A Regional Assessment of Water Use in the U.S. Food System

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INTRODUCTION

Water is a finite natural resource that is vital to the world's economy. The National Water-Use Information Program (NWUIP) of the U.S. Geological Survey (USGS), reports that 349 billion gallons of freshwater were withdrawn daily in the U.S. in 2005. Figure 1 shows these water withdrawals by county, highlighting the amount of water withdrawn in the west.

Water is particularly important to the food system as an input in crop and livestock production. USGS data indicate that 128 billion gallons of freshwater per day were withdrawn in 2005 for irrigation. This amount represents 37 percent of the freshwater water withdrawals and 31 percent of total water withdrawals[1]. The U.S. Department of Agriculture (USDA) reports that agriculture accounts for 80 percent of consumptive water use in the United States, defined as water lost to the system (2013a). Figure 2 shows 2005 irrigation water withdrawals by U.S. counties and, again, the concentration of withdrawals in the western region of the United States.

Water withdrawals for livestock totaled 2.14 billion gallons per day in 2005, representing 0.6% of total freshwater withdrawals in that year. In Figure 3, livestock water withdrawals are shown at the county-level. The west is a major water user, but Midwestern states located above the Ogallala Aquifer also use substantial water for livestock.

Concerns over future water stress or scarcity worldwide are prevalent. First, world population is projected to grow to 9.6 billion by 2050. The growing population begets a growing demand for food and consequently, water. As evidence, water withdrawals grew at a faster rate than the world's population between 1950 and 2013 (Norby & Klucas). The increase in food demand is relevant to the United States, a top agricultural exporter. U.S. exports of agricultural

[1] The distinction between a water withdrawals and consumptive water use is important. Water withdrawals are returned to the source. Water producing electricity at a hydroelectric power plant is an example of a water withdrawal. Conversely, consumptive water use removes the water from the supply such as when livestock or humans drink water. Although power plants withdraw the most water in the 2005 USGS data, irrigation has a higher percentage of consumptive water use. Water use is synonymous with water withdrawals in the USGS data and this paper.

goods reached $135.8 billion in fiscal year 2012 and have exceeded U.S. agricultural imports since 1970 (Hanrahan, 2013).

As a subset of food demand, total meat consumption in the U.S. has been increasing since the early 1900s (Daniel, Cross, Koebnick, & Sinha, 2011). Meat consumption is growing worldwide as well, especially in developing countries where incomes are rising. For example, China's per capita pork consumption has increased from under 20 pounds per capita in the mid-seventies to 86 pounds per capita in 2012, surpassing U.S. pork consumption (Larsen, 2013). Although livestock water withdrawals pale in comparison to irrigation water withdrawals, more water is embodied in animal-based products compared to plant-based products (Hoekstra, 2012).

Secondly, there have been recent and notable weather events in the U.S. Extreme drought struck the Midwest in 2012, damaging or destroying crops, predominantly the soybeans and field corn grown there. The USDA (2013b) reports that approximately 60 percent of farms experienced drought by mid-August of that year. In the west, California has been experiencing an ongoing drought which resulted in 2014 being the driest year on record (USDA, 2014). Climate change may increase the frequency or magnitude of extreme weather events such as droughts. Alternatively, climate change may be characterized by temperature variability or changes in precipitation patterns, which could also affect water resources and agricultural production.

With the growing population and climate change, water resources face stress from both the consumption and production sides indicating that water use in the food system is an important and timely topic. Organizations such as the National Research Council (2012) and the U.S. Environmental Protection Agency (2013) have necessitated water research. In February 2015, the Dietary Guidelines Advisory Committee (DGAC) submitted their report to the

Secretaries of the U.S. Department of Health and Human Services and the USDA preceding the Dietary Guidelines for Americans which are released every five years by the two federal agencies. In addition to providing their diet and nutrition recommendations, the committee also underlined the environmental implications of diets and the necessity to consider sustainability. Water use is one of the environmental impacts the DGAC cites along with greenhouse gas emissions, land use, and energy use.

