Energy-Water Crosscut Program Support (LCA)

NATIONAL ENERGY TECHNOLOGY LABORATORY

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Solutions for Today | Options for Tomorrow

U.S. DEPARTMENT OF ENERGY

Introduction

- **Thermoelectric power is the largest sector responsible for water withdrawals**
- **Investigate reliability for power plants in responding to changes in water resource scarcity**
- **Develop a robust and efficient method of determining water use for power generation sector**
- **Identify plants that have large water stress footprints (WSF) and thus opportunities for improvements**

Dieter, C.A., Maupin, M.A., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2018, *Estimated use of water in the United States in 2015*: U.S. Geological Survey Circular 1441, 65 p., https://doi.org/10.3133/cir1441.

Thermoelectric Water Consumption

Agenda

- Characterizing monthly thermoelectric water consumption at the plant level – data sources and representativeness
- Ranking of water consumption by thermoelectric plants regionally
- Water Scarcity Assessment – overview of next steps to integrate monthly plant water consumption characterizations into AWARE-US model (Available Water Remaining US at the county level lower 48 - ANL)

Data Sources

- **EIA-860 and EIA-923**
  - EIA-923 provides annual data on power generation and fuel consumption for power plants
  - EIA-860 collects information about generators and environmental data at power plants
- **NREL**
  - Data on minimum and maximum ranges for a wide range of generator-cooling technology types (Macknick 2011)
- **USGS**
  - Estimated use of water in the United States in 2015

EIA Data Filtering and Aggregation

- **Retired and canceled generators were removed**
  - cancelled prior to completion & operation
  - retired generators at existing plants
- **Unique pairing codes created**
  - E.g., generator and cooling codes were paired
- **Recirculating water-cooling technologies were combined**
  - Similar in technology and consumption
  - Recirculating – Induced Draft, Forced Draft, and Natural Draft

Code	Cooling System Description
OC	Once through with cooling pond
ON	Once through, with no cooling pond
RC	Recirculate: Cooling Pond
Rt	Recirculate: Forced Draft
Rt	Recirculate: Induced Draft
Rt	Recirculate: Natural Draft
DC	Dry Cooling
HRI/HRF	Hybrid: Dry and Induced/Forced Draft
OT	Other

Code	Generation System Description
CGCC	Coal Integrated Gasification Combined Cycle
CSC	Conventional Steam Coal
OG	Landfill Gas
MSW	Municipal Solid Waste
NGCC	Natural Gas Fired Combined Cycle
NGSC	Natural Gas Steam Turbine
NU	Nuclear
OG	Other Gases
OWB	Other Waste Biomass
PC	Petroleum Coke
PL	Petroleum Liquids
ST	Solar Thermal with Energy Storage
ST	Solar Thermal without Energy Storage
WB	Wood/Wood Waste Biomass

EIA Data Representation & Quality Assessment

- **Empty entries present in EIA data**
  - 33.1% of entries have neither water withdrawal or consumption values
  - 23.7% of net generation entries are blank
- **Blanks populated by**
  - Merging data
  - Calculations
- **Mismatched data**
  - Cooling units listed in EIA-923 but not in EIA-860
  - Cooling units in EIA-860 but no consumption
    - Average consumption used for generator-cooling technology

Summer Capacity of Steam Turbines (MW)	Gross Generation from Steam Turbines (MWh)	Net Generation from Steam Turbines (MWh)	Water Withdrawal Volume (million gal)	Water Consumption Volume (million gal)	Water Withdrawl Intensity Rate (gal/MWh)	Water Consumption Intensity Rate (gal/MWh)
249			4,028	0		
249			5,818	0		
249			3,677	0		
249			3,250	0		
249			2,552	0		
249			3,927	0		
249			4,012			
249			2,552			
249			3,514	0		
249			1,491			
249			4,630			
249			2,685	0		
55	2,181	1,760	4,028	0		
55	1,608	1,176	5,818	0		
55	0	-173	3,677	0		
55	0	-163	3,250	0		
55	0	-269	2,552	0		
55	3,019	2,326	3,927	0		
55	4,660	3,749	4,012			
55	0	-338	2,552			
55	0	-264	3,514	0		
55	0	-179	1,491			
55	0	73	4,630			
55	0	-252	2,685	0		

Duplicate Entry Errors

Barry Plant in Alabama, 2015

- **Multiple combinations of generators, boilers, and cooling units**
- **E.g. Barry Plant in AL**
  - Generator 4 & 5 both tied to cooling units 4 & 5
  - Water use reported based on cooling unit
  - Counting the same withdrawal and consumption twice
  - Allocation is necessary

Plant Name	Year	Month	Generator ID	Boiler ID	Cooling ID	Water Withdrawal (million gal)	Water Consumption (million gal)
Barry	2015	1	4	4	4-5	6,188	308
Barry	2015	2	4	4	4-5	8,119	59
Barry	2015	3	4	4	4-5	16,895	368
Barry	2015	4	4	4	4-5	19,266	78
Barry	2015	5	4	4	4-5	16,021	237
Barry	2015	6	4	4	4-5	19,838	372
Barry	2015	7	4	4	4-5	20,482	653
Barry	2015	8	4	4	4-5	19,899	477
Barry	2015	9	4	4	4-5	19,706	452
Barry	2015	10	4	4	4-5	17,508	32
Barry	2015	11	4	4	4-5	17,297	298
Barry	2015	12	4	4	4-5	18,457	174
Barry	2015	1	5	5	4-5	6,188	308
Barry	2015	2	5	5	4-5	8,119	59
Barry	2015	3	5	5	4-5	16,895	368
Barry	2015	4	5	5	4-5	19,266	78
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Barry	2015	8	5	5	4-5	19,899	372
Barry	2015	9	5	5	4-5	19,706	653
Barry	2015	10	5	5	4-5	17,508	477
Barry	2015	11	5	5	4-5	17,297	452
Barry	2015	12	5	5	4-5	18,457	32
Barry	2015	1	A1CT	U6C	U6C		62

