Trends and Variation in California's Water Footprint

Julian Fulton & Heather Cooley (Pacific Institute),
Susana Cardenas & Fraser Shilling (UC Davis)

California uses goods and services made in the US and elsewhere, requiring water and impacting aquatic systems. This is equivalent to California's Water Footprint. This Footprint has grown in the last 20 years, beyond what might be expected from population growth alone. This report describes trends analysis for the Footprint, as well as estimation of the variation and confidence intervals around the mean.

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Julian Fulton and Heather Cooley

(Pacific Institute)

&

Susana Cardenas and Fraser Shilling

(University of California, Davis)

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About the Authors: **Julian Fulton** is a Ph.D. candidate in the Energy and Resources Group at the University of California at Berkeley and a research affiliate with the Pacific Institute Water Program. **Heather Cooley** is the Co-Director of the Pacific Institute Water Program. **Susana Cardenas** is a graduate student in UC Davis' Ecology Graduate Group, where she specializes in measuring ecosystem services and values. **Fraser Shilling** is a research scientist at UC Davis, Department of the Environmental Science and Policy and the project lead of the Water Sustainability Indicators Framework, California Water Plan Update 2013.

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I. Summary and Organization of the Report

This report describes two main findings of the Water Footprint (WF) for California: the change in the total WF and changes in components of the WF over time; and sources of variation in the WF. California's WF has increased over the last 20 years, beyond what would be expected from an increase in population. Twenty years ago, California sustained itself using primarily goods produced in California. It now gets most its goods from sources outside the state, from sources within the US and elsewhere. This has resulted in the state's current WF being primarily located outside the state. The WF for agricultural goods consumed in California, the vast majority of the WF, are from a combination of naturally-occurring precipitation and moisture ("Green Water") and water applied during irrigation ("Blue Water"). The amount of water applied for specific crops varies among and within years, resulting in variability around the mean WF of between ± 13% (1992) ± 9% (2007).

The first section of the report discusses time as a source of variation in total WF, including evaluation of trends in important components of the WF (e.g., agriculture and energy production). The second section of the report discusses sources of variability in the WF and how this variability changes over time. The final section of the report discusses overall conclusions and remaining questions.

II. Evaluating Trends in California's Water Footprint

II.A. Introduction

Throughout much of the twentieth century, California's water use increased as the population and economy grew. Since the 1970s, however, total water withdrawals for agricultural and urban purposes in California have remained more or less stable (Figure 1). During this same period, the state's population nearly doubled, and the economy quadrupled in constant dollar terms (CDF 2011; USDC-BEA 2012). These trends suggest that California's overall water productivity has improved, both as a function of per capita use and economic output. This water productivity increase has resulted from the adoption of more efficient practices in nearly all sectors of society, from households and businesses to farms, factories, and power plants, as well as reductions in water-intensive manufacturing and growth of the service sector (Gleick et al. 2005; Rich 2009; Hanak et al. 2012).

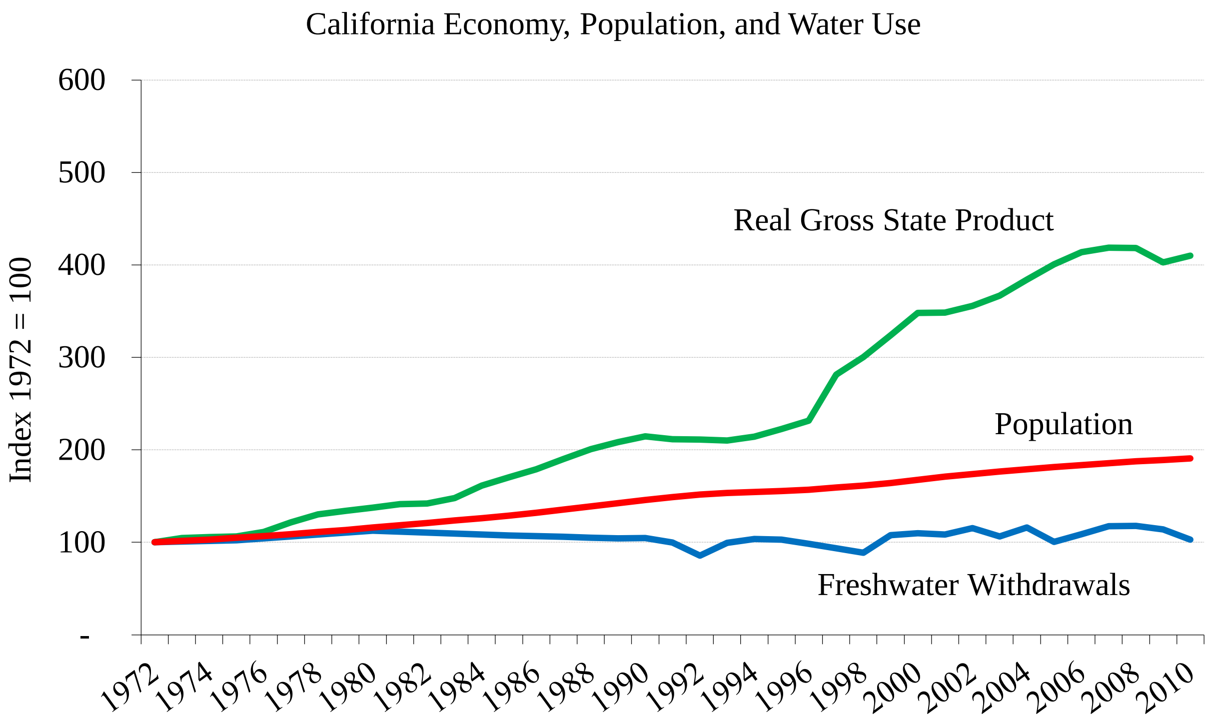

Figure 1. Trends in California's Population, Freshwater Withdrawals, and state-level GDP

Sources: DWR various[1]; CDF 2011; USDC 2012

These metrics of increasing productivity, while useful, do not fully capture the total amount of water required to support California's growing population and economy and therefore provide an incomplete picture of California's overall water use. Many of the goods consumed in California – and the water required to produce those goods – are imported from locations outside the state's borders. Likewise, many of the goods produced in California are exported to other regions. This movement of goods effectively results in the transfer of the benefits and burdens of water use into and out of California.

Traditionally water management has been thought of as a local or regional issue, but globalization has forged increasing interconnectedness among people and economies. As shown in Figure 2, California has rapidly integrated into the global economy in recent decades. The value of international imports is now almost three times what it was two decades ago, while domestic imports (i.e., goods imported into California from other U.S. states) have also grown substantially in price-adjusted terms (USDC-BC 2010). Exports have also grown, although

[1] These data have been collected by DWR staff from older versions of Bulletin 160 (1972-1985), Annual Reports prepared by District Staff (1989-1995) and the Water Portfolio from California Water Plan Update 2013 (1998-2010)

to a lesser extent (see **Error! Reference source not found.**).[2] Thus as Californians' consumption patterns have become more integrated with the global economy through trade, the water embedded in those trade flows – also referred to as "virtual water" – plays an increasing role in California's overall demand for water and its relationship with water resource conditions outside the state's borders.

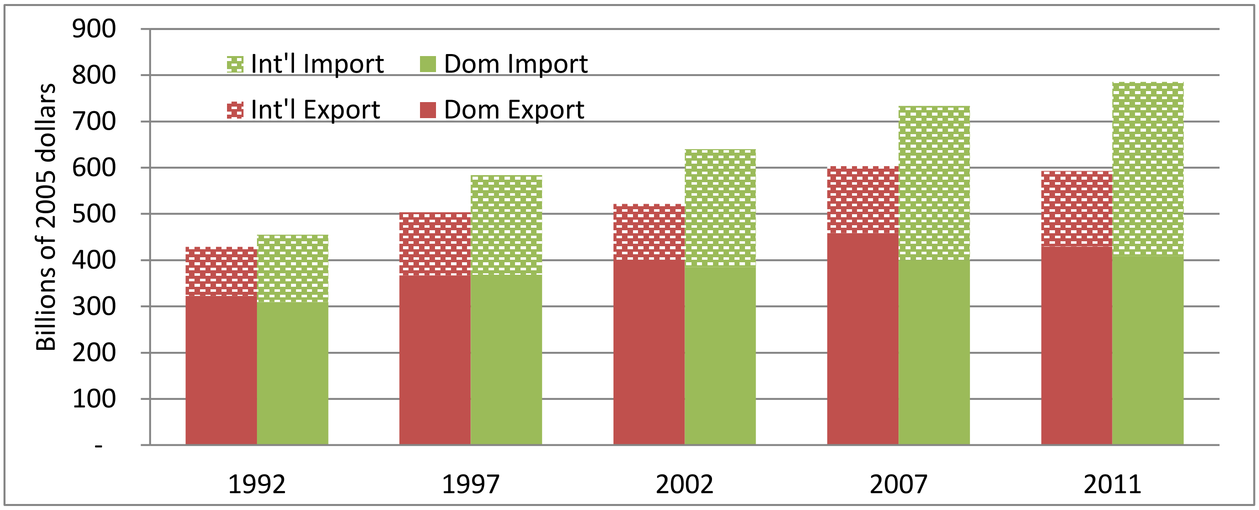

Figure 2. Trends in California's International and Domestic Trade

Source: U.S. Department of Commerce, Census Bureau

The "water footprint" has emerged as one tool for quantifying and evaluating the complex ways in which human activities affect and are affected by the world's water resources. In 2012, the Pacific Institute completed the first comprehensive assessment of California's water footprint (Fulton et al. 2012). The assessment estimated that California's total water footprint in 2007 was about 64 million acre-feet, more than double the annual average combined flows of the state's two largest rivers, the Sacramento and San Joaquin Rivers. The water footprint of the average Californian is about 1,500 gallons per day (GPCD), slightly less than the average American (1,600 GPCD) but considerably more than an average resident in other highly industrialized countries (1,100 GPCD) (Mekonnen and Hoekstra 2011). Additionally, the study found that about 70 percent of California's water footprint is external, meaning that Californians are highly dependent on water resources from outside the state's borders. Over two-thirds of this water is from other U.S. states while less than one-third is from foreign countries.[3]

[2] Throughout the report the terms export and import are used to imply movement across California's border to both international and domestic trading partners.

[3] For further discussion and more detailed analysis on the types of products and locations related to California's water footprint, see Fulton et al. (2012).

This report extends our initial assessment in three ways. First, we expanded the scope of products beyond agricultural, industrial, and direct uses, to include energy products, e.g., electricity, natural gas, and transportation fuels. All of these forms of energy require water at various production stages, from extraction to generation. Second, we evaluated historic trends in California's water footprint over the past two decades as a result of changes in production, trade, and consumption patterns. Lastly, we analyzed the water footprints of California's ten hydrologic regions.

II.B. Water Footprint Applications

A water footprint assessment can be conducted at various scales for a variety of purposes. For example, an individual may conduct a personal water footprint assessment and based on the results, change his/her consumption patterns, i.e., reduce overall consumption levels and substitute water-intensive products with less water-intensive products. Additionally, a corporation may conduct a water footprint assessment to examine water risk to its operations and identify actions to minimize those risks. In this section, we provide additional examples of various water footprint applications.

Potential WF User Groups

- Water managers
- Agricultural community
- Corporations
- Environmental groups
- Tax/Ratepayer organizations
- General public

Water footprint assessment as a tool for the general public

As the general public becomes more aware of resource challenges around the world, there is a growing interest in characterizing our dependence and impacts on these resources. Over the past decade, there has been a proliferation of footprint accounting methods, e.g., carbon footprint, ecological footprint, and water footprint.

As described above, the consumption of goods and services requires the delivery of water through natural and engineered pathways and return of wastewater to the environment, and greater levels of consumption typically result in a larger water footprint. There are several factors that affect an individual's water footprint. These include:

1) Diet – food consumption is the largest component of an individual's water footprint and eating water-intensive produces, such as meat, will increase this water footprint;
2) Income – consumption of goods and services tends to increase with income, as those that make more money, tend to consume more products and more water-intensive products and services; and

3) Supply Chain Length – the further products and services are produced from the consumer, the greater the water footprint of consumption is likely to be.

Because there is variation in income in California and the US, as there is elsewhere in the world, it is useful to estimate water footprint using income classes as one way to control for this variation. The Water Footprint Network has developed an online calculator that estimates the water footprint based on income.[4] The calculator can be used by individuals, or in combination with Census data to estimate the water footprints of communities.

Water footprint assessment as a tool for corporations

Corporations, as the suppliers of goods and services that individuals consume, play a large role in determining the water footprint of products they offer. Over the past several years, corporations have been using water footprint assessments to evaluate their water-related risks (Morrison et al. 2010, CDP 2010, Hoekstra et al. 2011). A corporate water footprint assessment includes two major components:

- the **operational water footprint**, i.e. the direct water use by the business in its own operations, and
- the **supply-chain water footprint**, i.e. the water use in the business's supply chain.

Typically, the supply-chain water footprint, often ignored in traditional water assessments, is much larger than the operational water footprint. Among the corporations that have conducted water footprint assessments include SABMiller, the Coca Cola Company, PepsiCo, Dole Food Company, Barilla Pasta, and Levi Strauss & Co. (e.g., Coca-Cola and The Nature Conservancy, 2010; SAB Miller and the World Wildlife Fund-UK, 2011; Jeffries et al., 2009).

The different methodologies and their application are still being developed and transparent case studies are needed that apply the techniques across the entire supply chain, thereby reflecting the effects of European production and consumption on water scarce river basins outside Europe.

