

Estimating U.S. Manufacturing Water Use

*Prakash Rao, Darren Sholes, William R. Morrow III Lawrence Berkeley National Laboratory
Joe Cresko, U.S. Department of Energy*

ABSTRACT

In order to understand the implications of the energy-water nexus on the competitiveness of the U.S. manufacturing sector, there is a need to better quantify the nexus within a facility's boundaries. As a first step, estimates of U.S. manufacturing water use are required. A lack of data on manufacturing water use characteristics hampers efforts to make these quantifications.

In lieu of primary data, this paper will present a method for better understanding U.S. manufacturing water use characteristics. This methodology consists of three elements. The first element develops the data requirements for developing a manufacturing facility's water footprint within the context of the watershed. The second element develops top down estimates of the water data identified in the first element at the national, state, and county-levels by subsector. These estimates are developed through leveraging Canadian water use data and correlations to the U.S. based on subsector operational characteristics. The third element uses the data from the second to identify subsectors that are most vulnerable to water access issues. This element recognizes that evaluations based solely on total water use may diminish the importance of water in some sectors. This paper will present preliminary results from applying the first and second elements of this estimation method. This paper seeks to begin the process and present a potential pathway for better quantifying the energy-water nexus for the manufacturing sector. Such quantifications can help policymakers make informed decisions regarding research, development, and deployment efforts for water conservation within the manufacturing sector.

Introduction

The water-energy nexus describes the interdependence of the two resources. Water is used to convert energy, as well as a medium to store (i.e., thermal and potential energy storage) and turn energy into useful work (i.e., hydraulic or steam uses). Similarly, energy is required at every point within the water network: extraction, treatment, transport, end-use, and discharge. State/regional water-energy programs, joint energy and water utility programs, and corporate sustainability efforts can be aided by better understanding the connection between water and energy. In particular, quantitative analysis describing the water-energy nexus can inform areas to prioritize and focus efforts.

Within the manufacturing sector, the water-energy nexus is not well understood (Rao et al. 2015). The scant information available raises questions for further investigation. For example, an estimated 11% of manufacturing water use is for steam (Walker et al 2013). However, little is understood about the remaining 89% of manufacturing water use. In particular, little is known about the energy requirements for water use in the manufacturing sector. As stated by the Pacific Institute: "...lack of information (or failure to disseminate that information) hinders effective action...[and] details on end uses of water are limited" (Gleick et al 2003). Understanding how water is used within the manufacturing sector is a first step towards understanding the water-energy nexus within it. Without more information on manufacturing water use, states, utilities,

and manufacturers cannot take effective action on reducing the energy requirements for water and vice versa in the manufacturing sector.

In lieu of primary data collection at the national level, this paper will provide the most detailed estimates of current U.S. manufacturing water withdrawals. It extrapolates available information to estimate U.S. manufacturing water withdrawals by subsector, state, and county. Further, estimates are provided on overall and consumptive water use to aid in understanding watershed impacts from manufacturing water-use. Finally, this paper will compare water and energy use by subsector to better understand the water-energy nexus within the manufacturing sector. It will conclude with recommendations for improving the estimates developed here. The estimates made in this paper represent an initial attempt to understand manufacturing water use characteristics. Refinement through validation and data collection (heretofore unavailable) will be required. However, by providing initial estimates of manufacturing water use at various levels of spatial resolution, this paper seeks to promote further investigations, the development of tools and resources, and utility/state efforts related to the water-energy nexus within manufacturing.

Background

The best quantification in the U.S. of manufacturing water use is provided by the United States Geological Survey (USGS). Every five years, the USGS estimates manufacturing water withdrawals¹. However, in its most recent surveys, only estimates for manufacturing self-supplied water are provided. Self-supplied water is sourced from on-site surface or ground resources. Manufacturers may also purchase water from their local municipal water authority. The last reported share of municipal water delivered to the manufacturing sector was for 1995. Using recent and past information from the USGS, it is estimated that 75% of manufacturing water withdrawals are from self-supplied sources (Maupin 2014, Sulley 1998). The USGS breaks down the self-supplied water withdrawals by state, but not by manufacturing subsector.

Using USGS data, manufacturers withdrew 20,940 million gallons of water per day in 2010. This accounted for 6% of water withdrawals in the U.S, and is the 4th largest sector behind thermoelectric (45%), agriculture (36%), and domestic (8%). 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). Further, agricultural water withdrawals may be protected from water curtailments, as was the case with the 2015 state mandate to reduce water use in California by 25%. Removing the thermoelectric and agricultural sectors, manufacturing water withdrawals accounted for 31% of the remaining sectors in 2010.

