Water Footprint Outcomes and Policy Relevance Change with Scale Considered: Evidence from California

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Abstract

Methods and datasets necessary for evaluating water footprints (WFs) have advanced in recent years, yet integration of WF information into policy has lagged. One reason for this, we propose, is that most studies have focused on national units of analysis, overlooking scales that may be more relevant to existing water management institutions. We illustrate this by building on a recent WF assessment of California, the third largest and most populous state in the United States. While California contains diverse hydrologic regions, it also has an overarching set of water institutions that address statewide water management, including ensuring sustainable supply and demand for the state's population and economy. The WF sheds new light on sustainable use and, in California, is being considered with a suite of sustainability indicators for long-term state water planning. Key to this integration has been grounding the method in local data and highlighting the unique characteristics of California's WF, presented here. Compared to the U.S., California's WF was found to be roughly equivalent in per-capita volume (6 m^3d^{-1}) and constituent products, however two policy-relevant differences stand out: (1) California's WF is far more externalized than the U.S.'s, and (2) California depends more on "blue water" (surface and groundwater) than on "green water" (rainwater and soil moisture). These aspects of California's WF suggest a set of vulnerabilities and policy options that do not emerge in national-level assessments. Such findings demonstrate that WF assessments may find more policy relevance when scaled to analytical units where water-related decision making occurs.

Keywords: water footprint; virtual water; analytical scale; California

1. Introduction

As pressures on water resources intensify globally, there is growing interest in evaluating the complex ways in which human activities affect the world's water resources (Postel et al. 1996; Vorosmarty et al. 2000; Alcamo et al. 2007; Hoekstra and Chapagain 2008; Gleick and Palaniappan 2010). "Water footprint" assessments have emerged as a tool for identifying the links between consumption of everyday goods and services in one location and water use associated with their production in other, sometimes distant, locations.

The water footprint (WF) of a product (good or service) has been defined as the quantity of fresh water consumptively used both directly and indirectly throughout its production chain (Hoekstra et al. 2011). Consumptive use refers to the portion of withdrawn water that is made unavailable for reuse in the same basin, such as through conversion to steam, loss to evapotranspiration, seepage to a saline sink, or contamination (Gleick 2003). A WF is typically divided into three components: green water, which is precipitation and in-situ soil moisture; blue water, which is surface or ground water; and grey water, which is the volume of freshwater needed to assimilate pollutants from a production process back into water bodies at levels that meet governing standards.

Because a WF is based on the set of goods and services consumed, it can be calculated at different levels of consumer activity, i.e., for individuals, households, regions, states, nations, or even all of humanity. The WF of an individual or a group of individuals is the aggregate WF of products used by that individual or group of individuals over a given period of time. It includes the total amount of water required in the location where water use occurs. A WF, then, provides an estimate of how much water, from where, and what kind of water a society demands through its consumption patterns.

The WF concept has developed substantially in scientific literature over the last decade and resulted in numerous publications and extensive datasets, many of which have emerged through the work of the Water Footprint Network. The WF's conceptual validity with respect to hydrologic sciences and its value in water resource management have also been discussed at length in this and other journals (Kumar and Singh 2005; Yang and Zehnder 2007; Pfister and Hellweg 2009; Aldaya et al. 2009; Wichelns 2010; Ridoutt and Huang 2012; Gawel and Bernsen

2013). Noting the novelty and limitations of the method, our priority here is to highlight the importance of analytical scale when using the WF tool to draw conclusions about a particular place, its connection to global water resources, and the relevant policy options for addressing sustainability concerns.

The vast majority of WF scholarship has chosen as its unit of analysis the nation state, and with consideration of interactions between nation states (Mekonnen and Hoekstra 2011; Konar et al. 2011; Dalin et al. 2012). This is likely due to the fact that most production and trade statistics – essential to the calculation of the WF – are gathered and reported at the national level. However for the United States, as with many countries, a national-level WF is functionally an average of smaller and potentially diverse constituents. Therefore it is important to understand how the WF of a smaller unit might differ from that of a larger unit, since (a) the phenomenon of interest, that is the connections between consumption patterns and global water resource concerns, may differ, and (b) the decision making and ability to enact relevant policy may also differ.