Water footprint assessment as a tool for water managers

The concept of virtual (or embedded) water can help inform water-management decisions. For example, coupling virtual water with economic information describing the production value of a crop can strengthen agricultural water management. For example, Spain was the first country in the European Union to include a water footprint analysis into its river basin management plans. The analysis, conducted in 2009, included questions on when and where water footprints exceed water availability, how much of a catchment's total water footprint is used in producing

[4] http://www.waterfootprint.org/?page=cal/waterfootprintcalculator_indv

exports, and the amount and value of crops produced per unit of water (WFN 2012). Also in Spain, a 2010 study found that 'high virtual water, low economic value' crops, such as cereals, are widespread in the region, due in part to a legacy of subsidies in the region. An expansion of low water consumption and high economic value crops, such as vineyards, was identified as a potentially important measure for more efficient allocation of water resources (Aldaya et al. 2010). The study concludes that the agricultural sector will need to modify its water use if it is to achieve significant water savings and environmental sustainability. Pricing is one mechanism to allocate water to those crops that generate the highest economic value at low water demand (Bio Intelligence 2012a).

II.C. Analytical Approach

A water footprint assessment provides a metric and methodology for quantifying virtual water. Because water is constantly circulating and serving multiple uses, the water footprint accounts only for that portion consumptively used, or “water withdrawn from a source and made unavailable for reuse in the same basin, such as through conversion to steam, losses to evaporation, seepage to a saline sink, or contamination (Gleick 2003).” A water footprint is based on the goods and services consumed and can therefore be calculated at different levels of consumer activity, i.e., for individuals, households, regions, states, nations, or even all of humanity.

This analysis uses methods to calculate a water footprint advanced by the Water Footprint Network, which are described in detail in the *Water Footprint Assessment Manual* (Hoekstra et al. 2011). The basic approach for calculating a water footprint is to multiply consumptive water use factors (gallons-per-unit of product) of various products with statistics on the production, trade, and consumption of those products. It includes additional quantitative and qualitative features about the water used, including where the water comes from and the kinds and quality of water used.

Green Water = Rainwater and soil moisture used directly

Blue water = Surface or ground water that is physically applied

Grey Water = Volume of water poluted by runoff and effluent

A water footprint has three volumetric components pertaining to consumptive water use: green water, blue water, and grey water. Green water is the amount of precipitation and soil moisture that is directly consumed in an activity, such as in growing crops. Blue water is the amount of surface or groundwater that is applied and consumed in an activity, such as in growing crops or manufacturing an industrial good. Finally, grey water, is the amount of water needed to assimilate pollutants from a production process back into water bodies at levels that meet governing standards, regardless of whether those standards are actually met. [5] The green, blue and grey water metrics are calculated for individual processes in particular places and then aggregated based on the consumption patterns of the unit of interest (individual, state, etc.).

The green, blue, and grey water components of a water footprint assessment are often combined and reported as a single value in the literature. Each, however, has distinct ecological, social, and economic contexts. Green water pertains to rainwater and soil moisture occurring where crops are grown and thus may potentially reduce water available for other land uses, alternative crops, or native vegetation. Blue water, by contrast, represents an intentional abstraction and allocation of surface or groundwater resources for irrigation, municipal, and industrial uses, often requiring pumping and conveyance systems to extract and deliver water. Grey water, as defined in the water footprint literature, is an indicator of water quality rather than a measure of consumptive water use. Even though the contamination of surface waters is by definition a consumptive use, contaminated water can often still serve multiple uses, such as for navigation or cooling. In order to eliminate double counting of upstream grey water footprints by downstream blue water uses in this analysis, we focus on California's blue and green water footprint. Additional analysis is needed on California's grey water footprint to depict a more comprehensive water footprint picture of the state.

We calculated California's water footprint using a top-down balancing approach as shown in Figure 3. The total water footprint of goods and services consumed in California has an internal component and an external component (top row). The internal water footprint is calculated as the water footprint of goods and services produced within California minus the water footprint of goods produced in California and exported out of the state. The external water footprint is calculated as the water footprint of goods which are imported into and consumed within California. The water footprint of traded services is not considered in this analysis. In the following section we describe the data sources used in the analysis in greater detail.

Internal water Footprint			+	External water Footprint	=	Total water footprint of goods consumed in California
Water footprint of goods and services produced in California	-	Water footprint of goods produced in California and exported	+	Water footprint of goods imported and consumed in California	=	

[5] Not to be confused with wastewater that is reused on a site, which often goes by the name "greywater."

Figure 3: California's water footprint accounting framework

Source: modified from Hoekstra et al. 2011

II.C. Methods and Data Sources for Calculating Water Footprint Factors

Figure 4 depicts the modeling framework used to calculate the elements in Figure 3. Each element of California's overall water footprint from Figure 3 is shown in a purple box, while the components used to calculate those elements are in blue boxes. Each line connecting the boxes depicts a process step in collecting and combining various data sources. The following sections discuss these data sources and how they were used.

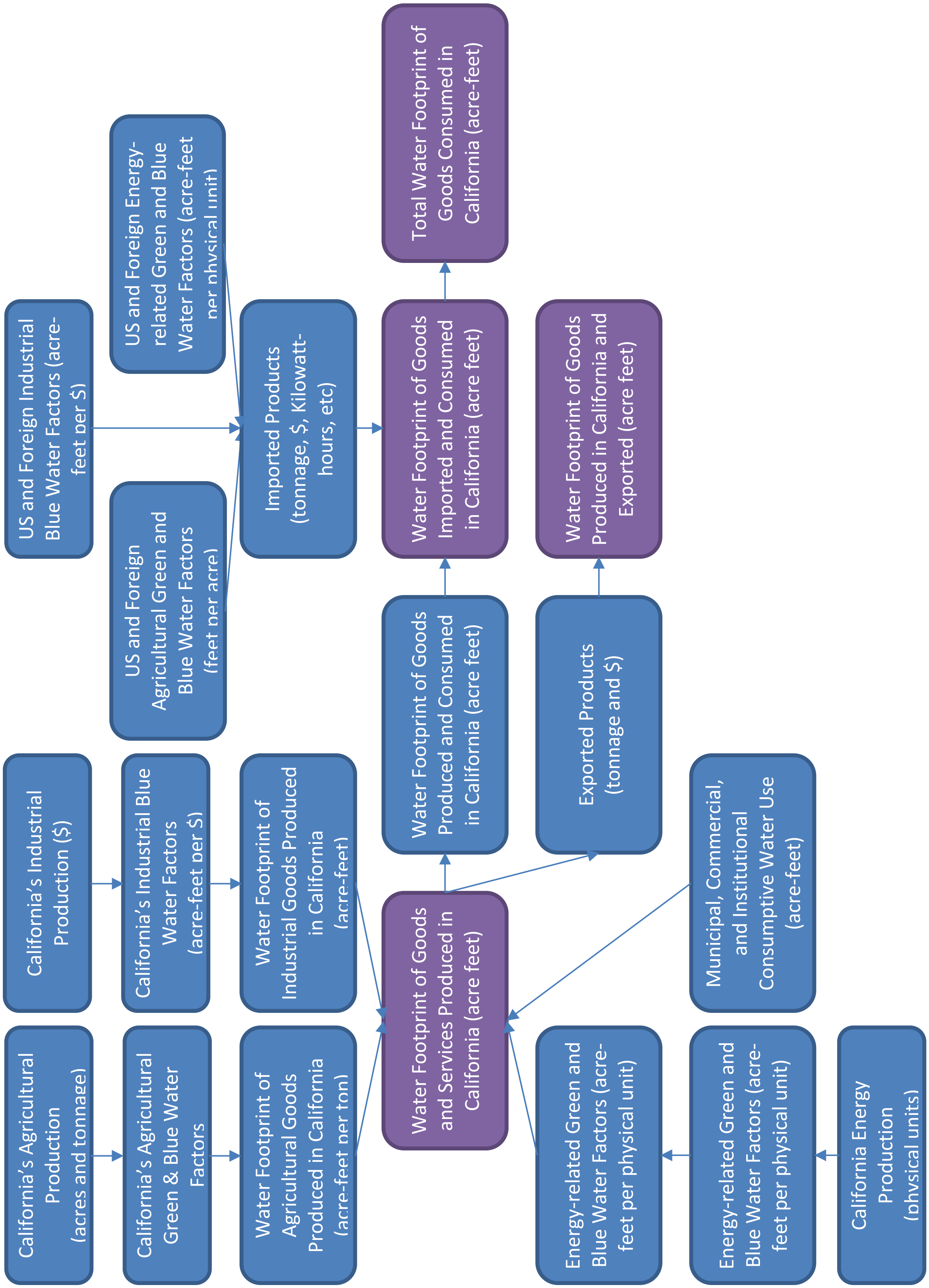
Total Water Footprint of Goods Consumed in California (acre-feet)
US and Foreign Energy-related Green and Blue Water Factors (acre-feet per physical unit)
US and Foreign Industrial Blue Water Factors (acre-feet per $)
Imported Products (tonnage, $, Kilowatt-hours, etc)
Water Footprint of Goods Imported and Consumed in California (acre feet)
Water Footprint of Goods Produced in California and Exported (acre feet)
US and Foreign Agricultural Green and Blue Water Factors (feet per acre)
Water Footprint of Goods Produced and Consumed in California (acre feet)
Exported Products (tonnage and $)
California's Industrial Production ($)
California's Industrial Blue Water Factors (acre-feet per $)
Water Footprint of Industrial Goods Produced in California (acre-feet)
Municipal, Commercial, and Institutional Consumptive Water Use (acre-feet)
Water Footprint of Goods and Services Produced in California (acre feet)
California's Agricultural Production (acres and tonnage)
California's Agricultural Green & Blue Water Factors
Water Footprint of Agricultural Goods Produced in California (acre-feet per ton)
Energy-related Green and Blue Water Factors (acre-feet per physical unit)
Energy-related Green and Blue Water Factors (acre-feet per physical unit)
California Energy Production (physical units)

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Figure 4: Modeling framework of water footprint calculation

Agricultural Products

For this analysis, we used California-specific data to estimate the water footprint of goods and services produced in California.[6] Consumptive water use factors for non-energy products were derived from several California Department of Water Resources (DWR) data sources. Consumptive use factors for agricultural products were derived from the California Simulation Evaporation of Applied Water (Cal-SIMETAW) model (Orang et al. 2013), which reconstructs seasonal crop evapotranspiration (ETc) estimates (in units of acre-feet per acre) for 20 crop categories from 1992 – 2009 using recorded weather and cropping pattern data. ETc values were further divided between evapotranspiration of applied water (ETaw) and effective precipitation (EP).[7] ETaw values were used as blue water factors to calculate the blue water footprint of agricultural products. Green water factors were calculated as EP plus residual soil moisture (in other words, ETc minus ETaw). These factors were available at the combined Detailed Analysis Unit-County level (DAU-Co), which could then be aggregated to an individual county, hydrologic region, and the state as a whole.

Agricultural production statistics were taken from California County Agricultural Commissioner's statistics, which provided county-level harvested acreage and production tonnage for 281 agricultural commodities from 1992 – 2010. Harvested acreage of each commodity was multiplied by blue and green water factors for the appropriate DWR crop category to get the total quantity of water required to produce a given crop.[8] Water use for a given crop was then divided by production tonnage for that crop to derive blue and green water footprint factors in units of acre-feet-per-ton of product. These product-level water footprint factors were then combined with trade statistics, as described below.

It is important to note that California has non-irrigated agriculture. Specifically, most pasture and some grains are entirely rainfed. The California County Agricultural Commissioner's reports include data on both rainfed and irrigated agriculture. The land use dataset used in Cal-SIMETAW, however, only provides data on irrigated agriculture. To determine the amount of land devoted to rainfed crops, we subtracted Cal-SIMETAW irrigated land area statistics for crop categories from total land area provided in the California County Agricultural Commissioner's reports. For rainfed agriculture, we only apply green water factors available from the Cal-SIMETAW dataset.

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[6] Note that we used different data sets from Fulton et al. (2012) in order to look in more detail at annual changes over longer time periods.

[7] Cal-SIMETAW yearly values are for a "water year," which is Oct. 1 – Sept. 30. We assumed that water used for production in, for example, water year 2007 (Oct. 1, 2006 – Sept. 30, 2007), all pertains to products harvested in calendar year 2007. 2010 water use values were calculated as the average of 2005-2009.

[8] See Appendix 1 in Fulton et al. (2012) for the commodity categories used in this analysis.

Producing animal products, like meat and dairy, consumes a large amount of water, primarily to grow the forage and fodder required to feed the animals. Data on the production of animal products were obtained from the 2007 USDA Census of Agriculture. Using international biomass-to-product conversion rates published in (Mekonnen and Hoekstra 2010a), we estimated the amount of feed required to produce these animal products. According to these sources, an estimated 63.2 million tons of biomass were needed for animal production in California in 2007. The biomass estimates were multiplied by the water footprints of feed and forage crops, calculated as described above, to estimate the amount of water required to produce animal products. The water footprint of animal products, calculated on a gallons-per-ton basis, for 2007. When trade data were applied, as discussed below, the water footprint factor was developed for 2007 and applied to all other years analyzed. Other water uses, e.g., for washing and hydrating animals and for the processing of animal products, are typically only around 1% of animal product water footprints (Mekonnen and Hoekstra 2010a) and were not included in this analysis. The biomass demand from California's animal product industries exceeds the supply from in-state sources, thus imported feed crops make a major contribution to the production of animal products in California.[9]

Industrial Products

The water footprint associated with industrial products produced in California, as well as direct residential, commercial, and institutional uses, was derived using Water Portfolios from past California Water Plan Updates.[10] In some cases, only water withdrawals were reported. For these, we assume that 31% of water withdrawn was consumed.[11] For industrial products produced outside of California, we used national average water footprint factors on a gallons-per-dollar basis as developed by Mekonnen & Hoekstra (2011). We then combined these factors with trade data to estimate virtual water flows associated with industrial products into and out of California.

