An Introduction to Consumptive Use of Water in South Carolina

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Abstract. Effective water resource management requires understanding the supply of and the demand for water. In South Carolina, as in other places, water demand is often determined using total withdrawal volumes. However, the volume of water that is withdrawn can be significantly different from the volume that is actually consumed, which becomes unavailable for downstream uses. Water used for energy generation is commonly excluded from evaluations of total withdrawal volume because it is often assumed to be no or low consumptive use, meaning much of the withdrawn water is returned to the source and remains available for downstream uses. Additionally, energy production withdrawal volumes may be significantly higher than other sectors' usage and make it difficult to further compare water use of other sectors. Consumptive use volumes are not readily available for South Carolina and can be challenging to determine. However, estimates of consumptive use could allow more meaningful comparisons between water use sectors' impacts. The objective of this short communication is to briefly discuss data sources, outline two relatively simple methods for calculating consumptive use with available data, identify challenges and opportunities for additional research, and provide preliminary estimates of consumptive water use volumes per water use sectors in South Carolina. Expanded discussion of consumptive water use of thermoelectric energy generation is included due to the significant total water withdrawals and unique challenges with calculating consumptive use of this sector. These results inform water resource planning and identify additional research opportunities.

INTRODUCTION

While South Carolina is often considered "water rich," severe droughts and increasing water use have emphasized the importance of planning to support sustainability of water resources. To manage water resources effectively, policymakers need to understand the supply of water (i.e., the expected available volume of water at any time) and the demand for water from different sectors. In simplified terms, the supply of surface water for a basin is the sum of the annual surface water flow and net transfers into or out of the basin. Discharges related to groundwater withdrawals may supplement surface water flows; a full analysis of this is a topic for a separate article. While meaningful, less critical factors (e.g., evaporation, evapotranspiration, soil moisure) are beyond the scope of this article.

The demand for water is often evaluated using total withdrawal volume. A more refined metric is consumptive water use volume, which is the amount of water that is not returned to the source near the withdrawal location, and directly impacts the amount of water available downstream. The consumptive use percentage of total withdrawals can vary significantly between water use sectors, individual users, and even over time for the same user. While the literature highlights the importance of consumptive use in water resource management (Wada et al. 2014), South Carolina's annual water use reports focus mainly on the amount of water withdrawn, and largely exclude water used for energy generation from discussion (South Carolina Department of Health and Environmental Control 2018). Determining consumptive use can be challenging for various reasons, including the absence of measured consumptive use volumes in many cases. In this situation, secondary sources of data may be used to estimate, or calculate, consumptive water use.

The objective of this short communication is to briefly discuss data availability, outline methods for calculating consumptive use, provide preliminary estimates of consumptive water use volumes for water use sectors in South Carolina, and identify challenges and opportunities for additional research.

WATER WITHDRAWAL REGULATION, USE, AND DATA

In South Carolina surface water users that withdraw more than three million gallons (MG) in any month need a permit or registration, which is issued by the South Carolina Department of Health and Environmental Control (SCDHEC). The permitted volume is typically the highest amount a water user can legally withdraw and is determined in accordance with the South Carolina Surface Water Withdrawal, Permitting Use, and Reporting Act (South Carolina Code of Laws 2011). This act and corresponding regulation require each water user to report their monthly water withdrawal volumes on at least an annual basis, and the permit application asks for an estimate of consumptive use percentage (South Carolina Code of Laws 2011; South Carolina Department of Health and Environmental Control 2012). For a more complete overview of South Carolina's water use regulations, please see the Land Grant Press article "Water Withdrawal Regulation in South Carolina" (https://lgpress.clemson.edu/publication/water-withdrawal-regulation-in-south-carolina/).

