Potential Effects of Climate Change in Thermoelectric Cooling Systems

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ABSTRACT: Climate change is expected to alter the meteorological, hydrological, and ecological regimes on which the operation of thermoelectric cooling systems depends. Local weather conditions affect the capacity of cooling towers, constructed ponds, and natural water bodies to transfer waste heat from steam condensers to the atmosphere. We consider how utilities make decisions about cooling water systems amidst climate change, evolving regulatory criteria, and evolving water management policies. Utilities will adapt to climate change and other impetuses with the aim of maximizing cooling system performance and, ultimately, dependable capacity, efficiency, and energy production of fossil and nuclear generating units. Climate change science needs to be developing tools and information that will enable utilities to plan for climate effects.

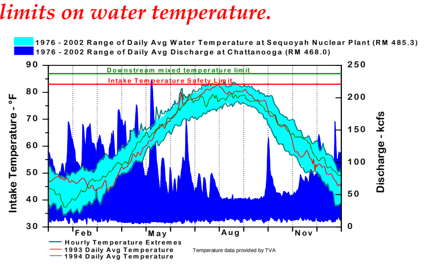
Climate and thermoelectric cooling linkages

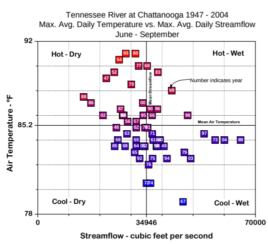
Open-cycle cooling – *high withdrawal, low consumption*

Open-cycle, or once-through, cooling systems withdraw large amounts of circulating water directly from and discharge directly to streams, lakes, reservoirs, and embayments through submerged diffuser structures or surface outfalls. Open-cycle systems depend upon adequate cool ambient water to support generation at full capacity.

Intake (left) and surface outfall channel (right) for a 1300-megawatt coal-fired generating station on the Ohio River. The station withdraws approximately 1,500 million gallons per day of water.

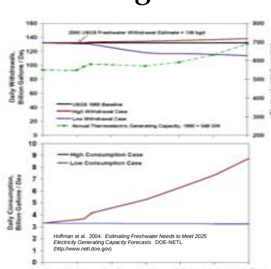
Historically, summertime weather extremes have required throttling or shutdown of thermoelectric units to comply with environmental or safety limits on water temperature.





The historical influence of climate on once-through cooling systems and thermoelectric power generation may be characterized by the joint distribution of summertime water temperature (or air temperature as a surrogate) and stream flow

Increasing demand for cooling water



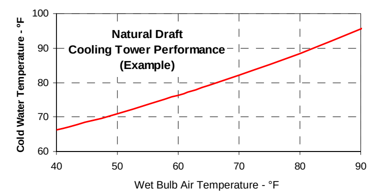
Based on National Energy Modeling System (NEMS) forecasts, the EIA projects increasing demand for energy through 2025 and increases in thermoelectric generation (87 GW coal-fired, 3.5 GW nuclear). The source of cooling for this new generation (saline once-through systems, freshwater once-through systems, or consumptive closed cycle and dry-cooling systems) depends on evolving regulations, technology, and regional differences in water availability.

Even without climate change, expanding thermoelectric generation will intensify competition for freshwater resources.

Limited water availability and waste heat assimilative capacity can ***constrain the development of new thermoelectric generation****. For example, expansion of a the North Anna Nuclear Power Station, located on 9,600-acre Lake Anna in Virginia, has been delayed by concerns that* ***increased evaporative losses*** *from an expanded and combined wet-tower and open-cycle cooling system would* ***threaten water quality, fisheries, and recreation****. Similar conflicts are arising throughout the U. S.*

Closed-cycle cooling – *low withdrawal, high consumption*

Closed-cycle, or recirculating, cooling systems transfer waste heat from circulating water to air drawn through cooling towers. Conventional wet cooling towers depend on evaporative heat exchange and require a continuous source of freshwater to replace evaporation losses.

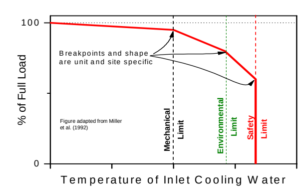


The ability of cooling towers to provide cold water to steam condensers of thermoelectric units decreases with increasing air temperatures and, for wet cooling, increasing humidity. Wet closed-cycle cooling systems are less susceptible to outfall temperature limits than open-cycle systems but require energy to lift water and, for mechanical draft designs, to induce air flow—thus reducing the net efficiency of thermoelectric units.