Energy Products

California's energy system is complex. The extraction, processing, refining, and generation of energy products take place within the state's borders, but there are also significant exchanges at all of these production stages with neighbors and distant trading partners. To account for these energy flows, the California Energy Commission's Public Interest Energy Research program has sponsored ongoing work at Lawrence Berkeley National Laboratory to create and

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[9] California exports some animal feed and forage crops, namely alfalfa, and those exports were excluded as an input to animal products within California.

[10] These data have been collected by DWR staff from older versions of Bulletin 160 (1972-1985), Annual Reports prepared by District Staff (1989-1995) and the Water Portfolio from California Water Plan Update 2013 (1998-2010).

[11] This estimate was based on the average for all urban uses from 1998-2005 as provided by the Technical Guide from the California Water Plan Update 2009.

maintain the California Energy Balance (CALEB) database. CALEB manages highly disaggregated data on energy supply, transformation, and end-use consumption for about 30 different energy commodities, from 1990 to 2008 (de la Rue du Can et al, 2010). Figure 5 shows an example flow chart produced by CALEB for 2008, represented in trillion British thermal units of energy (BTUs). We used CALEB data on the physical units of energy (barrels of oil, million cubic feet of natural gas, etc.). To identify the origin of imported supplies we used additional information from the California Energy Commission on electricity (CEC 2013) and from the Energy Information Administration on natural gas (EIA, 2013a) and oil (EIA, 2013b).

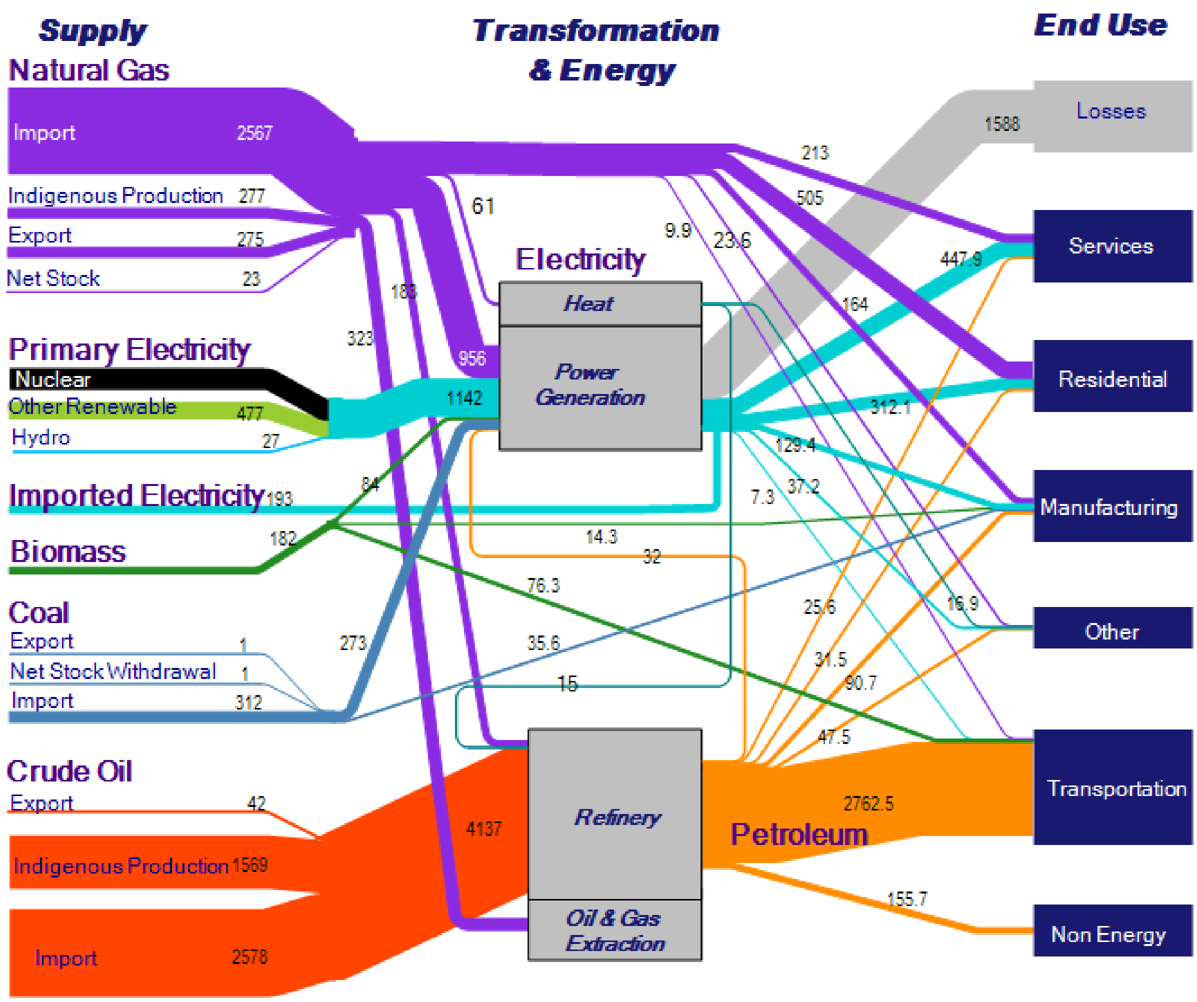

Figure 5: 2008 California Energy Flow Chart (in trillion British thermal units of energy)

Source: de la Rue du Can et al. 2010

Consumptive water use factors for energy were derived from several sources. The National Renewable Energy Laboratory (NREL) recently completed a review and harmonization of life cycle factors given by numerous publications on various electricity feedstock and generation technologies (Meldrum et al. 2013). We used NREL's median factors for natural gas, coal, biomass, and nuclear supplies at the extraction, upgrading, and generation stages, as well as hydropower. For extraction, processing and refining of oil products we used factors from Wu et al. (2009). For bioethanol production in the US we used weighted average factors from Mekonnen and Hoekstra (2010), including refining and on-farm green and blue water requirements of bioethanol feedstocks. Grey water footprints of energy products were not calculated as part of this analysis.

Trade Data

As seen in Figure 2, California exports and imports many goods and services. The water footprint associated with traded goods and services is called a "virtual water flow." To calculate these virtual water flows we combined water footprint factors, as described in the previous section, with trade statistics from the US Department of Transportation's Freight Analysis Framework (FAF^3) for 1997, 2002, 2007, and 2010 (Southworth et al. 2011). FAF^3 combines Census Bureau and other data into a consistent modeling framework over time, and organizes data according to the 2-digit level of the Standard Classification of Traded Goods (SCTG) for both domestic and international trading partners. FAF^3 data were not available for 1992. We therefore used US Department of Transportation's Commodity Flow Survey (CFS) for 1992 (USDC-BC 1993), which is also organized by SCTG. Because the CFS only includes domestic trade flows, we assumed that the proportion (by weight) of international to domestic trade flows in 1992 were the same as in 1997.

To calculate the water footprint of products produced in California and exported outside the state, i.e., "embedded water exports," trade data were multiplied by blue and green water footprint factors. For agricultural products, green and blue water footprint factors (gallon per ton) were aggregated to the 2-digit SCTG level for each trade year and multiplied by export weights. For industrial products, export values (dollars of sales) for each trade year were multiplied by the average national industrial blue water footprint factor as provided by Mekonnen and Hoekstra (2011).

To calculate embedded water imports, trade data were multiplied by blue and green water footprint factors. For agricultural products, blue and green water footprint factors from Mekonnen and Hoekstra (2010a, 2010b) were used by taking a weighted average among US states as well as international trading partners and then aggregated to SCTG categories. For industrial products, we also used average US and global blue water footprint factors from Mekonnen and Hoekstra (2011) and multiplied them by the value of imported industrial products from US and international trading partners. As these datasets are averaged for 1996 – 2005, they were assumed to be the same for each trade year.

For the analysis of water footprint trends in California, the availability of trade data limited our analysis to 5-year increments from 1992 to 2007, as well as 2010. For each trade year, California's Water Footprint was calculated using the accounting framework shown in Figure 3.

Regional Analysis

We also evaluated regional water footprints related to embedded water flows among California's ten hydrologic regions (HRs). While production data were available for these regions, data were not available for trade and the consumption of products between and within the regions. Thus, it was not possible to determine whether embedded water stayed within HRs for local consumption or was transferred for consumption in other parts of the state. Regional trade or consumption data would allow for a more detailed analysis of regional embedded water flows within California.

In this analysis, each HR was assessed according to four criteria:

1. Population: the number of people living within each HR.
2. Regional water footprint of goods and services produced in California and consumed within the HR.
3. Water footprint of goods produced in the HR and consumed in California.
4. Water footprint of goods produced in the HR and exported from California.

To calculate regional water footprints we assumed that California residents consumed the same quantity and type of products, regardless of where they live, and that the distribution of where those products were produced was the same for all residents. Fox example, Per-capita green and blue water footprint estimates were calculated based on California's internal water footprint, i.e., excluding the external component, because we were only interested in the movement of California water within the state. These estimates were multiplied by population estimates for each HR, which are given in Regional Reports in Volume 2 of the California Water Plan Update.

To evaluate embedded water flows among regions in California, we used data from Cal-SIMETAW (Orang et al. 2013) to estimate the amount of blue[12] and green water that each of California's ten HRs contributes to California's total water footprint for water year 2007. We then applied state-level trade data to estimates of blue and green water to distinguish between embedded water that was exported out of California and that which contributed to consumption within California.

[12] The source of blue water used in production, i.e. groundwater, local surface water or transferred water, was not distinguished in this analysis.

II.D. Results and Discussion

The Water Footprint of Energy Consumption in California

We use energy for a variety of purposes, from transporting people and goods around the state, to powering our homes and businesses. Californians use less energy per person than residents of 47 other states; however California as a whole is the second most energy-consuming state due to its large population (EIA, 2012). While large amounts of energy are produced in-state, California also relies heavily on external sources of electricity, natural gas, and oil.

Here, we provide an assessment of California's Water Footprint associated with the consumption of energy products within the state (herein "Energy Water Footprint"). Figure 6 shows the amount of water required to produce the energy consumed in California between 1990 and 2008. As can be seen, prior to 2003, California's Energy Water Footprint was about 1.5 MAF. During this period, Methyl Tertiary Butyl Ether (MTBE) was added as an oxygenate to automotive gasoline to boost octane and reduce air pollution, especially ground-level ozone and smog. By the end of 2002, however, MTBE was detected in groundwater aquifers across California and subsequently banned in the state. MTBE was replaced with ethanol starting in 2003. This change, as shown in Figure 6, led to a four-fold increase in California's Energy Water Footprint. In 2008, the most recent year in our analysis, the total Energy Water Footprint was 5.6 million acre feet (MAF). Over two-thirds of this amount (4.0 MAF) was green water and the remainder (1.6 MAF) was blue water. The green water component of California's Energy Water Footprint is entirely attributable to bioethanol, most of which is blended with gasoline. The blue water requirements of bioethanol add a smaller, yet still significant, amount to California's Energy Water Footprint (0.4 MAF).

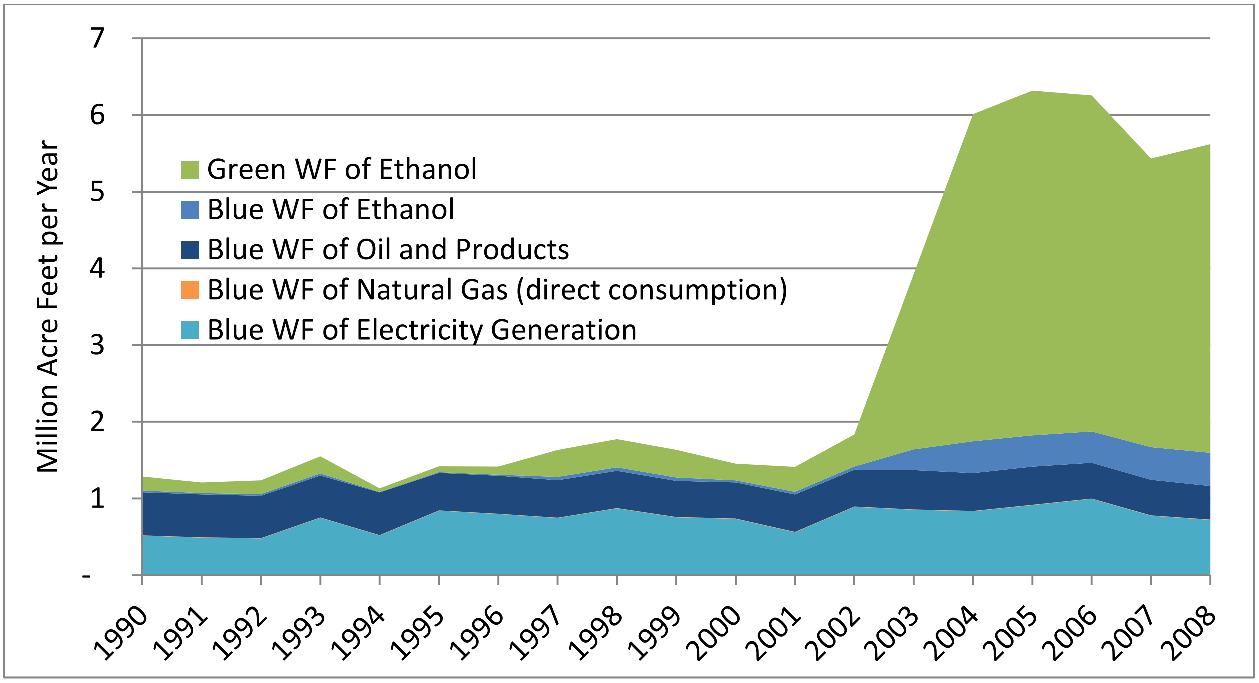

Figure 6: California's energy-related green and blue water footprint, 1990-2008

This process of increased blending of bioethanol in California's gasoline has also accelerated an externalization of the state's Energy Water Footprint. Figure 7 shows that from 1990 to 2002 about half of California's Energy Water Footprint was external. Today, nearly 90% is external. The import of bioethanol from the U.S. Midwest is the primary driver of this phenomenon, although increased imports of other fuels, such as oil and natural gas, has also played a minor role.