SCDHEC compiles reported water usage information and makes it available through various online databases, such as the SC Watershed Atlas (https://gis.dhec.sc.gov/watersheds/) or by request to staff. SCDHEC also prepares an annual overview of water use volumes in South Carolina. The authors were able to obtain full data sets through 2017, and therefore discuss water withdrawals in 2017 for consistency throughout this article. In 2017, the total reported surface water annual withdrawals in South Carolina were 16.8 trillion gallons (South Carolina Department of Health and Environmental Control 2018). The report details water withdrawals by river basin and by the following water use sectors: aquaculture, golf course, hydroelectric, industrial (facilities with self-supply), irrigation (i.e., agriculture), mining, other, nuclear power, thermoelectric, and public water supply (includes residential, commercial, and industrial uses supplied by the utility). Sectors with small volumetric withdrawals, such as aquaculture and mining, have been excluded from analysis for this short communication. For more complete overview of South Carolina's water use, please see the Land Grant Press article "Water Withdrawal Amounts in South Carolina" (https://lgpress.clemson.edu/publication/water-withdrawal-amounts-in-south-carolina/).

Power generation is responsible for 98.2% of the total reported surface water withdrawal volume in South Carolina, collectively "withdrawing" more than 16.7 trillion gallons in 2017 (Figure 1) (South Carolina Department of Health and Environmental Control 2018). By far, hydroelectric power generation accounts for most of the reported "withdrawal," specifically 88.1% in 2017 (South Carolina Department of Health and Environmental Control 2018). Because this water is utilized as the water moves through a waterbody (or dam) and is typically considered to have no or only minimal water consumption (beyond accelerated evaporation of reservoirs, which is beyond the scope of this article) (SC Department of Natural Resources Land, Water and Conservation Division 2009), we have excluded it from this analysis to allow for a clearer evaluation of remaining water usage, as is common practice.

"Thermoelectric" includes nuclear, as it is a type of thermoelectric power generation (US Government Accountability Office Center for Science, Technology, and Engineering 2005), and is the largest remaining water withdrawal at 10.1% of the total water withdrawals in South Carolina (South Carolina Department of Health and Environmental Control 2018). Within this sector, the main water uses are for cooling and steam production; each result in increased water temperature causing direct evaporation and increased temperature of return flow water (which may further accelerate evaporation in the waterbody).

RETURN FLOWS

Under the Clean Water Act (CWA) point sources that discharge water into the waters of the United States need to obtain a National Pollutant Discharge Elimination System (NPDES) permit and typically must report their discharge volumes. In South Carolina, SCDHEC maintains databases related to water withdrawal and discharge information for all water use sectors. The SC Watershed Atlas online tool (https://gis.dhec.sc.gov/watersheds/) provides quick access to information including location and permit number for water withdrawals (e.g., surface water withdrawals, surface water withdrawal registrations) and return flows (e.g., NPDES discharge locations). More detailed records, such as monthly reported water withdrawal volumes, are available by request to agency staff.

DATA COMPILED FOR SOUTH CAROLINA SURFACE WATER MODELS

In 2014, to prepare for upcoming state water planning efforts, the South Carolina Department of Natural Resources (SCDNR) led the development of surface water models to combine information from several data sets regarding individual water users. SCDNR's technical consultant, CDM Smith, developed a model for each of South Carolina's eight major river basins. The Simplified Water Allocation Model (SWAM) is a water accounting tool that includes volumes for surface water withdrawals and permitted discharges. For purposes of the model, consumptive use for each individual water user was estimated by linking water withdrawals and return flows utilizing data from a variety of potential sources including SCDHEC databases; the US Department of Agriculture, the South Carolina Department of Agriculture, and the South Carolina Farm Bureau records; anecdotal