Constraints for Thermoelectric Cooling

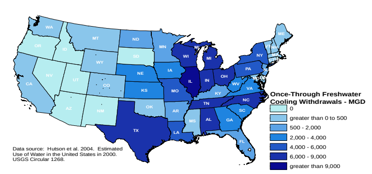
Thermoelectric generation loss to cooling water constraints is critical because it coincides with peak summertime demands for energy to cool buildings—typically when other higher cost generation sources are already at maximum output.

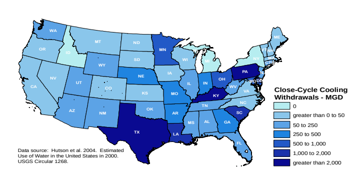
Weather-induced increases in the temperature of water supplied by close-cycle or open-cycle systems to main steam condensers reduce generation efficiency and capacity because turbine backpressure increases. Extremely high inlet temperatures require shutdown to avoid unsafe operating conditions for nuclear-powered units.



Larger and more frequent extremes in a future of changing climate could impact cooling operations and decision making, and even prompt reevaluation and modification of water temperature limits and withdrawal criteria

Regional Issues





Once-through cooling is prevalent in the eastern U.S and Midwest (left) due to the historical abundance of freshwater from developed river systems. Closed-cycle cooling (right) is more evenly distributed—albeit in semi-arid regions where consumptive use (evaporation from wet cooling towers) becomes problematic during drought.

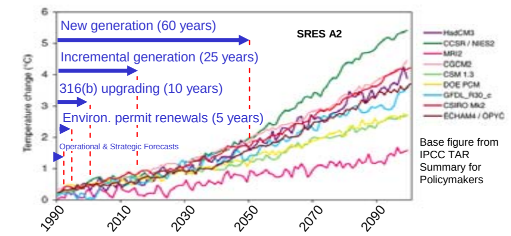
Ecological concerns are returning to cooling water system design and operation

Recent rule-making for ***Section 316(b) of the Clean Water Act*** *requires utilities to reduce impingement and entrainment of aquatic organisms at power plant cooling water intakes. Conversion from open-cycle to closed-cycle cooling at existing plants is one option for complying with rules, and new thermoelectric units will likely require closed cycle cooling systems to comply. As a result,* ***cooling water constraints for U.S. thermoelectric generation in the long-run will increasingly result from extremes of air temperature and humidity rather than stream flow or water temperature extremes.*** *However, open-cycle cooling systems accounted for 91 percent of water withdrawals for thermoelectric cooling water in the U.S. in 2000 (Hutson et al. 2004). Installation and operating costs of converting to closed-cycle cooling are site-specific and high enough that, as a first alternative, utilities will consider adaptation of open-cycle intakes for the remainders of facility lifetimes.*

Thermoelectric cooling and climate change science

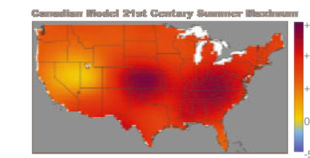
Relevance for cooling water systems

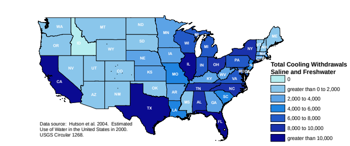
Significant climate change could occur within the planning, construction, and operating lifetime of incremental and new thermoelectric generation capacity.



Typical horizons for thermoelectric cooling decisions and operations are compared to the rate of climate change for a specific scenario and ensemble of model results.

Comparison of summer maximum temperature change distribution from one climate model (the Canadian Climate Centre scenario presented in the USGCRP National Assessment) to cooling water withdrawal distribution shows that the potential for impact is greatest in the Southeast, Midwest, and Northeast, and Texas.