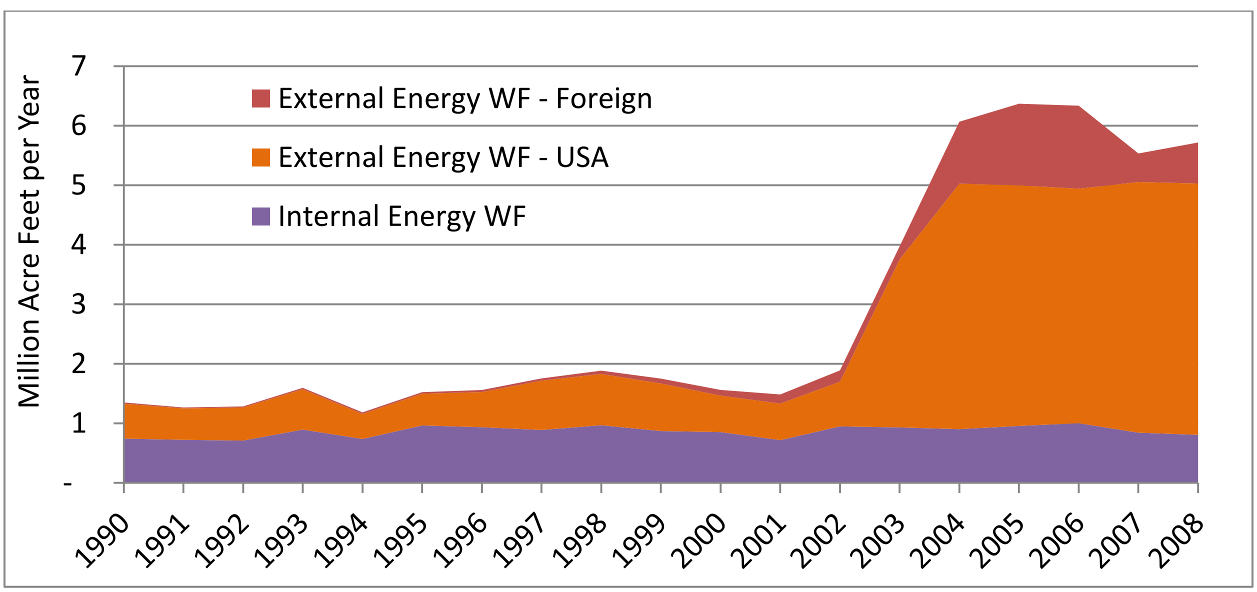

Figure 7: California's energy-related internal and external water footprint, 1990 – 2008

California's Energy Water Footprint has major implications for understanding sustainable resource management in the context of the water-energy nexus. California's energy system is complex, and changes in the system can have an implication for water resources. Our analysis shows that substituting MTBE with bioethanol increases California's water footprint. Producing bioethanol feedstock (e.g., corn) in California has not proven to be economically viable, and as a result, the water requirements for gasoline additives have come from outside the state's borders, primarily from the U.S. Midwest. Summer droughts of 2012, and the subsequent reductions in ethanol production, highlighted the risk involved in an energy system that derives inputs from vulnerable areas (EIA, 2012). Perhaps ironically, the legislation that mandated MTBE substitution with bioethanol was motivated by the human health risks that MTBE contamination poses to groundwater, thereby shifting a water quality impact that ultimately affects the availability of water resources to a direct water quantity impact. This suggests that energy policies designed to minimize risk, whether from power plant air pollution or groundwater contamination by MTBE, must also take into consideration the impacts to other resource systems, especially water. Similarly, expanding in-state energy extraction and generation may also have its downsides. Unconventional fossil fuel extraction, such as shale gas and oil shale, poses risks to water resources that would become localized if in-state intensification is pursued. Ultimately there may be more relative tradeoffs than absolute solutions in California's Energy-Water Nexus. Nevertheless, the Energy Water Footprint is a useful tool for integrating decision making for the sustainability of multiple resources.

Trends in California's Water Footprint

California's total Water Footprint has changed over time in response to population and economic growth (Figure 8). Three observations can be drawn from this trend. First, the overall Water Footprint has increased over time at a rate (4% per year) that exceeds population growth (1.4% per year). As a result, the Water Footprint of the average Californian has grown from 1,600 gallons per capita daily (GPCD) in 1992 to about 2,300 GPCD in 2010, suggesting that Californians are consuming more water-intensive products and/or more products than in the past. It appears California's water footprint is more tightly correlated with economic growth, which has proceeded at an average rate of 5.2% per year in real terms, than population growth. In general these findings suggest that population growth, coupled with economic growth, can increase demand for water resources unless efficiency gains are made across the supply chain of products that the population and related economic activities consumes.

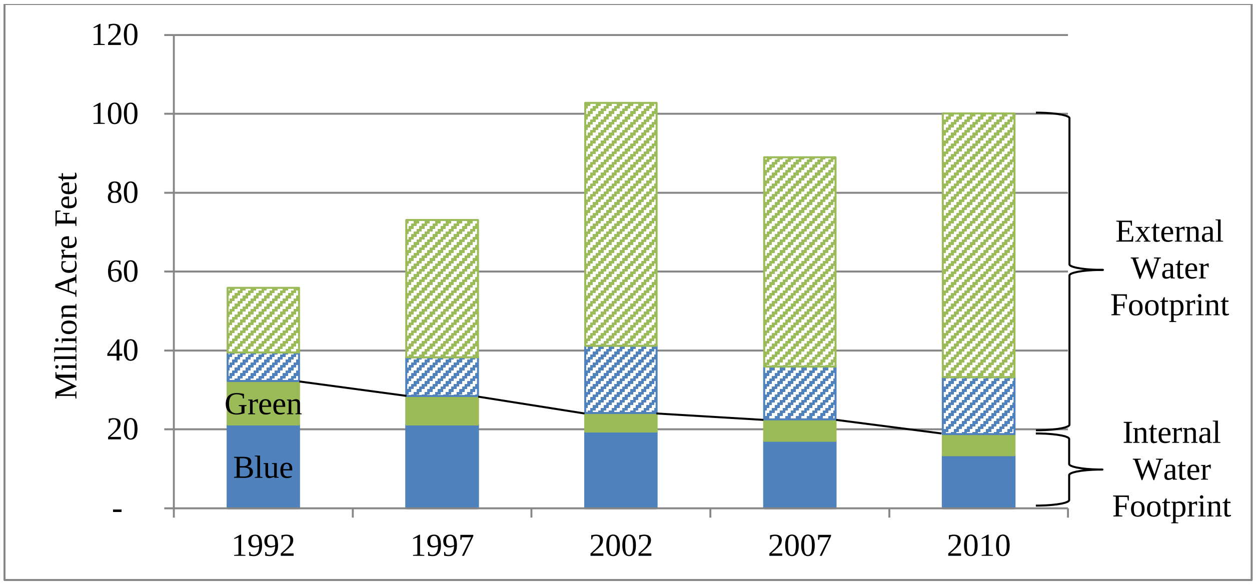

Figure 8: Trend of California's green and blue water footprint, by internal and external components, 1992 - 2010

Second, California's Water Footprint has become increasingly dependent on green water, from 51% in 1992 to 72% in 2010. The growing contribution of green water to California's Water Footprint raises concerns about the risk of relying on precipitation and the potential impacts of climate change. For example, recent droughts in the U.S. Midwest have affected grain supplies in California and provided evidence of California's susceptibility to global climatic changes in regions outside of its borders (EIA 2012). Incidentally, increased dependence on blue water could also expose California to potentials impacts of climate change since, ultimately, sources of blue water such as surface water reservoirs and groundwater aquifers, and rivers, canals, and streams are also directly dependent on the overall precipitation in an area. Nevertheless, management of blue water offers some flexibility to cope with year-to-year variations in precipitation.

Third, and perhaps most dramatically, California's Water Footprint has become increasingly externalized, from 38% in 1992 to 76% in 2010, meaning that we now rely far more on water resources from outside of our borders to support our consumption patterns than we did in the early 1990s. Most of this water is from other parts of the United States, but the percentage of virtual water from outside of the United States has nearly doubled from 21% to 41% over this time period. The further externalization of California's Water Footprint raises concerns about our ability to manage water resource impacts and risks associated with our demand for goods and services.

The values calculated in this trends analysis are higher than our initial calculations (Fulton et al, 2012) for three primary reasons. First, we included California's energy water footprint, accounting for an additional 5.5 MAF in 2007. Second, consumptive use factors were higher in

Cal-SIMETAW than in the previously-used model (DWR's Land and Water Use Survey) due to its modification of crop water requirement and soil moisture contribution parameters. Finally, the FAF[3] database included modeled values for traded goods that were omitted in the previously-used database (Commodity Flow Survey) for confidentiality reasons in some industries.

Virtual Water Exports

The water embedded in California's exports is not captured in its Water Footprint. However, it has important implications for statewide water management. As shown in Figure 9, more of California's water resources are being used to produce goods that are exported and consumed outside the state's borders (Figure 9). In 1992, 12 MAF was used to produce goods consumed outside of California. By 2010, that number had increased to 26 MAF. The value generated by exports has declined on a per-unit of water basis. In 1992, total exports produced $0.11 per gallon in revenue for the state whereas by 2007 exports were producing $0.07 per gallon.

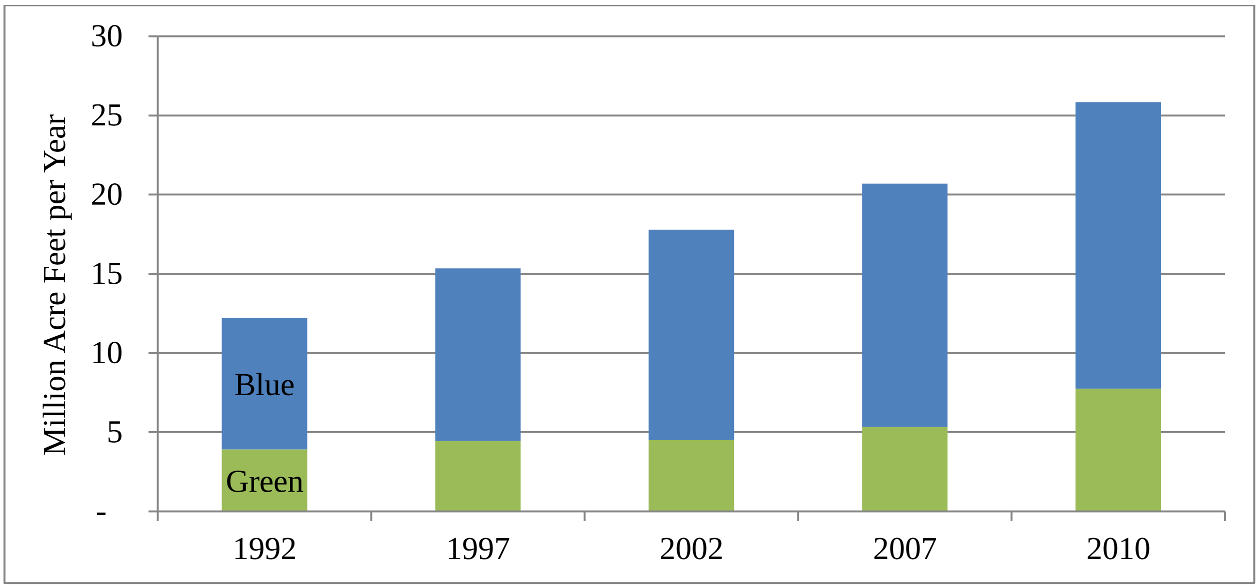

Figure 9: Trend in green and blue water embedded in California's exports, 1992 – 2010

Regional Analysis of California's Water Footprint

Other sections of the California Water Plan Update describe how water is physically moved and distributed around the state. There are also, however, transfers of embedded water from where water is put into production to the location where the product is ultimately consumed. This section provides a regional assessment of how California's internal water footprint in 2007 was distributed among the state's ten Hydrologic Regions (HRs) (10).

In this analysis, each HR was assessed according to four criteria:

1. Population: the number of people living within the HR.
2. Regional water footprint of goods and services produced in California and consumed within the HR.
3. Water footprint of goods produced in the HR and consumed in California.
4. Water footprint of goods produced in the HR and exported out of California.