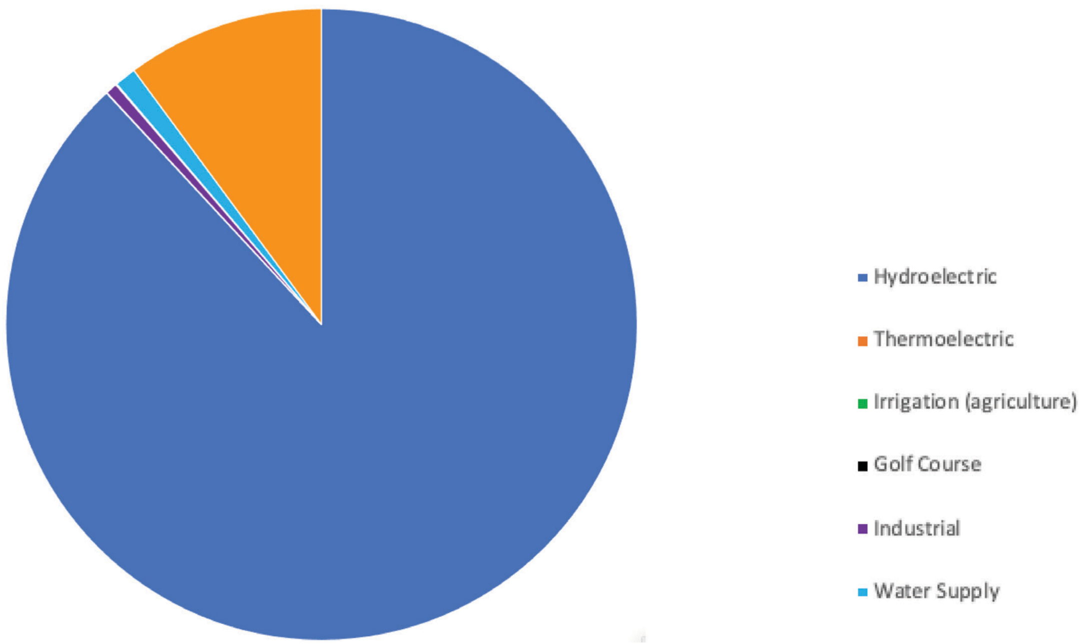

Figure 1. Pie chart showing relative volume of major surface water withdrawals by water use sectors in South Carolina, in 2017 (South Carolina Department of Health and Environmental Control 2018).

information from users; dam operators; etc. These findings are summarized in the model report for each river basin, which were published in 2017 and are available on SCDNR's Surface Water Model web page (https://hydrology.dnr.sc.gov/surface-water-models.html), and are consolidated for all river basins in Table 1.

The SWAM model assumes a consumptive use of 100% for agricultural irrigation (CDM Smith 2017), which aligns with USGS findings for South Carolina (Dieter et al. 2018). Golf courses, also considered 100% consumptive, typically use sprinklers to apply water that is utilized by plants and lost to evapotranspiration (ET) (CDM Smith 2017).

Water Suppliers provide water for indoor and outdoor use by customers, which commonly include residential, commercial, and industrial users that are not self-supplied. Water used indoors may be collected and treated by a sanitary sewer provider and discharged to a waterbody near the treatment facility—in this case, it may be possible to match the water withdrawal and wastewater treatment discharge(s) to determine consumptive use volume. Alternatively, water may be collected in an onsite treatment system (commonly known as a septic system) and infiltrated into the ground rather than returned directly to the source; while this water may eventually return to a waterbody, due to the time delay or physical distance from original source, this is typically considered 100% consumptive use. In some instances, public water supplies originate in one basin but are utilized and discharged into a different river basin. In this case, the interbasin transfer would be considered 100% consumptive for the original basin, as the water is no longer available for those downstream users.

SPECIAL CONSIDERATIONS FOR THERMOELECTRIC CONSUMPTIVE WATER USE

The volume of water withdrawal and consumptive use for thermoelectric power production can vary widely as these amounts are influenced by the type of fuel and cooling systems utilized (US Government Accountability Office Center for Science, Technology, and Engineering 2015). A single facility may have multiple generating units with a variety of cooling systems; utilization of a specific unit can depend on energy demands, maintenance schedules, or other factors making it extremely difficult to accurately estimate a facility's "normal" percent consumptive use.

The US Energy Information Administration collects information on power generation and currently provides it through the Electricity Data Browser online database (https://bit.ly/3sVW7AN). This online tool provides multiple options for evaluating data as well as downloadable data including both water withdrawal and consumptive water use at the plant level for facilities. This database is currently in beta version, so accuracy of data should be verified.

Table 1. Percent consumptive water use for major water use sectors in South Carolina based on data used in the SWAM models. Source: CDM Smith 2017.