While the U.S. lacks data on manufacturing water use, the Canadian national government has conducted a biennial Industrial Water Survey (IWS) since 2005 through Statistics Canada. The IWS provides information about the intake, recirculation, costs, sources, treatment and discharge of water used for the Canadian manufacturing sector at the 3-digit North American Industrial Classification System (NAICS) level. Intake includes both self-supplied and municipal sources. Additionally, breakdowns by end use (e.g., process, cooling, condensing, steam, sanitary service, and domestic) for each subsector are provided. The results from the survey are made public.

¹ USGS labels manufacturing as industries within the North American Industrial Classification System codes 31 – 33 and construction as “industrial”. This paper will assume construction water use is negligible and consider “manufacturing” to encompass NAICS codes 31-33.

The U.S. and Canadian manufacturing sectors have some similarities. Both countries are part of the Group of 7, an intergovernmental forum of the world’s highly industrialized economies in countries that consider themselves democracies. Both are the largest trading partner of the other. Value added for manufacturing represents a similar share of gross domestic product for both countries – 12% for the U.S. and 11% for Canada. Further, both have seen similar declines in manufacturing employment between 2008 and 2015: -8.1% for the U.S. and -9.1% for Canada (Levinson 2017). Comparisons between the U.S. and Canadian manufacturing sectors are facilitated through the joint use of NAICS. Through use of the system, each country categorizes its manufacturing subsectors the same way.

Differences do exist between the two economies. In particular, the U.S. has had a more productive manufacturing sector than Canada, as measured in output per labor hour. This gap has been growing with the U.S. experiencing a 47% increase between 2002 and 2015 compared to Canada’s 20% increase over the same time period (Levinson 2017). The productivity gap may be due to the U.S. manufacturing sector producing more high-valued goods, such as electronics.

Method

The following method uses Canadian water and employment data for its manufacturing sector to establish water intensity metrics. These are then used with U.S. employment and available water data for its manufacturing sector to provide more detailed estimates of U.S. manufacturing water use than previously available. The method seeks to quantify manufacturing water use by manufacturing subsector at the state and county-levels.

The first element of the methodology is to create a qualitative water balance of a manufacturing facility. This balance will be used to identify the manufacturing water use characteristics to extrapolate from the Canadian data set. The water balance uses a “control volume” engineering approach where all the potential avenues for water entering and exiting a facility are identified. Such a water balance is shown in Figure 1. Water can enter the facility through public supply or ground/surface, fresh/saline self-supplied water sources. Water can exit the facility through discharge to the municipal wastewater system, direct discharge to surface/ground (usually after being treated), product, evaporation, or sludge for offsite treatment. Water uses that result in water leaving the facility through product, evaporation, or sludge is referred to as “consumption”. Consumptive water uses are not available for others within the watershed to use, and therefore has a greater impact on the local watershed than water that is returned to it. Water recycled within a facility will circulate within the facility boundary and does not have an impact on the qualitative water balance, but will reduce the quantity of intake water.

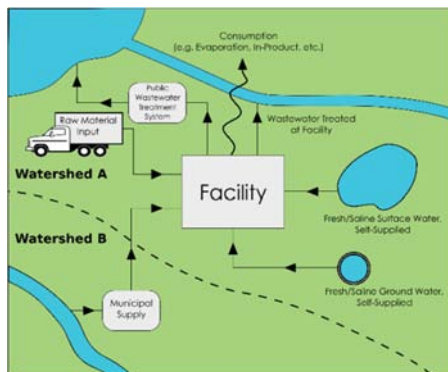


Figure 1: Qualitative water balance of a manufacturing facility

Using the water balance in Figure 1, estimates of water intake, broken down between self-supplied and from a municipality, as well as consumptive water use were the initial focus. These will provide insight into where manufacturers source their water and the amount of water used that depletes local water sources.

