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Research Poster Summary

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Title: A model for relating environmental variation to water permit violations at thermoelectric facilities

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Abstract:

A regression model is presented which relates cooling water withdrawal rates and discharge temperatures at two mid-size thermoelectric facilities to electricity demand and ambient air temperature using historical data. Both facilities employ open-loop cooling systems, which have substantial water demands. Open-loop facilities comprise roughly one third of U.S. generation capacity. High water demands put facilities and downstream aquatic habitats at risk during heat waves and droughts, and put facility managers in a position to decide between reducing their power generation and violating their permit limits. National Pollutant Discharge Elimination System (NPDES) permits place limits on cooling water withdrawals and effluent (discharge) temperatures. Human health is put at risk when power plants fail to generate electricity. The flora and fauna of receiving waters are put at risk when effluent temperatures and/or withdrawal rates are too high. Two power plants in Massachusetts were chosen as suitable case studies. A multi-decadal database of daily air temperatures, and monthly electricity generation values, water withdrawal rates, and industrial wastewater discharge temperatures was compiled from National Climate Data Center records, Energy Information Administration records, and state environmental records. Results of a multiple linear regression analysis suggest that air temperature and electricity demand are useful predictors of effluent temperatures, but poor predictors of water withdrawal rates.

Key Words: energy, water, NPDES permitting, thermoelectric, cooling

Introduction

Steam-cycle thermoelectric generation facilities (power plants) need water to create electricity. In the case of open loop cooled power plants, the quantity of water used is often very large. Open loop cooled power plants withdraw water from local water resources and then discharge the water back into the resources at a higher temperature. To do so, they must obtain **National Pollutant Discharge Elimination System** (NPDES) permits, which are meant *to limit withdrawal rates and discharge temperatures for the purposes of aquatic ecosystem conservation* (DOE, 2006).

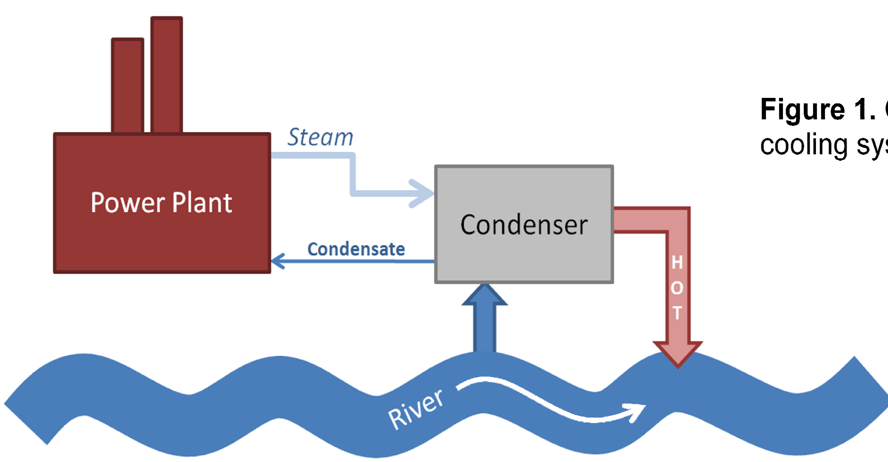


Figure 1. Open loop cooling system.

Graphic: Sheldon, S., 2011

Materials and methods

Two power plants in Massachusetts were chosen as case studies based on plant age (40+ years old), generator system type (steam-cycle), cooling system type (open loop), generation capacity (100-300 megawatts), proximity to Clean Water Act §303(d) listed impaired surface waters, and data availability. They are **Cleary-Flood** Power Plant and **Somerset** Power Generating Station on the Taunton River (see below).

Dziegielewski et al. (2006) identified ambient air temperature and net electricity generation as significant predictors of water withdrawal rate and effluent (discharge) temperature. Air temperature and electricity generation vary by season (see box plots on page 3). Average daily high air temperature by month (**A**) at each plant was estimated using an inverse distance interpolation of nearby air temperature gages (NCDC, 1970-2010). Energy generation figures (**G**) were available for most months during the study period (EIA, 1970-2010). A multiple linear regression analysis was performed in SPSS using observed effluent temperatures (**T**) and cooling water withdrawal rates (**Q**) at each plant (EPA, 1994-2010).