Water Use Allocation

Outlier Analysis for Multitype Plants

- **Allocated water use among multiple generator-to-cooling types**

Plant Code	Plant Name	Month	Generator ID	Cooling ID	Net generation (MWh)	Generator Count	Ratio split	Total Water Consumption Adjusted (million gal)	Water Consumption Intensity Adjusted (gal/MWh)
3	Barry	1	4	4-5	56352	2	0.35	108	1908
3	Barry	2	4	4-5	144128	2	0.35	21	142
3	Barry	3	4	4-5	153587	2	0.35	128	835
3	Barry	4	4	4-5	150186	2	0.35	27	182
3	Barry	5	4	4-5	167995	2	0.35	83	493
3	Barry	6	4	4-5	142640	2	0.35	130	910
3	Barry	7	4	4-5	172826	2	0.35	228	1318
3	Barry	8	4	4-5	114060	2	0.35	166	1458
3	Barry	9	4	4-5	130105	2	0.35	158	1211
3	Barry	10	4	4-5	122865	2	0.35	11	91
3	Barry	11	4	4-5	106193	2	0.35	104	978
3	Barry	12	4	4-5	116235	2	0.35	61	522
4	Barry	1	5	4-5	-3371	2	0.65	201	n/a
5	Barry	2	5	4-5	-4544	2	0.65	38	n/a
3	Barry	3	5	4-5	249318	2	0.65	239	960
3	Barry	4	5	4-5	340151	2	0.65	51	150
3	Barry	5	5	4-5	109351	2	0.65	155	1414
3	Barry	6	5	4-5	380250	2	0.65	242	637
3	Barry	7	5	4-5	420389	2	0.65	425	1012
3	Barry	8	5	4-5	413282	2	0.65	310	751
3	Barry	9	5	4-5	367997	2	0.65	294	799
3	Barry	10	5	4-5	217971	2	0.65	21	95
3	Barry	11	5	4-5	206431	2	0.65	194	939
3	Barry	12	5	4-5	238501	2	0.65	113	475

Outlier Analysis

Outlier Analysis for Monotype Plants

- **Interquartile range analysis**
  - Found outlier boundaries
- **Replaced outliers w/ average values based on power plant type**
- **Reassigned extreme generator-cooling types**

Gen-Cool	Water Consumption Intensity Rate (Gallons / MWh)
CSC-OC	234
CSC-ON	92
CSC-RC	457
CSC-Rt	416
NGCC-Rt	226
NGSC-ON	432
NGSC-RC	2448
NGSC-Rt	541
NU-ON	27
NU-Rt	594
OG-ON	25288
OT-Rt	538
PC-Rt	120
PL-Rt	728
WB-Rt	488

Outlier Analysis

Outlier Analysis for Multitype Plants

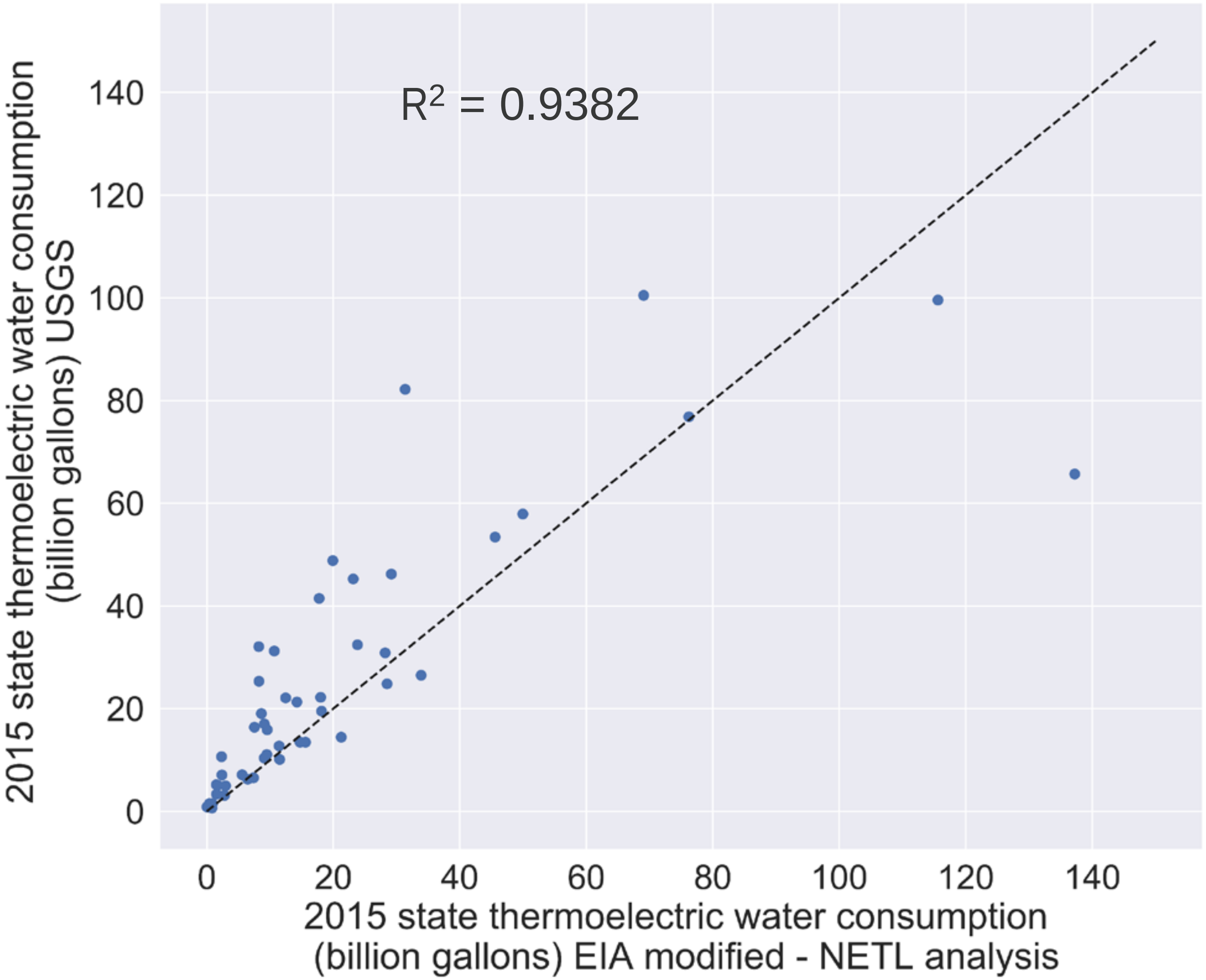
- **Smooth out monthly anomalies**
- **Final outlier replacement**
  - Median values used
  - Updated multi-type allocation factors
- **Exported to Excel**