In order to use the Canadian data to arrive at the desired estimates for the U.S., a normalizing metric was needed that was both linked to water use and provided the necessary level of spatial granularity to produce estimates for each state, county, and 3-digit NAICS Sector. The county-level was sought because the impacts of water use are felt strongest at the local-level. Number of employees was selected because of its availability and granularity in the Canadian Annual Survey of Manufacturers and U.S. County Business Patterns (CBP) data sets. Other variables, such as total energy consumption, total electricity consumption, value add, and number of establishments were explored as well. However, none of these, aside from number of establishments, were available at the county level in the U.S. Number of employees was selected over number of establishments due to its ability to better account for establishment size. An establishment may have orders of magnitude difference in the number of employees, and a large and small establishment would be considered equivalent in terms of water use.

Water intake intensity in Canada was calculated for each sector, from 2005 to 2013, every two years. The water intake intensity was then averaged for each Sector. Due to data availability, Sectors 315 (apparel), 316 (leather and allied product), 323 (printing and related support), 337 (furniture and related product), and 339 (miscellaneous) were combined into an "Other" category when developing the water intake intensity.

The CBP annually reports number of employees by county and 3-digit NAICS code in the U.S. The average water intake intensity metric for each subsector from Canada was multiplied by the number of employees for each subsector within each county in CBP, including the "Other" combined sector. The resulting value was used to calculate the percentage of water for manufacturing that each subsector uses within each county. Each percentage was applied to the estimated manufacturing water withdrawals (self-supplied and municipal) for each county based on USGS estimates. Water withdrawals are used as a proxy for water intake. The 1995 USGS values for share of public water supply used for manufacturing were used. The result was the absolute water withdrawals by subsector and county.

County-level estimates were rolled up to the state and national levels. To calculate consumption, the absolute water withdrawals for each subsector were multiplied by consumptive use fractions specific to each subsector, derived from the Canadian data. A summary of the data sources used in this analysis can be found in Appendix A. For reference, a summary of the NAICS codes within the manufacturing subsector (31-33) is provided in Appendix B.

Results

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

- Total water withdrawals by source for U.S. manufacturing by state and county
- Total water withdrawals and consumption by manufacturing subsector broken down by state and county

Total water withdrawals for U.S. manufacturing by state and county

Figure 2 uses USGS data to estimate total manufacturing water withdrawals (self-supplied plus municipal) by state and county. Indiana, Louisiana, Texas, Pennsylvania, and

Tennessee are the states with the largest total water withdrawals. Lake and Warrick Counties in Indiana, Brazoria County in Texas, Sullivan County in Tennessee, and Saint Charles and Iberville Parish in Louisiana are among the counties with the highest total water withdrawals.

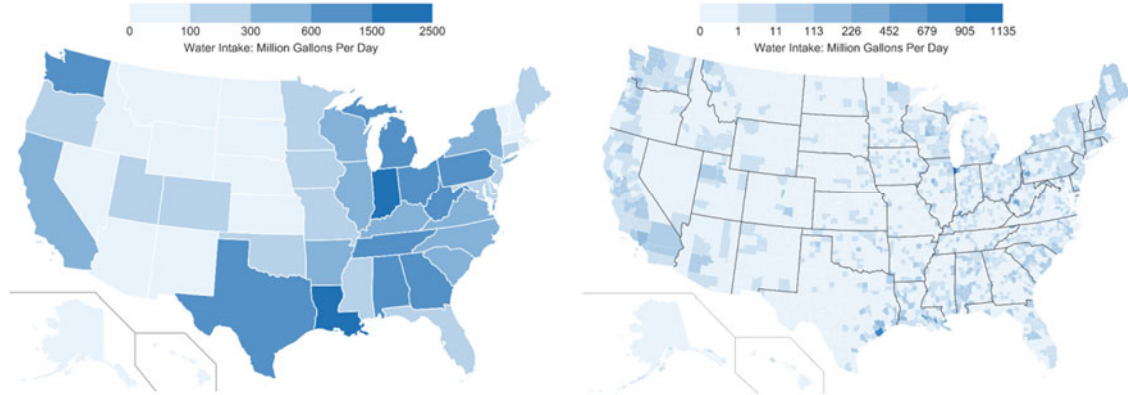


Figure 2: Estimates of manufacturing total water withdrawals (self-supplied plus municipal) by state (top) and county (bottom) using USGS data

The county-level estimates also reveal an important finding regarding the local-variations in total manufacturing water withdrawals. While nationally industrial water withdrawals are only a small portion (~6%) of total US water withdrawals, it is estimated to be greater than 75% of total water withdrawals for 60 counties. It is at the local level where water withdrawals and consumption have greatest impact.