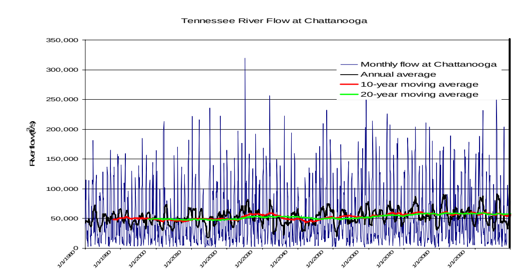


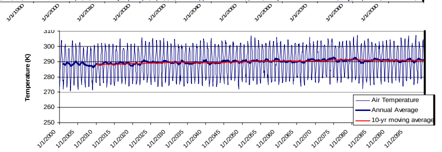


Depending on the rate of climate change, aggregate thermoelectric generation may not be able to keep pace with increasing demand in the short-run as increasing ambient temperatures trigger constraints on generation capacity of older units. Efforts are underway to model the effects of climate change on energy demand (Hadley et al., ORNL, in review), but market-based NEMS energy outlooks (see http://www.eia.doe.gov/oiaf/aeo/overview/index.html) do not include water resource or cooling system limitations on future generation capacity.

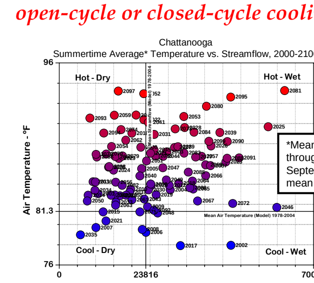
Climate change scenarios for cooling water analyses

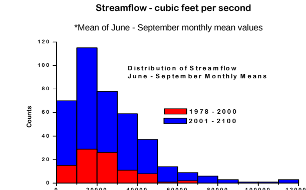
The time series of river flow and air temperature at Chattanooga shown at right are from a climate change scenario known as A1B from the IPCC4 Assessment. It was generated using the DOE-NCAR Community Climate System Model (CCSM3), with a subgrid orography scheme by Steve Ghan at PNNL to capture the effects changes in topography have on climate processes. The A1B scenario uses the assumption that CO2 ramps up to 720 ppm by 2100.





Net result for this scenario: less summertime generation at facilities with either open-cycle or closed-cycle cooling systems.





A preliminary analysis of the A1B scenario data reveals one example of how cooling conditions might evolve over the 21st century for generation in the Chattanooga vicinity. In this example, a slight upward trend in stream flow would provide a marginal benefit for once-through cooling, but would be offset by increasing summertime air temperatures that trigger limits on cooling water intake and downstream mixed temperatures. Closed-cycle cooling would also become less effective as ambient temperature and humidity increased. Utilities would need maintain generation capacity by upgrading existing cooling systems or shifting generation to newer facilities with more cooling capacity. Without technology-based improvements in cooling system energy efficiency or steam-cycle efficiency, overall thermoelectric generation efficiency would decrease.

Designing for climate change

In the long-run, thermoelectric generation must be designed for increasing ambient temperatures to avoid cooling constraints.

- *Micheletti and Burns (2002) assert that to avoid excessive lost-energy penalties, wet cooling towers should be designed to for the local 1% exceedence value of average daily wet bulb temperature, and once-through systems should be designed for the local maximum daily average water temperature. Because lost-energy penalties associated with emerging dry cooling system designs are more volatile, designers will need extreme statistics for summertime local hourly air temperatures.*

To move beyond the use of historical data for engineering design, electric utility planners must be convinced that climate model output and derived data can resolve extreme values of temperature and stream flow at scales relevant to cooling systems and energy production.

Model projections of future global and regional climate will always be uncertain, and model resolution will likely remain quite coarse in both space and time from the perspective of decisions concerning cooling operations and design. An interactive dialogue and joint research efforts among design engineers, decision makers, and regional climate modelers will be needed to find a common ground in the scale and precision of model output that is both useful in decision making and scientifically achievable and credible.

Next Steps

1. *Regional case studies of lost-generation under climate change scenarios for upgraded and new thermoelectric generation with wet and dry closed cycle cooling and open-cycle cooling. Case studies would (a) identify data and modeling needs for utility planners and climate change scientists and (b) quantify the effects of using historical data versus climate change predictions for new plant design.*
2. *National assessment of expected generation losses attributable to cooling constraints under multiple climate change scenarios. This study could leverage current EPA and DOE studies and results for aggregate impacts of Clean Water Act 316(b) limitations on thermoelectric generation.*
3. *Incorporation of cooling water lost generation results into the CCSP Synthesis and Assessment Product 4.5, Effects Of Global Change On Energy Production and Use*

Conclusion:

Climate change is likely to constrain thermoelectric generation in the 21st century by degrading cooling capability and power plant efficiency. More research and development needs to be focused on making climate change science and predictions available and credible to utility planners and designers.

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