Plant Code	Plant Name	Year	Month	Generator ID	Cooling ID	Cooling Type	Generator Type	Water Consumption Intensity Rate (gal/MWh)	Water Consumption Intensity Adjusted (gal/MWh)
628	Crystal River	2015	1	5	5	Rt	CSC	622	444
628	Crystal River	2015	3	5	5	Rt	CSC	408	408
628	Crystal River	2015	5	5	5	Rt	CSC	279	279
628	Crystal River	2015	6	5	5	Rt	CSC	191	444
628	Crystal River	2015	7	5	5	Rt	CSC	338	338
628	Crystal River	2015	8	5	5	Rt	CSC	489	444
628	Crystal River	2015	10	5	5	Rt	CSC	904	481
628	Crystal River	2015	11	5	5	Rt	CSC	0	444
628	Crystal River	2015	12	5	5	Rt	CSC	1784	481

Comparison of NETL/EIA Data to USGS

State-Level, 2015

- **Aggregated by state**
- **USGS tends to show higher values**
  - Use of theoretical modeling vs. reported values
  - Any point on the dotted line indicates a perfect match between USGS & NETL's modified EIA data

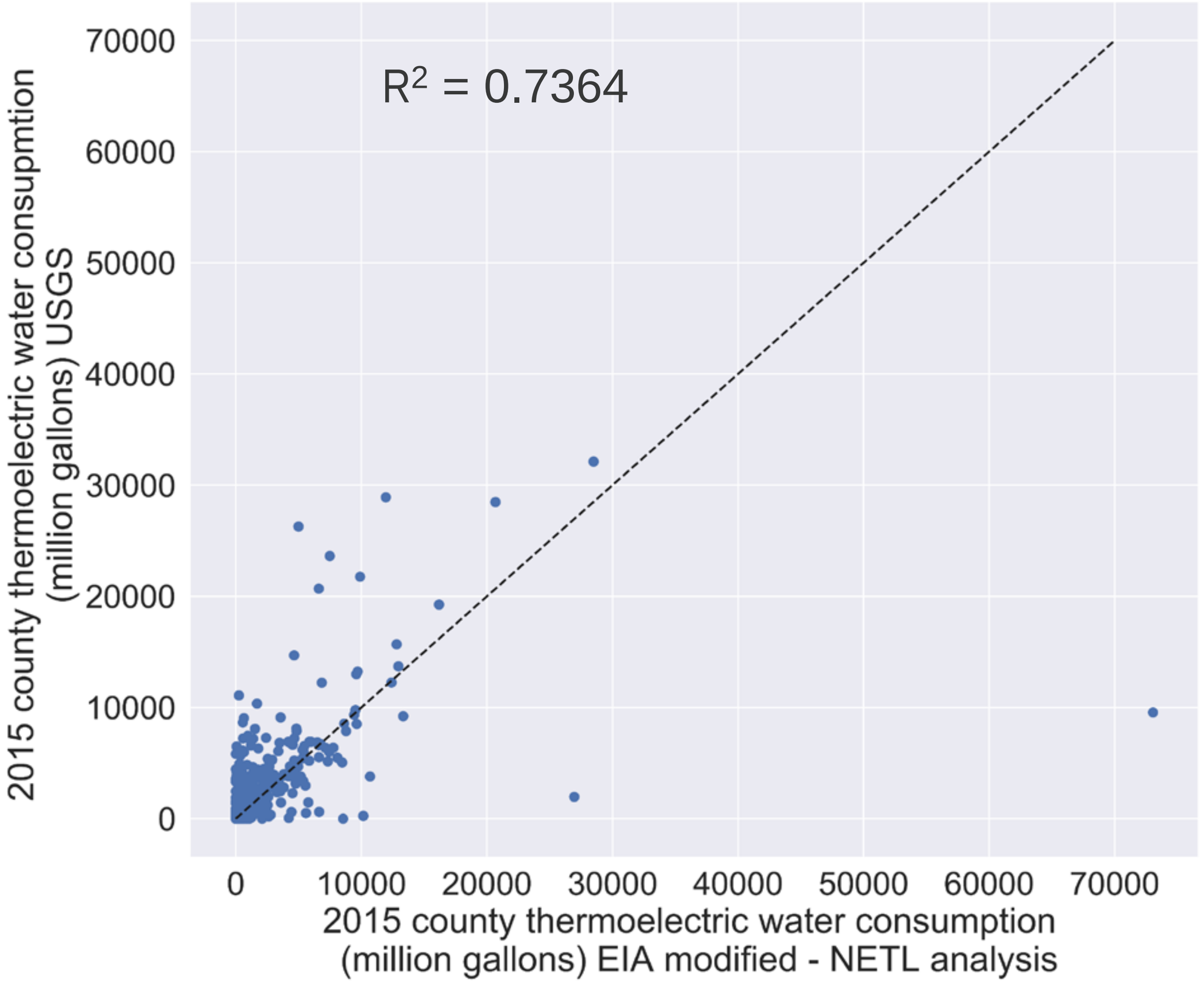


Dieter, C.A., Maupin, M.A., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2018, *Estimated use of water in the United States in 2015*: U.S. Geological Survey Circular 1441, 65 p., https://doi.org/10.3133/cir1441.

Comparison of NETL/EIA Data to USGS

County-Level, 2015

- **Aggregated by county**
- **USGS tends to have higher values again**
- **NETL outlier from Martin plant in Florida**
  - In the process of exploring this plant in more detail



Quality Check