Figure 3 shows a breakdown of withdrawals by source (self-supplied fresh ground and surface, self-supplied saline, and municipal). While 75% of manufacturing water use is from self-supplied sources at the national-level, it varies from state to state. For example, most of the water for manufacturing in Arizona, Massachusetts, Oklahoma, and New Jersey is from municipal supply.

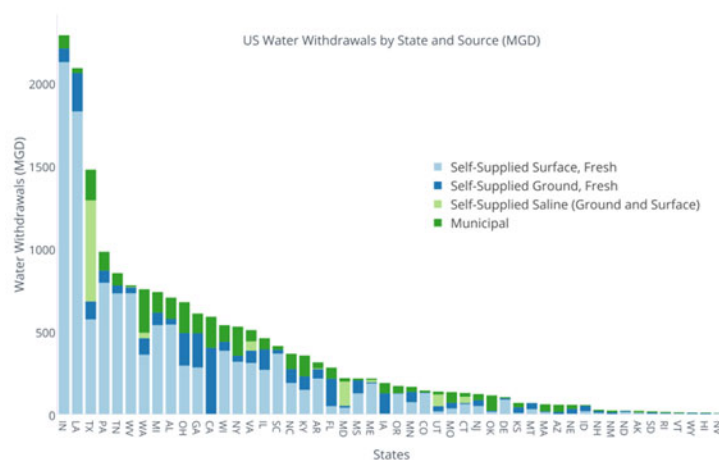


Figure 3: Breakdown of total water withdrawals by source (self-supplied ground and surface, self-supplied saline, and municipal) for each state

Total water withdrawals and consumption by subsector and state

Figure 4 provides a breakdown of U.S. manufacturing total water withdrawals and consumption by subsector. In order, the pulp and paper (322), primary metals (331), chemicals (325), petroleum refining (324), and food (311) sectors have the greatest water withdrawals of any manufacturing subsector. See Appendix B for a listing of 3 digit NAICS code for reference.

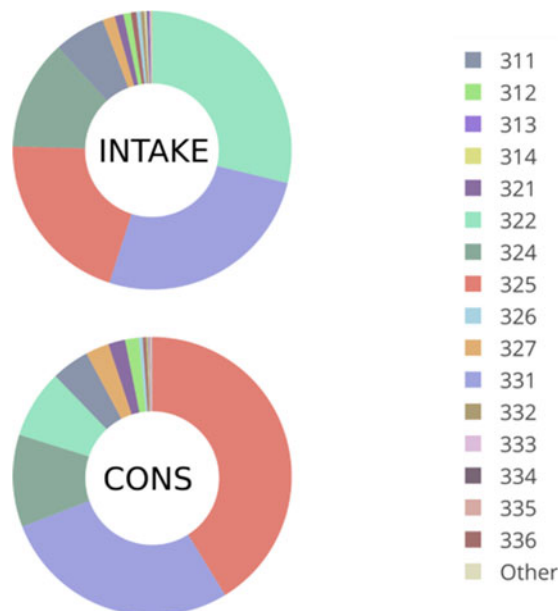


Figure 4: U.S. manufacturing total water intake (top) and consumption (bottom) by subsector using USGS and Canadian data

Figure 4 also provides a breakdown of estimates of U.S. manufacturing water consumption by subsector. The same sectors that have the largest total intake also have the largest consumptive use. However, the rankings are different. In order, the chemicals, primary metals, petroleum refining, pulp and paper, and food sectors have the largest water consumption.

Figure 5 shows the estimates for state manufacturing water withdrawals broken down by subsector. These estimates allow for a better understanding how each state's manufacturing sector uses water. This level of detail is unavailable from USGS data alone. For example, while Indiana has the largest water withdrawals for manufacturing of any state, it is primarily used by the primary metals subsector (~83%). Similarly, ~92% of Maine's water withdrawals are for the paper and pulp subsector. Other states, such as Michigan, Texas, and North Carolina, have more diversity in their water intake by subsector.