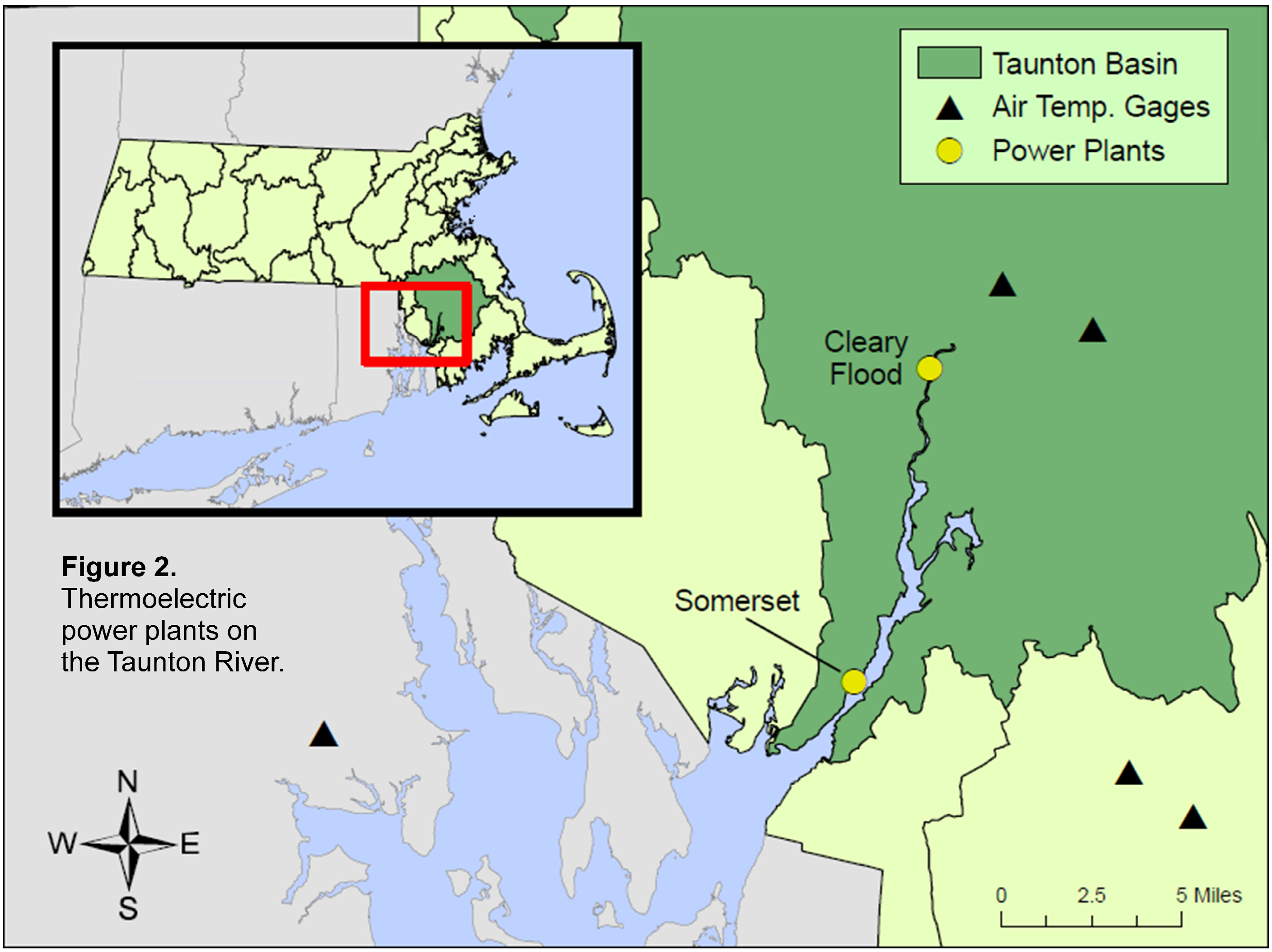


Figure 2. Thermoelectric power plants on the Taunton River.

Data: ESRI, MassGIS, NCDC; Graphic: Sheldon, S., 2011

Results: Input Parameters

The models attempt to estimate either **effluent temperature** (**T**) or **cooling water flow through plant** (**Q**), based on **air temperature** (**A**) and **net energy generation** (**G**). Box plots reveal seasonal trends and that each parameter is normally distributed. Electricity generation values for Cleary-Flood were log-normalized.