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- **NREL published a water consumption and withdrawals review in 2011**

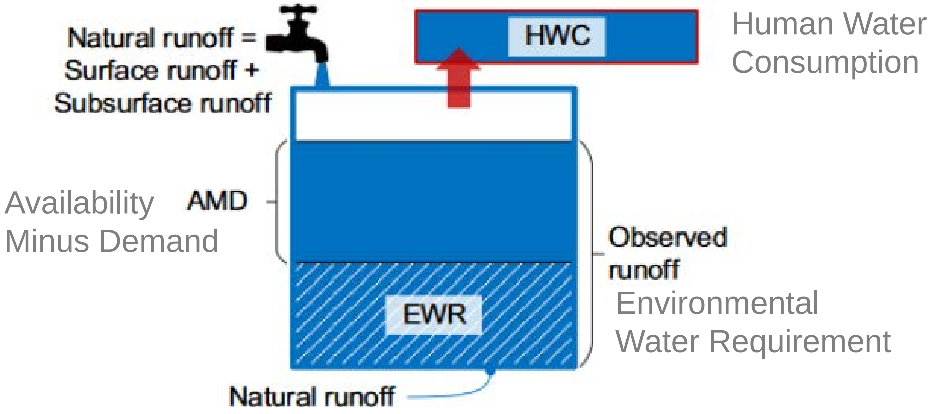
- **Checked against NREL water consumption estimates**
  - 75% match in gal/MWh (every units for every month)
  - Additional 12% within +/-100 gal/MWh

Fuel Type	Cooling Technology	Technology	Median (gal/MWh)	Min (gal/MWh)	Max (gal/MWh)
Nuclear	Tower	Generic	672	581	845
	Once-through	Generic	269	100	400
	Pond	Generic	610	560	720
Natural Gas	Tower	Combined Cycle	198	130	300
		Steam	826	662	1170
	Once-through	Combined Cycle	100	20	100
		Steam	240	95	291
	Pond	Combined Cycle	240	240	240
	Dry	Combined Cycle	2	0	4
	Inlet	Steam	340	80	600
Coal	Tower	Generic	687	480	1100
		IGCC	372	318	439
	Once-through	Generic	250	100	317
	Pond	Generic	545	300	700
CSP	Tower	Trough	865	725	1057
		Power Tower	786	740	860
	Dry	Trough	78	43	79
		Power Tower	26	26	26
	Hybrid	Trough	338	105	345
		Power Tower	170	90	250
Biopower	Tower	Steam	553	480	965
		Biogas	235	235	235
	Once-through	Steam	300	300	300
	Pond	Steam	390	300	480

J. Macknick, R. Newmark, G. Heath, K. Hallett, 2011. *A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies*, Technical Report NREL/TP-6A20-50900 (Accessed Nov. 13, 2018)

Definitions and Equations

EWR is the amount of water required to sustain a riverine ecosystem.

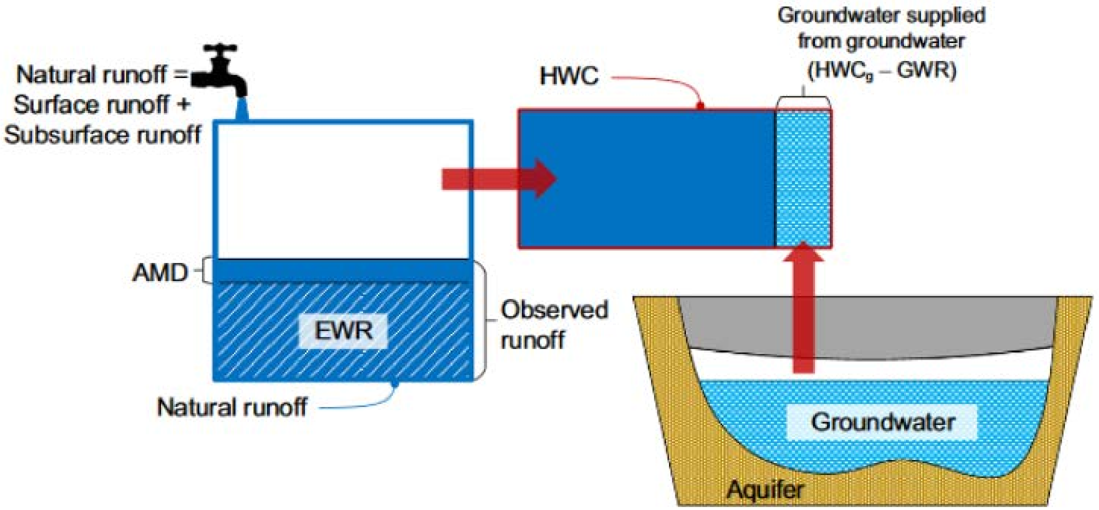


Availability Minus Demand (AMD)

