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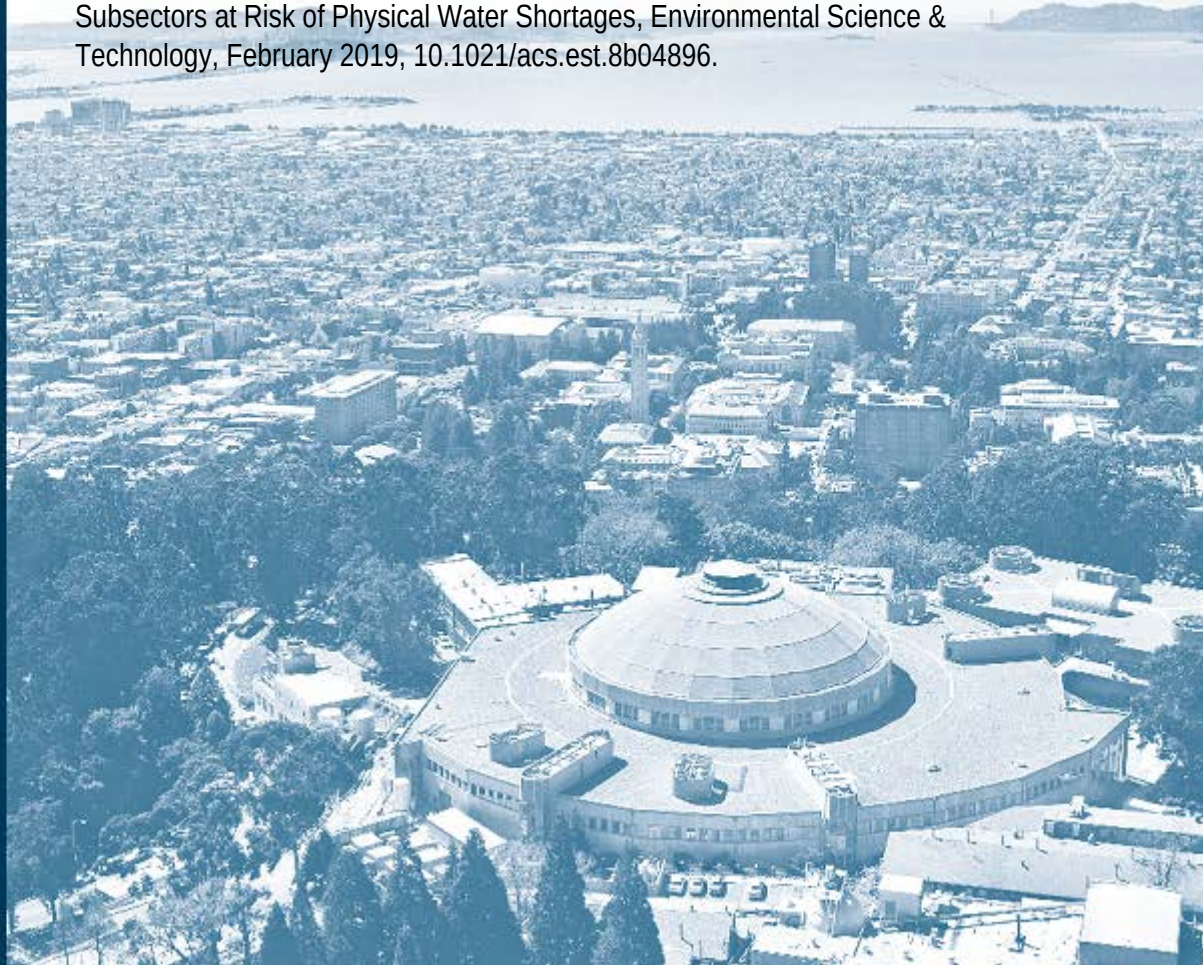

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Evaluation of U.S. Manufacturing Subsectors at Risk of Physical Water Shortages

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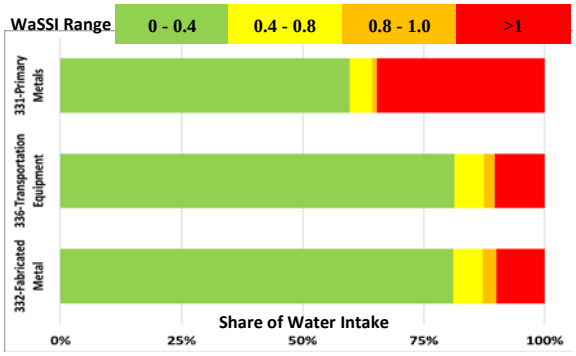
ABSTRACT

The potential impact of water shortages on U.S. manufacturing is unknown. While water for manufacturing constitutes an estimated 6% of U.S. water intake, the data (i.e. location, quantity, and purpose of water intake) needed to determine this impact does not exist. This paper will identify manufacturing subsectors at risk of physical water shortages by applying a method for estimating U.S. manufacturing water intake at the necessary spatial and sectoral resolutions. First, the data requirements to quantify a manufacturing facility's water footprint within the context of the watershed are developed. Second, using international data, estimates of water intake at the national, state, and county-levels by each U.S. manufacturing subsector are developed. Third, manufacturing subsectors that are most vulnerable to risks of physical water shortages are identified. Based on the results, the Paper, Primary Metals, Chemical, Petroleum and Coal Products, and Food subsectors have the largest intake, respectively. However, the Primary Metals, Fabricated Metals, Transportation Equipment, Petroleum and Coal, and Plastics and Rubber subsectors are at the greatest risk of physical water shortages based on

concentrations of water intake in water-stressed regions. The results can be used to develop strategies to mitigate the risks of water shortages on the U.S. manufacturing sector.