Relevant research on water resources using the input-output (IO) methodology include Blackhurst, Hendrickson, and Vidal (2010) and Mubako, Lahiri, and Lant (2013). Blackhurst et al. (2010) use 2003 data in an economic input-output life cycle assessment. They rank economic sectors by total water use and find that grains and animal products are significant water users. However, they find that animal products use less total water per dollar of output compared to grains or other food crops. Mubako et al. (2013) compare virtual water trade in California and Illinois using a multiregional IO model, distinguishing between blue, green, and saline water.

This paper has two objectives; first, to assess the U.S. food system's water use and second, to conduct a supply chain analysis of water use throughout the food system. The results of this research are valuable because they quantify direct and indirect water use by economic sector, and specifically, that which is related to food in the United States. This research also informs for policy discussions surrounding food system sustainability.

METHODOLOGY

The National Research Council (2002) suggests input-output as an approach to model water use. For a description of the input-output methodology, see Miller and Blair (1985) or, for a concise summary of the matrix algebra, see Section 4.1 in Mubako et al. (2013).

We employ an input-output material flow analysis (IOMFA) which extends the conventional IO matrix in economic units to include hybrid units. Canning, Charles, Huang, Polenske, and Waters (2010) use an analogous approach to examine energy use in the U.S. food system. We build off of the water research by Blackhurst et al. (2010). We refine their estimates using different allocation metrics and building the national table up from county-level data. Additionally, we distinguish between groundwater and surface water.

Data Development

The USGS has collected water use data in the United States since 1950 and reports the estimates in five year increments. The USGS data include water use by county and by source in the following categories: aquaculture, industrial, irrigation, livestock, mining, public supply, and thermoelectric power. To asses water use in the U.S. food system, we allocate the USGS water data by category to the narrower economic sectors in the ERS-IO. The ERS-IO matrix, developed by USDA's Economic Research Service, includes almost 500 economic sectors and is based on the Bureau of Economic Analysis's (BEA) most recent benchmark industry accounts from 2007.

As a first step in allocation, a concordance is created to assign a USGS water use category to each sector in the U.S. economy. From a spreadsheet provided by USGS, we begin with the 1987 Standard Industrial Classification (SIC) codes categorized by water use category. Using the SIC codes, the North American Industry Classification System (NAICS) 1997, and Bureau of Economic Analysis benchmark industries from 2007 as intermediaries, the final concordance assigns ERS-IO sectors to water use categories.

Next, additional data sources are necessary to allocate the water use data since a large portion of water is self-supplied. We used a variety of metrics in allocation which are summarized in Table 1. We allow for geographical heterogeneity of water resources and use, by using county-level data on irrigated acreage by crop from the 2007 Census of Agriculture coupled with state-level data on water application rates by crop from the 2008 Farm and Ranch Irrigation Survey to allocate the irrigation water use. Some of the data from the Census of Agriculture are suppressed, so we estimate the suppressions using a constrained maximum likelihood estimator (CMLE) model which relies on hierarchical relationships within the data as constraints (Canning, 2012). This methodology is also used by Etemadnia, Goetz, Canning, and Tavallali (2015) when faced with suppressed Census data. Similarly, the livestock water use category is allocated using estimated county-level livestock inventory data from the 2007 Census of Agriculture. These data are coupled with daily water intake rates by animal (Lovelace, 2009). County-level industrial employment data from the 2007 County Business Patterns was another source used to allocate the USGS data.

Conversely, for the water that is publically-supplied, the coefficients (share of total output) from the economic accounts in our expanded ERS-IO matrix are used to allocate water use from the USGS categories to the specific economic sectors. USGS did not estimate self-supplied water use for commercial industries, so it is assumed to be zero.