$$AMD_i = [Natural\ runoff - HWC - EWR]_i$$

Available Water Remaining Characterization Factor

$$[AWARE\ CF]_i = \frac{AMD_{ref}}{AMD_i}$$

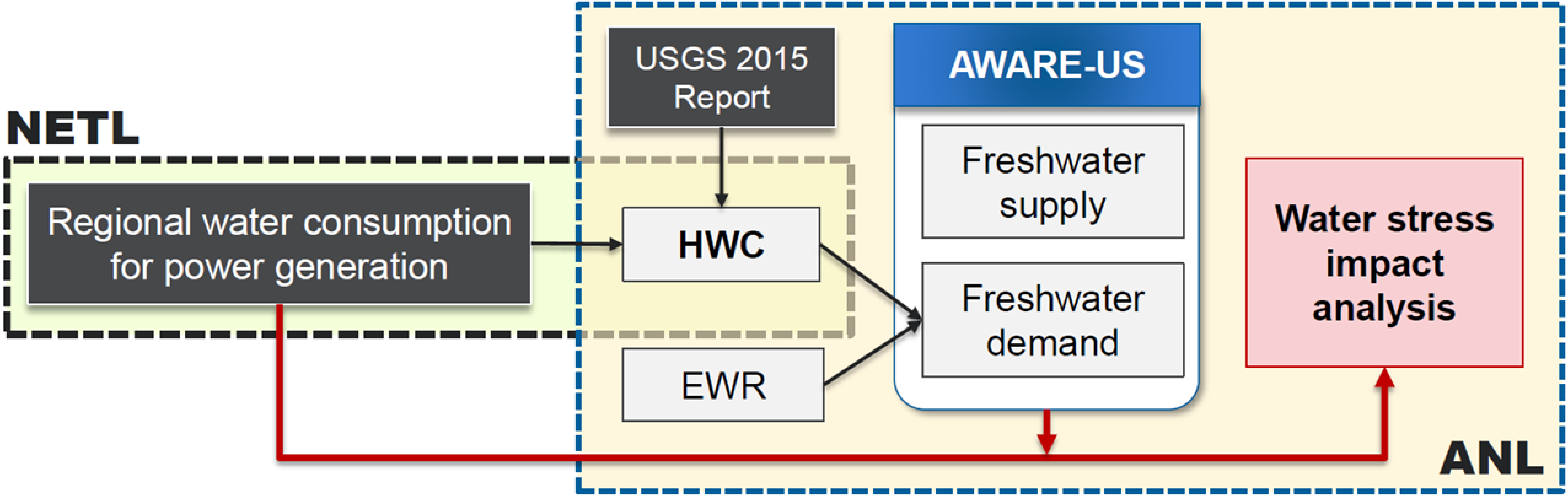


Water Scarcity Footprint

$$[Water\ scarcity\ footprint]_i\ (m^3 eq.) = [Water\ consumption]_i\ (m^3)\ x\ [AWARE\ CF]_i$$

Lee, Uisung, et al. "AWARE-US: Quantifying water stress impacts of energy systems in the United States." *Science of the total environment* 648 (2019): 1313-1322.

Collaboration with NETL and ANL



Human Water Consumption (HWC)

