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Water use for electricity in the United States: an analysis of reported and calculated water use information for 2008

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Abstract
Water use by the electricity sector represents a significant portion of the United States water budget (41% of total freshwater withdrawals; 3% consumed). Sustainable management of water resources necessitates an accurate accounting of all water demands, including water use for generation of electricity. Since 1985, the Department of Energy (DOE) Energy Information Administration (EIA) has collected self-reported data on water consumption and withdrawals from individual power generators. These data represent the only annual collection of water consumption and withdrawals by the electricity sector. Here, we compile publically available information into a comprehensive database and then calculate water withdrawals and consumptive use for power plants in the US. In effect, we evaluate the quality of water use data reported by EIA for the year 2008. Significant differences between reported and calculated water data are evident, yet no consistent reason for the discrepancies emerges.

Keywords: energy water nexus, electricity, freshwater demands

1. Introduction

Pursuant to the Federal Energy Administration Act of 1974 (Public Law 93-275), the US Department of Energy (DOE) Energy Information Administration (EIA) collects data on the operations, management, and ownership of electricity generators and distribution companies in the United States. Since 1985, the agency has collected self-reported data on water consumption and withdrawals from individual power generators. These data represent the only annual collection of water consumption and withdrawals by the electricity sector. This information is used by the United States Geological Survey (USGS) in its periodic accountings of water use[5] in the United States, and is compared with data from state agencies and information from individual power plant facilities (Kenny *et al* 2009). Water use by the electricity sector represents a significant portion of the national water budget. According to the most recent federal data, electricity generation accounts for 41% of total freshwater withdrawals (Kenny *et al* 2009), and 3% of total water consumed in the United States (Solley *et al* 1998). Although there are regional differences in the relative importance of water availability for

[5] Water use is defined here to indicate both water withdrawals and consumptive uses.

electricity generation, pressures on water resources related to a growing populace, exacerbated in many regions of the US by variable and changing climate regimes (Karl *et al* 2009), require planning that is informed by an accurate accounting of water use for generation of electricity. Integrated planning strategies are becoming important components of the planning portfolios of federal, state, local, and private entities.

However, it has been reported that the data collected by EIA are inaccurate and incomplete reflections of water use by the electricity sector (GAO 2009). This has prompted researchers to develop mechanisms for estimating water requirements for electricity generation (Macknick *et al* 2011, 2012) so as to better inform water resource planning. Macknick *et al* (2012) collect and assess data from the literature in order to estimate operational water coefficients for US domestic electricity generation. These coefficients are reported as the amount of water withdrawn or consumed per unit of electricity generated, and can thus be applied to energy generation statistics in order to estimate water use.

Here, we compare water use data reported by EIA for the year 2008 with calculations derived from water use coefficients from Macknick *et al* (2011, 2012), which are based on published literature, applied to reported electricity generation. Differences between EIA reported data and the range of calculated water use are examined, and comparisons with other available data are offered.

2. Methods

In order to calculate water use by the electricity sector, EIA data from 2008 were acquired and compiled from EIA forms 860 and 923 into a comprehensive database. (A simplified version of the database used for this analysis is available at www.ucsusa.org/ew3database.) The original, comprehensive, compiled database contains over 40 fields, but the aspects important for this analysis are generator-specific data on primary cooling technologies, prime mover type, fuel type, reported generation, reported water consumption and withdrawals, cooling water source, and geographic location. Once compiled, a series of national-level, literature based water use coefficients (Macknick *et al* 2011, 2012) were applied to the reported electricity production at each generator. Data compiled from the EIA include information at the plant, generator, boiler, and cooling structure scales[6]. In order to apply the water coefficients, these four levels of information had to be aggregated (or parsed) at the electricity generating unit (EGU) scale. The water coefficients were then mapped to each EGU based on characteristics including prime mover type, fuel type, cooling system, and associated technologies[7]. The processes and assumptions in compiling the database, scaling information therein, mapping the EGU to water coefficients, and interpreting the results in a regional context are outlined in more detail below.

Table 1. Total number of EGUs in the database not requiring cooling.

Hydropower	3811
Natural gas, combustion turbine	2495
Oil, combustion turbine	2163
Biomass, combustion turbine	1187
Wind	477
Natural gas, dry cooling	112
Photovoltaic	66
Biomass, dry cooling	12
Oil, dry cooling	7
Coal, dry cooling	6

2.1. Database basis

The database is a compilation of information collected by the EIA in the year 2008 on Forms 860 and 923. EIA Form 860 is the 'Annual Electric Generator Report' form, a 60-page questionnaire that collected data on the characteristics of 19 558 generators (in approximately 5900 plants) for the year 2008. Form 860 collects information separately about generators (capacity, ownership, age, major fuel use, and co-generation), boilers (design firing rate, compliance with various air regulations, and associations with generators and emissions controls), and cooling systems (cooling type, cooling tower type if applicable, cooling pond size, design parameters for pumps). Of the 19 558 generators reported, 15 694 reported that they were in operation in 2008. The 3864 generators not operating are likely small peaking plants that were not necessary. Even among the 15 694 that were in operation, approximately 2500 had capacities below 1 MW, including dozens that were only 100 kW and were used less than 20 h in 2008.