Input-Output Material Flows Analysis

With the water data allocated properly, we use an IOMFA to estimate direct and indirect water use. Direct water is defined as the water an industry uses itself whereas indirect water, also known as embodied or virtual water, is the water used in the industry's inputs. For example, the direct water use in cattle production would include drinking water for the cattle and servicing water used on the farm. Indirect water use, in this case, includes irrigation used to grow corn for feed.

In the ERS-IO, we identify the row that represents publically-supplied water commodities and convert the units of measurement from dollars to physical units. Water is distinct from other resources analyzed with IOMFA since the majority of the water is self-supplied. Therefore, we augment rows to the matrix for self-supplied fresh surface water and self-supplied fresh ground water, already in physical units. By deriving the Leontief inverse of this hybrid ERS-IO matrix containing data in both dollar units and physical units, the element in any column intersection with a water commodity row reports total water withdrawals required, both directly and indirectly, to accommodate the final market sale of one dollar's worth of any final demand commodity "j." Total water withdrawals, w, and food-related water use, w^f, are measured as:

1) $w = H \cdot y$

2) $w^f = H \cdot y^f$

where 'H' is the submatrix from the Leontief inverse of the hybrid table containing all water commodity rows, y is the total final demand vector comprising annual U.S. gross domestic product (GDP) plus annual international imports, and y^f is total annual personal consumption expenditures of US food consumers on food, beverages, and foodservices.

Supply Chain Analysis

To accomplish our second objective and further characterize the water use in the U.S. food system, we conduct a supply chain analysis. We partition the ERS-IO accounts to differentiate how much water is being used at each stage of the food system including the farming and agribusiness, processing, packaging, transportation, wholesale and retail trade, food services, and households.

We apply an industry-based total requirement method that partitions the input-output table into two industry groups; supply chain industries (Group 1) and non-supply chain industries (Group 2). Group 2 industries are eliminated from the aggregated tables, but their value-added contributions to the output of supply chain industries are exactly allocated to Group 1 industries through a double matrix inversion procedure (Leontief, 1967). This method involves thinking about the other sectors as “subcontracting” sectors. The sectors of interest (“contracting”) each purchase total requirements of subcontracting sectors and those amounts are absorbed into the contracting industry’s output.