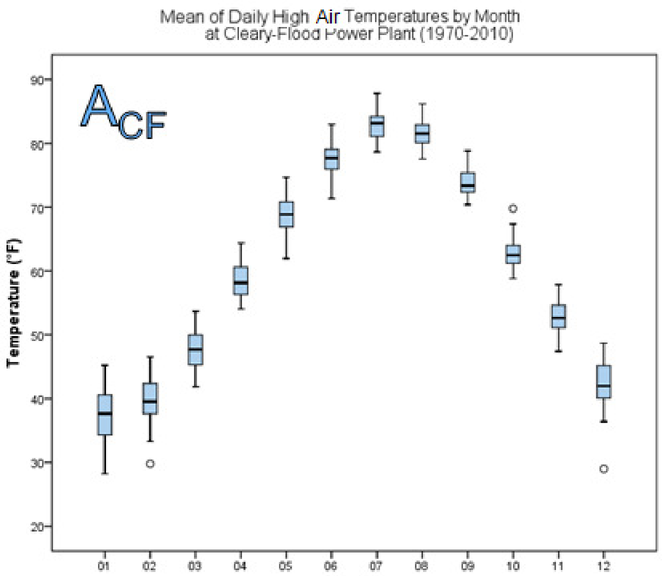
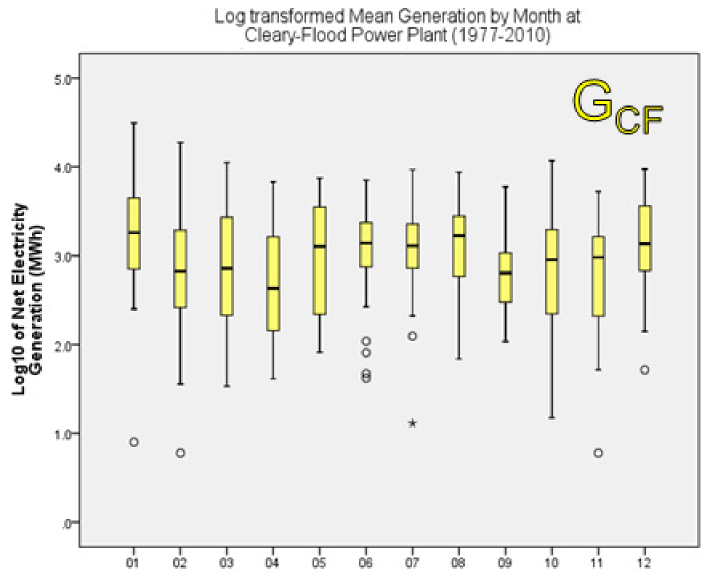


Figure 3.



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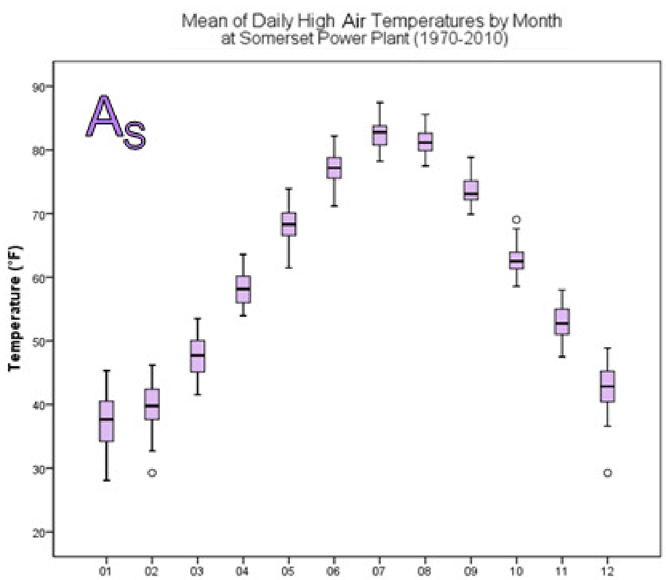


Figure 5.