Operational information at the plant, generator, and cooling system scale are reported in EIA Form 923, the 'Power Plant Operations Report'. The 2008 dataset includes reported and estimated monthly power generation at 5242 electrical plants (nearly the entire set of operational plants in 2008). Form 923 also maintains detailed schedules, including Schedule 8, Part D, a database of 1531 cooling systems associated with boilers at reporting generators. This cooling system information includes estimated withdrawal and consumption rates (in cubic feet per second). Of the 19 558 electricity generation units (EGU) for which data were collected by the EIA in 2008, 4545 were of a type (prime mover) which we determined required cooling. (The remainder were largely hydroelectric facilities; natural gas-, oil-, or biomass-fueled combustion turbines; or non-water using solar of wine facilities, table 1.) Of the water-cooled EGUs, only 3583 EGU at 1748 plants were operational in 2008. EGUs were tagged as requiring cooling if they included steam driven turbines, heat recovery steam generators on combined cycle units, single-shaft combined cycle units, or binary cycle geothermal turbines. This analysis assumes that combustion turbines, combustion turbine components of

[6] For this analysis, a 'plant' represents a power producing site and the aggregation of components all the way from the fuel input to the electrical output. An electrical generating unit (EGU), or 'generator' represents the turbine structure, or the specific element that translates physical energy to electrical energy.

[7] The one exception is combined cycle systems where water coefficients are based on the plant scale.

combined cycle EGU, internal combustion engines, and wind, photovoltaic, and hydroelectric generators do not require water for cooling.

Of 3583 water-cooled operational units identified, only 2757 reported electricity generation at the EGU level in Form 923 Schedule 5A. The remaining units required estimation of the net generation at the EGU scale where only plant information was available. If the EGU was the only unit at the plant, then the plant generation from EIA Form 923 was attributed to the EGU; this applied to a single EGU in this analysis. For the remaining 1872 EGU, a simple algorithm was applied. If a plant had any units that reported to Schedule 5A, the generation from those units was deducted from the overall plant generation as reported to the primary Form 923. The remaining generation at the plant was apportioned through all remaining generators in proportion to nameplate capacity. This assumes that all generators at a plant have the same capacity factor. Plants where EGU are retired, on standby or reported no generation are not included.

Negative net generation values exist for 649 of the 19 558 EGU in the database, most of which have a very low capacity factor. In some instances, Form 923 or Schedule 5A report negative net generations for the plant or the EGU, respectively[8]. In other cases, the algorithm above returns a negative value for residual generation. These facilities are not included in the results reported here, under the assumption that these units are run for capacity purposes only and have a higher parasitic load than use.

2.2. Database development: data reported to EIA

To associate cooling water data with specific generators (rather than boilers), the reported withdrawals and consumption at each cooling system were allocated to the EGU that utilizes that system. Cooling systems are associated with boilers, and boilers are associated with EGU. However, at any connection, there may be multiple stages that merge or divide (i.e. a single cooling system utilized by multiple boilers, which feed multiple EGU). Although there is information that allows for characterization of those linkages, information is not readily available that accurately diagrams the complex connections. To best estimate water use at the EGU scale, we adopt a terminology for the way that energy flows or is utilized between plants, generators (EGU), boilers, and cooling structures (figure 1). In this case, we refer to the use of energy at different plant components as 'passing' energy from component to component and parsing or aggregating it between components. First, we assume that each EGU passes generation down to each boiler associated with that EGU in equal parts, and again generation passes down from those boilers to their associated cooling systems in equal parts. If a boiler serves more than one EGU, the generation (or partial generation) from all served EGU is summed to the boiler. The same applies at the cooling system level relative to the boiler. Water use is passed 'up' to all boilers served by the cooling system, pro-rated by the amount of generation assumed to be served by each boiler. This water use is again passed up to the EGU served by those boilers, again pro-rated by the generation of the EGU served by those boilers.

[8] These values may be legitimate for units that run at spinning reserve only, or provide peaking capacity but have a higher parasitic load than generation in most operational hours. Of the 3583 units in this water use analysis, only 29 were estimated to have negative generation (at very small values), and of those, all but three reported the negative generation directly to Form 923 Schedule 5A.