To address these concerns, we report here the results of our recent assessment of California's WF (Fulton et al. 2012) and compare those results with previous WF studies that refer to the U.S. as a whole. California was chosen for several reasons. As the state with the largest population and GDP in the nation (about one-eighth on both counts), California represents a substantial share of U.S. economic activity, both in terms of consumption and production. Among U.S. states, however, it is unique climatically and hydrologically, with minimal precipitation during the summer and fall and very little runoff flowing to other states or nations. Thus, California makes a good comparative case because while its size suggests it to be representative of the whole, its unique physical characteristics create a counterpoint to examine why its WF may be different.

Related research in this field that delves into the subnational scale has looked at regions within Australia (Lenzen 2009), China (Guan and Hubacek 2007; Zhao et al. 2010), India (Verma et al. 2009), and Spain (Dietzenbacher and Velázquez 2007; Aldaya et al. 2009). The goal of these studies, by and large, has been to understand the interactions between subnational and national units in terms of the WF of traded products, or "virtual water" flows. This is typically done using environmentally extended economic input-output methods, which are useful in capturing inter-industry demands within and between geographically-defined production matrices. Similar work was carried out for California a half century ago (McGauhey et al. 1960) but subnational studies of this nature in the U.S. have since been absent in the literature. The novelty of our work differs from these previous studies in our focus on the WF of consumption within our selected subnational unit, rather than its interactions with other units. In the following two sections, we present the methods used and results from our assessment of California's WF, concluding with a comparison with results at the national level. In the discussion section, we address the implications of our findings in the context of ongoing water management and policy initiatives in California.

2. Methods and Data

The basic approach in calculating a WF is to combine consumptive use factors (volume of water-per-unit of economic production) of blue, green, and grey water for individual products with statistics on production, trade, and consumption of those products. Direct uses of water, such as residential consumption, are also considered. The method has been advanced by the Water Footprint Network (WFN) and our analysis used methods described in their Water Footprint Assessment Manual (Hoekstra et al. 2011). We used as much locally-relevant information as possible for California, and in a manner that closely replicates methods used by WFN for national assessments. Furthermore, we limited the scope of our assessment to crop, animal, and industrial products, as well as direct uses of water, in order to make our study comparable to the national study. Some of the economic sectors that were excluded in our study and from the national-level study, for example energy, would likely add noticeably to overall WF values (see King and Webber, 2008; Scown et al., 2011).

The total WF of products consumed in California in 2007 (the last year for which comprehensive production and consumption data are available) has an internal component and an external component (Figure 1, top row). The internal WF is calculated as the WF of products produced within California minus the WF of products produced in California and exported out of the state. The external WF is calculated as the WF of products that are imported and consumed within California.

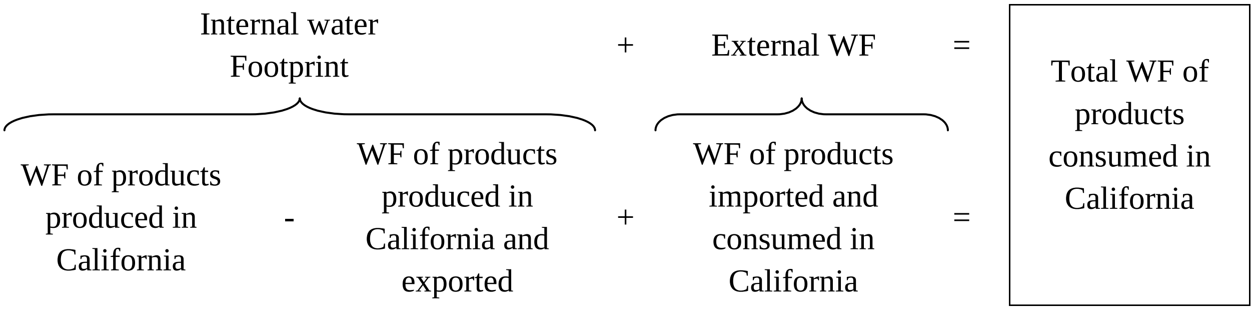

Figure 1. California's water footprint accounting framework, modified from Hoekstra et al. (2011).

The following sections describe the data and calculations that were used for each component of California's WF. First, we describe how the WF of products produced in California was calculated using methods described in Hoekstra et al. (2011) and locally-relevant data. Second, we describe available data for the the WF of products produced outside of California. Finally, we discuss how trade data were applied to provide a geographical picture of California's internal and external WFs.

2.1. The Water Footprint of Products Produced in California

For our analysis, we used California-specific data to get an accurate estimate of the WF of crop, animal, and industrial products that are produced inside of California.