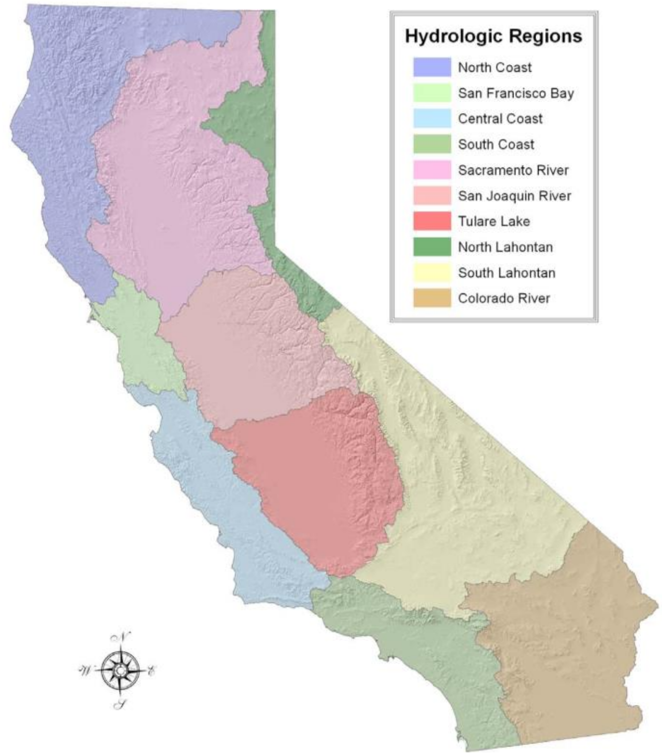

Figure 10: California's ten hydrologic regions

Results based on these criteria are discussed below and shown for each HR in Figures 11**Error! Reference source not found.** to 14.

Figure 11 compares California's HRs by population. Over half of the population (19 million people) lives in the South Coast HR. The San Francisco Bay HR is the second most populated HR, with 6.2 million people. Because we assume that all Californians have the same per capita water footprint and the same ratio of blue to green water, the most populous HRs have the largest water footprints (Figure 12). Together, the South Coast and San Francisco Bay HRs account for 70% of California's population and thus water footprint.

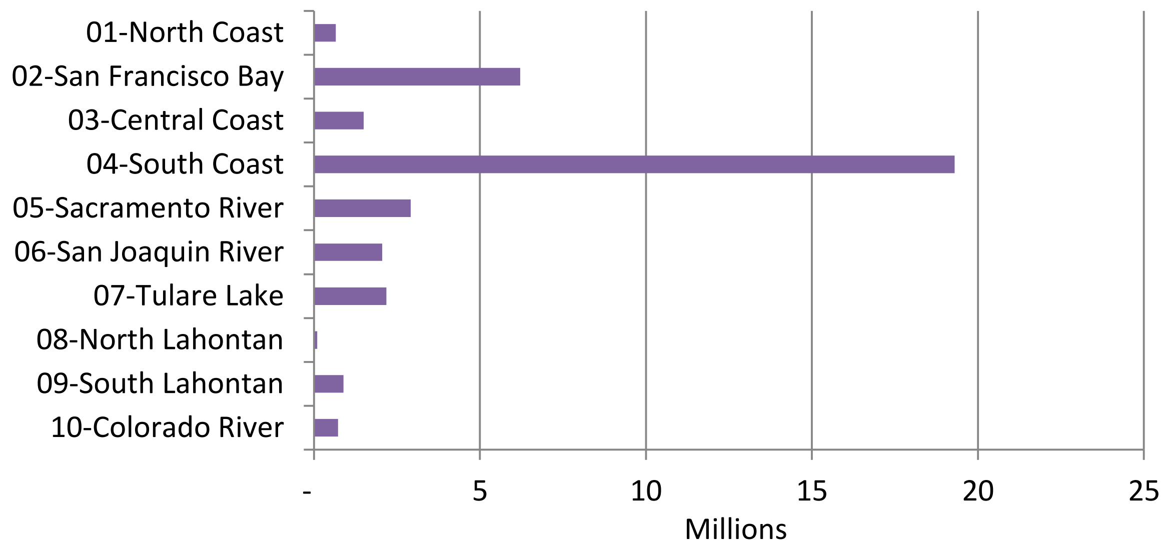

Figure 11: Population of California's 10 hydrologic regions

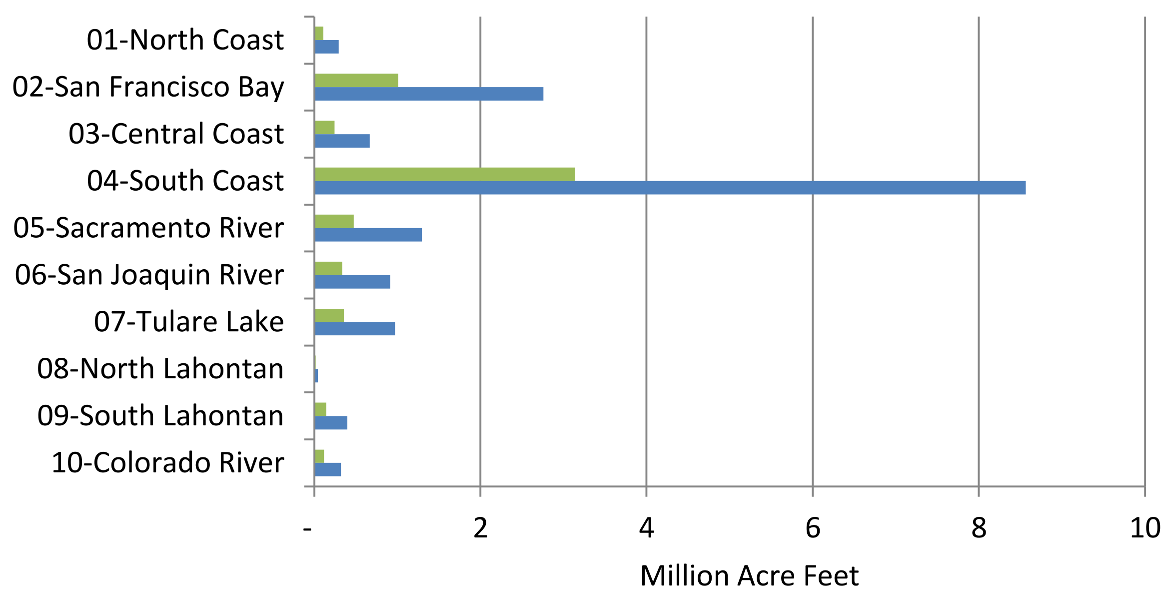

Figure 12: Green and blue water footprints related to goods produced and consumed in California, by hydrologic region

The next dimension compares the water footprint of goods produced in each HR and consumed in California (Figure 13). Each HR uses a different amount of green and blue water in production. Together, this is the volume of water in each HR that is used in the production of goods and services that are ultimately consumed in California. By this measure, the South Coast and San Francisco Bay HRs contributes less than 1 MAF to the state's overall water footprint. These regions are highly urbanized and have little productive farmland, so overall water use is lower than in other HRs. By contrast, the three HRs of the Central Valley - Sacramento River, San Joaquin River, and Tulare Lake - contribute 70% of the state's internal water footprint. The largest contribution of green water to in-state consumption comes from the Sacramento River region at 1.6 MAF, followed by the North Coast (1.1 MAF). For blue water supply, Tulare Lake provides the most (5.7 MAF), followed by San Joaquin River (3.6 MAF) and Sacramento River (3.3 MAF), and to a lesser extent the Colorado River HR (1.5 MAF).

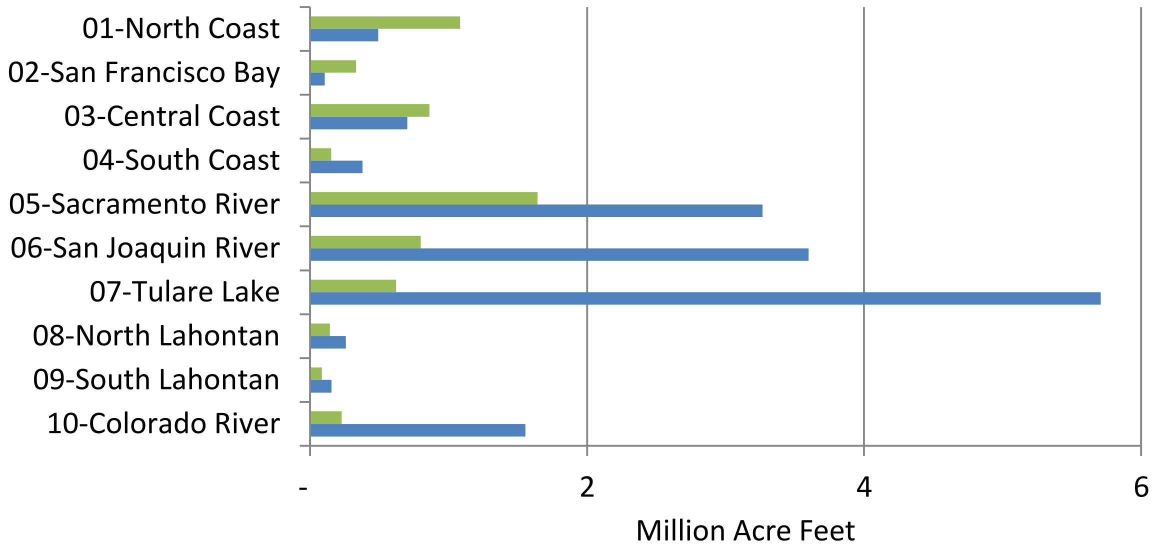

Figure 13: Green and blue water footprints contribution to California's water footprint, by hydrologic region

The final dimensions considered, blue and green virtual water export, is water that has been consumptively used within the HR for the production of exported products. These quantities do not count towards California's water footprint but are nevertheless illustrative of whether water is used in different HRs for in-state consumption or for export. Figure 14 shows that green virtual water exports originate mostly from the Sacramento River (1.3 MAF), followed by Tulare Lake (0.7 MAF) and San Joaquin River (0.6 MAF). Greater differences exist for virtual blue water export, which is highest from Tulare Lake (4.5 MAF), followed by San Joaquin River (2.8 MAF), and Sacramento River (2.7 MAF).

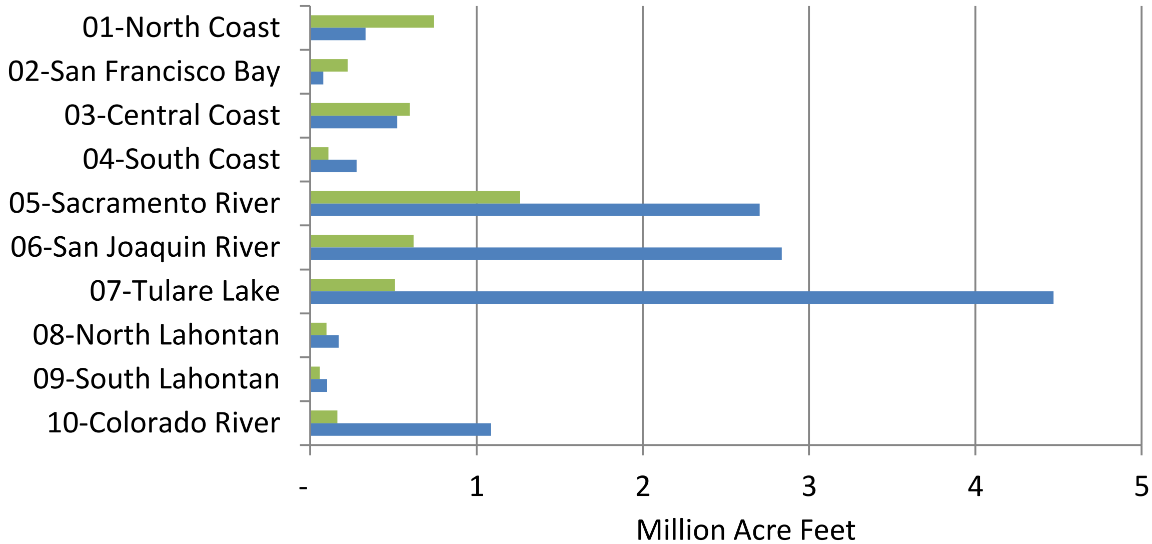

Figure 14: Green and blue virtual water export out of state from California's hydrologic regions

To a large extent, the movement of embedded water within the state reflect the geographic distribution of Californa's population, water resources, and productive agricultural land. Much of the state's population is concentrated in arid areas. Nevertheless mapping these features can help planning and decision making in several ways. For example, exchanging embedded water can be an alternative to transfering bulk water when other conditions for production are favorable, e.g., availability of arable land. Furthermore, the interconnection of water resources provides further motivation for regional coordination to address California's water challenges, especially engaging with residents and planners in those areas with large water footprints.

Additional data collection and modeling work could support greater insight into interregional flows of both direct and embedded water within California. For example, using proprietary input-output databases from IMPLAN could provide additional resolution on how products are produced and traded within California. Ongoing efforts in other resource arenas, such as energy and carbon, could also provide synergy for embedded water work. One example is the PECAS (Production, Exchange, Consumption, Allocation System) model administered by the Institute of Transportation Studies at UC Davis which is now being supported by the California Energy Commission's Public Interest Energy Research program to provide analysis on interregional energy flows.

II.E. Conclusions

California's economy consistently ranks among the ten largest in the world and is closely linked with interstate and global commerce. Much of our economic prosperity is derived from exporting goods and services and, likewise, many imports are integral to our high living standards. In terms of water, this means that our “water footprint” falls not only on water resources from within the state’s borders, but also on water resources in locations where goods that we consume are produced. A water footprint analysis is useful in understanding the complex interconnections between local water resource management and water use impacts and risks related to California’s place in the global economy.