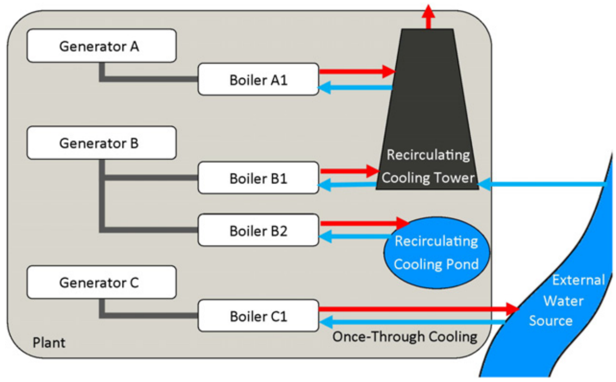

Figure 1. Schematic demonstrating relationships among plants, generators, (EGU), boilers, and cooling structures. As shown, multiple boilers may be associated with each generator, each cooling structure may be associated with multiple boilers, and each plant may include multiple instances of each type of equipment. Blue arrows depict the flow of cool water; red arrows depict the flow of heated water.

Out of the over 3500 units requiring water for cooling, 20% do not have a boiler association (and therefore no recorded water use available), 50% have a single boiler association, and the remaining record more than one boiler. The units associated with more than one boiler only represent 8% of the generation in this analysis. However, not all of the boilers record a cooling system association, and of those that do, not all reported cooling water use (either withdrawals and/or consumption). Only 1526 cooling structures at 729 plants report to the Form 923 Schedule 8D; of these cooling structures, 74% (1133) report both withdrawals and discharges. Consumption is calculated as the difference between withdrawals and discharges.

Once this information has been passed through the boiler level and back to the EGU level, estimated withdrawals are available for 38% of the EGU (1374) in this analysis that we determined require cooling, and consumption for 26% (952). These EGU account for 52% and 38%, respectively, of the reported total electricity generated by EGU requiring cooling in 2008. The 3613 EGU requiring cooling make up only 24% of the total number of EGU reported, but more than 85% of the total reported electricity generation in 2008.

The type of cooling structure used by each power plant is self-reported to the EIA through Form 860. The cooling systems that can be selected include once-through using fresh, saline, or cooling pond(s) or canals(s); recirculating with either forced, induced, or natural draft towers; or recirculating through a cooling pond or canal. Options for towers included mechanical draft or natural draft, wet- or dry-cooled, or a combination wet-dry process. To associate specific EGU with particular cooling structures 'types' and towers, we followed a trace-through similar to the water use system described above. However, because the types are discrete values, the first boiler's first listed cooling structure type was associated with each EGU. After tracing cooling structures through to EGU, only about 70% EGU that we determined require cooling report a cooling structure to the EIA.

To adequately characterize water use for electricity generation for the purposes of managing a water portfolio, the specific source of water for cooling must be identified (e.g. the name of the water body or aquifer). Water source names were taken from the 2008 EIA Form 860 Schedule 2, which provides self-reported data for cooling water sources. Since this dataset did not provide water source information for nuclear plants, some additional water source names were obtained for plants from the 1996–2000 EIA Form 767. After the information was compiled, more than 80% of power plants that require cooling did not report their water source to the EIA. Moreover, more than 30 plants listed generic terms such as 'lake' or 'river' as their source, and no power plant listed a specific groundwater aquifer or well. However, categorization of the type of water used was possible using the information provided. Water types were categorized as follows:

- Ocean: coded to all plants with 'channel' 'ocean', 'bay', 'harbor' 'sea' in their source name.
- Surface water: coded to all water source data with 'river' or 'lake' 'pond' 'creek' or 'reservoir' or 'stream'.
- Groundwater: coded to all water source data with 'aquifer', 'well' or 'groundwater'.
- Municipal water: If SW or groundwater definition could not be determined, coded to all water source data with 'agency', 'city', 'municipal' or 'authority'.
- Waste water: coded to all water source data with 'reuse', 'waste', 'WWTP', 'treatment'.
- Mixed sources: these were indicated by the source names and coded accordingly.
- Unknown ocean: all plants with no source water name, and located within 1 mile of shoreline.
- Unknown freshwater: all plants with no source water name, and located more than 1 mile inland.

Using this methodology, water source data were assigned for 100% of the plants that report water withdrawal and consumption to the EIA. This accounted for >98% of calculated water withdrawals, >95% of calculated water consumption, and >81% of total generation in 2008.