Water Use	Mean % Annual Consumptive Use	Median % Annual Consumptive Use	Range of % Monthly Consumptive Use
Hydroelectric (including pumped storage)	0	0	(0, 0)
Power (thermoelectric, including nuclear)	38.78	26.00	(0.08, 86.40)
Power (thermoelectric, excluding nuclear)	51.23	66.42	(0.10, 86.40)
Power (thermoelectric, only nuclear)	5.60	1.00	(0.08, 21.60)
Industrial	34.59	20.79	(0, 100)
Water Supply	47.41	42.48	(0, 100)
Irrigation (agriculture)	100	100	(100, 100)
Golf Courses	100	100	(100, 100)

METHODS

The options for calculating consumptive water use depend on data availability, which can differ among water sectors. The first method relies on SWAM data inputs, which contains assumptions of consumptive use for all water use sectors. These assumptions provide a useful starting point for estimating consumptive use. In some situations, such as thermoelectric, estimating consumptive use can be complicated, and expansion of the data may provide more accurate results. The second method incorporates NPDES permitted return flows with individual water withdrawals to calculate consumptive use. This method requires a much larger data set and presents different complications, which are discussed. While each of these options may appear simple, compiling the data and accounting for the nuances of consumptive use for different water-use sectors significantly increased the complications of this exercise.

METHOD 1: CALCULATING CONSUMPTIVE USE VOLUME AS A PERCENTAGE OF WITHDRAWAL UTILIZING SWAM DATA

The first method uses estimates of percent consumptive water use for individual water users based on SWAM data inputs, using the following formula:
where consumptive water-use percentages were not available from SWAM for a given user, we used the mean consumptive water-use percentage for the appropriate water-use sector (Table 1).

$$consumptive\ use = annual\ withdrawal\ \times \%\ consumptive\ use \quad (1)$$

METHOD 2: CALCULATING CONSUMPTIVE USE VOLUME BASED ON WITHDRAWAL AND RETURN FLOW

The second method requires significantly more data and can be utilized only when a NPDES-permitted discharge can be associated with a reported water withdrawal—assuming the permit includes a discharge volume reporting requirement. This method calculates consumptive water use for individual water users based on reported volumes of both withdrawal and discharges, using the following formula:

In theory, this method should provide a more refined estimate of the consumptive use of a facility for a given year—assuming reported volumes are accurate. However, in practice, discharge values are often only estimated and not directly measured. As a result, when using this method, the results should be evaluated closely for potential data errors.

$$consumptive\ use = withdrawal - return\ flow \quad (2)$$

For example, we find that facilities sometimes reported return flow volumes larger than withdrawal volumes, indi-cating that there may be inaccuracy in the reporting or data collection, discharge of groundwater withdrawals, infiltra-tion of stormwater, or an unknown contributing factor for an individual facility or specific timeframe. In our analysis, we assume that when discharge is greater than the withdrawal for a facility for a given year, their consumptive use for that year is zero.

RESULTS

METHOD 1: CALCULATING CONSUMPTIVE VOLUME AS A PERCENT OF WITHDRAWAL UTILIZING SWAM DATA

These results indicate that thermoelectric and water supply are the largest consumptive water uses in the state (Figure 2 and Table 2) and the agricultural use of water is increasing over time (Figure 3).

As mentioned previously, results using this method are impacted by the limitations with the data available from the SWAM models. For example, nearly 1,400 users do not have specific consumptive water-use data, including 961 public supply and 351 industrial users. In these cases, we used the average values per appropriate water sector for those missing values. However, doing so may result in inaccurate representation of actual consumptive use from a specific facility. An additional limitation with this method is that the data inputs to SWAM assume that the monthly consumptive use percentage is constant from year to year, which can be an issue if annual weather, equipment upgrades, or policy updates result in significant changes in consumptive water-use percentages.

