MEMORANDUM

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TO: Lisa Biddle and Paul Shriner, EPA
FROM: Kelly Meadows and John Sunda
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SUBJECT: Summary of Materials on Evaporative Losses

In December 2012, Tetra Tech was tasked with reviewing materials regarding evaporative losses of water from cooling towers as compared to once-through cooling systems. A summary of the materials and analyses gathered to date are listed below, with some brief discussion about the information presented or conclusions reached.

Introduction

A common industry comment regarding closed-cycle cooling is the evaporative loss of water from a cooling tower. By design, a wet cooling tower evaporates water to dissipate the waste heat from the electricity generation process. Industry representatives claimed that this water is then removed from the waterbody and would not be available for other uses downstream. This may be problematic in some areas, particularly those with drought conditions or other high water demands. EPA noted that once-through cooling also causes evaporation, as the heated plume discharged by the facility would also be subject to evaporative losses.[1] These evaporative losses of the source water would continue long downstream. EPA also noted that such losses are likely minimal where the source water is an ocean, but in the case of an inland water such as a river, where once-through cooling removes a huge portion of the river flow for cooling, such evaporative losses would theoretically approach the same losses of a cooling tower. The purpose of this memo is to compare the likely loss rates of water for the two cooling system types.

Materials on Evaporative Losses

Each source of information and data on evaporation is described briefly below. A table at the end of this section (where evaporation values reported are also converted to gallons per MWh

[1] Note that there are a number of site-specific variables that will affect evaporation, such as local climatological conditions, delta T of the condenser, and morphology and flow of the receiving stream. It is difficult to analyze on a national scale, so most approaches appear to use either generic scenarios or specific examples.

(gal/MWh)) provides a summary of the range of values reported in a format that allows for direct comparison.

EPRI publication (2002) (DCN 10-6891): *Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production—The Next Half Century,* EPRI, Palo Alto, CA: 2002. 1006786. This document is often cited by other materials and was likely one of the only resources on the subject for some time. Recent efforts (such as the Tt modeling discussed below and the Energy-Water Nexus research presentations) have greatly expanded upon the available data. EPRI estimated once-through fossil plant water consumption levels of 300-400 gal/MWh versus closed-loop water consumption levels of 480-720 gal/MWh. This resulted in a generally cited rule of thumb that closed-cycle evaporative losses are approximately 2.5 times greater than those for once-through systems.

Tetra Tech memo to project file (2011): Tetra Tech conducted a water quality modeling analysis using data for two power plants; the model predicted evaporative losses in the downstream effluent plume. The modeling suggested that losses were approximately 0.3-0.5% of the cooling water flow, as compared to approximately 1.5-1.8% for cooling towers at the same sites. When converted to gal/MWh these values become 68-183 gal/MWh consumption for once-through and 480-620 gal/MWh for closed-cycle. The values are somewhat lower but are similar order of magnitude as the other estimates summarized here.

Diehl's draft article *Estimating Forced Evaporation from Surface Water*: Presented at the Energy-Water Nexus. The paper stated that published estimates of forced evaporation range from "0.015 to 4.5 (2 – 1190 gal/MWh) liters per kilowatt-hour (L/kWh) for cooling ponds and 0.45 to 12 L/kWh (119 – 3170 gal/MWh) for once-through cooling." The presentation provides a new analysis and concludes that "forced evaporation from cooling ponds is estimated to be 1.2 to 1.4 L/kWh (317 – 370 MWh) for fossil-fueled plants and from 1.5 to 1.8 L/kWh (396 – 476 MWh) for nuclear plants."

Tidwell/Sandia Laboratory presentation *Value of Water in Energy Production* (DCN 12-6851): Presented at the Energy-Water Nexus. The presentation has a lot of data on water consumption, including data by fuel type. Consumption ranged from approximately 400 to 700 gal/MWh for recirculating systems at coal fired plants and 100 – 250 gal/MWh for once-through cooling coal systems, and 600 – 800 gal/MWh for cooling ponds.

NETL (2008) (DCN 10-6871): *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements. DOE/NETL-400/2008/1339, September 2008.* The analysis estimates the effects on national water use for various scenarios of water use for power plants. Unfortunately, the analysis does not account for downstream evaporative losses, so this data is not further useful in this comparison.

GAO publication (2009) (DCN10-6870): *ENERGY-WATER NEXUS: Improvements to Federal Water Use Data Would Increase Understanding of Trends in Power Plant Water Use. United States Government Accountability Office, October 2009*. The document primarily discusses material that is not already known, with a focus on the available data that could be collected by various federal agencies to better understand the water use patterns.

DOE (2006) (DCN 12-6852): Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water. December 2006. The document provides a broad view of water and energy, with specific data on evaporative consumption. Values for fossil plants range from 100-300 gal/MWh for once-through cooling systems to 180-480 gal/MWh for cooling towers. Values for nuclear facilities range from 400 gal/MWh (once-through) to 720 gal/MWh (cooling towers). Values are also provided for cooling ponds.

NSF (2013) (DCN 12-6847): *Workshop Report: Developing a Research Agenda for the Energy Water Nexus. December 2013.* The document presents materials resulting from a National Science Foundation grant to establish research priorities for the water-energy nexus. The analysis uses 300 gal/MWh for once-through cooling and 480 gal/MWh for closed-cycle.

International Energy Agency (2012) (DCN 12-6853): World Energy Outlook 2012. The document provides a broad view of energy use and water withdrawals and consumption. Prior years' editions did not address consumptive losses. The ranges presented for evaporative consumption were collected from documents summarized above.