2.1.1. Crop Products

The California Department of Water Resources (CDWR) regularly models annual evapotranspiration rates of applied water (ETAW) and of precipitation (EP) for 20 crop categories (see Appendix 1 in Fulton et al., 2012). These data are reported on a per-acre basis in CDWR's Land and Water Use Survey (LWUS), which we compiled for the years 1998-2005. As 2007 data were not yet available, we used average ETAW and EP factors from this time period to represent blue and green water consumptive use factors, respectively, for the 20 crop categories.

For land area in agricultural production in California, the CDWR LWUS also reports irrigated crop area (ICA) for each crop category. However, as CDWR does not survey non-irrigated crop area, i.e., purely rainfed agriculture, we used County Agricultural Commissioner's (CAC) Data provided by the U.S. Department of Agriculture (USDA), which reports "harvested acres" for 281 distinct commodities on an annual basis. We related each CAC commodity to one of CDWR's 20 crop categories according to Appendix 1 (Fulton et al. 2012) in order to check the difference between harvested acreage (according to CAC) and irrigated crop area (according to CDWR) for the years 1998-2005. In most cases, the difference was less than 10%, indicating that purely rainfed, non-irrigated agriculture is uncommon in California. However, substantial acreage of pasture and grains was not irrigated, so blue water consumptive use factors were only applied to the proportional acreage of those crops that were irrigated.

For the remainder of crops, blue and green water consumptive use factors were multiplied by the actual harvested acreage (2007) of the 281 CAC commodities. The total volumes of green and blue water for these 281 commodities were divided by commodity production statistics (also contained in the CAC dataset), resulting in a dataset of green water and blue water consumptive use in units of water volume-per-weight of produced product. The crops in the USDA dataset were then coded to a list of commodities that we generated (see Appendix 2 in Fulton et al., 2012) that could be related to traded products. Because many products are traded in a condition that is different from the "farm-weight" (as reported by CAC), standard conversions were applied using factors from Mekonnen and Hoekstra (2010a) and USDA (1992). Grey water factors for crop production in California were not calculated using local data, but rather derived using state-level data from Mekonnen and Hoekstra (2010a) so as to match the methods and scope of pollutants covered in the national study.

2.1.2. Animal Products

Producing animal products, like meat and dairy, consumes a large volume of water, primarily due to growing the forage and fodder crops used to feed the animal. Other water uses such as for washing and hydrating animals and for the processing of animal products are typically only around 1% of animal product WFs (Mekonnen and Hoekstra 2010b) and are therefore not included in this analysis. The WFs of feed and forage crops, calculated as described above, were allocated to animal products based on international biomass-to-product conversion rates published in Mekonnen and Hoekstra (2010b). Data on the production of animal products were obtained from the 2007 USDA Census of Agriculture. According to these sources, an estimated 57.3 million (metric) tons of biomass were needed for animal production in California in 2007. Data on animal feed in California is limited, so the supply of biomass to the animal products industries was assumed to be composed of crops specified by CAC as feed or silage, as well as alfalfa, hay, and pasture. California pasturelands were assumed to generate 336 tons of biomass per square kilometer, which is consistent with findings from George et al. (2001). The biomass demand from California's animal product industries exceeds the supply from in-state sources, thus imported feed crops also make a large contribution to the production of animal products. California exports some animal feed and forage crops, chiefly alfalfa, so those exports were treated as separate commodities and excluded as an input to animal products within California. Careful attention was paid to avoid double counting the WFs of animal feed and animal products.

2.1.3. Industrial Products and Direct Use

The WF associated with industrial production within California was calculated using the best available local data. The most recent dataset for industrial water use in California comes from CDWR's 1995 survey of commercial, industrial, and institutional water use. The dataset was not published but was analyzed by Gleick et al. (2003). In the report, water withdrawal factors were developed for 20 manufacturing sectors on a per-employee basis. Subsequent work translated these factors into gallons-per-dollar of revenue for each sector (Cox 2011). These factors represent total blue water use, i.e., consumptive and non-consumptive uses. Using California-level data from USGS, we estimated that consumptive blue water use represented 28% of water withdrawals in the industrial sector (Solley et al. 1998).