METHOD 2: CALCULATING CONSUMPTIVE USE VOLUME BASED ON WITHDRAWAL AND RETURN FLOW

Due to the unique challenges for calculating consumptive use of thermoelectric, we identified Method 2 as an alternative that may improve accuracy of consumptive use for this sector. Figure 4 and Table 2 show the total consumptive water volume based on estimated withdrawal and discharge volumes (Method 2), and the average consumptive use percentage values reported by SWAM (Method 1), for thermoelectric. Our results show that, on average, the two methods of estimating water use result in a similar trend in consumptive water use, with Method 2 resulting in lower overall consumptive use volumes as compared to Method 1. In theory, Method 2 should more accurately handle annual variations that may be triggered by equipment modifications, technology upgrades, or policy updates.

However, using return flow along with withdrawals to estimate consumptive use has a few limitations. First, return flow data availability and accuracy can be complicated by several factors, including changes to water-use regulations and reporting requirements, variability in accuracy of individual user reporting, and the difficulty of compiling information from multiple databases. As noted earlier, when reported return flow volumes were larger than withdrawal volumes, we assume that consumptive use for that year is zero. This may result in underestimate of actual consumptive use and should be further evaluated.

DISCUSSION

Evaluating volume of consumptive use can allow meaningful comparison of all water-use sectors and inform effective water management and planning. This article discusses two options for determining consumptive water use in South Carolina. Overall, our findings show that Method 1 is practical, easy to understand, and relatively simple to apply. The data utilized is regularly available: water withdrawal volumes are reported each year and many consumptive

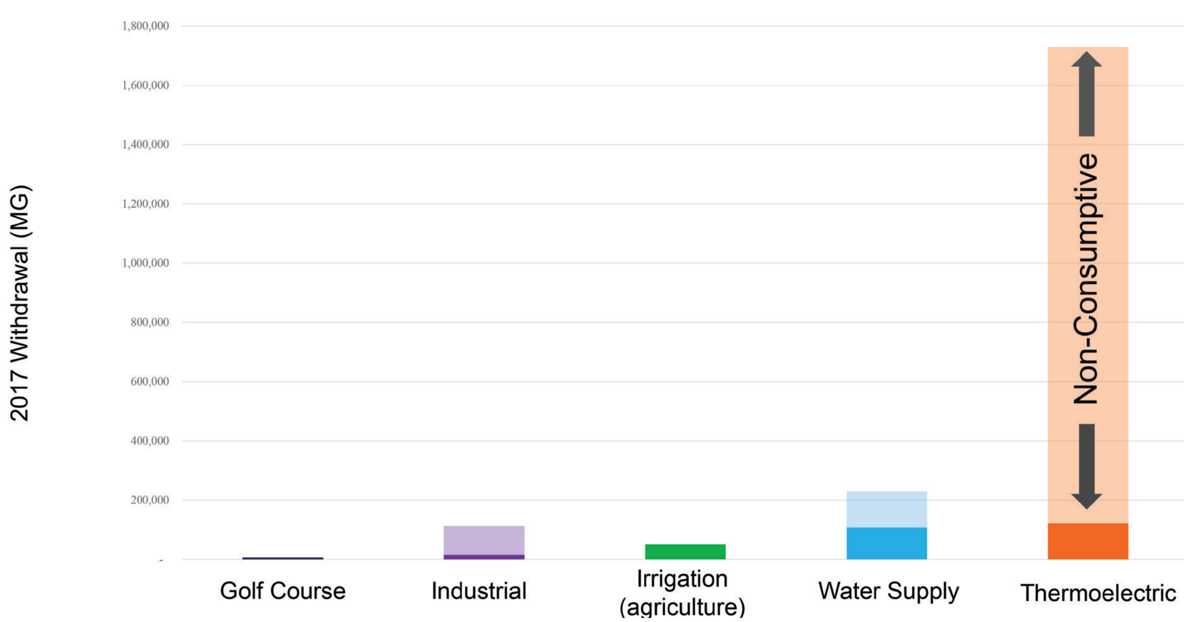

Figure 2. Comparison of major withdrawals (million gallons) (South Carolina Department of Health and Environmental Control 2018), excluding hydropower, and estimated consumptive use volume by water-use sectors in South Carolina in 2017.