2.3. Verifying and correcting reported data

The latitudes and longitudes for 6600 plants were acquired from EIA via a separate request in 2010. The accuracy of these geographic data varied, but the data were sufficient to allow a manual identification using Google Earth of the plant of interest (based on location, type, and size) within several miles of the geocoded location. The 2-digit hydrologic unit code (HUC) and 8-digit HUC were assigned to each plant. EPA also collects latitude and longitude information for fossil generating units above 25 MW, available through the Clean Air Markets Division.

Reported cooling system data were checked using Google Earth. Those EGU that did not report a cooling system were located, when possible, via Google Earth, and we identified a cooling type associated with the units. We assumed that generally all units with the same fuel type at one plant used the same cooling structures, unless that was clearly not the case, in which case we either found independent data sources, or surmised which units used different cooling systems based on visual identification. Those EGU that did report cooling systems were located and spot checked.

Comparison of EIA reported cooling type characterizations with observations highlighted some obvious inconsistencies. For example, the W A Parish Generating Station near Thompsons, Texas is reported by EIA as a 'recirculating with cooling pond' plant, while the Fayette Power Project near La Grange, Texas is designated as a 'once-through with cooling pond'. Both of these plants use a closed cooling pond for once-through cooling. 'Cooling pond' was designated for plants such as these that sit on constrained water bodies maintained for their use. Some plants mischaracterize wet-cooled towers as dry-cooled. The Trimble County Station near Bedford, Kentucky lists itself as a 'recirculating, forced draft' cooling system with a 'mechanical, dry' cooling tower. However, direct inspection and public records, including website and company promotional material, show that the plant uses a natural draft (wet) cooling tower.

For each plant identified as requiring cooling, with >60 MW capacity, the cooling type was checked using Google Earth, EIS, state level reports, utility websites, and background internet research of the facility; where necessary, plants were reassigned a cooling system type based on the evidence found. Of the 3576 EGU, 848 units (representing 32% of generation) were manually corrected or had new information added to the database. Only 970 units less than 60 MW of capacity that generated electricity in 2008 did not report to the EIA; these units represented only 1.8% of total generation and were therefore not manually corrected.

Cooling types were reassigned by first determining if the plant had a natural draft or cellular cooling tower structure on-site, or if the plant had a dry-cooling system rack. If neither cooling system could be located, the closest water body was found, and a discharge plume, intake structure, or canal was located for once-through cooling systems. For most plants utilizing once-through cooling, both the intakes and discharge structures are clear, and canals or special cooling diversions in local water bodies can be easily identified. Sites were carefully vetted before it was determined that a plant used a form of once-through cooling. All plant sites that were reported by EIA as having a cooling pond or canal for recirculating or once-through systems were checked using Google Earth.

Our analyses revealed 9 power plants that have cooling towers downstream of their boiler condensation loop, and instead attached these towers to discharge canals or streams. This information was not recorded in the EIA database. These towers, located sufficiently distant from plants with explicitly once-through cooling systems, represent environmental compliance cooling: cooling towers in place to reduce the temperature of effluent. An example of this type of cooling structure can be found at Browns Ferry Nuclear Station near Decatur, Alabama. Under the Clean Water Act of 1972, states can set limits for power plant thermal effluents in order to 'assure the projection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on that body of water' (33 USC Section 1326). Therefore, the plant operates towers to cool effluent when the plant might otherwise violate regulations. Plants with this form of environmental compliance towers have very different cooling and water use characteristics then either once-through or tower-cooled plants. These facilities were designated as once-through, and identified in the database in the 'environmental compliance' column. However, water consumption by these towers is not included in this analysis.

2.4. Generating calculated water withdrawals and consumptive use

Water withdrawal and consumption coefficients for power plants were taken from Macknick *et al* (2011, 2012) and aggregated into functional fuel, prime mover, and cooling system categories. Water coefficients were applied to the database at the EGU scale, with the exception of combined cycle facilities where data was aggregated to the plant scale to reflect the water coefficients available from data for those types of facilities. The median, 90th, and 10th percentile water coefficients (gallons MWh^{-1}) were applied to the best estimate generation (MWh) to calculate a range of water withdrawals and consumption. The revised geolocation data and water type data were used to sort power plants by water resource region. Freshwater use data (from both EIA and as calculated) were then compiled and analyzed on the HUC-2 and HUC-8 level. (Note: freshwater refers to all non-ocean water sources.) Ocean sources were not included because accounting for freshwater use was deemed more relevant for assessing the quality of power plant data in a decision making context.