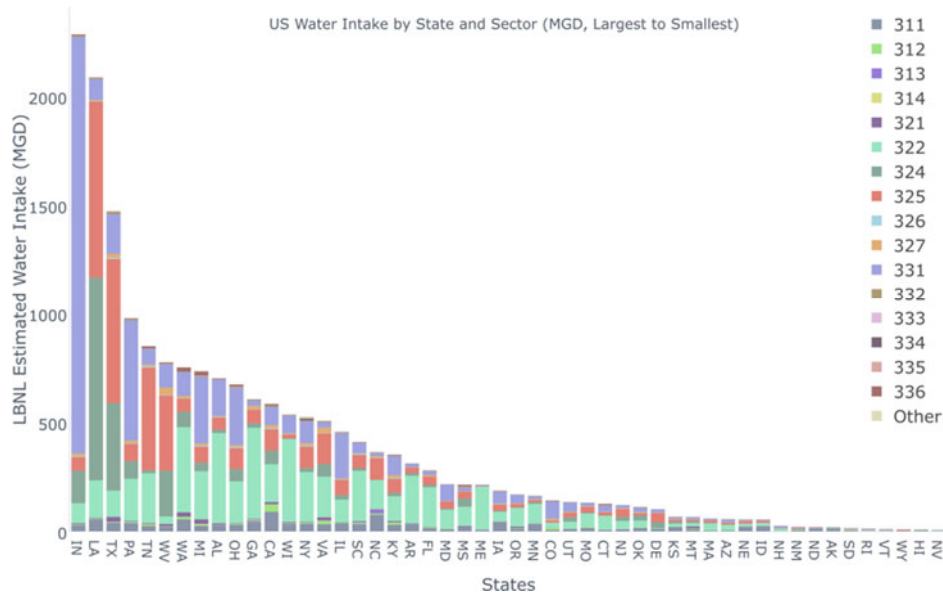


Figure 5: Estimates of manufacturing total water withdrawals by subsector and state using USGS and Canadian data

Figure 6 provides estimates of water consumption by state and subsector. Two of the top ten states in water consumption are drought prone, Texas and California. Consumptive water uses can exacerbate drought conditions and impose further stress on water supplies. Knowledge of the consumptive water use levels can aid state and regional water planners prepare and mitigate drought and/or water stress conditions.

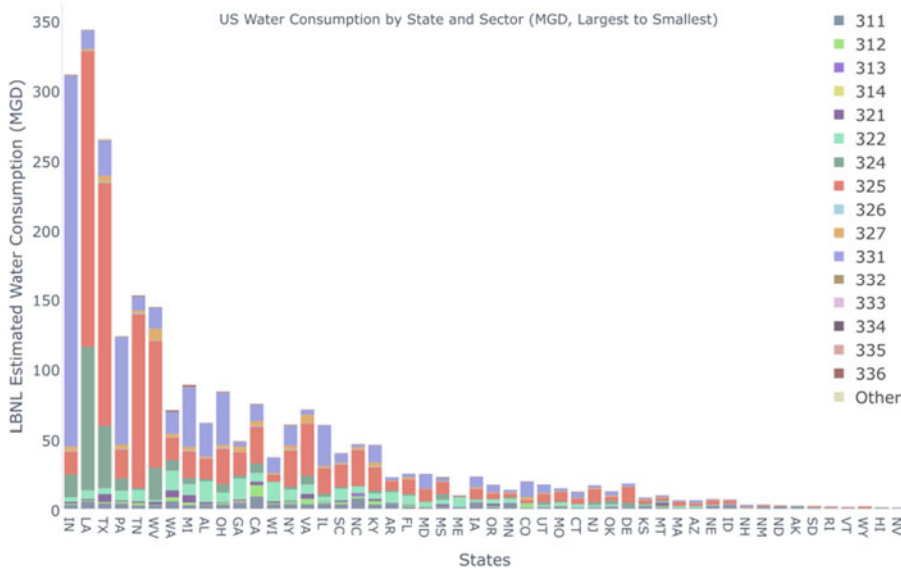


Figure 6: Estimate of water consumption by manufacturing subsector and state using USGS and Canadian data

Estimates of water withdrawals at the county level across the U.S. for the food (311), beverage and tobacco (312), pulp and paper (322), petroleum refining (324), chemicals (325), and primary metals (331) sectors can be found in Figure 7.