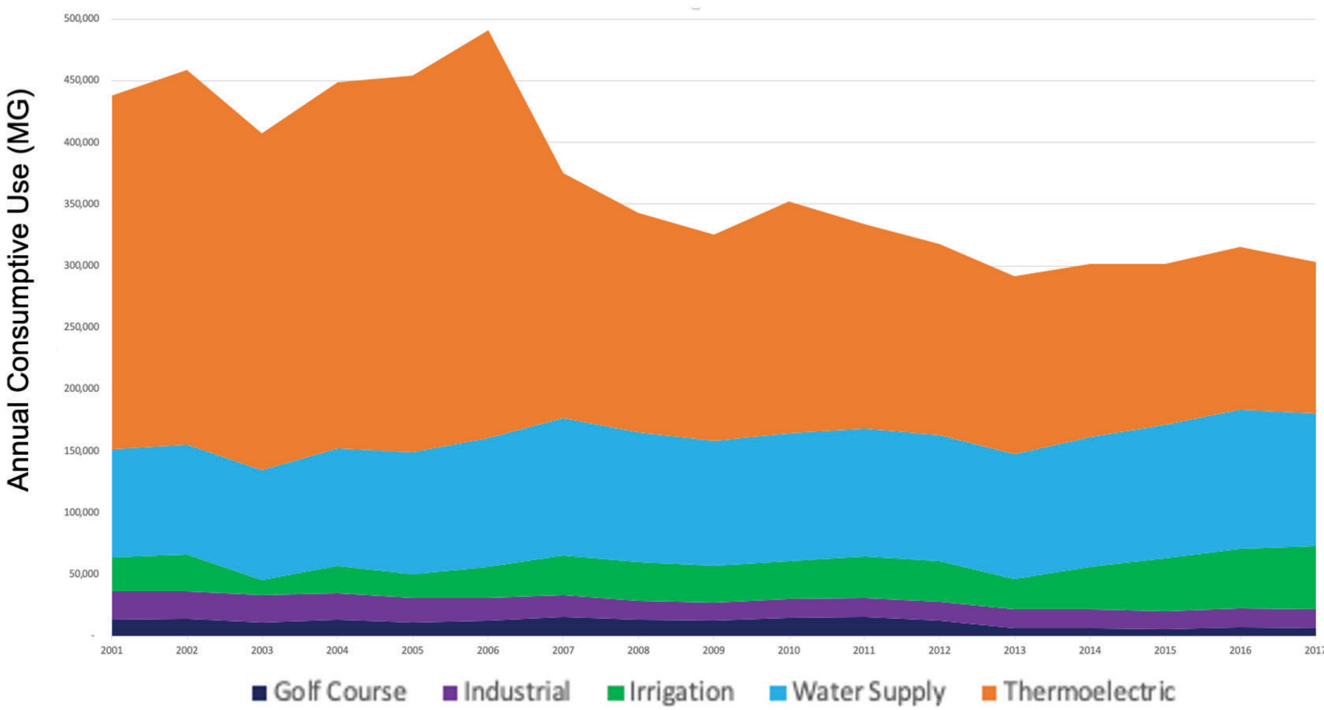

Figure 3. Estimated annual consumptive use volume (million gallons) per major water-use sectors in South Carolina.

Figure 4. Comparison of thermoelectric estimated annual consumptive water use (million gallons per year) using Method 1 and Method 2.

use estimates were previously compiled for the SWAM models or, for new withdrawals, this information should be included on permit applications. However, the consumptive use percentages remain the same from year to year, which may not represent changing conditions. Method 2 captures changing withdrawal and discharge amounts at the facility level and may help us understand unique conditions with an individual water user. However, discharge data may not be accurately reported or may have stormwater infiltration that could introduce "false" 0% consumption. Future research could link reported discharge volumes with local precipitation to assess if higher rainfall is a driver of lower consumptive use and to increase the understanding and accuracy of this data.