These industrial blue water factors were then applied to inflation-adjusted revenues in all manufacturing sectors as reported in the U.S. Census Bureau's Economic Census of 2007. It is important to note that this approach assumes that the water use factor has not changed and therefore does not account for efficiency improvements within industrial sectors that may have occurred since 1995. While this assumption likely overestimates the blue water footprint of industrial products, data are not currently available to develop more accurate estimates. Grey WF factors for industrial products were not available at the state level, so national level statistics (assumptions are described in Section 2.2) from Mekonnen and Hoekstra (2011) were used.

Direct consumption in the residential, commercial and institutional sectors were derived from supporting Technical Guide from the California Water Plan Update 2009 (CDWR 2009). These data show that the average consumption rate for all urban uses from 1998-2005 was 31% of withdrawal, and this percentage was applied to withdrawal volumes in the residential, commercial, and institutional sectors to determine their average blue WF volumes.

2.2. Water Footprint of Products Produced Outside of California

Many products that are consumed in California are produced in other U.S. states and other countries. For agricultural products, we used WF factors developed by WFN. Using country-level data from the United Nations Food and Agriculture Organization (FAO), Mekonnen and Hoekstra (2010a) calculated blue, green, and grey WF factors for over 300 crops and crop-derived products in 225 countries. Factors have also been calculated for over 100 animal products in 202 countries (Mekonnen and Hoekstra 2010b). These factors are based on the weight of the product, i.e., cubic meters of water-per-ton of product. All products are reported using codes from the Harmonized System (HS), which corresponds to trade data, as described below.

Industrial consumptive use factors are not differentiated by product in any global dataset. Mekonnen and Hoekstra (2011) calculated average blue and grey water factors per-dollar (value added) of industrial production for 230 countries based on FAO-reported industrial withdrawal and an assumption that blue water consumptive use is 5% of withdrawal (note that this assumption is much smaller than for California since FAO industrial withdrawal statistics often include thermoelectric uses (Kohli and Frenken 2011)). Green water is assumed to not factor into industrial production. Industrial grey water factors are calculated using United Nations Statistics Division data showing country-level average percentage of wastewater that is treated. That percentage is multiplied by the amount of industrial water withdrawn but not consumed (95% of withdrawal) (Mekonnen and Hoekstra 2011).

2.3. Trade

Trade data are needed to calculate California's internal and external WFs. The U.S. Census Bureau collects state-level trade data with domestic and international trade partners. Domestic trade is reported in the Commodity Flow Survey (CFS), conducted every five years in coordination with the Bureau of Transportation Statistics (BTS). We used CFS data from 2007, the most recent year available, to calculate domestic shipments to and from California. State of origin, destination, shipment weights, and values are organized by both the North American Industrial Classification System (NAICS) and the Standard Classification of Transported Goods (SCTG) at the two digit level. For industrial goods, the NAICS data provides the same level of resolution as the WF factors mentioned above, allowing us to map domestic virtual water flows on a per-dollar basis. For agricultural goods, however, the SCTG trade data are disaggregated into 9 categories, so blue, green, and grey water coefficients were generated as a weighted average over several agricultural industries (for example all fruits and vegetables are combined into one category) in order to estimate the virtual water flows inside the U.S. This is a major data limitation in our study, and we note that it adds uncertainty in domestic virtual water flows.

International trade data are organized according to the Harmonized System (HS) of classification and are available at a much finer resolution of products than domestic data. State-level HS data are tracked annually by the U.S. Census Bureau and reported in its "USA Trade *Online*" system. Exports from California to global trading partners are available for 2007 on a value and weight basis. We included 285 exported products, which were aggregated into 75 product categories (Appendix 3 in Fulton et al., 2012). Data on imports to California are available for 2008, which we assumed are comparable to 2007 levels, and are reported on a "state of final destination" basis, meaning that goods destined to other states that go through California ports are not counted. We included 389 imported products, with the additional products not included in Appendix 3 (ibid) being categorized as "other" and listed in Appendix 4 (ibid).

Data from USA Trade *Online* only reports weight values for commerce traded by sea and air, thus missing the weight of overland agricultural trade with Canada and Mexico. For these agricultural trade flows, we transformed the values of overland shipments to weights using value-to-weight ratios from BTS' North American Transborder Freight Database, as well as aggregations of 10-digit value-to-weight ratios derived from USA Trade *Online*. For industrial trade flows, monetary values were sufficient to be applied to industrial WF factors from trading partner countries.