3. Results and discussion

According to our calculations, total national water withdrawals and water consumption by thermoelectric in 2008 were 51 460 billion gallons (between 25 861 and 73 943 billion gallons) and 1576 billion gallons (between 1050 and 2256 billion gallons), respectively. Of these, 86% of withdrawals and 96% of consumption were from freshwater (non-ocean) sources. According to the 2008 EIA data, total water withdrawals were 53 871 billion gallons and consumptive uses were 4165 billion gallons. Compared with the 2005 USGS value for water withdrawals for thermoelectric (49 084 billion gallons), our median estimate is for water withdrawals 5% higher, and the EIA estimate is 10% higher. Although the USGS does use EIA data to develop thermoelectric water use estimates, ancillary datasets from state agencies, utilities, and individual power plants are used by the USGS for its periodic comprehensive water surveys (Kenny *et al* 2009). For this reason, we should not expect consistency between the USGS and EIA datasets.

Although the aggregate, nationwide estimates of water withdrawals reported by EIA and USGS are near the middle of the range created by the 10th and 90th percentile water withdrawal coefficients, significant regional differences exist between the water information reported to EIA and calculations of freshwater consumption and withdrawal based on the water coefficients (figure 2). (Regional USGS data were not evaluated.) At the water resource region scale (HUC-2), EIA data freshwater use by power plants were below the lower bound of calculations (10th percentile) calculations for both withdrawals and consumption in the Souris-Red-Rainy and Alaskan Basins. For the Great, Rio Grande, Texas-Gulf, and Arkansas Basins, both freshwater withdrawals and consumptive use data as reported exceeded the upper bound of calculations (90th percentile). These indicate trends in over or under reporting in these regions. In other basins, there is no consistent relationship between reported and calculated data for withdrawals and consumptive use.

The differences shown in figure 2 account for the aggregate of many power plants within large regions. These aggregate totals may mask basins where both over and under reporting have occurred. A more refined spatial analysis of the difference between EIA reported and our calculated water use statistics is shown in figures 3(a) and (b). As shown in table 2, EIA reported withdrawal and consumption estimates are below our minimum estimates, based on the 90th percentile water use factors, for 58% and 75% of the power plants, respectively, which corresponds to 50% and 69% of the HUC-8 basins, respectively. At the same time, EIA reported withdrawals and consumed volumes exceed our estimates for 25% and 15% of the HUC-8 basins, respectively. Only 25% and 16% of the HUC-8 basins, and 18% and 12% of the power plants, have EIA reported volumes within the 90th to 10th percentile range of our withdrawal and consumption factors, respectively.

The inconsistencies between reported and calculated water use may be the consequence of unreported or misreported information from power plants reflected in the EIA data, inaccuracies in the literature coefficients, errors in identifying the appropriate coefficient to apply to a particular generation unit, imperfect assumptions in quality control within the database, and missing power plant data.

3.1. Application of the water use coefficients

The large ranges between our lower and upper estimates reflect the ranges in withdrawal and consumption factors reported in Macknick *et al* (2011, 2012). The use of water use coefficients for calculations requires simplifying assumptions that contribute to the observed discrepancies between reported and calculated data. Imprecisions or inaccuracies in this analysis carry over from the use of unmodified, published data in developing those coefficients, which may have inconsistent boundary conditions (e.g., inclusion of water use for auxiliary

