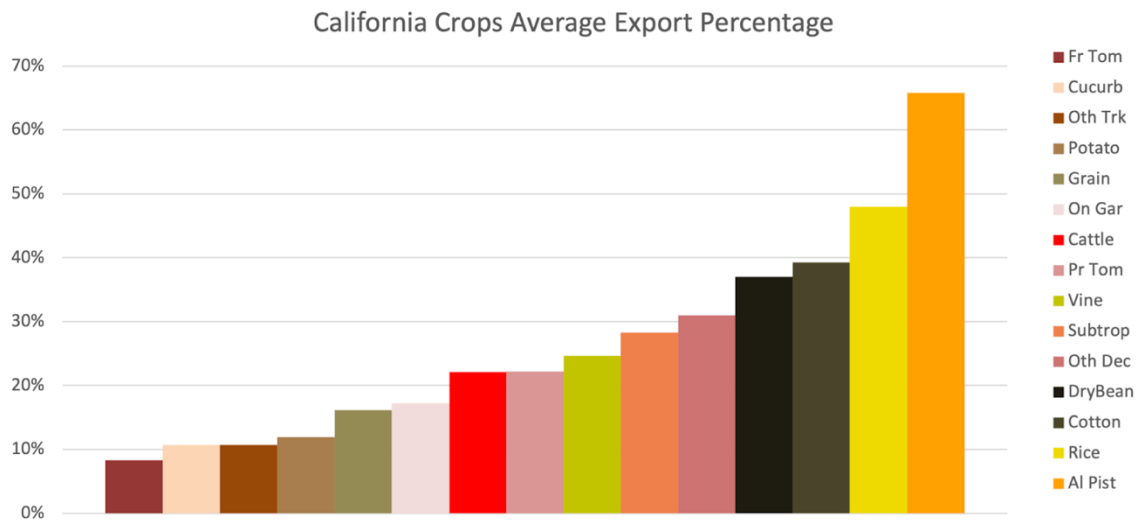


Figure 8. California Crops Export Percentage

One clear and important relationship can be seen between these two figures. The same five crop categories that are the most water intense per 1,000 lb production (Almonds / Pistachios, Dry Beans, Cotton, Rice, and Other Deciduous (including apricots, apples, walnuts, and cherries, among others)), are also the five most-exported categories. Specifically, almonds and pistachios consume an average of 2.3 acre-feet per 1,000 lb and export an average of 66% of their overall production. Dry Beans, as another example, use 1.4 acre-feet of water per 1,000 lb and export 37% of their overall product.

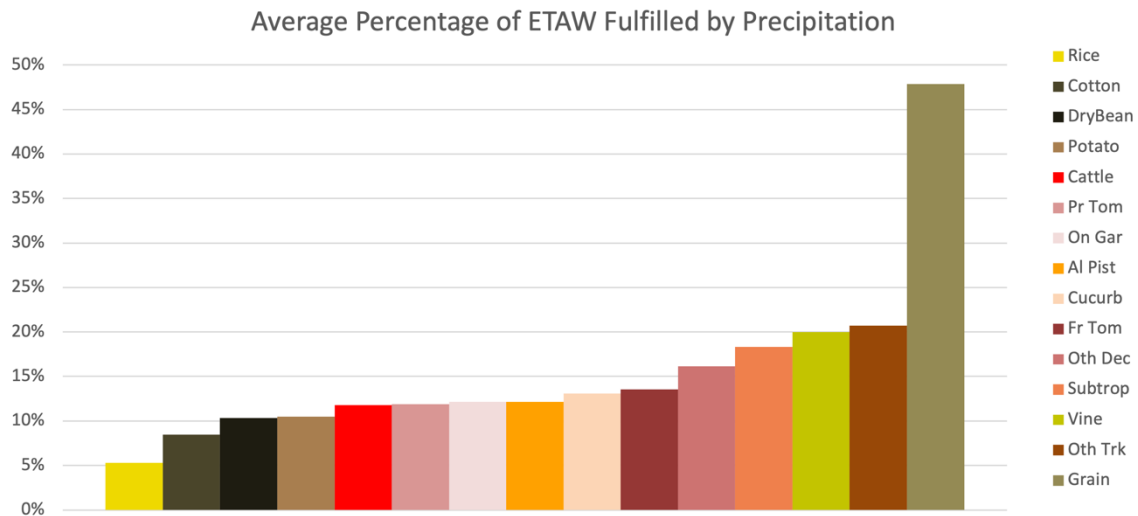


Figure 9. Average Percentage of ETAW Fulfilled by Precipitation

Figure 9 shows the average percentage of Evapotranspiration of Applied Water (ETAW) that is fulfilled by effective precipitation (EP). This metric can represent the fraction of blue water that is supplied to a crop's growth, as opposed to irrigated green water. In this plot, lower percentage values designate more reliance on manmade water conveyance systems, i.e., a less sustainable crop. Although Almonds and

Pistachios fall squarely in the middle of this classification at 12%, other water-intense crops shown in Figure 7 are represented at the lower end of the graph, namely rice, cotton, and dry beans. This further underscores that water-intense crops are not being grown in areas of plentiful water supply (high EP values), but in areas where significant water diversions are needed to support the crop's growth.