TOC/Abstract A



1. Introduction

Water shortages are of increasing concern to both state water planners and manufacturers in the U.S. In a 2014 survey conducted by the U.S. Government Accountability Office, 40 of 48 state water planners (two states did not respond) reported anticipating water shortages at the state, regional, or local-level in their state within the next ten years. Forty-two of 48 state water planners anticipated water shortages within their state in the next ten to twenty years [1]. From the perspective of the manufacturing community, a 2015 Carbon Disclosure Project (CDP) report listed the U.S. as a top country where facilities in the Industrials and Consumer Staples sectors are at risk of water shortages. The list was developed using survey responses from CDP partners. The other countries listed are China, India, and Japan for the Industrials sector and Mexico, Brazil, and India for the Consumer Staples sector [2]. The consequences of water shortages include production disruptions, closing plants, retrofitting process to be waterless, relocating plants (or not siting them at all), and increases in water costs.

Little is understood about U.S. manufacturing's vulnerability to water shortages, leaving policymakers and corporate decision makers unprepared to address them. This is due in large

part to a dearth of information on quantities, purposes, or geographic distribution of water intake [3–7]. In this paper, the manufacturing sector will be defined as the subsectors spanning the North American Industrial Classification System (NAICS) codes 311-339. For a listing of the manufacturing sectors at the 3 digit NAICS level as used in this paper, see the Supplemental Information. Blackhurst et al (2010) estimated U.S. industrial (defined to include more economic sectors than considered here) water withdrawals using input-output models. However, these estimates are at the national–level and, as stated by the authors themselves, should not be used for regional evaluations of the kind needed to better understand water shortages [8]. Wang et al (2014 and 2015) have made additional estimates of industrial (again, defined to include more economic sectors than considered here) water withdrawals and conducted analyses of the drivers leading to changes in water withdrawal intensity over time [9,10]. However, these too are made at the national-level. The last comprehensive survey of U.S. manufacturing water intake was in 1984 and is now out-of-date [11].

More information on manufacturing water intake characteristics would enable policymakers and manufacturers to take actions to safeguard against water shortages. Examples of such actions include: evaluating the impact of water shortages on U.S. manufacturing competitiveness, identifying sector/regions to focus water conservation efforts, establishing national water saving targets, developing requirements/guidance on water footprinting (at the facility-level) and accounting (at the regional/national-level), and developing high-impact research and development portfolios and technical assistance.

This paper identifies manufacturing subsectors in the U.S. at risk of physical water shortages by relating the geographic distribution of their water intake to the location of water stressed regions in the U.S. This paper will: 1) identify counties in the U.S. that are water

stressed, 2) estimate manufacturing water intake by 3-digit NAICS manufacturing subsector at the state and county-levels in the U.S., and 3) combine 1 and 2 to rank the manufacturing subsectors most at risk of physical water shortages.

2. Background on identifying water stress regions in the U.S.

There are a variety of indices for determining water stress [12,13]. One is the Water Supply Stress Index (WaSSI) as introduced by Sun et al. (2008) [14]. This index is a ratio of a region's total water demand (manufacturing and all other sectors) to the amount that is replenished, as shown in Equation 1.

$$WaSSI = \frac{Water\ Demand + Water\ System\ Loss}{Surface\ Water\ Supply + Groundwater\ Supply + Return\ Flows}$$

Equation 1: Definition of WaSSI[14]. WaSSI values used in this paper were taken from the WaSSI Ecosystems Services Model[15]

The *WaSSI Ecosystems Services Model* from North Carolina State University, the U.S. Department of Agriculture, and the U.S. Forest Service calculates the WaSSI at the 8-digit Hydrologic Unit Code (HUC), as defined by the U.S. Geological Survey (USGS)[15]. While water supply estimates are based on hydrologic models for each HUC (e.g. evapotranspiration, soil storage, snow accumulation and melt, etc.), the water demand component is estimated from 2005 county-level USGS data, rescaled to HUC-8.

The HUC-8 divides the continental U.S. into 2,264 watersheds. Since non-water related data sets (e.g., U.S. Economic Census, Bureau of Labor Statistics, Energy Information Administration energy consumption surveys) report on geographic/administrative/political

subdivisions (e.g., state, county), any effort to correlate a watershed's WaSSI to other regional information (e.g., demographics, economic data, water intake) must map the watersheds to these subdivisions. The number of watersheds under the HUC-8 division aligns most closely to the number of counties in the U.S. (3,142 as of 2013) than any other HUC disaggregation, and therefore appropriate for the present analysis. The 6-digit HUC subdivides the U.S. into 379 units, while the 10-digit HUC subdivides it into 22,000.

Using the *WaSSI Ecosystems Services Model*, a long-term WaSSI over the period from 1985 to 2010 for each HUC-8 can be estimated. The WaSSI for the HUC-8 encompassing a county was assigned to that county. In instances where a county contained multiple HUCs, the simple arithmetic average of all WaSSIs within the county was used. It was not possible to perform a weighted average of all WaSSIs within a given county because water supply and demand data is not spatially resolved to a level finer than the HUC-8 or county-level. Using this approach, 85 of the 3,142 counties in the U.S. have a long-term WaSSI > 1. A WaSSI of 1 serves as the demarcation for a region withdrawing more water than is naturally replenished. For a list of these 85 counties, the reader is referred to the Supplemental Information.

3. **Water intake for U.S. manufacturing**

3.1 Water balance around a manufacturing facility

In order to develop a qualitative understanding of manufacturing water intake, a water balance around the control volume of the facility will be described here. This water balance is depicted in Figure 1. A manufacturing facility may draw its water from a variety of sources. Some common sources are shown in Figure 1: municipal water supply (either potable or recycled), self-supplied saline or fresh surface water, self-supplied saline or fresh ground water,

and as part of the raw materials. Self-supplied water is drawn from on-site sources. Raw materials for the manufacturing process may contain water (e.g., wood, food). There may be other potential sources of water supply not shown in Figure 1, such as storm water. Water recycled within a facility does not cross its boundaries and is not a distinct category of water intake. The facility may dispose of its water via a variety of options including to a municipal wastewater treatment site, onsite treatment before disposal to surface or ground water, evaporation, or with the final product.