2.4. Uncertainty

In using state-level data sources, uncertainty was introduced at several stages of our analysis. The WFs of crop, animal, and industrial products produced in California were subject to both statistical and modeling uncertainties. Land use and production data from the LWUS, the CAC, the 1995 CDWR survey, as well as the Economic Census are subject to survey and sampling errors. None of these datasets reported a quantified estimate of error, however the Economic Census discusses sources of sampling and non-sampling error in USDC-CB (2007). Assumptions embedded in LWUS modeling – on crop coefficients, reference evapotranspiration, effective precipitation, etc. – are provided by Hillaire and Cornwall (2004). Modeled estimates aggregated to the state level generally corresponded with statewide estimates of consumptive water use; however, spatial and interannual variations due to climate or production technologies were not captured in our approach. In many cases, averaging allowed for data to converge around 2007; however, results should not be taken as a function of particular regional climatic or economic conditions in 2007.

The WFs of products produced outside of California, but that contribute to California's WF through virtual water import, are subject to many of the same sources of uncertainty (Mekonnen and Hoekstra 2011). Quantification of WF uncertainty has been attempted in very few studies and locations. Zhuo et al. (2014) performed a sensitivity analysis of WFs for four crops in the Yellow River Basin, finding that climatic variables alone could account for a ±20% variation in total WF. Sun et al (2013) found similar results through a time-series analysis of maize WF values in Beijing.

Uncertainty in trade data is also an important factor that can compound overall uncertainty in California's WF. As mentioned above, the lower resolution of domestic trade data compared to international trade data is one such source of uncertainty. The Census Bureau does not report error estimates for international trade data. It does estimate sampling errors for domestic trade data, reported as coefficients of variation. In the case of California's domestic imports and exports, coefficients of variation ranged from 6 to 48 percent.

In light of differing availability of uncertainty estimates in the data, we have not attempted to quantify overall uncertainty in our analysis, and the exactness of results should be used with caution. Nevertheless, findings can be seen as *indicative* of California's WF configuration and, to the extent that they can be compared with the U.S. as a whole, can offer insights for state-level policy consideration in light of ongoing water resource management challenges. Adaptive management of water resources calls for acknowledging the inevitability of uncertainty in water systems and incorporating ranges of uncertainty into decision making (Pahl-Wostl 2006; Keur et al. 2008; Pahl-Wostl et al. 2010). Water footprint analysis presents the additional layer of global trade and attendant uncertainties associated with economic statistics, and any subsequent policy decisions must consider (and be presented with) the relevant uncertainties.

3. Results

3.1. The Water Footprint of California

We estimated that California's statewide WF in 2007 associated with the consumption of agricultural and industrial goods, as well as residential, commercial, and institutional water consumptive use was 55 km^3 (cubic kilometers) of green water, 24 km^3 of blue water, and 51 km^3 of grey water (Figure 2).

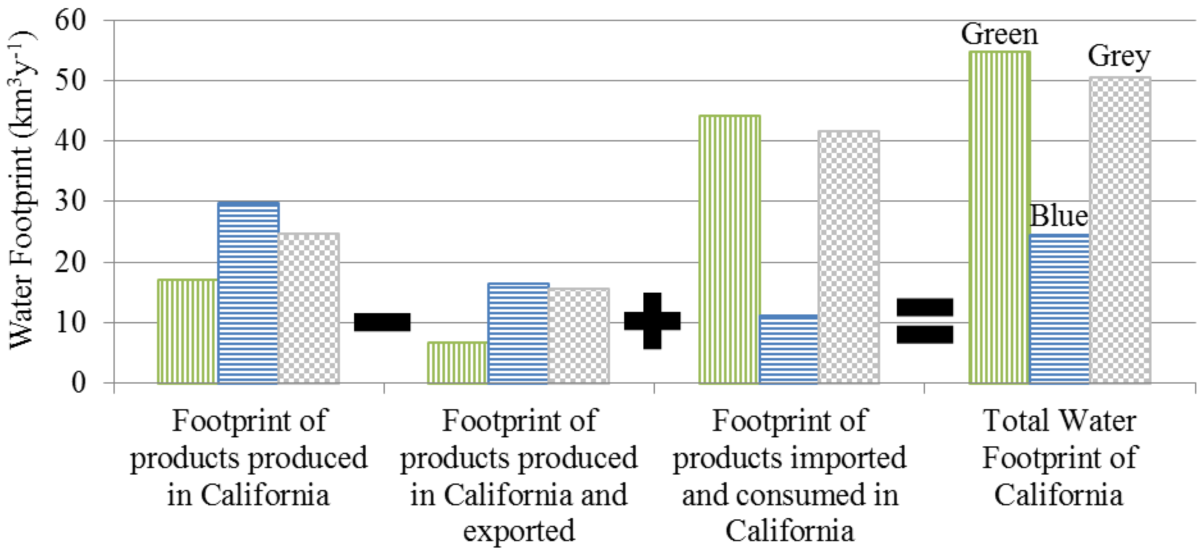

Figure 2. California's green, blue, and grey water footprints in 2007 (cubic kilometers per year)