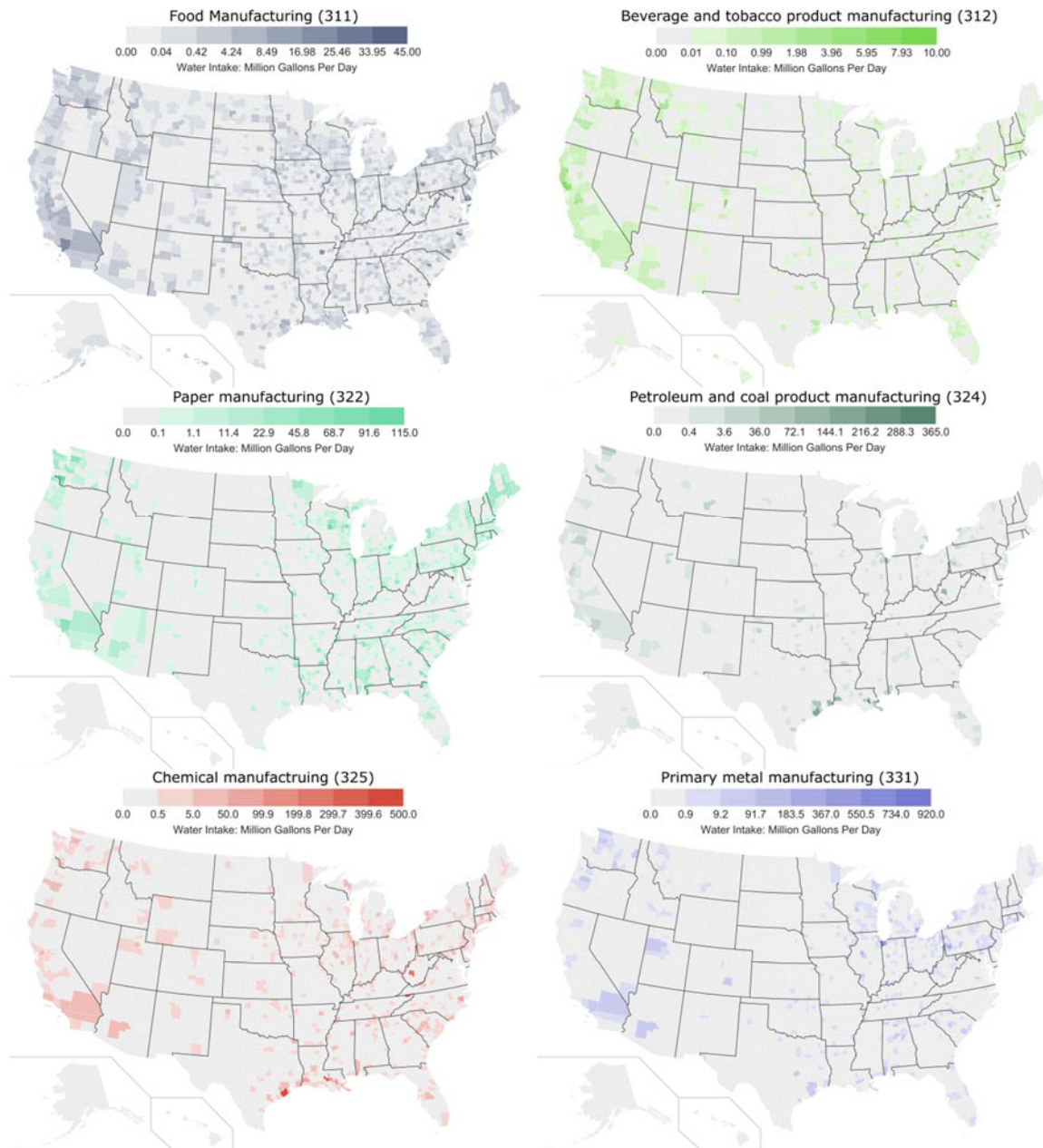


Figure 7: Estimates of water withdrawals for several manufacturing sectors

The county level estimates provide further details into how manufacturing water withdrawals are distributed. These estimates can show concentrations of manufacturing water withdrawals, particularly by subsector. Figure 8 shows the distribution of manufacturing water withdrawals for the chemical subsector across the U.S. by county. West Virginia is the 4th largest user of water for the chemical subsector. However, the chemical sector water withdrawals are not spread out across the state, but concentrated in Kanawha County. Kanawha County is home to major chemical companies including Dow, DuPont, and FMC Corporation.