Our 2012 report - *California’s Water Footprint* - was the first of its kind, both for its fresh perspective on water use in California and for its novelty in carrying out an assessment at the sub-national level. Several insights emerged from this study. For example, we found that 70% of California’s water footprint is associated with goods produced outside of its border, indicating that California is net importer of virtual water. The reverse is true for the U.S. as a whole, where 70% of the nation’s water footprint is associated with goods produced inside its borders. Such a contrast highlights the importance of carrying out water footprint assessments at different scales as well as the relevance of findings to policy and management institutions at difference levels of government.

A second round of analysis was supported by California’s Department of Water Resources and extended our initial assessment in three dimensions. First, we expanded the scope of products beyond agricultural, industrial, and direct use, to include energy products like electricity, natural gas, and transportation fuels. Water use in California’s energy system was found to be most intensive for transportation fuels, especially since the state mandated the use of ethanol as an oxygenate in gasoline in 2004. Second, we have identified trends in the evolution of California’s water footprint over the past two decades, finding that California’s water footprint has grown by approximately 60% since 1992, while the population has grown by 25% and gross state product has doubled in real terms. Third, we have analyzed how water embedded in products is transferred within California’s ten hydrologic regions. The distribution of physical water through canals and other infrastructure is a key feature of California’s water management, and the movement of “virtual water” adds a new dimension that can aid water-related decision making.

Our findings raise several corresponding concerns with respect to sustainability. First, population growth can increase demand for water resources unless efficiency gains are made across the supply chain of products that the population consumes. The observation that California’s Water Footprint is growing at a faster rate than population indicates that Californians are consuming either *more* water-intensive products and/or more products. Second, the proportional contribution of green water to California’s water footprint raises concerns about the risk of relying on precipitation and the potential impacts of climate change. Recent droughts in the American Midwest have affected grain supplies in California and provided evidence of -susceptibility to global climatic changes outside of the state’s borders.

Third, the externalization of California's Water Footprint raises concerns about our ability to manage the water resources related to our footprint. California's water resources are increasingly being devoted to exports, while our consumption becomes increasingly reliant on embedded water in imports (see "External Water Footprint" above). This poses additional challenges for managing our interaction with water sustainably by considering the risks and potential impacts to water systems outside of our borders.

III. Measuring Water Footprint Variability

III.A. Introduction

Water Footprint estimates can vary depending on the variability associated with the specific components in their calculation. Sources of variation include: 1) natural variation in the water cycle, including rainfall and water available to dilute pollution; 2) variation due to crop types and irrigation regimes, 3) variation in actual evapotranspiration rates relative to assumed rates, 3) inter-regional differences in water use for a particular product, 4) inter-annual variation in the consumption of goods and services, 5) variation in water-impacting consumption behavior (e.g., dietary choices), and 6) variation in consumption rates based on individual income and other social or economic factors.

Agricultural/food production is the largest component of the water footprint, representing 93% of the WF in 2007 (Fulton et al. 2012). Considering the importance of agricultural water demand in California, this section includes an estimate of the impact of the variability in the water footprint of agriculture production on the total water footprint of the state. This section also examines how income and dietary choices affect an individual's water footprint.

III.B. Methods

Data Sources and Transformations: Agricultural Production Variability

Blue water footprint and green water footprint of agricultural production come respectively from estimates of the total volume of evapotranspiration of applied water in agricultural crops (ETaw) and the total volume of effective precipitation (EP) multiplied by the irrigated agricultural area. ETaw and EP estimates by year were obtained from the Cal-SIMETAW model (Orang et al. 2013). This model was developed by the California Department of Water Resources and the University of California, Davis to perform daily soil water balance and determine crop evapotranspiration (ETc), evapotranspiration of applied water (ETaw), and applied water (AW) for use in California water resources planning.

The Cal-SIMETAW provides seasonal water balance estimates at two geographical scales within

California: detailed analysis unit (DAU) and county. The ETaw and EP values for the smallest scale unit of the model (DAU) were used in the analysis. The DAU scale was used in order to have a range of ETaw and EP values for each crop type. The database provides ETaw and EP estimates in volume units and as factors, the latter being the estimate of the volume over the irrigated crop area (ICA) by scale unit. Factors were used in the analysis of variability. In order to account for scale, values of the DAU distribution are scaled up to the state level, each DAU factor was weighted by the ICA for that DAU for the corresponding crop and divided by total ICA for that crop in each year. Once each DAU weighted factor was summed up by crop by year, weighted ETaw and EP factors were then consistent with the statewide factors used in the overall water footprint analysis done at the state level.

Data for the other elements of the total water footprint estimate, including the water footprint of international trade and internal consumption, were from Fulton et al. (2012).

Data Sources and Transformations: Income and Diet-Based Variability

The income tables for specific California counties (Orange, San Bernardino, Los Angeles, and Riverside) were downloaded from the “Fact Finder” tool on the Census Bureau website. These tables included proportion of population in each major household-income category (e.g., $50,000 to $74,999 per year), as well as basic statistics about household composition and total number of households.

Data Sources:

Census 2011, American community Survey 2011 estimates of income by county (http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_11_1YR_S1902&prodType=table)

Water Footprint Network, Quick Water Footprint Calculator (http://www.waterfootprint.org/?page=cal/waterfootprintcalculator_indv)

Water demand delivery data from Santa Ana Watershed Project Authority (http://www.sawpa.org)

Analysis: Agricultural Production

Nine crops were selected for assessing the impact of agricultural water footprint variability on total water footprint. These crops are: grain, alfalfa, cotton, pasture, vine, other truck crops (vegetables besides the ones listed in other categories), almond and pistachios, corn, and rice. The crops selected represent the most water demanding crops grown in California, due to the extent of their irrigated crop area and higher ETaw and/or EP factors. For this analysis, we assessed the variability associated with the blue water footprint, i.e., ETaw factors. The same procedure can be replicated for the green water footprint calculation using EP values.

The variability of ETaw factors around their mean was determined. The range of ETaw factors at the DAU level per crop per year were used to define the 95% confidence interval. Using the upper and lower bounds of the 95% confidence interval of each distribution per crop, we calculated the percent difference of the 5th percentile and 95th percentile relative to the mean and applied these estimates to the statewide ETAw and EP factors. The change in the blue water footprint for each specific crop by year was calculated by multiplying these factors by the ICA of each specific selected crop (Table 2). The values obtained were included in the calculation of the blue water footprint for agricultural production, while holding constant the values for the other crops.

Finally, the variability of the total water footprint for the state was obtained. Once the two upper and lower values of blue water footprint of agricultural production were obtained following the steps above, they were applied to the total water footprint. The percentage variation of these values compared to the original water footprint value indicates the impact of the agricultural water footprint variability on total water footprint for the state.

Analysis: Income and Diet

The median value in each category was calculated and used to estimate the water footprint. The Quick Water Footprint Calculator was used to calculate water footprint based on gender, diet, and income. Three diet choices were provided: vegetarian, average meat consumption, and high-end meat consumption. For most calculations, “average meat consumption” was chosen to represent the largest number of people. Because most households have two adults of opposite gender, the average of male and female water footprint was used and household income was assumed to represent two adults for the purposes of the water footprint calculation.

III.C. Results

Agricultural Production

The impact of the variability of the blue water requirements of the nine agricultural crops selected was assessed based on three components of California’s water footprint (Table 1). The water footprint of agricultural production varies between -26% and +34% around the mean, and keeps constant throughout the four years evaluated. The corresponding estimated variation of California’s blue water footprint does not differ greatly from the water footprint of agricultural production (-24% to +29% variability), because agricultural production represents ~ 80% of the blue water footprint of the state. The variability of water demand from the main crops evaluated resulted in a variation of -12% to +14% for California’s total water footprint. This variation has been decreasing over time. For example, in 1992, variation of the total WF varied between -12% and +14% around the mean and in 2007 variation was -8% to +10% around the mean. Possible explanations could be the application of better technologies to reduce the water demand by crops across the state and higher demand on other components of the water footprint. One important caveat to consider is that the estimates of variation are dependent on the model from which the ETaw factors were obtained and its assumptions.

Table 1. Variability in California Water Footprint and its components due to variability of water footprints of the nine main crops statewide

	1992	1997	2002	2007
% Variability in CA Water Footprint of Agricultural Production				
Lower bound*	-27	-27	-27	-26
Upper bound*	+33	+33	+34	+33
% Change in CA Blue Water Footprint				
Lower bound*	-24	-24	-20	-23
Upper bound*	+29	+29	+25	+29
% Change in CA Water Footprint				
Lower bound*	-12	-10	-7	-8
Upper bound*	+14	+12	+9	+10

Note: * Lower and upper bounds of the 95% confidence interval.

Note: The average percentage change of the ETaw factors of the upper and lower bounds of the 95% confidence interval, of all nine crops for the four years included in the analysis, was 37%.

Table 2. Variability of ETAW factors and blue water footprint (acre-feet) around the state mean per crop for years 1992, 1997, 2002, 2007.

		ETAW factors per crop per year				Blue WF per crop per year (feet-acre)		
		-95th	State mean	+95th	ICA	-95th	State mean	+95th
Grain	**1992**	0.8749	1.2645	1.6541	895,760	783,710	1,132,691	1,481,672
	1997	1.0556	1.6023	2.1489	902,580	952,808	1,446,181	1,939,554
	2002	0.9614	1.4279	1.8945	655,620	630,298	936,180	1,242,062
	2007	0.9274	1.3825	1.8375	533,928	495,185	738,139	981,094
Rice	**1992**	3.0200	3.1366	5.9400	419,800	1,267,796	1,316,731	2,493,612
	1997	3.0400	3.0599	6.1300	552,700	1,680,208	1,691,233	3,388,051
	2002	3.1900	3.0406	6.1700	556,300	1,774,597	1,691,500	3,432,371
	2007	2.9500	3.0927	6.1200	583,020	1,719,909	1,803,097	3,568,082
Cotton	**1992**	1.7546	3.0650	4.3753	1,192,720	2,092,797	3,655,667	5,218,537
	1997	1.5900	3.0372	4.4844	1,072,435	1,705,203	3,257,234	4,809,265
	2002	1.5812	3.1787	4.7761	671,180	1,061,290	2,133,468	3,205,647
	2007	1.5946	3.1256	4.6566	456,506	727,940	1,426,850	2,125,761
Corn	**1992**	1.3880	2.2389	3.0898	398,800	553,535	892,869	1,232,204
	1997	1.3387	2.1318	2.9248	641,580	858,915	1,367,689	1,876,463
	2002	1.4131	2.3137	3.2143	629,020	888,871	1,455,357	2,021,844
	2007	1.3988	2.2719	3.1449	771,467	1,079,123	1,752,669	2,426,216
Alfalfa	**1992**	2.2076	4.2650	6.3224	1,067,430	2,356,471	4,552,606	6,748,741
	1997	2.3125	4.3018	6.2911	1,033,277	2,389,503	4,444,982	6,500,461
	2002	2.3279	4.3095	6.2912	1,194,700	2,781,136	5,148,608	7,516,081
	2007	2.5554	4.3111	6.0667	1,072,726	2,741,288	4,624,601	6,507,915
Pasture	**1992**	2.7072	3.5620	4.4168	929,321	2,515,855	3,310,223	4,104,591
	1997	2.5514	3.4937	4.4361	867,660	2,213,719	3,031,379	3,849,038
	2002	2.4252	3.6141	4.8031	834,160	2,022,974	3,014,776	4,006,577
	2007	2.3726	3.6770	4.9815	766,372	1,818,302	2,817,987	3,817,672
Other Truck	**1992**	1.0123	1.6842	2.3562	742,426	751,534	1,250,430	1,749,326
	1997	0.9884	1.7508	2.5132	731,803	723,338	1,281,252	1,839,166
	2002	0.9777	1.7072	2.4367	855,890	836,829	1,461,186	2,085,542
	2007	0.9580	1.7235	2.4891	874,001	837,257	1,506,345	2,175,432
Almond/ Pistachio	**1992**	3.0194	4.4814	5.9434	501,870	1,515,350	2,249,083	2,982,815
	1997	3.0368	4.5857	6.1347	582,220	1,768,093	2,669,911	3,571,730
	2002	3.1915	4.6823	6.1732	726,130	2,317,435	3,399,979	4,482,523
	2007	2.9512	4.5372	6.1233	955,339	2,819,353	4,334,588	5,849,824
Vine	**1992**	1.7582	3.1290	4.4999	728,760	1,281,283	2,280,306	3,279,328
	1997	1.7527	2.9913	4.2299	809,495	1,418,797	2,421,446	3,424,094
	2002	1.7079	2.8602	4.0125	913,600	1,560,383	2,613,091	3,665,799
	2007	1.7973	2.8768	3.9563	871,013	1,565,499	2,505,743	3,445,987

Note: ICA = "Irrigated Crop Area" (acres) in California

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Effect of Income and Diet

Median and mean household incomes in each county were the following: San Bernardino ($51,247 & $65,472), Riverside ($52,883 & $69,898), and Orange ($72,293 & $96,627). There was considerable variation round these central tendency values, with 4.5% to 6.9% of households occupying the lowest income category (<$10,000) and 2.9% to 9.4% of households occupying the highest category (>$200,000).

Relationship between Water Footprint and Income

Beyond a base level of consumption of goods and services, estimated water footprint per capita increases linearly with income (figure 16). Diet affected both baseline water footprint and rate of change in footprint with income. Vegetarian diet had the smallest water footprint and high-end meat consumption the largest. This is because of the investment of virtual water in grains used to grow animals for consumption, compared to the direct consumption of plant material.