RESULTS

FORTHCOMING

DISCUSSION

FORTHCOMING

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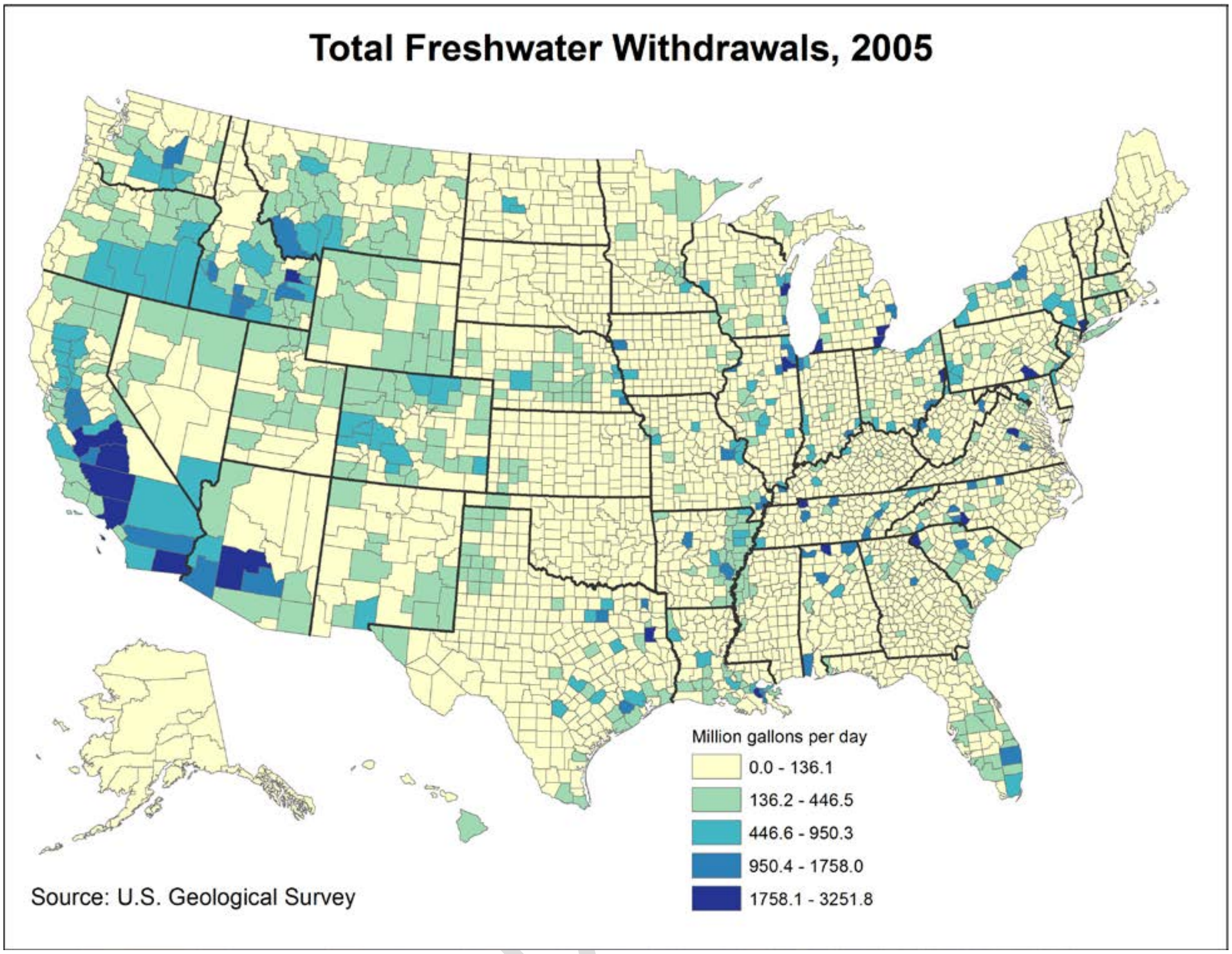

Figure 1. Total Freshwater Withdrawals, 2005.