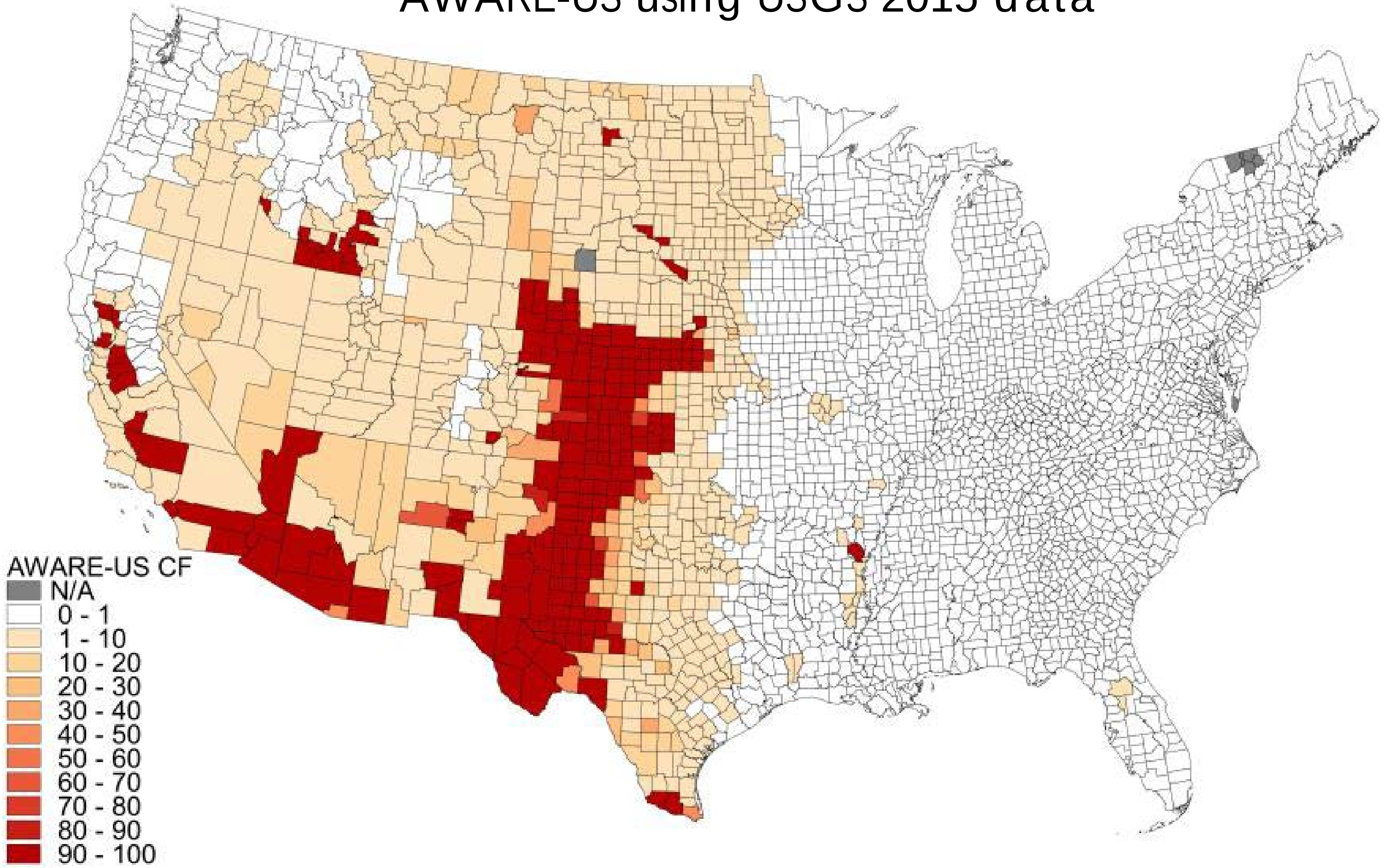
Environmental Water Requirement (EWR) is the amount of water required to sustain a riverine ecosystem.

AWARE-US

Water Stressed Counties

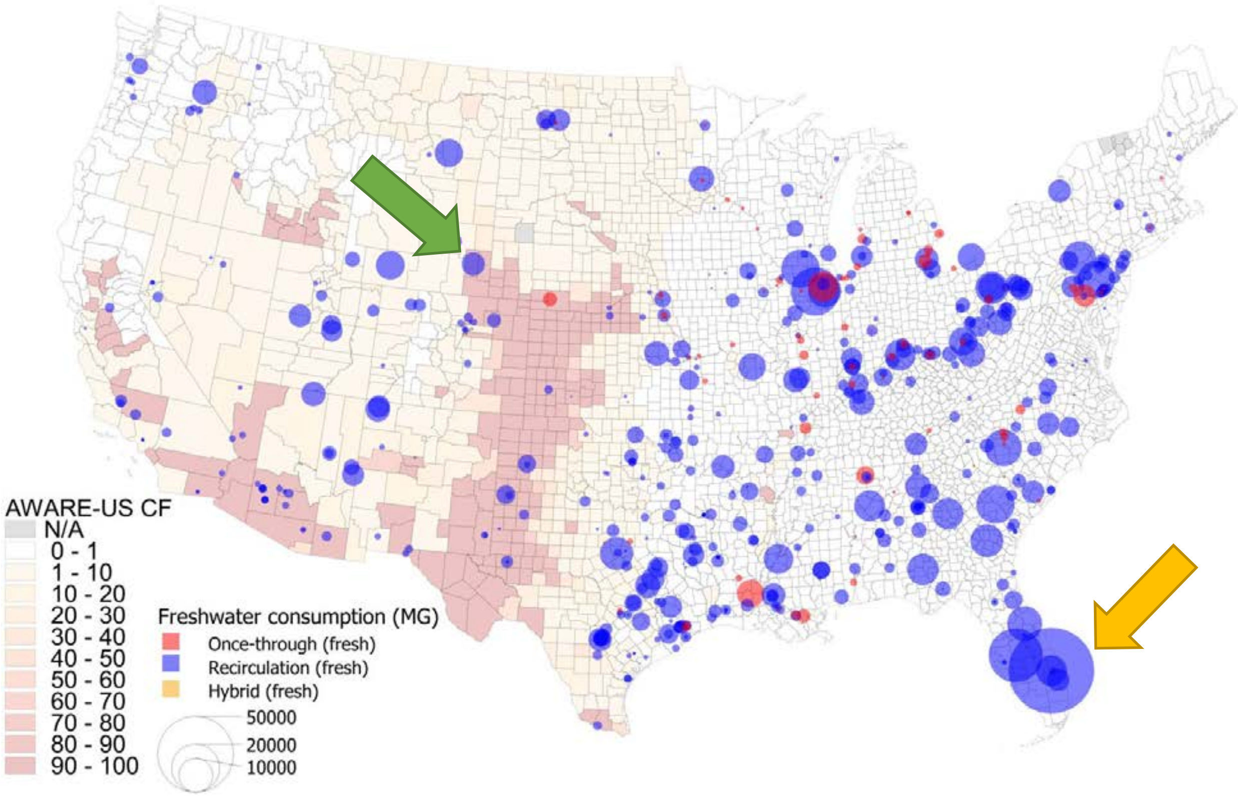
- **Developed by Argonne National Lab(ANL)**
- **Builds off Available Water Remaining (AWARE)**
  - Watershed Level
- **AWARE-US**
  - County level detail in the contiguous US
  - Focus on impacts from energy systems