GAO publication (2012) (DCN 12-6854): *ENERGY-WATER NEXUS:* Coordinated Federal Approach Needed to Better Manage Energy and Water Tradeoffs. *United States Government Accountability Office,* September 2012. The document discusses relevant general concepts but provides no data on evaporative consumption rates.

USGS (2013) (DCN 12-6855): *Methods for Estimating Water Consumption for Thermoelectric Power Plants in the United States*. United States Geologic Survey, 2013. Scientific Investigations Report 2013-5188. This document provides a thorough analysis of modeling for evaporative losses, but does not provide any explicit data on consumption rates.

Summary of the Range of Estimated Once-through and Closed-Cycle Evaporation

Cooling System Type	EPRI 2002	Tetra Tech 2011	Diehl 2012 (Pub. Est.)	Diehl 2012 (New)	Tidwell 2012	DOE 2006	NSF 2013
	gal/MWh	gal/MWh	gal/MWh	gal/MWh	gal/MWh	gal/MWh	gal/MWh
Once-through	300 - 400	68 - 183	119 - 3,170		100 - 250	100 - 400	300
Closed-cycle	480 - 720	480 - 620			400 - 700	180 - 720	480
Cooling Pond			4 - 1,190		600 - 800		
Cooling Pond- Fossil				317 - 370		480	
Cooling Pond- Nuclear				396 - 476		720	

Note: One MWh of energy would evaporate approximately 420 gallons of water. Most generating systems are >32% efficient. In a generating system that was 33% efficient where all waste heat was transferred to cooling water, the evaporation could be no greater than 840 gal/MWh. The actual value will be lower because not all waste heat ends up in the cooling system or as evaporation (e.g., some exits via flue gas, some heats the air). Accordingly, the upper end of the range of published values in the DOE document represent very inefficient generating systems.

General Review

Prior to this collection of data, industrial sources cited evaporative losses of cooling towers as 10 times that of once through cooling. The data identified here show the relative losses of cooling towers are at most a factor of 2.5 times that of once-through, and on average would be 2 or less. In summary, the studies show:

- The differences in evaporative losses are minimal in terms of gallons lost and in most cases are minor compared to river flow.
- In areas where water resources are limited (e.g. the desert southwest or the recently drought-stricken southeast), once-through cooling may not be a prudent option for new facilities and it may be a liability for existing facilities. EPA observed this in its site visits, where several facilities retrofitted to closed-cycle cooling in spite of drought conditions.[2] EPA found that such facilities could not obtain enough water to support once-through cooling, and the evaporative losses become a moot point.
- Similarly, for facilities located on smaller waterbodies, evaporative losses from once-through cooling will be significantly higher since the effluent comprises a larger percentage of the receiving stream, won't mix as quickly, and will remain heated longer, all leading to additional evaporation. Such heated water remains exposed to the environment downstream, and is thus exposed to evaporative forces for much longer than a similar volume of water passing through a cooling tower. Smaller receiving streams are also more likely to be affected by thermal discharges from the perspective of 316(a), which requires that the discharge not affect the "balanced indigenous population."
- Dry cooling and hybrid (wet/dry) cooling are available technologies that significantly reduce evaporative losses. Dry cooling systems require virtually no water withdrawals and hybrid systems consume about 15% less water through evaporation. EPA has recognized the availability and applicability of these systems for reducing evaporative losses for over 30 years.[3]
- The analysis presented above uses techniques that are broadly applicable to all parts of the United States, regardless of climate, waterbody type, fuel type, or other facility-specific factors.
- While EPA did not attempt to identify or quantify the meteorological effects, the water vapor in the evaporative plumes does not simply disappear; it will be incorporated into the atmosphere and may return to the original watershed in the form of precipitation.
- Cooling water withdrawals are a very small component of consumptive uses nationwide. As noted in EPA's *Closed-cycle Cooling Systems for Steam-electric Power Plants: A State-of-the-art Manual*, consumptive water uses by the steam electric sector was 1.2% of consumptive uses nationwide in 1975; agriculture was 85%, drinking water was 7% and mining was 7%. The Nuclear Energy Institute presented similar data, noting that a closed-cycle power plant typically consumes 23 gallons of water per day per household

[2] See the site visit reports for McDonough, Yates, Williams, and Nearman Creek (DCNs 10-6536, 10-6538, 10-6533, and 10-6524). While these facilities did not explicitly convert to cooling towers over 316(b) concerns, each facility concluded that, despite challenging conditions for evaporative losses (and other factors), closed-cycle cooling was the best technology.

[3] See *Closed-cycle Cooling Systems for Steam-electric Power Plants: A State-of-the-art Manual*, DCN 10-6845F.

> served with electricity, while the same average household uses 94 gallons per day for domestic uses, indicating that a conversion to closed-cycle cooling will lead to nominal increases in water consumption.[4] As a whole, a small increase in the consumption by closed-cycle cooling will be virtually indiscernible on a national scale.[5]"

Therefore, in general, this parameter was not deemed to pose a significant factor in deciding whether to install or retrofit closed-cycle cooling for most facilities.

[4] Nuclear Energy Institute fact sheet "Water Use and Nuclear Power Plants," May 2010. Available at http://www.nei.org/filefolder/Water_Use_Fact_Sheet_0510_1.pdf.
[5] See DCN 10-6845F, page 316.