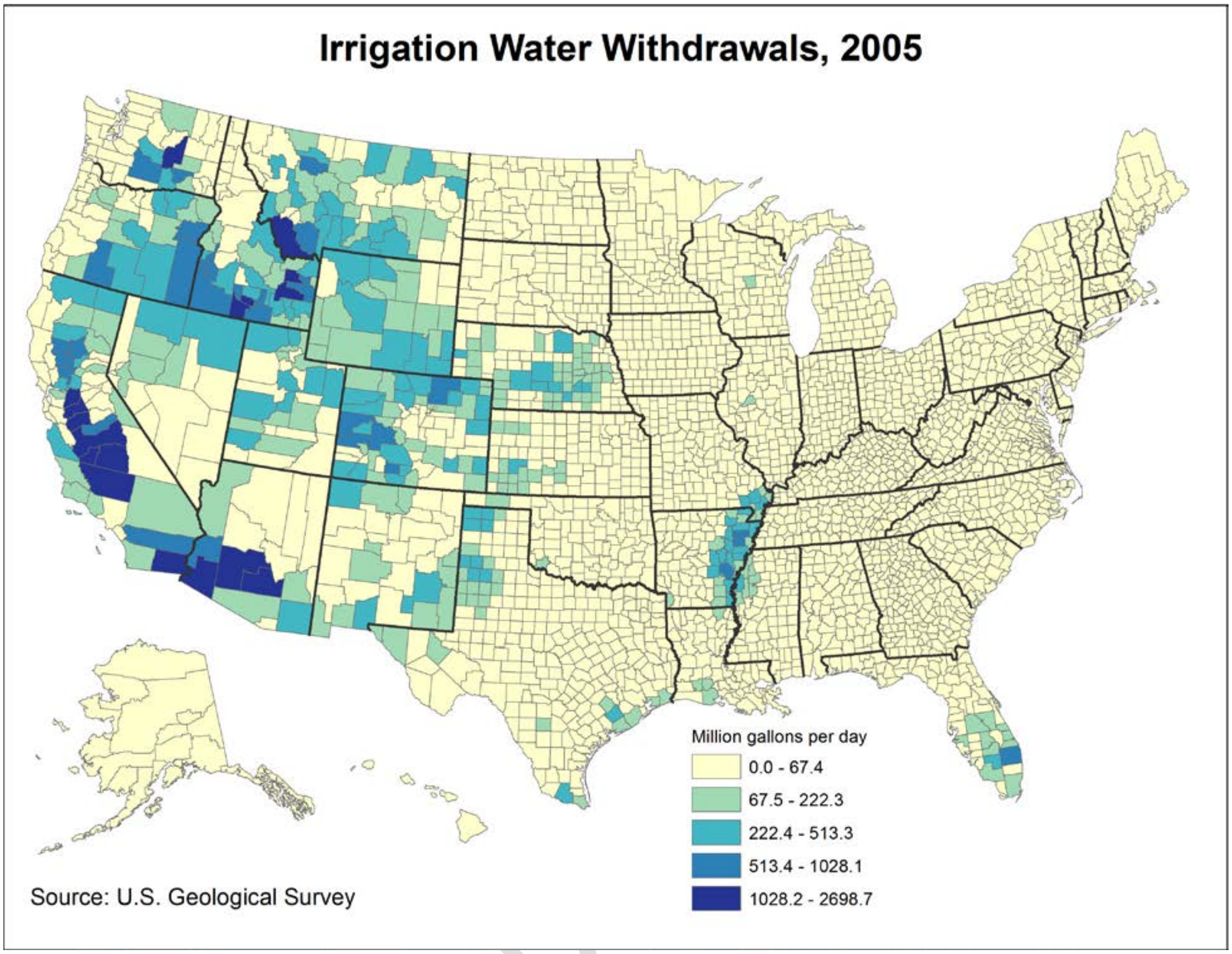

Figure 2. Irrigation Water Withdrawals, 2005.