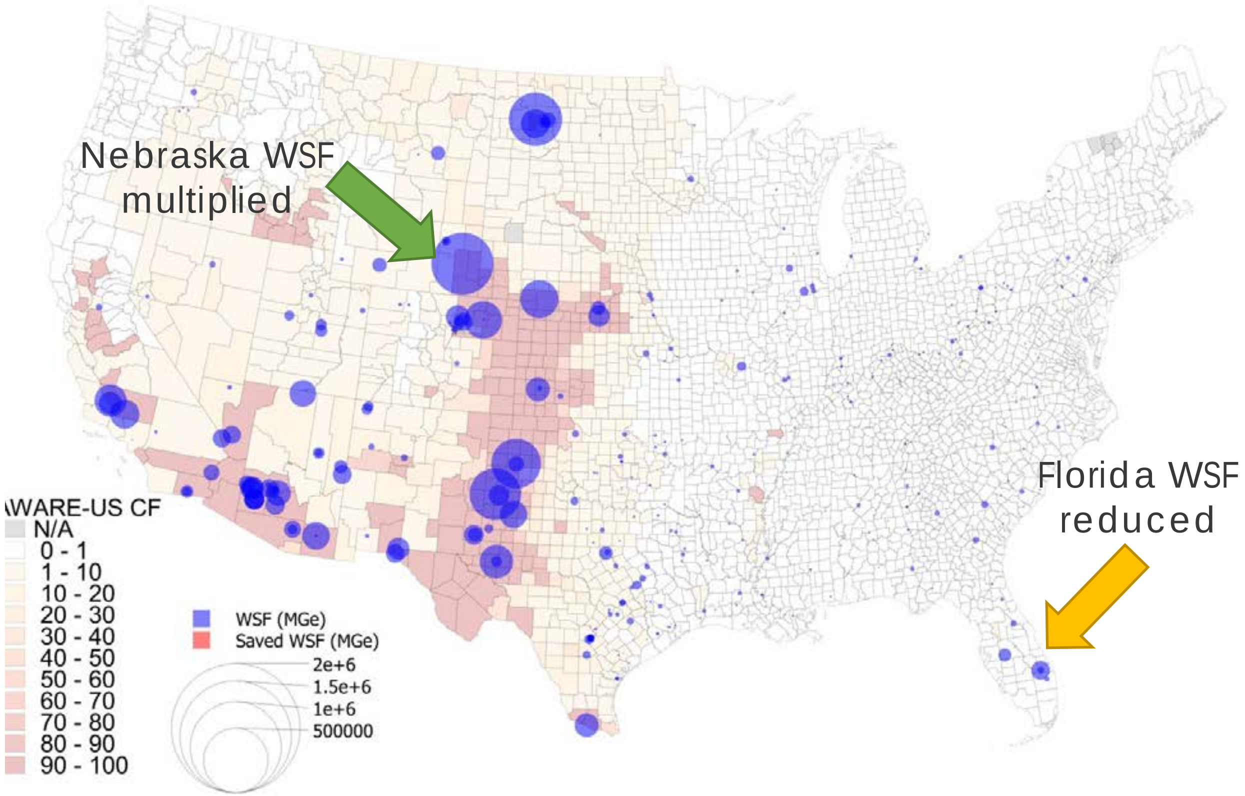
AWARE-US using USGS 2015 data



Water Scarcity by AWARE-US

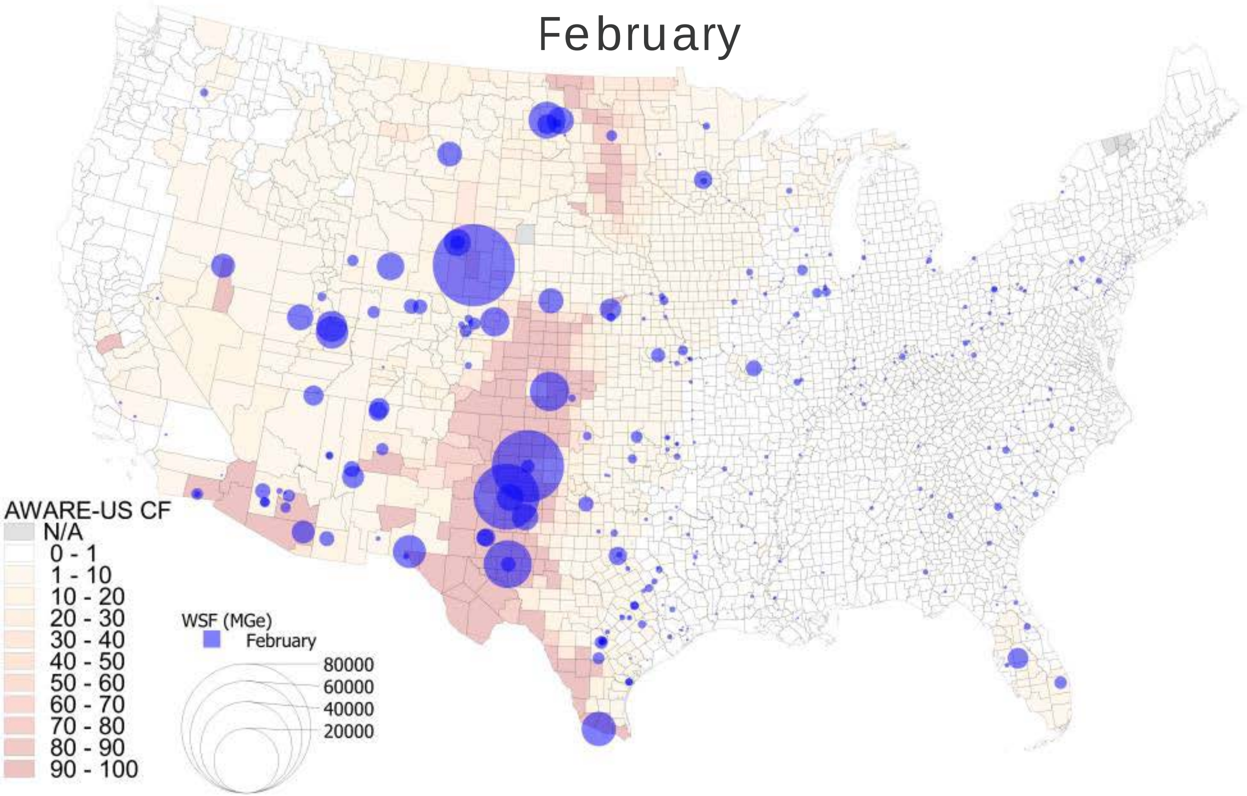
- Thermoelectric Cooling Consumption (Left) vs. Water Scarcity Footprint (WSF) (Right)
- Large WSFs due to thermoelectric demands are located where AWARE-US is high