We do not add these three values together in a combined WF as has been done in other WF studies. This is primarily because grey water 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 (Gleick 2003), contaminated water can and does often still serve multiple uses like navigation or cooling. Thus, in order to eliminate double counting of upstream grey water footprints by downstream blue water uses in this report, we present grey WF separately. We feel that the grey WF is a useful quantitative indicator for water quality issues, but that methodologically it should be reported separately from the green and blue water footprints. For these reasons only blue and green WFs will be compared with the national case in the next sections.

3.2. California–U.S. Water Footprint Comparison

In this section, we compare the WF of California with that of the U.S. on a per-capita basis. The WF of the U.S. is taken from a global assessment of national level water footprints (Mekonnen and Hoekstra 2011). California's combined green and blue WF is about 5.7 $m^3cap^{-1}d^{-1}$ (cubic meters per capita per day), which is just slightly lower than the average American's, at just over 6.0 $m^3cap^{-1}d^{-1}$. Figure 3 shows a comparison of California's WF (left column) with that of the U.S. (right column) along three dimensions.

First, in both cases the WF is related to similar classes of products (top row). Food makes up over 90% of the WF, followed by industrial products and direct consumptive use. Meat and dairy products make up about half of the food WF in both cases. These findings are not surprising since there is little reason to expect Californian's consumption patterns to be any different from the rest of the country. Rather, the approximate equivalent of product-level WFs may offer some validation for our chosen methods and data sources at the state level.

The second comparison shows the geographic distribution of California and U.S. WFs (middle row). About 30% of California's WF is associated with goods that are produced and consumed in California, referred to as California's *internal* WF. The *external* component is 70%: 50% from other places in the U.S. and 20% related to imports from other countries. In marked contrast, the WF of the U.S. is 80% internal.

The third comparison depicts the relative contribution of blue and green water to each WF (bottom row). California's WF is more heavily weighted in blue water, which is related to the abstraction of surface and groundwater used to produce the goods and services consumed in California. This is compared to the far larger percentage of green water, or precipitation and soil moisture, used to produce the goods consumed by the average American.