Figures 3 & 5. Data: NCDC, 1970-2010; Graphic: Sheldon, S., 2011

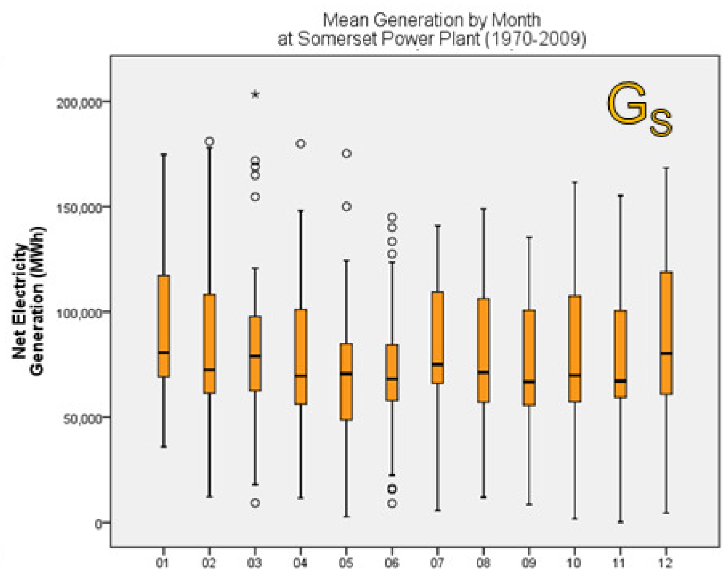


Figure 6.

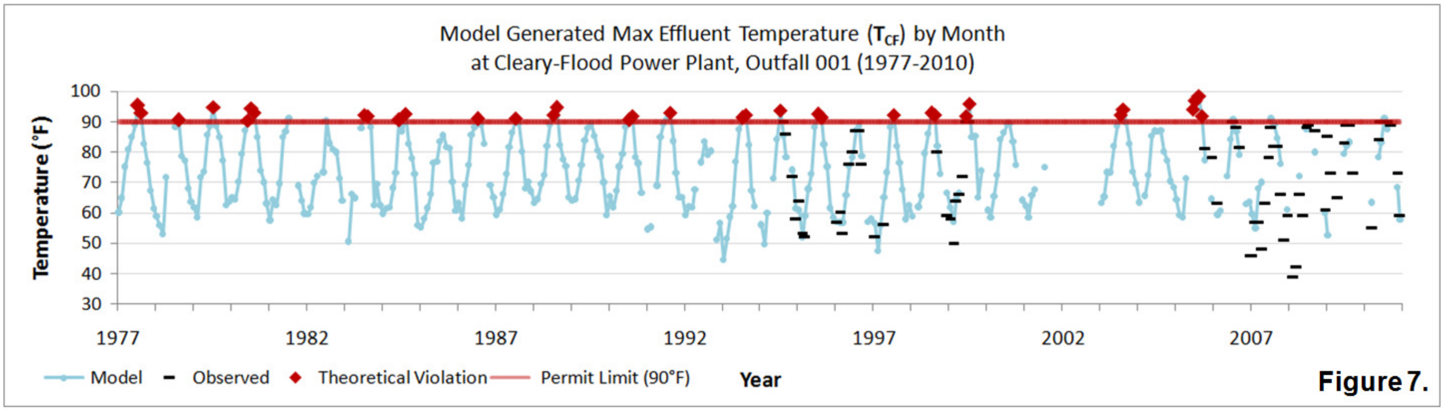
Figures 4 & 6. Data: EIA, 1970-2010; Graphic: Sheldon, S., 2011

Results: Model Output

Observed air temperatures and monthly generation values are used to hindcast (i.e., project backwards through time) the variables of interest. Permit limits (solid lines) and theoretical violations (diamonds) are shown. Observed values are shown as horizontal dashes.