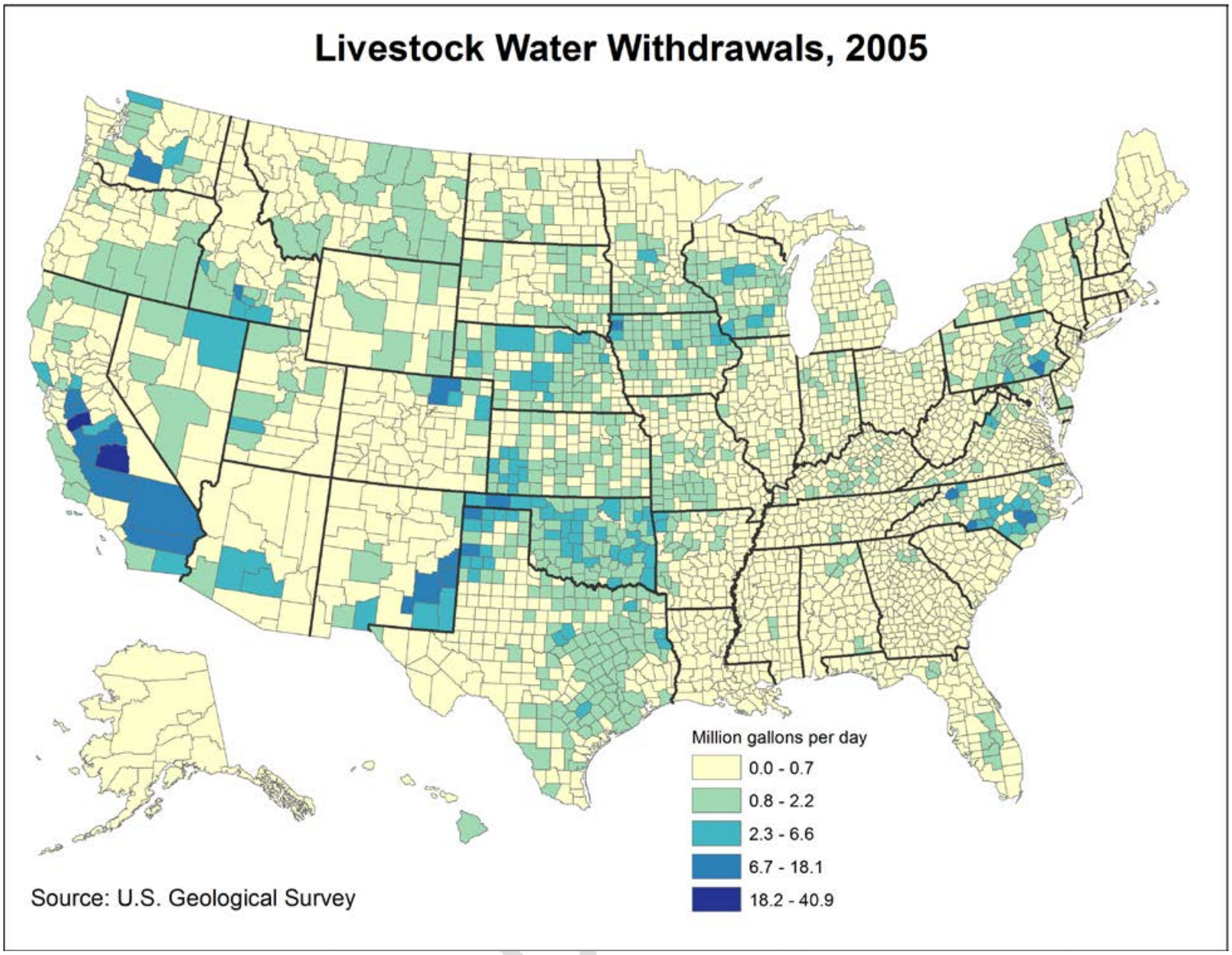

Figure 3. Livestock Water Withdrawals, 2005.

Table 1. Total Water Withdrawals by USGS Sector and Allocation Methodology

USGS Sector	USGS 2005 Water Use Estimate (Mgal/day)	USGS 2005 Water Use Estimate (%)	Allocation Metric	Allocation Data Source
Aquaculture	8,780	3%	N/A; assigned to one industry	
Domestic Deliveries	3,830	1%	N/A; assigned to final demand vector	
Industrial	17,000	5%	Employment data by county	County Business Patterns (2007)
Irrigation	128,000	37%	Acres irrigated by county by crop; water applied by state by crop	Census of Agriculture (2007); Farm and Ranch Irrigation Survey (2008)
Livestock	2,140	1%	Inventory by animal by county; water consumed by animal	Census of Agriculture (2007); Lovelace (2009)
Mining	2,310	1%	Employment data by county	County Business Patterns (2007)
Public Supply[a]	44,200	13%	ERS-IO coefficients	ERS-IO matrix based on data from the Bureau of Economic Analysis (2007)
Thermoelectric	143,000	41%	N/A, assigned to one industry	
Total	349,000	100%		

Note: All freshwater estimates. For the industries defined by USGS as commercial, the self-supplied water use was assumed to be zero since there is no estimate from USGS.

a: Net public supply is allocated, rather than total public supply, to the ERS-IO categories. Net public supply = (public supply – domestic deliveries), or 40,370 Mgal/day.