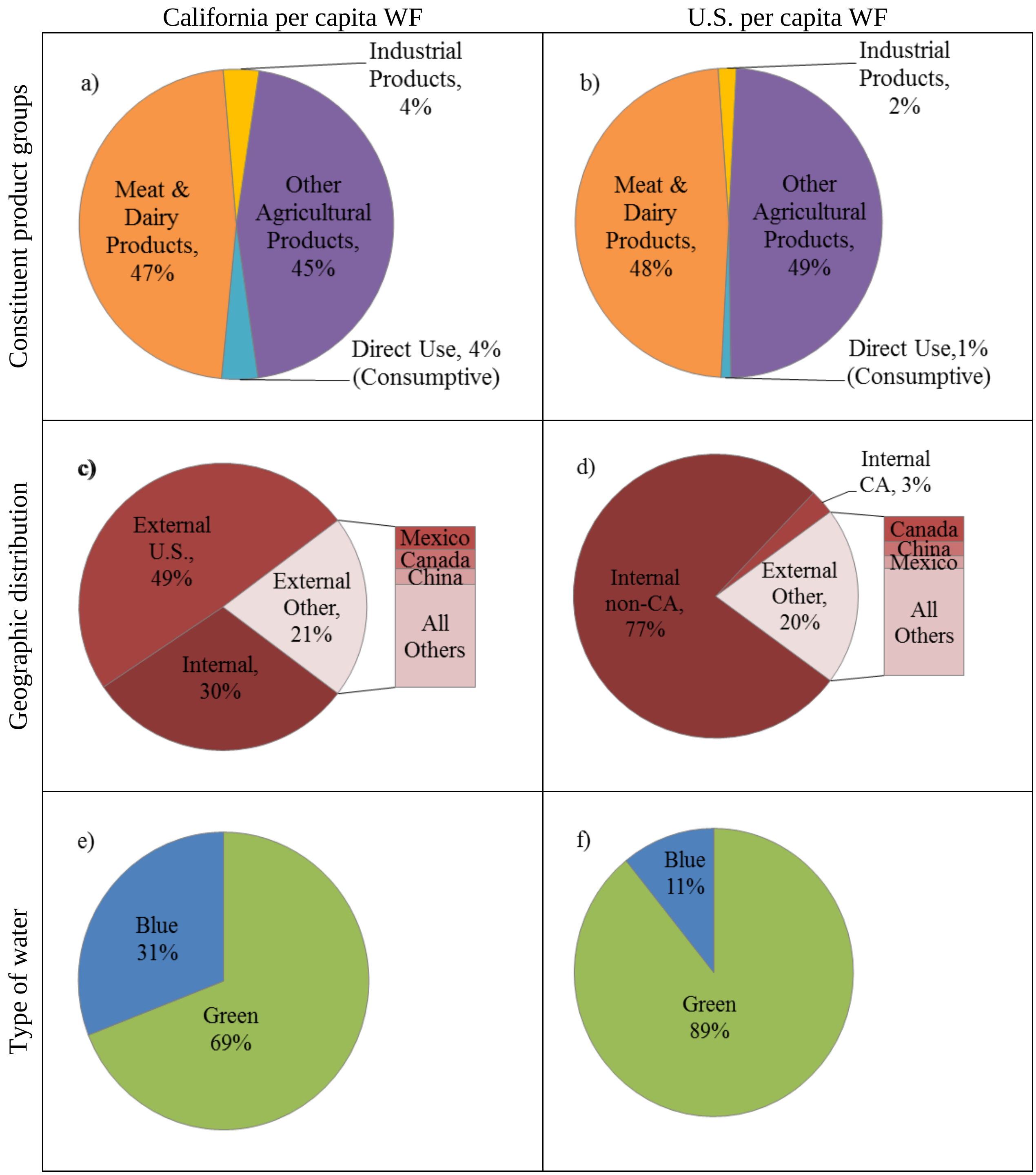

Figure 3. California's per capita WF (left column) and that of the U.S. (right column), which in volume are 5.7 and 6.0 $m^3 cap^{-1} d^{-1}$, respectively, compared along three dimensions: constituent product groups (top row), geographic distribution (middle row), and type of water (bottom row).

4. Discussion

Globalization has forged increasing interconnectedness among people, economies, and resources, including water resources that have traditionally been thought of as a local or regional issue. In light of these connections, better understanding is needed of the ways in which observed water resource challenges have important global dimensions. The WF is a tool and indicator for understanding the connections between consumption of everyday products and global water use. The WF indicator also offers new insights into water policy options and governance strategies (Hoekstra 2010). The results of the California WF assessment permit a deeper discussion of the implications of water strategies at multiple scales.

The comparison between the California and U.S. water footprints illustrates the similarities and differences that result from the scale of a WF assessment. With WF magnitude and constituent products being nearly identical, the WF of a national and a subnational unit can differ substantially in the source and type of water entailed. In our case, California's WF, compared to that of the U.S., is far more dependent on water from outside of its political boundaries, and more dependent on blue water, suggesting a different context and set of vulnerabilities for policy consideration.

These results raise a number of sustainability questions for potential policy consideration. For example, should California's per-capita WF be reduced and what are the possible mechanisms to do so? After all, the WF of the average American or Californian is roughly 50% larger than their counterparts in other highly-industrialized nations, and about 80% higher than the global average (Hoekstra and Mekonnen 2012a). Were the entire world's population to have American-level WFs, the demand on global water resources would more than double (ibid). To address this type of question, our findings indicate that an assessment at the national scale provides adequate information, since the WF of a Californian is quantitatively, and with respect to constituent products, the same as the WF of an American. Options for reducing the per-capita WF might urge changes in consumer behavior in favor of less water-intensive products like chicken instead of beef, or a reduction in overall meat consumption. While such a strategy may not sit comfortably within the domain of public policy, it could be seen as akin to a local water utility incentivizing its customers to reduce per-capita water use during a shortage or in order to allow for alternative uses like environmental flows or further development.