Calculating consumptive use for thermoelectric presents unique challenges due to the variability between consumptive use of individual units and frequency of operation of different units within the same facility. Using discharge volumes from NPDES reports allowed an alternative method for evaluating thermoelectric consumptive water-use volumes. We find

Table 2. Estimated annual consumptive water use (MG) per water use sector.

	Golf Course	Industrial	Irrigation	Water Supply	Thermoelectric (Method 1)	Thermoelectric (Method 2)
2001	13,297	22,492	28,108	87,575	286,747	177,339
2002	13,753	22,607	29,674	88,933	303,910	271,557
2003	10,674	22,275	12,179	89,525	272,503	202,403
2004	13,213	21,247	22,496	94,920	296,668	222,695
2005	11,069	19,348	19,923	98,334	305,888	220,680
2006	12,639	17,894	25,635	104,296	330,373	274,845
2007	15,777	17,158	32,031	111,228	199,037	110,627
2008	13,400	15,355	30,866	105,129	178,240	79,581
2009	12,401	14,724	29,642	101,189	167,234	80,787
2010	14,601	15,666	30,144	103,773	188,245	84,389
2011	15,225	15,752	33,750	102,992	165,899	64,550
2012	12,751	15,172	33,064	102,110	154,806	87,138
2013	6,578	15,282	24,293	100,892	144,180	66,615
2014	6,290	15,059	35,103	104,452	140,397	12,041
2015	5,617	14,755	42,593	108,095	130,539	12,456
2016	6,682	15,308	48,252	113,377	131,751	40,485
2017	6,386	15,168	51,564	107,574	122,067	8,666

that while only a small percentage of the water withdrawn for thermoelectric energy production is consumed, the volumetric amount of water consumed is still very large compared to the other water-use sectors in South Carolina. This result is in line with the existing literature (see e.g., https://shorturl.at/elS78). Given the amount of consumptive water-use volume for thermoelectric, it is worthwhile to include these volumes in comparisons of water-use sectors in South Carolina. In the future, a shift toward renewable energy production systems with less demand for on-site cooling water, such as wind and solar, could significantly decrease consumptive water use of operation.

Our findings show that consumptive volume of water for thermoelectric declined over time. This sharp decrease in water consumption may have been due to a variety of factors that could include regulatory changes that focused on reducing overall water withdrawals. Clean Water Act Section 316(b) aims to reduce the impacts to aquatic organisms from impingement and entrainment from large cooling water facilities (US Environmental Protection Agency 2014) and resulted in a shift from once-through cooling systems to recirculating, or closed-cycle, systems (US Government Accountability Office Center for Science, Technology, and Engineering 2015). Comparatively, once-through systems withdraw larger volumes, result in lower water temperatures (relative to recirculating systems), lose less to evaporation, and return a larger portion of the water withdrawn, resulting in a lower percent consumptive use. Recirculating systems, on the other hand, withdraw less water by reusing the same water more than one time, which results in higher water temperatures, evaporation rates, and percent consumptive use (US Government Accountability Office Center for Science, Technology, and Engineering 2015). We also find that the two methods that we analyzed produce meaningful differences in terms of the consumptive water use. Specifically, consumptive water use in Method 1 is higher than Method 2 by about 5% of the total withdrawal volume. This difference can be a significant portion of the total consumptive water use in dry years.

This early attempt at providing consumptive water-use volumes uncovered numerous challenges and identified many opportunities for additional research. While we further evaluated thermoelectric, hydropower's consumptive use is assumed to be zero, which ignores the accelerated evaporation from reservoirs that results in some level of water loss when compared with pre-reservoir conditions. For example, Grubert (2016) reports an average of about 1,600 gallons per MWh energy produced for hydropower generation in the United States.

Method 2 could be applied to additional water-use sectors, such as industrial, that may also be required to report NPDES discharge volumes. Additional sources of data can also further improve the estimation of consumptive use. Finally, we note that while consumptive water use is an important consideration, by itself, it cannot result in effective water management, but rather should be used to enhance understanding of water availability. For effective water management, water withdrawal and consumptive use need to be used along with hydrological models and behavioral models in response to water management policies.

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