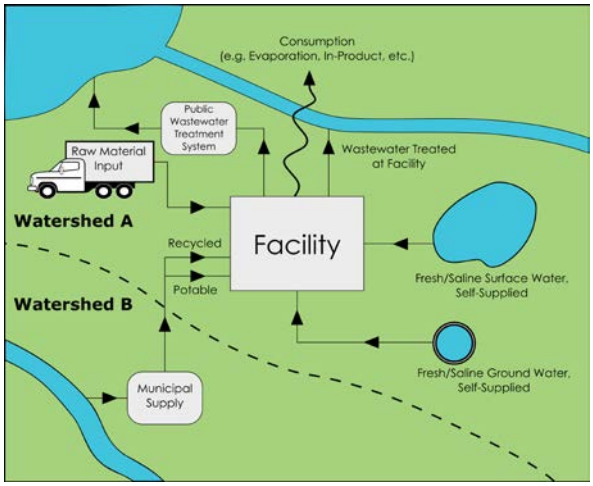


Figure 1: Qualitative water balance of a manufacturing facility. Adapted from Rao, P.; Sholes, D.; Morrow, W. R.; Cresko, J. Estimating U.S. Manufacturing Water Use. In 2017 ACEEE Summer Study on Energy Efficiency in Industry; American Council for an Energy Efficient Economy: Denver, CO, 2017; pp 104–115. Copyright 2017 ACEEE Summer Study on Energy Efficiency in Industry.[16]

Water ‘use’ is the water that enters a facility’s boundaries, whereas water ‘intake’ (defined in this paper) is the water withdrawn from a water source. Though there is a distinction between the two with the difference being water loss, this paper will use a one-to-one correspondence due to a lack of sufficient data on water losses in the manufacturing sector.

Municipal water systems in the U.S. experience on average 14% water loss between the source and facility, ranging from 4% - 53% [17,18]. However, water loss information is not available for every municipal system and therefore cannot be applied at the desired geographic resolution. Further, as will be presented in this paper, U.S. manufacturers rely on self-supplied water to a great extent and water loss information is not available for these sources. By assuming no losses between intake and water use, a conservative estimate of manufacturing water intake can be developed.

3.2 Available data on U.S. manufacturing water intake

The most robust quantification of U.S. manufacturing water intake is provided by the USGS. Every five years, the USGS estimates industrial water intake. USGS uses the term 'withdrawals' which is identical to 'intake' used in this paper. USGS labels "industrial" as industries with NAICS codes 31 – 33 and Construction. This paper will assume Construction water intake is negligible and consider the USGS industrial category to be equivalent to the definition of manufacturing used in this paper. This assumption is evaluated in the Discussion section.

In its most recent surveys, only estimates for manufacturing self-supplied water are provided. USGS breaks down the self-supplied water withdrawals by state and county, but not by manufacturing subsector. Quantities of water purchased by the manufacturing sector from public supplies (e.g., from the municipal water authority) are no longer reported by the USGS as of 1995.

Using recent (2010) and past (1995) estimates from the USGS, Rao et al. (2015) estimated that 75% of manufacturing water intake is from self-supplied sources. Overall,

manufacturers took in 20,940 million gallons of water per day (MGD) from self-supplied and municipal sources in 2010. This accounted for 6% of water intake in the U.S, and is the 4th largest sector behind thermoelectric (45%), agriculture (36%), and domestic (8%) [19–21]. While this may seem small, single-pass thermoelectric cooling of power plants is being phased out in some places through legislation or turnover of coal plants (steam cycle) to natural gas plants (combustion cycle) [22,23]. As the share of water for thermoelectric uses declines, the share for manufacturing will accordingly increase. While these national estimates provide a high-level understanding of how the U.S. uses its water, it does not provide any insight into the impact that a sector has on local water stress conditions. Water stress and the share of water intake by each sector is location specific, and regional evaluations are required to understand a sector's impact on water stress.

3.3 Available data on Canadian manufacturing water intake

Since 2005, the Canadian government's Statistics Canada has collected information on manufacturing water intake (self-supplied and municipal) at the 3-digit NAICS level through its biennial Industrial Water Survey (IWS). Canada is one of the few countries to conduct such a survey, making it a potential reference for estimating U.S. manufacturing water intake. Since both the U.S. and Canada classify their manufacturing subsectors sectors using NAICS, there is no need for any adjustments and accompanying assumptions to the categorization of the reported data. Other characteristics facilitating comparisons between the two countries include: both countries have highly industrialized economies; they are each other's largest trading partner; the value of manufacturing to each country's economy is similar as judged by comparing the value added from manufacturing to the gross domestic product (12% in the U.S. to 11% in Canada);

and both have experienced similar drops in manufacturing employment between 2008 and 2015 (-8.1% for the U.S. and -9.1% for Canada) [24].

4. Method for Estimating U.S. Manufacturing Water Intake

The following section describes the method used to estimate U.S. manufacturing water intake. It has been applied in previous work and described in greater detail here.[16] The method correlates Canadian manufacturing water and employment data to county-level U.S. manufacturing employment and water data to estimate U.S. manufacturing water intake at the desired spatial and sectoral resolution.

Three broad water intake characteristics were sought: purpose, geography, and source of the water intake. Each characteristic can be evaluated at varying levels of granularity. Increasing granularity will increase the ability to assess watershed, energy, risk, and economic impact from the water intake. For example, at the most general level of granularity, purpose can be defined as all sectors in the U.S. economy (e.g., agricultural, manufacturing, retail trade, etc.). At this level of granularity, little can be understood about water intake for manufacturing. From a policymaker's perspective, it would be more desirable to estimate water intake by a specific sector (e.g., manufacturing). Understanding that manufacturing encompasses a wide variety of disparate processes and accompanying water requirements, it is better still to understand manufacturing water intake by manufacturing NAICS subsector (e.g., 322 - Paper, 314 –Textile Product, 311- Food). Similarly, increasing levels of granularity for geography (nationwide to HUC-12 or smaller) and water source (distinguishing between all sources and fresh or saline, ground or surface, public or self-supply) are desired. The levels of granularity for each of the three broad characteristics are summarized in Figure 2. The solid red bow markers in Figure 2 indicate the existing level of granularity for each category after simple analysis using 1995 and

2010 USGS data (as described in the previous section). The hashed blue bows indicate the level of granularity used in the present paper in order to determine sectors at risk of physical water shortages. Currently, estimates of water intake for all U.S. manufacturing across all water sources can be estimated at the county-level. The method described below leads to estimates of water intake distinguished by water source across each manufacturing subsector at the county/HUC-8 level.