Other more complex sustainability questions might pertain to *how* or *what kind of* water resources are mobilized to fulfill a society's consumption habits, and the relative scarcity in locations where water is being used. These concerns have important policy relevance in addressing issues like climate change, where changing patterns of water availability pose risk to food and other provisioning systems. Here, WF findings are relevant not to consumer behavior but to the domains of policymakers or water managers that actually govern resource provision through a range of political and economic mechanisms.

When it comes to using WF findings to formulate policy, especially with respect to climate change planning, national and subnational decision makers face different considerations. In our case, there are significant differences between the national and state-level options. Since the national WF is largely internal (i.e., not dependent on water from outside the U.S.) and green (i.e., largely dependent on rainfed agriculture as opposed to irrigated agriculture), national policies should be oriented around domestic water issues and technologies that increase green water productivity. Conversely, California's water-related vulnerabilities are 70% external, and to a far greater extent (30%) related to blue water resources (note from Figure 2 that this 30% is not simply the same 30% that is internal, rather almost half of California's blue WF is external). Policymakers in California must therefore consider how important its dependence on external sources of water might be and whether there are strategies that can affect the management of water outside of their direct jurisdiction. Similarly, blue water resources entail different management strategies from green water and this must be considered when developing comprehensive tools for addressing the implications of water footprints.

These differences also raise the question about the effectiveness and practicality of climate-related adaptation strategies: a WF that is highly dependent on precipitation patterns and green water may be more vulnerable to climate change than one with the flexibility and reliability offered by some forms of irrigated management. We can see this in the context of recent efforts to expand supplemental irrigation in Alabama and Georgia on lands that previously were entirely dependent on precipitation and green water sources (AWAWG 2012). Climate change-relevant WF policies may thus differ significantly based on national versus subnational assessments. Our findings thus highlight the importance of explicit scale choice in conducting WF assessments that are used to inform policy responses. Scaling our analysis to the state level allowed a more accurate understanding of water resource dependencies, vulnerabilities, and impacts.

Other scales may provide important insights as well: for example a more appropriate unit of analysis might be a river basin, which forms a more hydrologically-unified basis for decision making than a traditional political unit. Indeed, the issue of appropriate governance scale is not new to the field of water management, as evidenced by debates around implementing Integrated Water Resources Management (Conca 2006). While it has been possible to use WF methods to estimate the WF of products *produced* within a river basin (e.g. Zeng et al., 2012), there remains a disconnect with the availability of trade statistics required to calculate the WF of products *consumed* within such a geographic region. Additional data collection and statistical interpolation techniques may help in scaling WF analyses in ways that are useful to river basin management.

Further iterating the WF methodology will also help its relevance in water resources management at various scales. Of particular concern is relating water footprint quantities to more qualitative indices of water scarcity, quality, and impacts to environments and livelihoods (Hoekstra and Mekonnen 2012b). The method could also improve its sensitivity to efficiency and productivity to reflect technological improvements, as well as its ability to integrate other factors in a sustainable production calculus like land, labor, and energy. Nevertheless, water resource managers are beginning to acknowledge the global dimension to their work, made ever more relevant through economic globalization and climate change. In California, CDWR has taken the step of integrating the WF into a framework of sustainability indicators being developed for long-term state water resource planning. While it remains to be seen how WF information might eventually be used to formulate policy, awareness of the vulnerabilities associated with dependence on external water resources such as the Colorado River is not new to California. Reduced flows, mismanagement, and allocation disputes in the Colorado River Basin have long been a source of vulnerability for Southern California’s water supply. But while the magnitude of this dependence has been below 10% of the state’s overall direct water supply, the external dependence of its WF is 70%. This presents new challenges that state decision makers may choose to take up in coming years. Other policy arenas in California may offer precedent for taking action on indirect resource use, as evidenced by California’s Global Warming Solutions

Act of 2006, which requires carbon emissions associated with imported energy to be counted toward the state's greenhouse gas inventory.

The WF tool is useful in describing the interconnectedness of people, economies, and resources, and suggests a global dimension that water managers must acknowledge in order to tackle today's water challenges. However, because most WF studies to date have relied on national and international data to illustrate this phenomenon, policy "solutions" have tended to conform to these analytical scales. WF findings have therefore gained little traction with existing governance institutions where most water management expertise and decision making still resides. Findings presented here suggest that the WF tool can be informative at the local to regional level of decision making when analytical units are relevant to jurisdictional units.

5. Acknowledgements

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