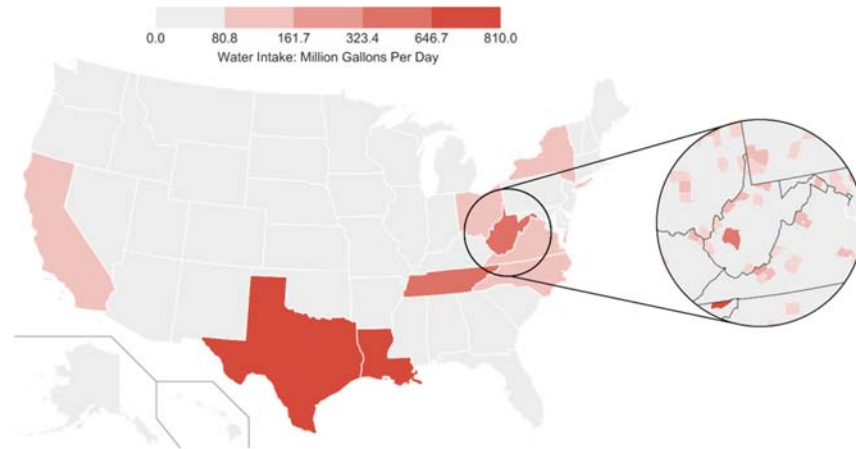


Figure 8: Total water withdrawals for the chemical subsector (325) in the U.S. using USGS and Canadian data with inset of West Virginia

Discussion

Manufacturing water-energy nexus

Water is used throughout manufacturing processes for heating, to exert force, cleaning, cooling, and domestic purposes. However, the connection between water and energy varies from subsector to subsector. It will depend on the specific uses of water and the water-intensity of its manufacturing operations; assembly operations may primarily use water for landscaping and domestic purposes, while a paper mill will use steam for its processes.

Table 1 compares the estimated manufacturing water withdrawals to total energy consumption (from the US DOE’s Manufacturing Consumption Survey) for each subsector. A ratio of energy consumption to water withdrawals provides a rough index to understand the relative magnitudes of water use and energy consumption between subsectors. Much of the energy consumption may not be attributable to water withdrawals and water withdrawals may not be directly correspond to water use at the facility (due to water losses in the distribution systems). Therefore, it should not be interpreted as a metric indicating the energy intensity of water use. Further, the metric does not have any significance within a given subsector, but is helpful to compare across subsectors. There is wide variation in this energy-to-water withdrawal metric across the subsectors. For example, the ratio is less than one for the pulp and paper and primary metals subsectors, but much greater than one for the non-metallic mineral product (i.e., glass and cement) and wood product manufacturing sectors. Table 1 also shows the same information for Canada. Calculating the same energy-to-water ratio for each subsector in Canada and comparing to its U.S. counterpart reveals differences in the water-energy nexus for the same subsector. For example, the energy-to-water ratio is 2 times greater in the U.S. food and beverage/tobacco subsectors than it is for its Canadian counterpart. Conversely, the energy-to-water ratio for the U.S. primary metals subsector is $\frac{2}{3}$ of its Canadian counterpart. The variation may be attributed to differences in subsector composition (i.e., product mixes), regional water policies and regulations, maturity of water management programs between the U.S. and Canada, and estimation errors from the methodology used in this paper. It is clear, however, that any generalizations about the energy-water nexus within the manufacturing sector are difficult to

make. Greater information on the end-uses and water use characteristics within the subsectors is required to gain additional insight into the manufacturing energy-water nexus.

Table 1. Total water withdrawals compared to total energy consumption for each manufacturing subsector for the U.S. and Canada

NAICS ID	Manufacturing Sector	CAN Energy-Water Ratio (TBtu/MGD)	US (Estimated) Energy-Water Ratio (TBtu/MGD)
311	Food	0.4	1.0
312	Beverage and Tobacco Product	0.3	0.5
313	Textile Mills	2.6	2.7
314	Textile Product Mills	1.8	1.1
321	Wood Product	5.0	2.5
322	Paper	0.4	0.4
324	Petroleum and Coal Product	1.4	1.4
325	Chemical	0.8	0.8
326	Plastics and Rubber Products	1.7	3.0
327	Non-metallic Mineral Product	3.0	2.6
331	Primary Metal	0.5	0.3
332	Fabricated Metal Product	5.1	3.7
333	Machinery	6.2	8.0
334	Computer and Electronic Product	1.6	4.2
335	Electrical Equipment, Appliance and Component	3.8	6.0
336	Transportation Equipment	2.4	2.3
Other	Other [315,316,323,337,339]	3.5	3.3

Next steps

The results presented here are intended to provide estimates of manufacturing water use characteristics within the U.S, not exact values. The estimated values are intended to show relationships and magnitudes. They can be used to better understand where water is used in the U.S. and how much water a subsector uses compared to other sectors. The results presented here may be used to guide further research into reducing the energy impacts of manufacturing water use (and vice versa) by identifying geographic areas and/or subsectors on which to focus research, technical assistance, outreach, and program development efforts.