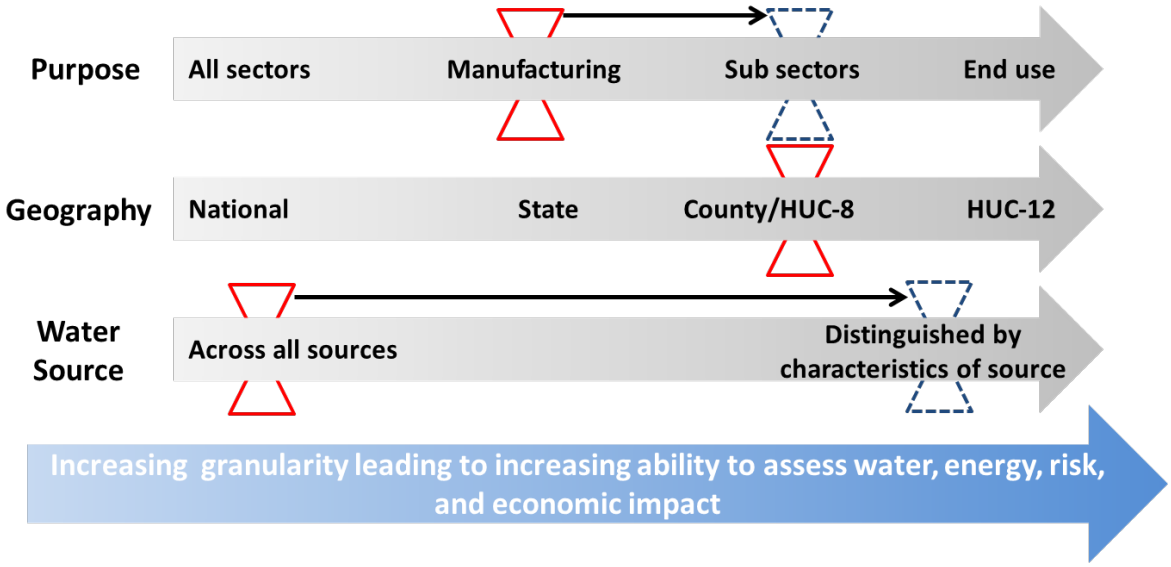


Figure 2: Levels of granularity for the three water intake characteristics estimated in the present paper. Red bows indicate the existing level of information from USGS. Hashed blue bows indicate the level of granularity developed in this paper.

Another important characteristic is time-of-use, which affects water availability and the impact of water intake on the watershed [25]. However, due data constraints, time-of-use is not considered in this paper.

To correlate the Canadian industrial water data to U.S. manufacturing, number of employees was used as a normalizing factor. Number of employees was selected because: 1) it is readily available for each country through the Canadian Annual Survey of Manufacturers and

U.S. County Business Patterns (CBP) and 2) CBP provides it at the state, county, and 3-digit NAICS level, thereby providing the level of granularity desired. CBP is released annually by the U.S. Census Bureau and provides economic data by industry and county in the U.S. Other normalizing factors were considered as well: total energy consumption, total electricity consumption, value add (a measure of production output), and number of establishments. Of these, only number of establishments is available at the U.S. county-level. Number of employees is preferred over number of establishments due to its ability to capture the size of the establishment. A small and large establishment may have significant difference in resource utilization, but both would be considered equivalent in terms of water intake if establishment was used as the normalizing factor. Further, employment data is used by the USGS (along with other factors) when developing their estimates, lending credibility to its use in the present method. [19]

Economic productivity (e.g., value add, units shipped, revenue) is often used as a normalizing factor in analyses such as the one conducted in this paper. However, economic productivity is a poor proxy for resource use since the influence of demand for the product can outweigh the influence of cost of materials/resources.

Using the Canadian data, the water intake intensity (WII) for each subsector in units of MGD/employee as defined in Equation 2 was developed.

$$WII_i = \frac{annual\ water\ intake\ in\ subsector\ i}{number\ of\ employees\ in\ subsector\ i}$$

Equation 2: Water Intake Intensity (WII)

The WII for each Canadian manufacturing subsector was calculated between 2005 and 2013 using IWS data. Due to insufficient data reported in the IWS, the 315 - Apparel, 316 - Leather and Allied Product, 323 - Printing and Related Support, 337 - Furniture and Related Product, and 339 - Miscellaneous subsectors were grouped into an "Other" category.

Since the USGS water data used for the analysis is from 2010, the arithmetic mean was taken of the five annual WIIs calculated for each manufacturing subsector. For the majority of subsectors, the WIIs did not show any trend over time and no conclusions regarding efficiency improvements or other trends over time could be defensibly discerned. Five biennial data points spread over a time period of less than a decade are insufficient to accurately characterize trends through linear regression or similar statistical techniques. Since 2010 falls in the middle of the time period of IWS collection (2005 – 2013), any linear trend in the data would be captured by the arithmetic mean.

The Number of Employees in the U.S. by county and 3-digit NAICS was taken directly from CBP. For each subsector, the average WII from Canada was then multiplied by the Number of Employees for each subsector and U.S. county to estimate the water intake by county and manufacturing subsector in the U.S.