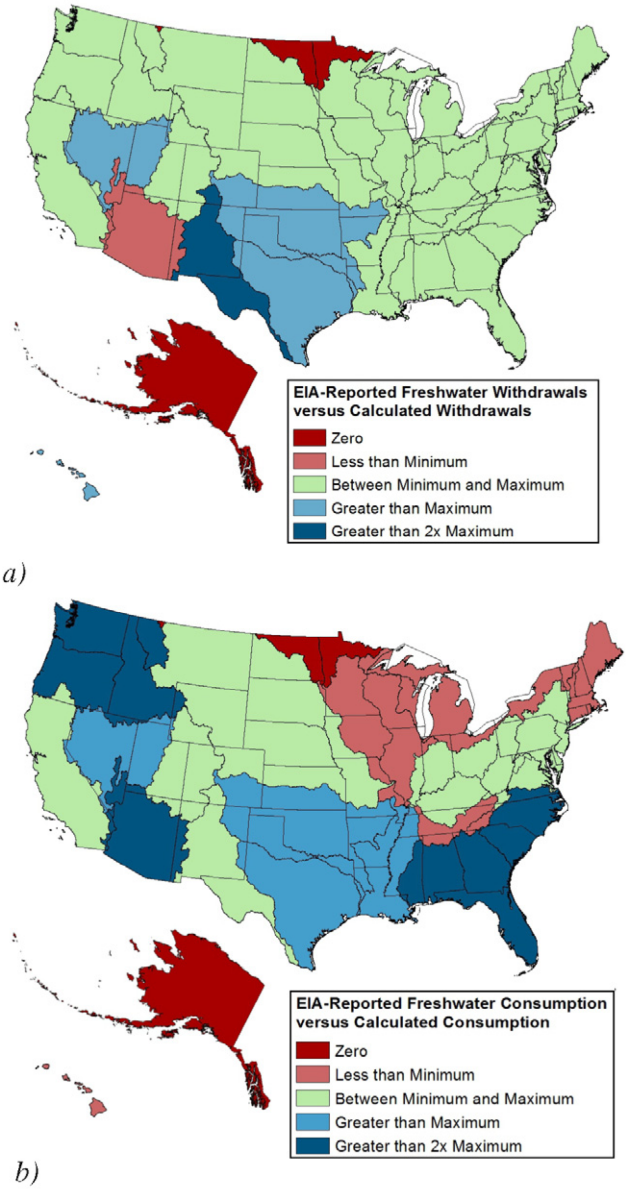

Figure 2. Difference between freshwater withdrawals (a) and freshwater consumption (b) reported by the EIA and calculations using water coefficients. The sum of reported EIA withdrawals and consumption for each HUC-2 basin is compared against the range created by the sum of our withdrawal and consumption estimates, respectively, which have endpoints corresponding to the 90th and 10th percentile withdrawal and consumption factors. If reported withdrawal or consumption exceeds our maximum estimate, it is binned as being either up to or greater than twice that maximum estimate. If it is between our minimum to maximum estimates, or less than our minimum estimate, it is binned as such. Regions with no reported withdrawals or consumption are binned as having ‘zero’ withdrawals or consumption, respectively.

processes in addition to cooling), are uneven in the number of data sources covering certain fuel-technology-cooling system combinations, and may utilize different methods for collecting water use information (Macknick *et al* 2011, 2012). In addition, the numbers underlying the coefficients represent national annual averages, thus omitting variations in water use data that may result from differences in geography as well as seasonal climatic conditions (Miller *et al* 1992, Giusti and Meyer 1977, Rutberg *et al* 2011). The dataset also does not consider the plant age, thermal efficiency, cooling system age, or water resource type, which can affect water usage (Yang and Dziegielewski 2007, Dziegielewski and Bik 2006). Lastly, the analysis aggregated fuel technology types (e.g., all coal steam plants with similar cooling systems were assumed to have the same water use rates) and cooling technology types (e.g., all pond-cooled systems for a particular prime mover type were assumed to have the same water use rates), thus reducing the granularity of power plant specific characteristics that could affect an individual plant’s water usage. Further discrepancies may arise from the simplifying assumptions and decisions made in refining the database (i.e. geolocation, EGU breakdown, cooling process designation).

Considering all these caveats, using the full range (between the 10th and 90th percentiles) for assessing the quality of the EIA reported data offers generous bounds for the expectations for reported data.

3.2. Unreported water use data

Compared with our calculations, more than 40% of the both total freshwater consumed and total withdrawn by power plants was unreported or misreported to EIA. Beginning in 2002, nuclear facilities were no longer required to report information to the EIA. Based on application of the water coefficients to reported electricity generation, freshwater for cooling of nuclear power plants accounted for 24% of the total calculated water consumed nationally by the electricity sector, and 27% of total calculated withdrawals. However, when nuclear power plants are omitted from our calculations, large differences with the EIA reported data still exist. In fact, as shown in table 3, the discrepancies between EIA reported data and our calculated 90th to 10th percentile range estimates do not differ substantially when nuclear power plants are excluded from our calculations versus when they are not. Removing nuclear power plants increases the EIA reported estimates versus our estimates, but it does not substantially alleviate the apparent reporting discrepancies.

Another water use missing from the EIA data are non-nuclear power plants that extract water for cooling but report no water withdrawals or consumptive uses. According to our analysis of the 2008 EIA data, more than 1000 water-cooled units that generated over 100 MWh of electricity each reported no water withdrawals or consumption. This missing fraction accounted for 4% of total calculated freshwater withdrawals and 6% of total freshwater consumption by power plants required to report to the EIA. Of these facilities, coal-fired power plants accounted for 69% of the unreported freshwater consumed and 80% of unreported freshwater withdrawals.