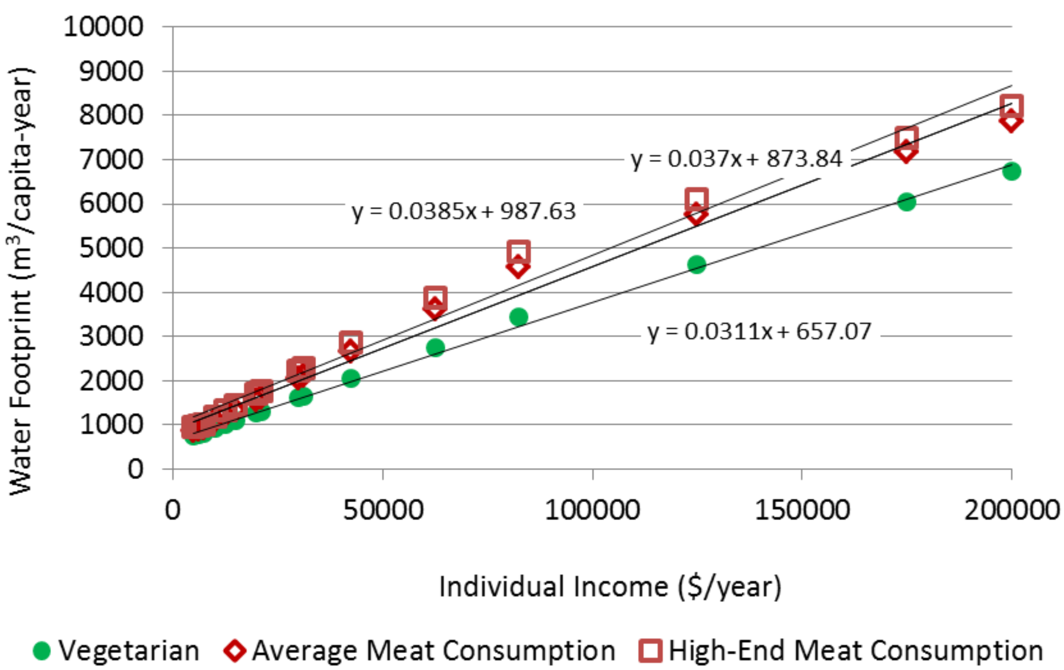
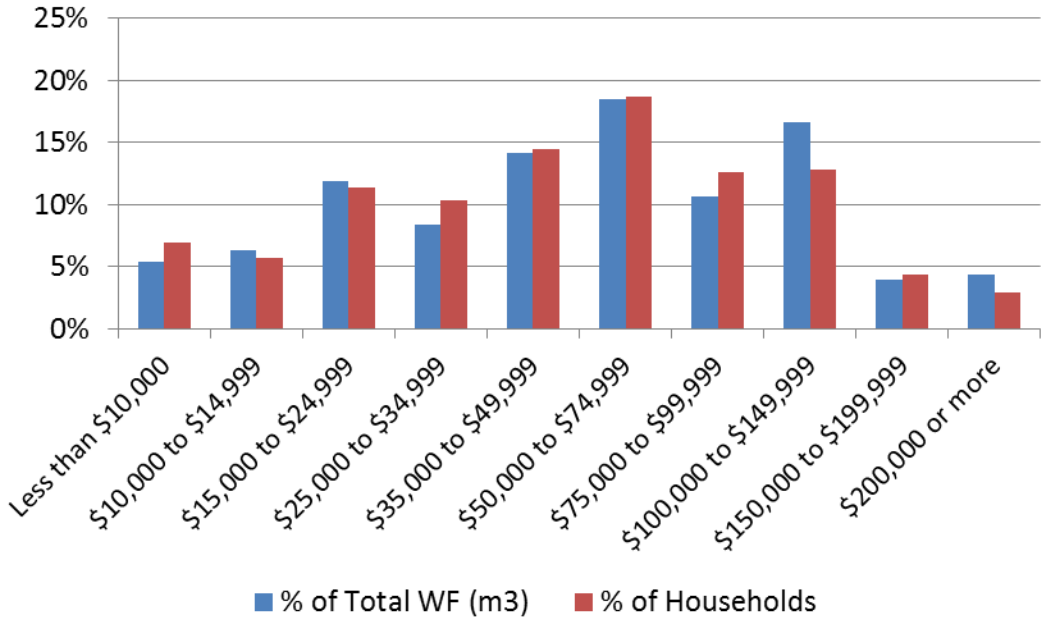


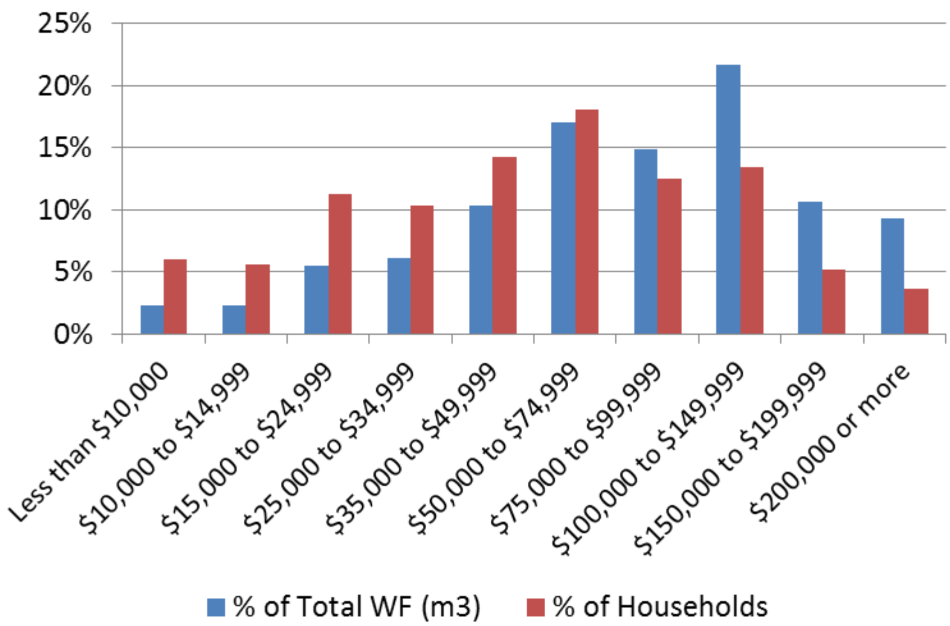
Figure 16. Rate of change in estimated water footprint (m^3/capita-year) with individual income ($/year) in the US.

Water Footprint and Income Class by County

The proportion of the total water footprint for a county associated with each income class was compared to the distribution of households associated with each income class (figure 17).

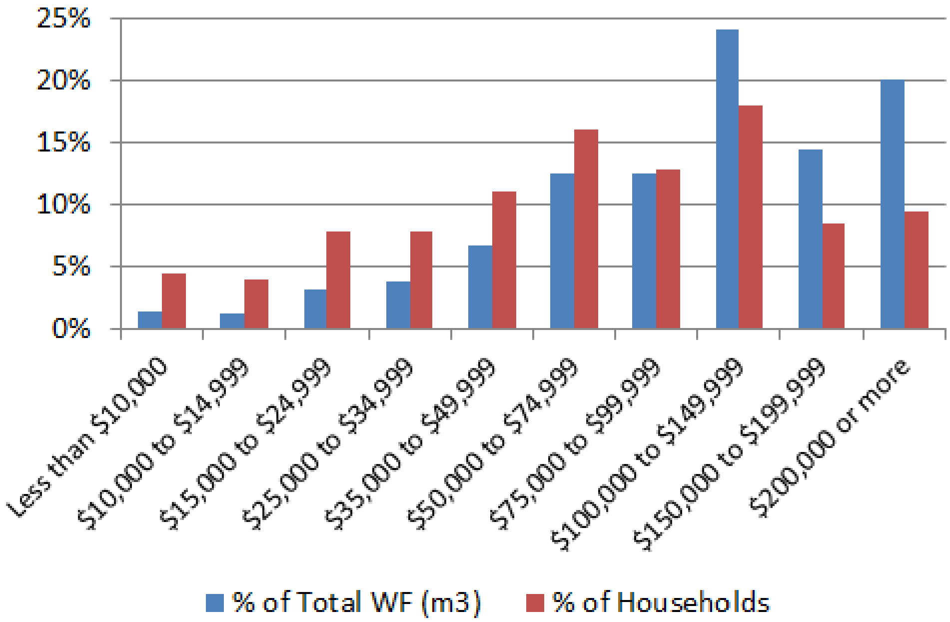

25%
20%
15%
10%
5%
0%
Less than $10,000
$10,000 to $14,999
$15,000 to $24,999
$25,000 to $34,999
$35,000 to $49,999
$50,000 to $74,999
$75,000 to $99,999
$100,000 to $149,999
$150,000 to $199,999
$200,000 or more
% of Total WF (m3)
% of Households

A


25%
20%
15%
10%
5%
0%
Less than $10,000
$10,000 to $14,999
$15,000 to $24,999
$25,000 to $34,999
$35,000 to $49,999
$50,000 to $74,999
$75,000 to $99,999
$100,000 to $149,999
$150,000 to $199,999
$200,000 or more
% of Total WF (m3)
% of Households

B

33



C

Figure 17 Proportion of people in each income class and proportion of total county water footprint associated with people in each income class for (A) San Bernardino, (B) Riverside, and (C) Orange Counties.

For San Bernardino County, the distribution of the water footprint by income class paralleled the distribution of income. For Riverside and Orange Counties, a greater proportion of the total county water footprint was associated with higher income classes. This is what would be expected because income distributions are skewed toward the high end, especially in Orange County where over half of the water footprint of the county is associated with the 3 household income classes >$100,000.

The average water footprint for 2011, weighted by income class, was 1,722 (San Bernardino), 2234 (Riverside), and 2,701 (Orange) m^3/capita-year (Table 3). The total water footprint for all 3 counties was 16.25×10^9 m^3 (13.18×10^6 ac-feet). The total water demand in 2010 through piped delivery systems from all sources for the SAWPA area was 1.36×10^6 ac-feet. Most of the population of the 3 counties resides within the SAWPA service area. Still, the water footprint was approximately 10 times the delivered water, by volume.

Table 3. County-based 2011 water footprint calculation based on income, number of households and number of people/household. Calculation made using the Water Footprint Network's Quick Water Footprint Calculator (http://www.waterfootprint.org/?page=cal/waterfootprintcalculator_indv).

	Orange	**Riverside**	**San Bernadino**
Average water footprint (m^3/capita-year)	2,701	2,234	1,722
Total annual water footprint (m^3/ac-feet)	$8.2x10^9/6.6x10^6$	$4.7x10^9/3.8x10^6$	$3.4x10^9/2.8x10^6$

III.D. Discussion

Water Footprint is a useful meme to characterize both our dependence on water and our impacts on water systems. Consumption of goods and services requires delivery of water through natural and engineered pathways and return of wastewater to the environment.

Measuring uncertainty in water footprint calculations is useful because it helps to build confidence in the footprint as a tool to inform decisions. It is also useful to find out how much individual and collective water footprint can vary due to environmental and consumption patterns because these patterns often involve choices. This means that people can decide to change their water footprint by changing their consumption of water-intensive foods and goods. It also means that decisions about crop production among sub-regions (e.g., within California) can include information about water intensity, which provides a role for water managers in improving sustainability of water use.

Agricultural production is the greatest contributor to an individual's water footprint. We found that variability in evapotranspiration of applied water among nine major crops resulted in the water footprint of agricultural production ranging about 30% around the mean water footprint across 4 years of analysis. This is a result of a combination of differences in water use for the same crop in different places and at different times. If all other sources of variation were ignored, then this variation would result in the California water footprint varying about 13%around the mean of 1,500 GPCD. This means that our estimate of the water footprint is pretty good.

Another source of variation in water footprint is in individual choices for consumable goods and services. One factor that seems to be a strong determinant of water footprint of consumption is income, with people making more money tending to consume more goods and thus have a larger water footprint (Hoekstra and Chapagain, 2007). To estimate the impact of variation in income within California on calculated water footprint, we assumed that the influence of national income levels on water footprint was approximately correct when used at finer scales, such as for a county within California. Because there is variation in income in California and in the US, as there is elsewhere in the world, it is useful to estimate water footprint using income classes as one way to control for this variation. The Water Footprint Network has developed an online calculator that estimates the water footprint based on income. This calculator was used in combination with Census Bureau data to estimate the water footprints for each of the 3 counties that make up the SAWPA service region.

If households in California act similarly to households around the world, then one large source of variation in water footprint will be rates and types of consumption, based on income. There was at least an 8-fold difference between the estimated water footprint of the lowest income class (household income <$10,000/year) and the highest income class (household income >$200,000/year). This disproportionate makeup of the county water footprint was reflected in the distribution of the water footprint by income class in Orange County, where >50% of the water footprint is associated with household incomes >$100,000/year, despite the fact that these groups make up <1/3 of the households. In contrast, San Bernardino County, which had lower median household income and water footprint, displayed a more even distribution of water footprint by income class.

Another factor causing variation in water footprint is diet, with vegetarian and vegan diets having lower WF than meat-containing diets (da Silva et al., 2013; Vanham, 2013). This is because it takes more water to produce meat than the caloric or weight-equivalent of vegetables/grains. Using the Water Footprint Network's online calculator, we found that for a moderate individual income of $30,000/year a vegetarian diet resulted in a 27% lower water footprint than a meat-containing diet. There is no similar calculator for a vegan diet, but it is likely that the water footprint for a person with a vegan diet will be considerably lower than for someone with a meat-containing or vegetarian diet.