The resulting water intake needed adjustment to align with the USGS estimates of water intake for all manufacturing in each county. This was done using the water intake values to calculate the water intake fraction (WIF) that each manufacturing subsector uses within each county. See Equation 3 for an example calculation of the WIF for the food sector in Alameda County, California:

$$\mathrm{WIF}_{311,\text{Alameda County}} = \frac{WII_{311,Canada}\ x\ (Number\ of\ Employees)_{311,Alameda\ County}}{\sum_{i=311}^{i=339}\ [WII_{i,Canada}\ x\ (Number\ of\ Employees)_{i,Alameda\ County}]}$$

Where $\mathrm{WIF}_{i,j}$ = water intake fraction for subsector i and county j

$\mathrm{WII}_{i,\mathrm{Canada}}$ = water intake intensity for Canadian subsector i

Number of $\mathrm{Employees}_{i,j}$ = number of employees in subsector i and county j

Equation 3: Example calculation of Water Intake Fraction (WIF) for the Food subsector in Alameda County, California

Each WIF was then multiplied by the total manufacturing water intake (self-supplied and municipal) for each county based on a combination of 1995 municipal and 2010 self-supplied USGS estimates. With this, the water intake by U.S. county and manufacturing subsector was determined. County-level estimates were summed to the state and national levels.

A listing of the data sources used in the analysis for this paper can be found in the Supplemental Information.

5. Results: Estimates of U.S. Manufacturing Water Intake

The following results were obtained when the method described above was applied:

1. Total water intake in MGD by water source for U.S. manufacturing by state and county
2. Total water intake in MGD by manufacturing subsector broken down by state and county
3. Percent of water intake in U.S. in physically water stressed counties for each manufacturing subsector

5.1 Total water intake by source for U.S. manufacturing by state and county

Figure 3 uses USGS data from 1995 and 2010 to estimate total manufacturing water intake (self-supplied plus municipal) by state and county in MGD. The states with the largest total water intake for manufacturing are, in order: Indiana, Louisiana, Texas, Pennsylvania, and Tennessee. The counties with the highest total water intake for manufacturing are, in order: Lake and Warrick Counties in Indiana, Brazoria County in Texas, Sullivan County in Tennessee, and Saint Charles and Iberville Parish in Louisiana.

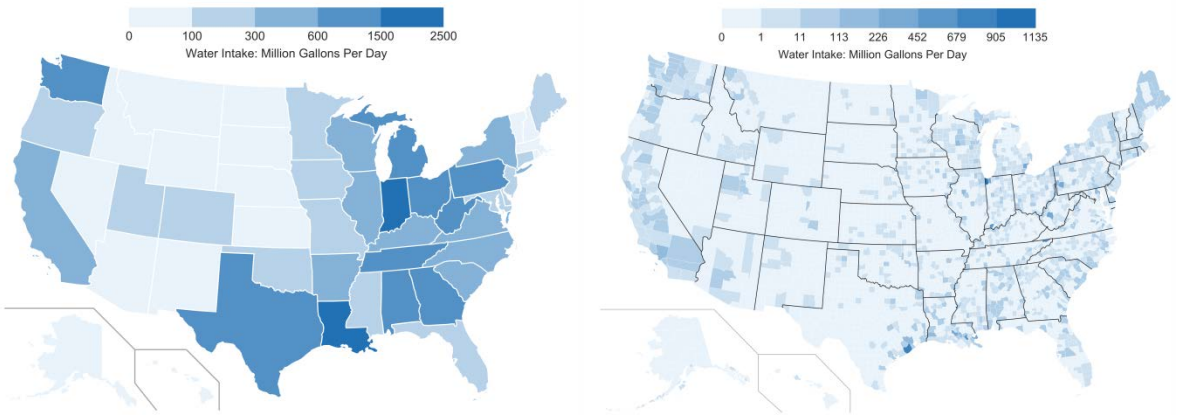


Figure 3: Estimates of manufacturing total water intake (self-supplied plus municipal) by state (left) and county (right) using USGS data in MGD. Reprinted from Rao, P.; Sholes, D.; Morrow, W. R.; Cresko, J. Estimating U.S. Manufacturing Water Use. In 2017 ACEEE Summer Study on Energy Efficiency in Industry; American Council for an Energy Efficient Economy: Denver, CO, 2017; pp 104–115. Copyright 2017 ACEEE Summer Study on Energy Efficiency in Industry.[16]

For 60 counties, it is estimated that manufacturing water intake accounts for more than 75% of the total water intake, which is far higher than the national share of total water intake from manufacturing (~6%). This indicates that the impact of manufacturing on a county's water supply and watershed varies greatly across the U.S., and impacts at the national-level may not accurately convey regional impacts. Also, of the 100 counties with the largest estimated manufacturing water intake, 8 have a long-term WaSSI > 1. These are (in order of manufacturing water intake): Lake and Porter Counties, Indiana, Wayne County, Michigan, Brown County, Wisconsin, Cook County, Illinois, Pueblo County, Colorado, San Bernardino County, California and Lucas County, Ohio.

Figure 4 shows the estimated breakdown of water intake in MGD by source. Though not evaluated here, water restrictions or regulations may be imposed on a source, such as

groundwater in states where subsidence is a concern. States whose manufacturing sector is heavily reliant on a single water source, such as Tennessee on surface water or California on groundwater, may seek to diversify their water portfolio to strengthen the resilience of their manufacturing sector.