3.3. Misreported data

Although unreported data and assumptions inherent in calculations contribute to the observed discrepancies, large

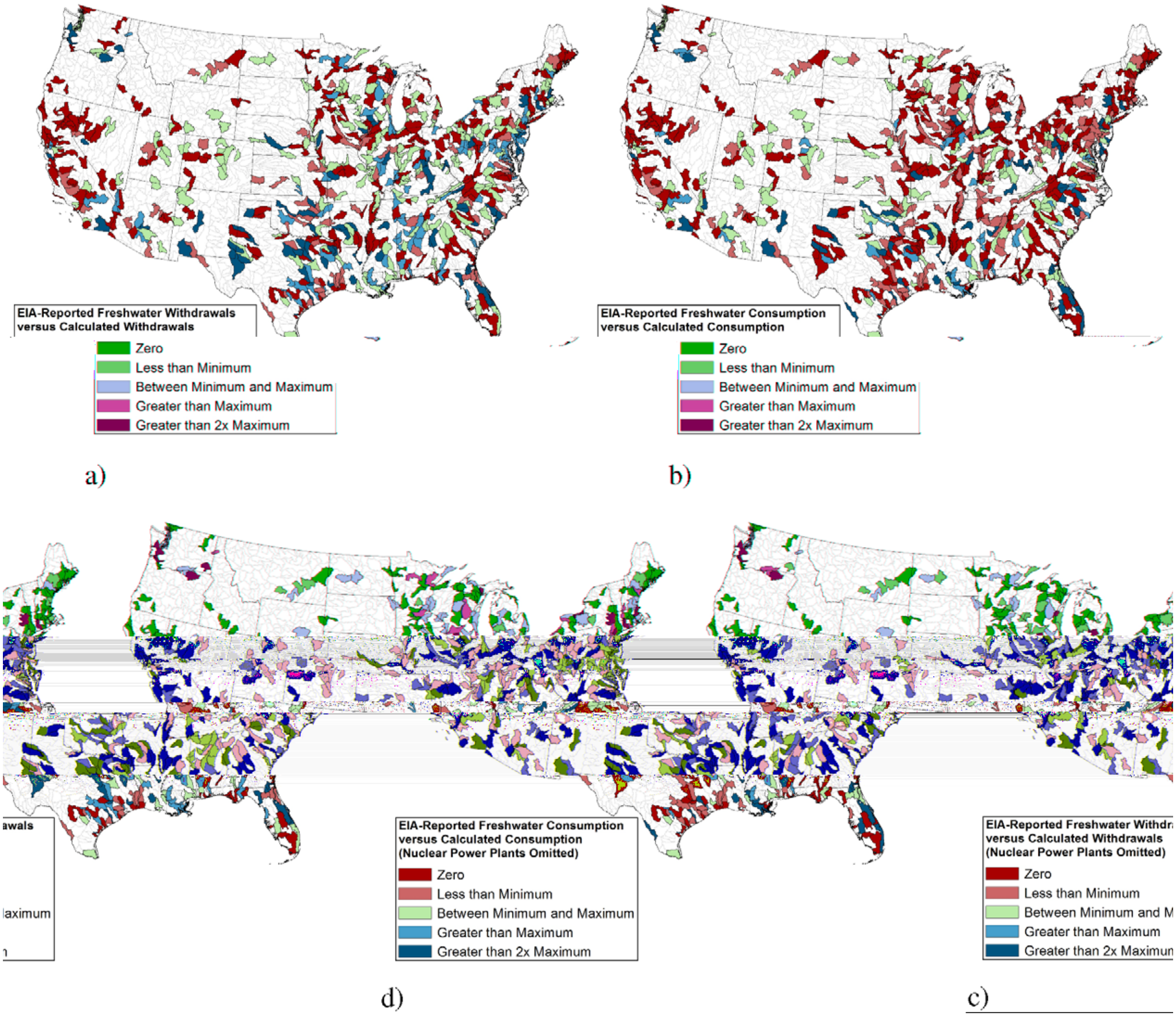

Figure 3. Difference between (a) freshwater withdrawals and (b) freshwater consumption reported by the EIA and calculations using water coefficients at the HUC-8 scale. Figures (c) and (d) show the same data with the nuclear power plant data (which was not required in 2008) omitted. Calculations and the key are the same as described in figure 2.

Table 2. Number and percentage of HUC-8 basins and individual plants for which the sum of reported EIA withdrawals and consumption lie above, within, or below our estimated range of withdrawals and consumption, respectively, as determined by the endpoints corresponding to the 90th and 10th percentile withdrawal and consumption factors.

	Withdrawal		Consumption	
	Count	Percentage	Count	Percentage
HUC-8 basins				
Less than 10th percentile	309	50	426	69
Within range	156	25	102	16
Greater than 90th percentile	155	25	92	15
Power plants				
Less than 10th percentile	709	58	928	75
Within range	226	18	150	12
Greater than 90th percentile	296	24	153	12

differences between the two datasets remain unaccounted for. While reporting to the EIA is mandatory, the data were not thoroughly vetted and little feedback was provided to generators on data quality or consistency GAO (2009). Generators were also not required to use standard mechanisms to record volumetric water use information; the 2008 EIA form 923 instructs that 'if actual data are not available, provide an estimated value', but there is no requirement to document the estimation method used. The 2008 EIA form also requested that operators record water withdrawals and discharge in average cubic feet per second (CFS). Consumption is given as the difference between withdrawals

Table 3. Number and percentage of HUC-8 basins and individual power plants for which the sum of reported EIA withdrawals and consumption lie above, within, or below our estimated range of withdrawals and consumption, respectively, as determined by the endpoints corresponding to the 90th and 10th percentile withdrawal and consumption factors, excluding nuclear power plants from the calculations. Note that HUC-8 basins with no thermoelectric power plants other than nuclear plants are omitted.