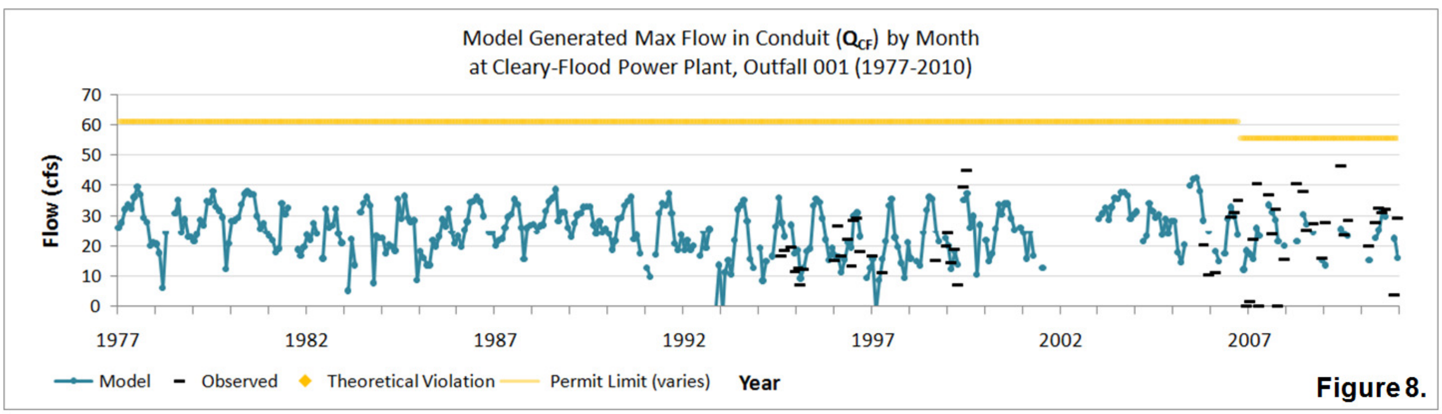
Cleary-Flood

$\mathbf{T_{CF}} = 11.667 + 0.069(A_{CF}) + 6.977(Log_{10}G_{CF})$



Data: EPA, 1977-2010 Sheldon and Frankic, 2011; Graphic: Sheldon, S., 2011

$\mathbf{Q_{CF}} = -22.407 + 0.297(A_{CF}) + 10.00(Log_{10}G_{CF})$



Data: EPA, 1977-2010 Sheldon and Frankic, 2011; Graphic: Sheldon, S., 2011

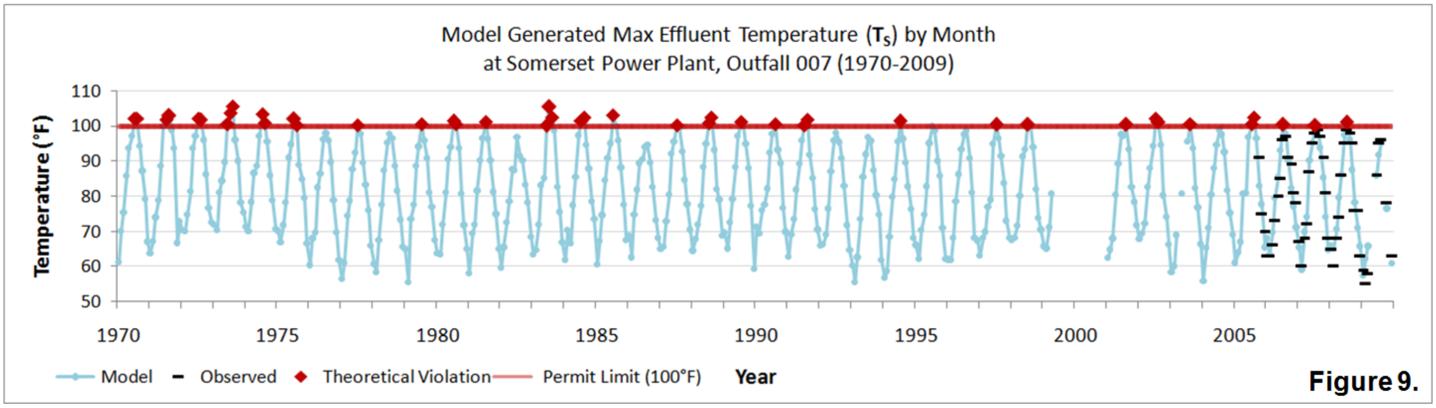
The quality of generation data for Cleary-Flood from before 1977 was questionable, so values from 1970-1976 were excluded, as were months where generation equaled zero. Useful generation data were Log_{10}-normalized (see box plots on page 3).

The T_{CF} model successfully described 78.6 percent of the data variation (Adj. $R^2 = 0.786$). The Q_{CF} model successfully described only 35.0 percent of the data variation (Adj. $R^2 = 0.350$). Explanatory variables for each were significant to varying degrees (see table on page 6).

The models identified a total of **34** potential past effluent temperature violations and **zero** withdrawal rate violations, yet no max temperature violations are on record. No withdrawal rate violations are on record.