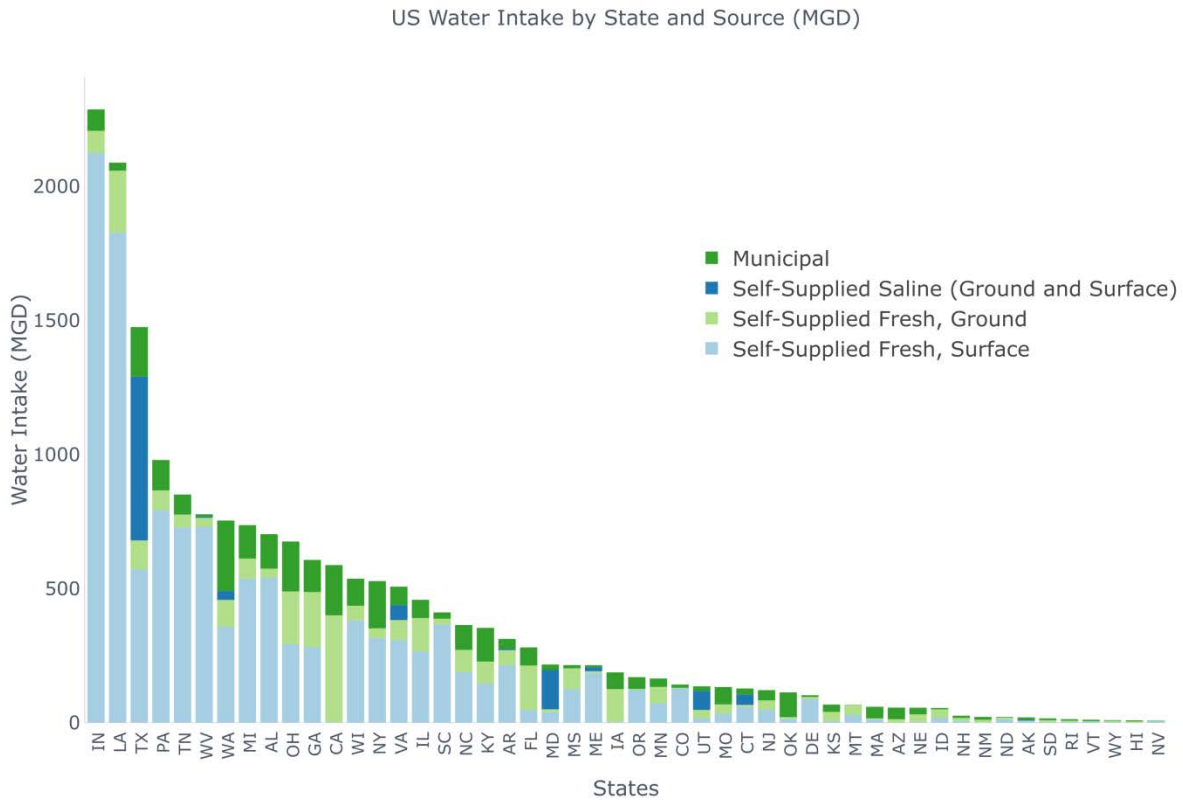


Figure 4: Breakdown of total manufacturing water intake in MGD by source (self-supplied ground and surface, self-supplied saline, and municipal) for each state. Adapted from Rao, P.; Sholes, D.; Morrow, W. R.; Cresko, J. Estimating U.S. Manufacturing Water Use. In 2017 ACEEE Summer Study on Energy Efficiency in Industry; American Council for an Energy Efficient Economy: Denver, CO, 2017; pp 104–115. Copyright 2017 ACEEE Summer Study on Energy Efficiency in Industry.[16]

5.2 Total water intake by subsector and state

Figure 5 provides a breakdown of U.S. manufacturing total water intake by subsector. The subsectors with the largest intake are, in order: 322 - Paper, 331 - Primary Metals, 325 - Chemical, 324 - Petroleum and Coal, and 311 - Food.

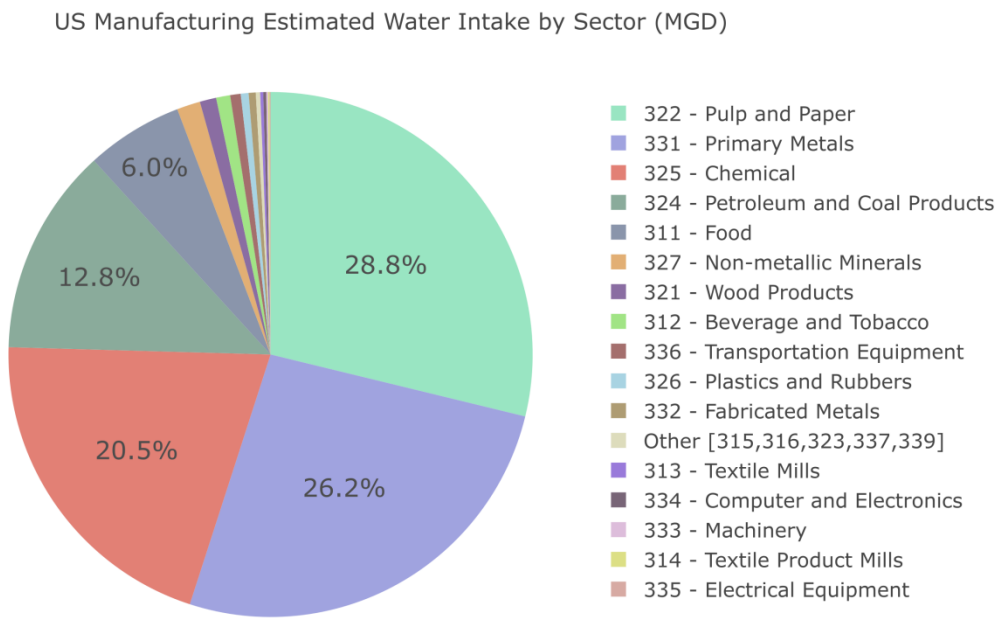


Figure 5: Estimates of U.S. manufacturing total water intake by subsector. Adapted from Rao, P.; Sholes, D.; Morrow, W. R.; Cresko, J. Estimating U.S. Manufacturing Water Use. In 2017 ACEEE Summer Study on Energy Efficiency in Industry; American Council for an Energy Efficient Economy: Denver, CO, 2017; pp 104–115. Copyright 2017 ACEEE Summer Study on Energy Efficiency in Industry.[16]

Figure 6 shows estimates of state-level manufacturing water intake in MGD broken down by subsector. These estimates allow for a better understanding of how each state's manufacturing sector uses water. Such an understanding can facilitate the development of drought/water-stress

mitigation strategies. Texas and California, two drought-prone states, have a diverse manufacturing base dominated by water-intensive industries (325 - Chemical, 322 - Paper, 324 - Petroleum and Coal Production). In these states, subsector-specific water conservation strategies, not general strategies, will likely be required.