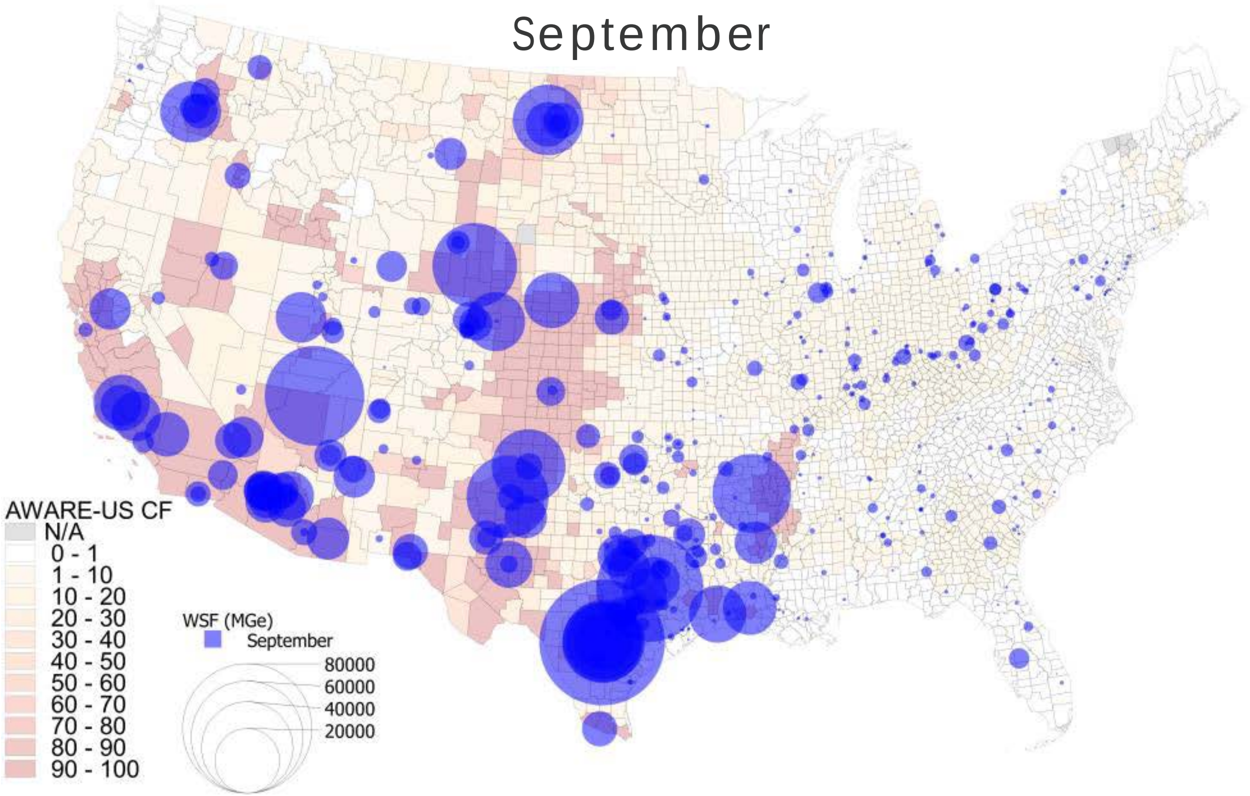




NETL Data with AWARE-US

- **Seasonal variation in Water Scarcity Footprints (WSF) using AWARE-US Characterization Factors (CF)**
- **Impacts from thermoelectric cooling water use change significantly based on scarcity**





Highlights

- **Used python to efficiently process the EIA datasets**
  - Easily evaluate any year
  - Reduces processing error and time

- **Scrubbed monotype plant data used to replace outlier values for multitype plants**

- **Water consumption for NETL data falls within expected ranges**
  - Sorted by cooling technology
  - Normalized per MWh basis

Future work

- **Continue to analyze data**
  - Work in parallel with ANL for feedback on data analysis
  - Explore outliers in NETL and USGS dataset
  - Further refine outlier analysis for EIA/NETL dataset

References

Dieter, C. A., Maupin, M. A., Caldwell, R. R., Harris, M. A., Ivahnenko, T. I., Lovelace, J. K., ... & Linsey, K. S. (2018). Estimated use of water in the United States in 2015 (No. 1441). US Geological Survey.

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