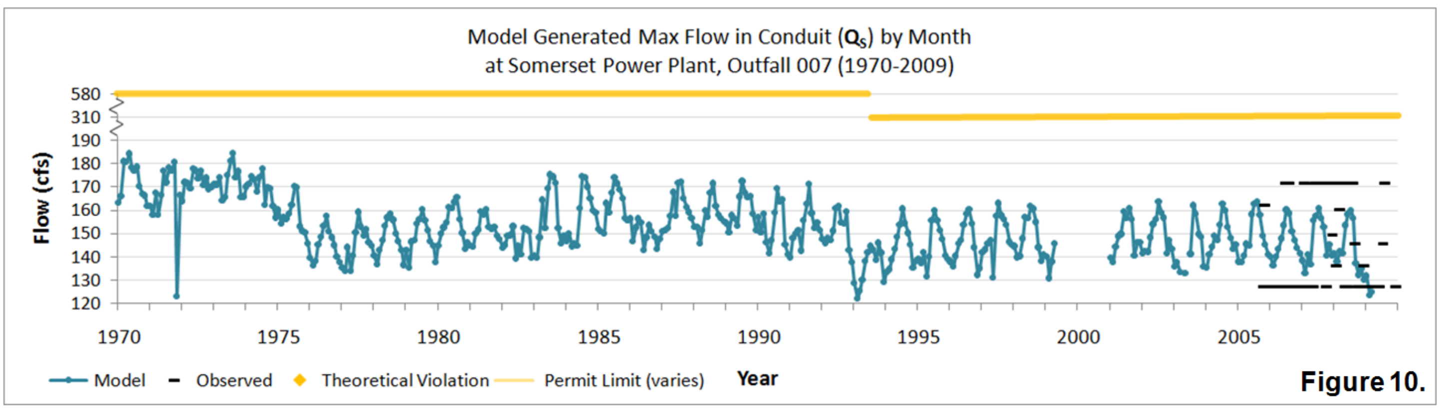
Somerset

$\mathbf{T_S}$ = 26.178 + 0.830(A_S) + 0.00007 (G_S)



Data: EPA, 1970-2009 Sheldon and Frankic, 2011; Graphic: Sheldon, S., 2011

$\mathbf{Q_S}$ = 99.342 + 0.484(A_S) + 0.00030 (G_S)



Data: EPA, 1970-2009 Sheldon and Frankic, 2011; Graphic: Sheldon, S., 2011

Months where generation equaled zero were excluded. The T_S model successfully described 90.1 percent of the data variation (Adj. R^2 = 0.901). The Q_S model successfully described only 19.6 percent of the data variation (Adj. R^2 = 0.196). Explanatory variables for each were significant to varying degrees (see table at bottom right).

The models identified a total of **38** potential past effluent temperature violations and **zero** withdrawal rate violations, yet no max temperature violations are on record. No withdrawal rate violations are on record.

Model Details

Plant	Model	R^2	Adj. R^2	St. Err. Est.	Exp. Variable	Coeff.	SE	β	t	Sig. (p)
Cleary-Flood	T_{CF}	0.794	0.786	6.604	(Constant)	11.667	6.911		1.688	0.097
					A_{CF}	0.0689	0.050	0.869	13.798	<< 0.001
					$Log_{10}G_{CF}$	6.977	2.310	0.190	3.020	0.004
	Q_{CF}	0.374	0.350	8.760	(Constant)	-22.407	9.167		-2.444	0.018
					A_{CF}	0.297	0.066	0.492	4.489	0.00004
					$Log_{10}G_{CF}$	10.003	3.064	0.358	3.264	0.002
Somerset	T_S	0.906	0.901	4.339	(Constant)	26.178	2.874		9.108	<< 0.001
					A_S	0.830	0.041	0.945	20.386	<< 0.001
					G_S	0.00007	0.00003	0.111	2.392	0.021
	Q_S	0.231	0.196	18.416	(Constant)	99.342	12.200		8.143	<< 0.001
					A_S	0.484	0.173	0.370	2.800	0.008
					G_S	0.0003	0.0001	0.305	2.308	0.026

Figure 11.

Data: EPA, 1970-2010, EIA, 1970-2010, NCDC, 1970-2010, Sheldon and Frankic, 2011; Graphic: Sheldon, S., 2011

Conclusion and Discussion

Data on **ambient air temperature** and monthly **electricity generation** are more complete and generally more precise than data on **effluent temperatures** and cooling water **withdrawal rates**.

Air temperature and monthly **electricity generation** may be good predictors of **effluent temperature**, but (by themselves) may be poor predictors of cooling water **withdrawal rates**.

Theoretical effluent temperature violations **outnumber** official (i.e., recorded) violations at both power plants.

The model may prove useful for crafting future permit limitations in light of changing climate conditions, energy demands, and technology.

Acknowledgments

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