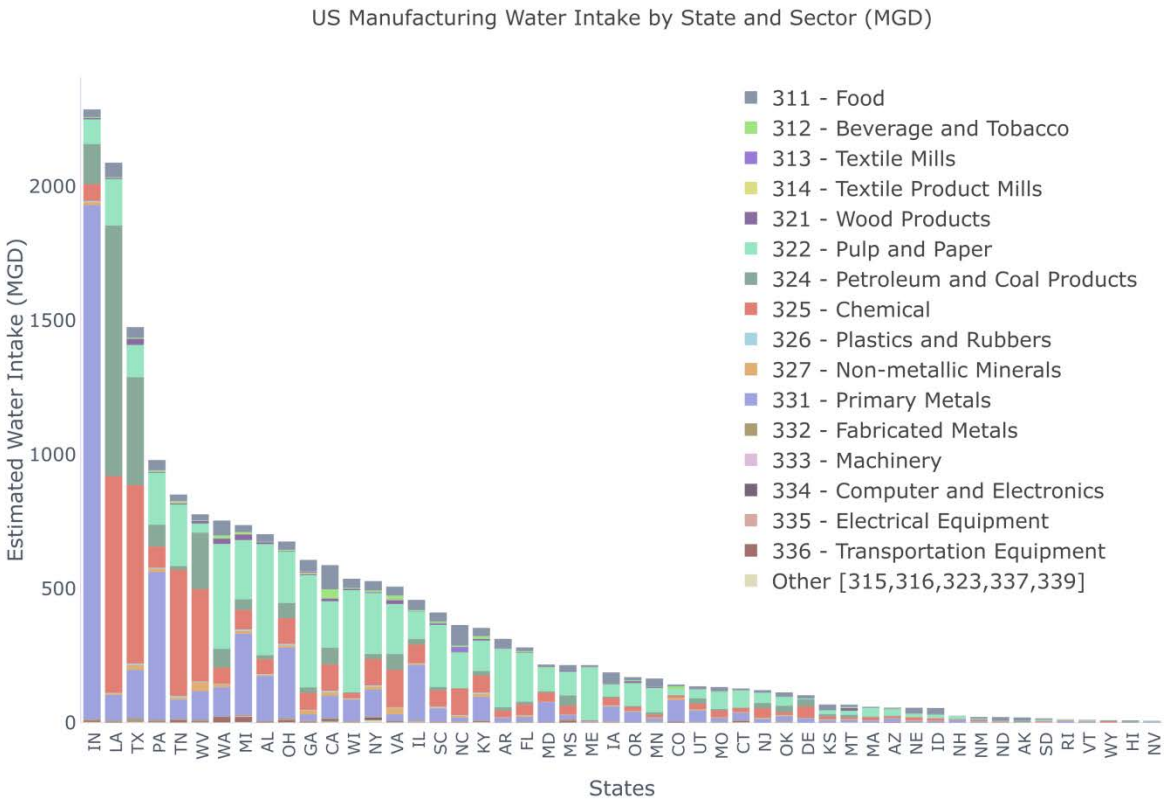


Figure 6: Estimates of manufacturing total water intake by subsector and state using USGS and Canadian data in MGD. Adapted from Rao, P.; Sholes, D.; Morrow, W. R.; Cresko, J. Estimating U.S. Manufacturing Water Use. In 2017 ACEEE Summer Study on Energy Efficiency in Industry; American Council for an Energy Efficient Economy: Denver, CO, 2017; pp 104–115. Copyright 2017 ACEEE Summer Study on Energy Efficiency in Industry.[16]

County-level estimates can reveal concentrations of manufacturing water intake, particularly by subsector. Figure 7 maps manufacturing water intake for the 325 - Chemical subsector. West Virginia (inset) is estimated to have the 4th highest intake for the 325 - Chemical subsector of any state. However, the water intake is concentrated in Kanawha County where major chemical companies, including Dow, DuPont, and FMC Corporation, have operations. The intent of Figure 7 is not to show the county(ies) with the highest concentration of water use for a particular sector, but to highlight that data visualizations similar to Figure 7 can help stakeholders quickly identify areas of high intake for specific industries. For county-level maps of water intake for other subsectors, see the Supplemental Information.

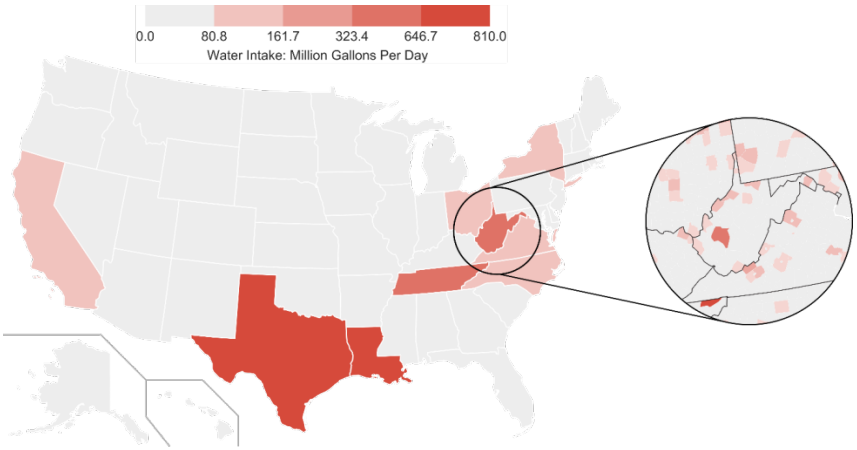


Figure 7: Total water intake in MGD for the 325 - Chemical subsector at the state-level using USGS and Canadian data. The inset shows the breakdown of water intake for the Chemical subsector in West Virginia to illustrate that intake may be concentrated. For example, Kanawha County in West Virginia has a high concentration of the state's Chemical subsector intake. Reprinted from Rao, P.; Sholes, D.; Morrow, W. R.; Cresko, J. Estimating U.S. Manufacturing Water Use. In 2017 ACEEE Summer Study on Energy Efficiency in Industry; American Council for an Energy Efficient Economy: Denver, CO,

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5.3 Evaluating Manufacturing Subsectors at Risk of Physical Water Shortage

With the WaSSI and the manufacturing water intake by subsector for each county estimated, the subsectors most vulnerable to physical water shortages can be identified. This was done by calculating the percent of overall water intake for each subsector that occurs in a water-stressed county. The results are shown in Table 1.