Although the annual change and overall trends of irrigated crop area (ICA) are largely unremarkable and not included here, it is worth mentioning how the ICA of almonds in particular has changed since 1999, according to the state's DWR estimates. In this twenty-year period, almond irrigation increased from 696 to 1,429 thousand irrigated acres, for an increase of 205%. Likewise, irrigation efficiency, or consumed fraction (CF), of applied water has increased in the past two decades as agricultural technology has improved. Overall average CF has increased from 0.70 in 1999 to 0.84 in 2019. Some crops have improved their irrigation efficiency at a higher rate than others (e.g. rice, from 0.51 in 1999 to 0.9 in 2019, as compared to Dry Beans, from 0.71 in 1999 to only 0.79 in 2019). Since almonds are a crop of particular importance within this study, it is worth it to note that the CF of almonds and pistachios roughly mirrors that of overall CF averages, with efficiencies of 75% and 84% in 1999 and 2019, respectively. Also, the export value of almonds and pistachios combined in 2019 was reported by the UC Davis AIC as \$6.9 billion, which was 37% of the overall export value in that year. This is compared with 1999, when almonds and pistachios accounted for \$713 million, 14.6% of that year's overall export value. These non-plotted data trends highlight that almonds and pistachios have drastically increased their irrigated crop acreage and export value in the past twenty years, while modest improvements in irrigation efficiency match that of overall crops.

CONCLUSIONS

This research identifies and synthesizes a few trends that have been described and debated in detail by others (Arax, 2019; Cooley, 2015; Hanak and Mounth, 2019; Kruzman, 2021a). As shown in Figures 3 and 4 and Table 1, California is virtually exporting more water than in previous years. This is not matched in an increase in total amount of agricultural water used, such that California is also virtually exporting a higher percentage of its agricultural-use water than it used to. These previous two trends are largely due to the substantial (66%) increase in almond and pistachio production over the last twenty years, a water-intensive, high value, primarily-exported crop category. While this analysis does provide a good estimate for crop-specific virtual water exports over the past twenty years in California, it does not necessarily refute some of the criticisms associated with the philosophical approach of the virtual water concept. While it is this author's opinion that these figures can lend some contextualization to a charged and territorial water supply debate among various state actors, it is for public policy experts to decide whether the acknowledgement of a water-subsidized agricultural global trade revises the calculus for water allotments and conveyance among environmental, human, and agricultural uses.

REFERENCES

- Allan, J.A. 1993. Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. In: ODA, Priorities for water resources allocation and management, ODA, London, pp. 13-26.
- Arax, M. 2019. *The Dreamt Land: Chasing Water and Dust Across California*. Alfred A. Knopf, New York.
- California Department of Water Resources (DWR). 2022. Agricultural Land and Water Use Estimates. <https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Agricultural-Land-And-Water-Use-Estimates>
- Cooley, H. 2015. California Agricultural Water Use: Key Background Information. Pacific Institute, <https://pacinst.org/wp-content/uploads/2015/04/CA-Ag-Water-Use.pdf>
- Dennis, W. 2010. Virtual Water and Water Footprints Offer Limited Insight Regarding Important Policy Questions, Water Resources Development, Vol. 26, No. 4, 639–651, December.

- Iyer, R.R. 2012. Virtual water: Some reservations, GWF Discussion Paper 1218, Global Water Forum, Canberra, Australia.
- Fulton, J., Cooley, H., and Gleick, P. 2012. California's Water Footprint. Pacific Institute, Oakland CA. ISBN: 1-893790-46-0.
- Fulton, J. 2014. With water, California's Bigfoot is imported. Pacific Institute, <https://pacinst.org/with-water-californias-bigfoot-is-imported/>
- Frontier Economics. 2008. The concept of 'virtual water' — a critical review, Report for the Victorian Department of Primary Industries, Australia.
- Hanak, E. and Mount, J. 2019. Water Use in California. Public Policy Institute of California (PPIC). <https://www.ppic.org/publication/water-use-in-california/>
- James, L. 2022. California agriculture takes \$1.2-billion hit during drought, losing 8,700 farm jobs, researchers find. Los Angeles Times. <https://www.latimes.com/california/story/2022-02-25/california-agriculture-takes-1-2-billion-hit-during-drought>
- Lund, J. 2014. California drought: virtual water vs. real water. UC Davis Center for Watershed Sciences, <https://californiawaterblog.com/2015/07/05/virtual-water-vs-real-water-in-california-2/>
- Kruzman, D. 2021a. U.S. Southwest, Already Parched, Sees 'Virtual Water' Drain Abroad. Undark.org, <https://undark.org/2021/05/31/foreign-farms-virtual-water/>
- Kruzman, D. 2021b. Foreign Firms Sucking "Virtual" Water from America's Parched Southwest. Mother Jones, <https://www.motherjones.com/environment/2021/06/foreign-companies-export-virtual-water-american-drought-southwest/>
- Merrett, S.W. 2003. 'Virtual water' and Occam's razor, Occasional Paper No 62, SOAS Water Issues Study Group, School of Oriental and African Studies/King's College London, University of London.
- Office of the United States Trade Representative (USTR), 2018. California, State Benefits of Trade. <https://ustr.gov/map/state-benefits/ca>
- Susanne, N. 2008. Strategic Virtual Water Trade – A Critical Analysis of the Debate, in W. Scheumann et al. (eds.), Water Politics and Development Cooperation, 123 doi: 10.1007/978-3-540-6707-76, Springer-Verlag, Heidelberg 2008
- University of California Agricultural Issues Center (UC AIC). 2022. California Agricultural Exports. <https://aic.ucdavis.edu/california-agricultural-exports-year-2000-through-latest-available-2/>
- United States Department of Agriculture, National Agricultural Statistics Service (USDA), 2022. USDA's National Agricultural Statistics Service, California Field Office. County Ag Commissioners' Data Listing. https://www.nass.usda.gov/Statistics_by_State/California/Publications/AgComm/index.php