To better understand sectors at risk of water shortages or curtailments, indices for water stress will be reviewed. The estimates developed here at the county level for water withdrawals and consumption can be mapped over the water stressed areas. The results can help to focus water conservation efforts on those subsectors having the greatest impact on local water supplies. Water-stress indices that consider long-term water conditions, rather than short-term ones, will be preferred.

Another next step will be to validate the assumption that one can infer U.S. manufacturing water intensity based on Canadian manufacturing water intensity. This assumption underlies the analysis method presented here. Its validation will determine if Canadian water data can be extrapolated to the U.S., and what additional corrections (beyond

number of employees) are needed to ensure improved accuracy. If the methodology can be validated, further estimates, including manufacturing water use by end-use (e.g., process, domestic, irrigation) can be developed. One potential way to validate this assumption is to conduct a bottom-up check of the estimates by reviewing any state or subsector water withdrawals summaries. To date, the authors are unaware of any such summary that is current, publicly available, and statistically representative. Through conducting the analyses presented here, it is hoped that a basis for collecting primary data can be established. Once established, there may no longer be a need to extrapolate Canadian water use data to the U.S.

Conclusions

This paper presents the first estimates of manufacturing water withdrawals and consumption in the U.S. by subsector and region in recent history that the authors are aware of. Based on USGS surveys and the Canadian Industrial Water Survey, these estimates offer an opportunity to gain better insight into the water-energy nexus within the manufacturing sector. Relationships between energy consumption and water use for each subsector were sought and revealed significant variation in how subsectors use water. The variation invalidates any attempt here or elsewhere to make gross characterizations of the energy-water nexus within the manufacturing sector. Further data collection and analysis is required, and any conclusions regarding the energy-water nexus will likely be subsector-specific.

Nevertheless, states, utilities, and manufacturers can leverage the results presented here to better understand the water use within their facilities. Resulting efforts could reduce the energy requirements for water withdrawals within the manufacturing sector, thereby offering another avenue for manufacturers to become more energy efficient.

Acknowledgements

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Advanced Manufacturing Office, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231

References

- Gleick, P.H., D. Haasz, C. Henges-Jeck, V. Srinivasan, G. Wolff, K.K. Cushing, and A. Mann. 2003. *Waste Not, Want Not: The Potential for Urban Water Conservation in California*. Oakland, CA. Pacific Institute
- Levinson, Marc. 2017. *U.S. Manufacturing in International Perspective*. Congressional Research Service. Washington, D.C.
- Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2014, *Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405*, 56 p.
- Rao, P., McKane, A., and Andre de Fontaine. (2015). *Energy Savings from Industrial Water Reductions, 2015 ACEEE Summer Study on Energy Efficiency in Industry*, Buffalo, NY

Solley, W.B., Pierce, R.R., and Perlman, H.A., 1998, Estimated use of water in the United States in 1995: U.S. Geological Survey Circular 1200, 71 p.

Walker ME, Lv Z, Masanet E. 2013. Industrial steam systems and the energy-water nexus. *Environ. Sci. Technol.* 47(22):13060–67

Appendix A: Data Sources

	U.S.	Canada
Water withdrawals	United States Geological Survey, Estimated use of water in the United States in 1995 United States Geological Survey, Estimated use of water in the United States in 2010	Industrial Water Survey – CANSIM 153-0047
Number of Employees	County Business Patterns 2010	CANSIM 281-0023
Energy Consumption	US DOE Energy Information Administration Manufacturing Energy Consumption Survey 2010	CANSIM 128-0006

Appendix B: North American Industrial Classification System (31-33)

311	Food manufacturing
312	Beverage and tobacco product manufacturing
313	Textile mills
314	Textile product mills
321	Wood product manufacturing
322	Paper manufacturing
324	Petroleum and coal product manufacturing
325	Chemical manufacturing
326	Plastics and rubber products manufacturing
327	Non-metallic mineral product manufacturing
331	Primary metal manufacturing
332	Fabricated metal product manufacturing
333	Machinery manufacturing
334	Computer and electronic product manufacturing
335	Electrical equipment, appliance and component manufacturing
336	Transportation equipment manufacturing
Other	Other Industries