Table 1: Share of water intake occurring in counties with a WaSSI ≥ 1 for the period between 1985 and 2010 (calculated as previously described) for each manufacturing subsector.

Sub-sector	Percent of water intake in counties with WaSSI ≥ 1
331 - Primary Metal	35
332 - Fabricated Metal Product	10
336 - Transportation Equipment	10
324 - Petroleum and Coal Product	9
326 - Plastics and Rubber Products	9
327 - Non-metallic Mineral Product	8
333 - Machinery	8
311 - Food	7
334 - Computer and Electronic Product	7
312 - Beverage and Tobacco Product	6
322 - Paper	6
335 - Electrical Equipment	5
314 - Textile Product Mills	3
325 - Chemical	3
313 - Textile Mills	2
321 - Wood Product	2
Other [315,316,323,337,339]	8

The following sectors are estimated to have the highest percent of their intake (in order) occurring in areas of physical risk of water shortages: 331 - Primary Metals, 332 - Fabricated

Metal, 336 - Transportation Equipment, 324 - Petroleum and Coal, 326 - Plastics and Rubber, 327 - Non-metallic Mineral, and 333 - Machinery. Comparing this to the subsectors with the greatest volume of intake reveals differences; 332 - Fabricated Metal, 336 - Transportation Equipment, 326 - Plastics and Rubber, and 333 - Machinery are not among the top seven subsectors by intake, but are among the ones with the greatest percent of intake in regions at risk of physical water shortages. As a consequence, water conservation efforts that focus solely on subsectors with the greatest water intake may not target subsectors with the greatest vulnerability to water shortages.

6. Discussion

6.1 Limitations of the WaSSI

The WaSSI was used in this paper because: 1) it captures the societal water demand in the context of water availability at local scales 2) it has been used by others to evaluate sectoral contributions to water stress[26] and 3) its calculation is publicly available through the WaSSI Ecosystem Services Model. However, the WaSSI, as described by Sun et al. (2008) and Averyt et al. (2013): 1) does not take into account storage (i.e., reservoirs) or regional water planning that can help allocate available supply, 2) considers all the supply and demand to be contained in the same watershed neglecting that some (especially those in urban areas) will import water from another (e.g., California State Water Project, Colorado River Compact), 3) does not consider limitations on groundwater pumping and consequences of overdraft, 4) does not consider seasonal variation in supply and demand which could lead to variations in water stress throughout the year, especially for watersheds that have dry and wet seasons, 5) does not consider that some of the water supply will be naturally used for environmental purposes such as

maintaining ecosystems and therefore not available for anthropogenic use, and 6) does not consider any impact on water quality from anthropogenic use. [14,26]

6.2 Refining water intake estimates

The estimates used in this paper to identify subsectors at risk of physical water shortages have some uncertainty. Sources of uncertainty include the use of employees as a normalizing factor, and compiling disparate data sets collected by different agencies during different years. Additionally, any imprecision with the source data will carry through to the estimates developed here. For example, the USGS water intake data is compiled from reports provided by each state. States use different methods to estimate water intake thereby introducing uncertainty when summed to the national-level.[8]

The estimates presented in this paper could be refined by comparing to other existing data sets. Some existing data sets include subsector information for a particular state, such as food processing in California [27], results from surveys conducted by the Texas Water Development Board on industrial water intake in the state, or effluent discharge permits (e.g., EPA's Discharge Monitoring Report). Compiling these "bottom-up" data sets and reconciling with the "top-down" estimates developed here may lead to adjusting the estimates and/or developing error ranges.

The assumption that Construction water intake is negligible leads to additional error/uncertainty in the estimates. A comparison to the Texas data shows Construction is less than 1% of the state's industrial water intake. This suggests that the assumption is valid.

Even if the above refinements could be incorporated, the estimates may still carry significant uncertainty and would not represent a sufficient replacement for primary data collection of water intake in the U.S. at better granularity than what is currently collected. In the U.S., energy data for the residential, commercial, and manufacturing sectors are collected using a

statistically representative sample of U.S. facilities every four years by the U.S. Department of Energy. Similar surveys are needed for water.

6.3 Incorporating other risk considerations

In addition to refining estimates to account for uncertainty, the evaluation of subsectors at risk could be expanded to consider more than just physical risk. There are multiple definitions of risk. The United Nations CEO Mandate uses two categories of risk aside from physical shortages: regulatory and reputational[28]. Regulatory risks are due to poor water supply oversight and/or management. Reputational risks are those associated with public perception of water mismanagement. The authors of this paper propose that risk factors specific to manufacturing also exist. Two such categories are the inability to substitute water in the facility/process (i.e., in the beverage industry) and vulnerability to climate change effects. Further examination of these will require quantifying reputational, regulatory, and climate change risks as well as subsectors and processes that are inherently water-dependent (i.e., beverage, paper).

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Supporting Information Available: Includes: 3-digits NAICS codes for each manufacturing subsector studied, list of counties with a mean WaSSI>1 during the period from 1985 to 2010, list of data sources used, numeric estimates of state-level manufacturing water intake by 3-digit NAICS, numeric estimates of manufacturing water intake by state and source, numeric estimates

of manufacturing water intake by 3-digit NAICS, mapping of water intake distribution by county for several manufacturing subsectors. This information is available free of charge via the Internet at http://pubs.acs.org.

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