	Withdrawal		Consumption	
	Count	Percentage	Count	Percentage
HUC-8 basins				
Less than 10th percentile	283	47	408	67
Within range	159	26	103	17
Greater than 90th percentile	164	27	95	16
Power plants				
Less than 10th percentile	653	56	872	74
Within range	226	19	150	13
Greater than 90th percentile	296	25	153	13

and discharge. Based on analysis of the EIA database, most operators assumed that the CFS value should represent the annual average withdrawals and discharge rate for each cooling system, if the plant were operating continuously throughout the entire year. Therefore, absolute annual withdrawals and consumption were often reported as the product of the rate (in CFS) multiplied by the seconds in a year (31.5 million).

Further, the terms ‘withdrawals’ and ‘consumption’ have different meanings when the layout of a plant’s cooling system is more complicated than a single intake or discharge, and the cooling technologies offered in the 2008 version of the EIA form do not necessarily represent the array of technologies actually used in practice. For example, there are power plants located on natural waters that are once-through facilities, but use evaporative towers to reduce effluent water temperatures. There is no categorization that captures this type of cooling orientation, and the water consumed by these cooling towers is not accounted for by EIA.

The 2008 EIA dataset is of highly variable data quality across the industry. For example, data on unit nameplate capacity and quantities of fuel consumed are highly specified and quantified variables used widely across the energy sector and are therefore fairly consistently reported. In contrast, the variables associated with water withdrawals and consumption were not currently connected to existing statute[9] and are not regularly reviewed by either state or federal entities.

Taken together, misreported water use information is undoubtedly contributing to the discrepancies shown in figure 3, but the impact of each individual error cannot be identified separately with the available information.

4. Conclusion

This analysis demonstrates the existence of substantial problems with the quality of existing data and supports the assertion that better reporting is needed if collected information is to be useful. Currently, the EIA is the only entity that collects annual water use by power plants across the US. The EIA already introduced improved data collection measures in 2009 and 2010, including a new requirement for power plants (including nuclear and thermoelectric renewables) to report water use. However, the methods employed here to evaluate the EIA 2008 dataset provide insight into how data collection may be further enhanced. Improved power plant geolocation data, and refined water source information (including water quality designation, and specific sources), will allow for greater utility of EIA water data for use in the water sector. Similarly, comparison of the reported and calculated freshwater use data highlights the relative importance of these quality data.

We found no apparent systematic biases in EIA compiled data, but rather several factors in combination create problems with both the calculated and reported datasets. Additional insight into the sources of these discrepancies could come from improved knowledge of the method for reporting water use, and more specific information about the cooling technologies used at a given power plant in the EIA datasets. Improved data about water use within a large sector of the US portfolio will enable water planners to improve assessment of resources across multiple scales. The new database, developed from extensive vetting of the best available data, offers a consistent dataset that may be of general use for water and electricity planners.

Considering that this analysis (along with EIA and USGS data collection methodologies) does not account for the water use associated with approximately 15% of annual US electricity generation, the water data compiled here are a modest accountings of thermoelectric water demands. The lack of any information regarding the water use by this fraction is an additional uncertainty that water planners may need to consider.

Improvements in EIA’s data collection would enhance data quality, and make federal water data more useful for water managers (GAO 2009). For arid states such as in the southwestern US, and other regions prone to drought such as the southeast, the misrepresentation of water withdrawals and consumption in federal data sets may be problematic for

[9] In 2011, EPA proposed a revised rule governing water intake structures at utility steam plants, which sets specific withdrawal thresholds (in millions of gallons per day) at which plants which obtain NDPES Permits must perform studies or mitigate damages to aquatic ecosystems from ‘impingement’ (when aquatic organisms become pinned to high velocity intake screens) and ‘entrainment’ (when organisms are pulled into intake and cooling structures).

regional water planning. Reporting of water use exceeding practical boundaries can also hinder management, particularly across integrated portfolios in places where water is scarce or reserves are unknown. Accounting for water demands is important for effectively managing supplies, particularly given the changing nature of domestic water resources (Karl *et al* 2009).

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