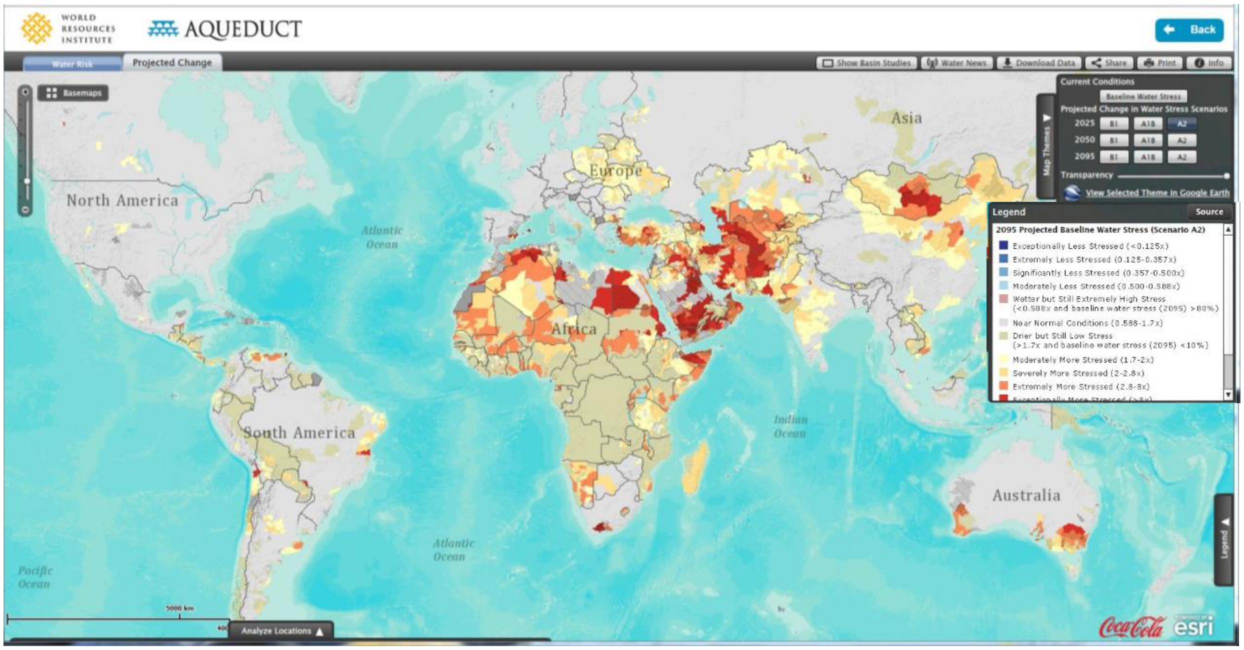
A higher water footprint is both a greater impact on world water systems and a sign of vulnerability. Maintenance of a high water footprint may not be sustainable in a water-constrained world. Meat-based diet and higher income classes in the study area both had larger water footprints than the county averages and global averages. These lifestyles may become less sustainable with increased water limitations, or, if maintained, put unsustainable strain on water limited systems.

IV. Issues, Data Gaps & Recommendations for Future Work

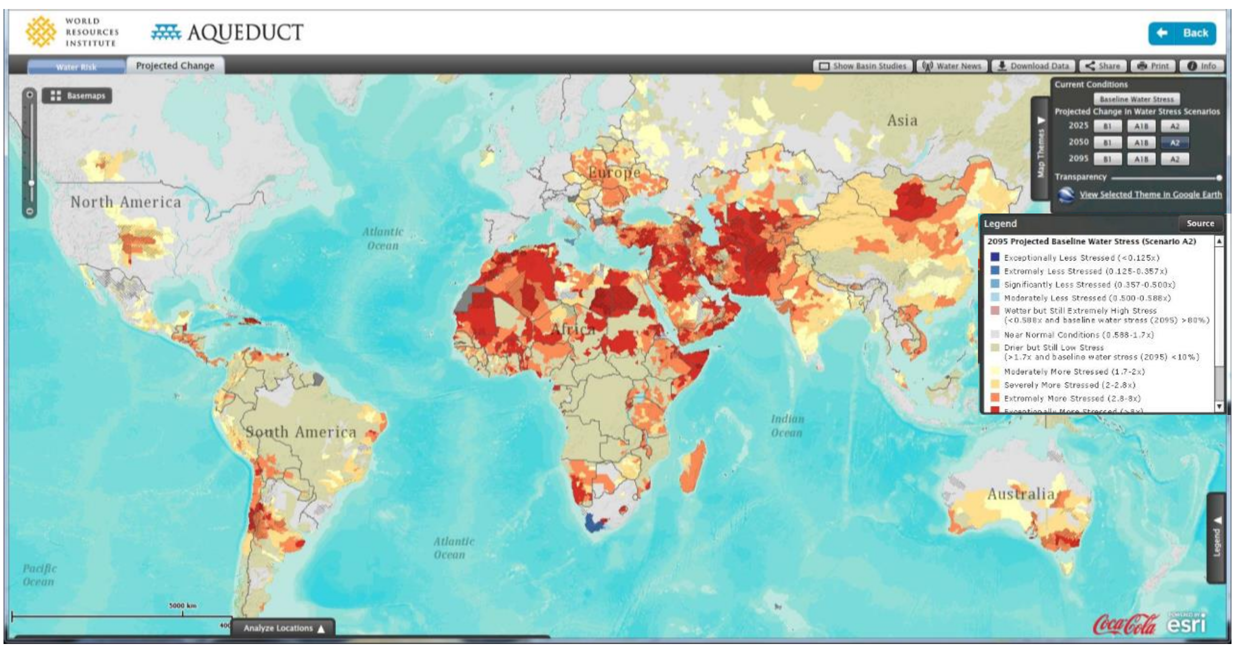
While the results provide a comprehensive analysis of California's water footprint, the analysis has several limitations. Using California-specific data presented several challenges in incorporating these data into the water footprint methodology and in interpreting the results. Trade data, particularly on the domestic level, is a limiting factor for developing an accurate geographic picture of California's water footprint. The different trade datasets used in our initial assessment and in the present assessment also provided some variability in our results. In particular, the resolution of SCTG (trade) categories, particularly in agricultural sectors, introduces a significant amount of uncertainty about the composition of embedded water imports and exports. We have also noted the need for more up-to-date and higher resolution data on industrial water use, better separation of "withdrawals" versus "consumption" by sector, and reconciliation of import and export reporting categories among state, national, and international databases. For dietary and income effects on water footprint, we relied upon the Water Footprint Network's online calculator, which may not be inaccurate when applied within a geographic region as it was applied here. Finally, better data are needed on the flow of goods and services between regions inside California so that we can develop a better understanding of how virtual water moves within and across regions. Despite these limitations, we believe that our analyses provide important insight into the volumes and trends of California's water footprint as well as the issues that it presents for the state.

A water footprint assessment, by itself, provides limited information about the relative advantages and disadvantages of relying on imports to support the state's population. This information, however, can be combined with a parallel assessment of water resource conditions in those regions, today and in the future. Several groups have developed water scarcity indices in an effort to compare water resource conditions around the world. For example, the World Resources Institute (WRI) developed a water stress indicator for countries and river basins around the world. Baseline water stress is defined as the ratio of the amount of water withdrawn from a basin to the amount available from natural sources and imports (Figure 18a).

Figure 18 provides a water stress index for every country and major river basin in 2025 and in 2095 under various climate scenarios. By 2025, most of the countries from which California imports goods and services (Figure 2) will potentially experience some water stress. By 2095, virtually all of the countries imported from and much of the mid-North American continent will potentially experience water stress (Figure 3b).



a



b

Figure 18X. Baseline Water Stress in 2025 (a) and in 2095 (b) by Country.

Note: Darker colors are an indication of the greater likelihood that stress will be experienced and the greater the severity of that stress.

The extent and severity of water stress indicated by these maps suggests risk to California's supply chain from global and US water stress. However, there are two big unknowns associated with these kinds of projections. First, the projections are based on climate models, which have their own uncertainties associated with them. Conditions may end up much worse or better than indicated. Second, every country and US state that has trade relations with California has their own priorities, based on local and regional needs and politics. As other regions become stressed, how they respond in terms of trade and water-intensive production remains uncertain. This combination of water and food insecurity is recognized by the US Department of Defense as one of the greatest risks facing the U.S. (CITE/QUOTE?).

This analysis provides a comprehensive overview of California's water footprint and how that footprint varies temporally and regionally. The analysis, however, has raised additional questions. In particular, we recommend the following studies for future work to address some of the limitations of the current study:

- Identify sources of applied water within California, such as distinguishing between groundwater and various surface water supplies.
- Explore ways to better integrate efficiency into water footprint analyses.
- Evaluate how climate change will affect California's water footprint.
- Evaluate how California's water footprint is expected to change in the future.
- Evaluate California's gray water footprint in more detail to obtain a better understanding of past, present, and future water-quality concerns.

V. Citations

CDF CD of F (2011) California Population Estimates, with Components of Change and Crude Rates, July 1, 1900-2011. http://www.dof.ca.gov/research/demographic/reports/estimates/e-7/view.php.

CEC CEC (2013) Total Electricity System Power. http://energyalmanac.ca.gov/electricity/total_system_power.html. Accessed 29 Aug 2013

Coca-Cola Company and The Nature Conservancy (2010). Product water footprint assessments, Practical application in corporate water stewardship.

De la Rue du Can S, Hasanbeigi A, Sathaye J (2010) California Energy Balance Update and Decomposition Analysis for the Industry and Building Sectors.

daSilva, V., K. Maracaja, L. Araujo, J. Neto, D. Aleixo, J. da Cunha Campos. 2013. Water footprint of individuals with different diet patterns. Ambi-Agua, Taubaté, v. 8, n. 1, p. 250-262, 2013.(http://dx.doi.org/10.4136/ambi-agua.967)

EIA (US Energy Information Administration) (2012a) Annual Energy Review.

EIA EIA (2013a) California International and Interstate Movements of Natural Gas by State. http://www.eia.gov/dnav/ng/ng_move_ist_a2dcu_sca_a.htm. Accessed 29 Aug 2013

EIA EIA (2013b) Petroleum and Other Liquids: Company Level Imports. http://www.eia.gov/petroleum/imports/companylevel/. Accessed 29 Aug 2013

EIA EIA (2012b) Drought has significant effect on corn crop condition , projected ethanol production. Today in Energy

Fulton J, Cooley H, Gleick PH (2012) California's Water Footprint. 53.

Gleick PH (2003) Water use. Annu Rev Environ Resour 28:275–314.

Gleick PH, Cooley H, Groves D (2005) California Water 2030 : An Efficient Future.

Hanak E, Lund J, Thompson B, et al. (2012) Water and the California Economy. 32.

Hoesktra, A.Y. and A.K. Chapagain. 2007. Water footprints of nations: Water use by people as a function of their consumption pattern. Water Resources Management, 21: 35-48.

Jeffries, D., V.J. King, M.M. Aldaya, E. Ercin, A. Hoekstra, and L.M. Canals. 2009. Assessing water impacts of tea and margarine with a water footprint/LCA approach. Pilot study in Unilever. Presented at the LCA IX Conference, Boston, 9/29-10/2/2009.

Mekonnen M, Hoekstra A (2011) National water footprint accounts: the green, blue and grey water footprint of production and consumption, Value of Water Research Report Series No. 50 (Volume 2: Appendices).

Mekonnen M, Hoekstra A (2010a) The green, blue and grey water footprint of farm animals and animal products, Value of Water Research Report Series No. 48 (Volume 2: Appendices). UNESCO-IHE, Delft, the Netherlands

Mekonnen M, Hoekstra A (2010b) The green, blue and grey water footprint of crops and derived crop products - Volume 2 : Appendices.

Mekonnen M, Hoekstra A (2010c) The green, blue and grey water footprint of crops and derived crop products, Value of Water Research Report Series No. 47 (Volume 1: Main Report).

Meldrum J, Nettles-Anderson S, Heath G, Macknick J (2013) Life cycle water use for electricity generation: a review and harmonization of literature estimates. Environ Res Lett 8:015031. doi: 10.1088/1748-9326/8/1/015031

Orang MN, Snyder RL, Shu G, et al. (2013) California Simulation of Evapotranspiration of Applied Water and Agricultural Energy Use in California. J Integr Agric 12:1371–1388. doi: 10.1016/S2095-3119(13)60742-X

Rich J (2009) Comparing Changes in Applied Water Use and the Real Gross Value of Output for California Agriculture: 1967 to 2007. Water 4:3.

SAB Miller and World Wildlife Fund UK (2011). Water futures, Addressing shared water challenges through collective action.

SERI SERI (2011) Under Pressure: How our material consumption threatens the planet's water resources. Vienna

Southworth F, Peterson BE, Hwang H-L, et al. (2011) THE FREIGHT ANALYSIS FRAMEWORK VERSION 3 (FAF3). Washington DC

USDA USD of AAMS (2001) GRAIN TRANSPORTATION REPORT.

USDC-BC UD of CB of C (2010) No Title.

USDC-BC UD of CB of C (1993) 1992 Census of Transportation , Communications , and Utilities.

USDC-BEA UD of CB of EA (2012) Regional Economic Accounts. http://www.bea.gov/regional/index.htm#gsp.

Vanham, D. The water footprint of Austria for different diets. Water Science and Technology, 67.4: 824-830 (doi: 10.2166/wst.2012.623)

Wu M, Mintz M, Wang M, Arora S (2009) Consumptive water use in the production of ethanonl and petroleum gasoline.