Food and Agriculture Organization
of the United Nations

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Reports

Cooling water for energy generation and its impact on national-level water statistics

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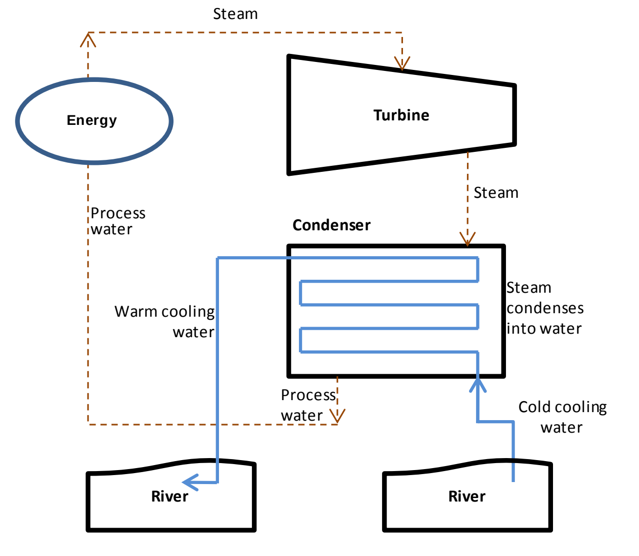
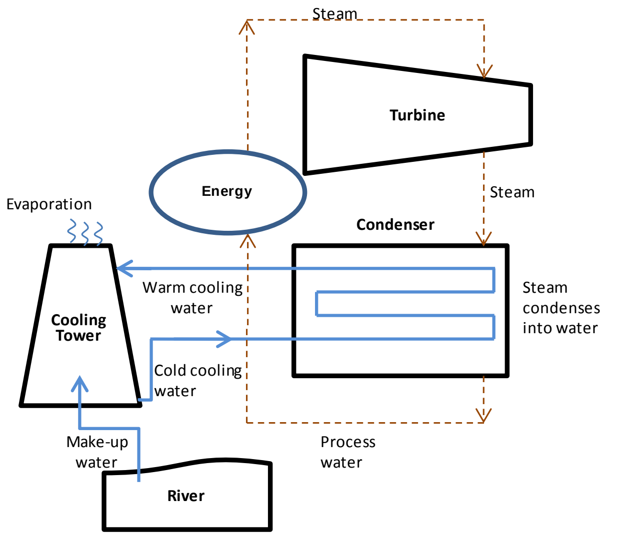
April 2011

Introduction

Cooling water for energy generation is accounted for differently in different countries. Due to the large amount of water required to cool energy generation plants, and in light of the predicted future increase in energy consumption for the coming years (DOE, 2010; WEC, 2007; IPCC, 2001), water withdrawals associated with power generation must be taken into consideration. This technical note has two purposes: 1) to act as a general informational resource and 2) to encourage governmental agencies responsible for water usage to gather and report information disaggregated by sub-sector (keeping thermoelectric withdrawals separate from industrial and hydroelectric withdrawals), and to determine the point at which lower water withdrawal designs are more favourable, even if the required capital cost is higher.

FIGURE 1
Summary of cooling technologies

a) Once-through cooling	b) Closed-loop cooling
	
Water passes through the condenser once and is returned to the water source. This is likely the most common cooling technology. Amount of water required: ⇧ ⇧ % of withdrawn water consumed: ⇩ ⇩ Amount of water consumed: ⇩ Capital cost: ⇩	Water is cycled between the condenser and a cooling tower (excess heat makes water evaporate from the tower). Very little makeup water is required to replace what is lost through evaporation. Amount of water required: ⇩ % of withdrawn water consumed: ⇧ ⇧ Amount of water consumed: ⇩ Capital cost: ⇧

[1] The AQUASTAT Programme of FAO collects, analyzes and disseminates information on water resources, water uses, and agricultural water management with an emphasis on countries in Africa, Asia, Latin America and the Caribbean. Water usage time series per country can be observed in the AQUASTAT database (see reference for link). Questions and comments can be directed to aquastat@fao.org.

Why do power plants need cooling water?

There is some amount of confusion since there are two loops in most thermoelectric power plants. These are explained below:

1) Thermoelectric power plants generally either burn materials (fossil fuels, wood, waste, etc.) or use controlled nuclear explosions to generate steam that turns a turbine connected to a generator. In Figure 1, this is represented by the dashed brown line. This water is process water, not cooling water, and is typically not discussed since the water is re-circulated and topped off as necessary. Therefore the water requirement in this loop is minimal. After the steam has turned the turbine, it passes through a condenser that converts the steam into water that can be evaporated into steam again. Of course, in order to turn the steam to water, a large amount of heat must be removed. This is most frequently done with cooling water, explained below.
2) Cooling water removes heat from the vapour (thereby converting it into water) in a non-contact heat exchanger, a device through which the process water comes in close proximity to the cooling water (close enough to transfer heat from one stream to the other), but the two streams do not mix. In Figure 1, this is represented by the solid blue line.

   This paper focuses on the main cooling technologies used in this non-contact heat exchanger: once-through and closed-loop (sometimes called closed-system or cooling towers), both of which use water for cooling. The benefits and downsides to both are noted at the bottom of Figure 1.

Problems faced with thermoelectric cooling water data accounting

The exact amount of cooling water required depends on the energy source used, cooling technology, plant efficiency, ambient temperature, and relative humidity, so is difficult to obtain exact national data without detailed records and the government capacity to process them. Data on thermoelectric water withdrawals is available for some countries, while other countries combine cooling water with industrial water withdrawal, or with hydroelectric power and yet others do not collect information on cooling water at all. Some of the problems with data accounting in the context of thermoelectric cooling water are presented and addressed below:

1) *<u>Confusion between thermoelectric water withdrawal and water consumption.</u>*

Depending on the cooling strategy employed, water that is withdrawn by thermoelectric plants may be mostly evaporated, or mostly returned to the water source (see Table 1). Due to this, the perception that a high withdrawal is accompanied by an equally high water consumption is incorrect. For example, in situations where once-through cooling is used, large volumes of water have to be allocated in order to fulfil their high withdrawal requirements. Most of this water will be available to users downstream even if there are no water users downstream that could benefit from this return water. By contrast, a plant that uses closed-loop cooling requires very little water to operate, but what water it does withdraw will not be returned to the system.

Conversely, there is a misconception that due to the large return rate of once-through cooling plants, all thermoelectric cooling water withdrawal is non-consumptive. The misperception is probably due to the fact that once-through cooling technologies extract water, pass it through a condenser and return the water to the water source (most often a river) immediately thereafter. Due to this, once-through cooling has no direct consumption, although temperature rises of 10-15°C might be expected in the receiving water body (EPRI, 2002a), which cause additional evaporation in the receiving water body (EPRI, 2002b; Williams and Tomasko, 2009). This indirect evaporation, also called “thermal pollution”, would not have occurred if the power plant in question would not have increased the water temperature, and therefore this water consumption must be attributed to the power plant. While it may appear that the indirect water evaporation is small, it becomes significant due to the large amount of water required to operate once-through cooling.

2) *<u>It is difficult/expensive to collect thermoelectric water withdrawal data since many power plants are self-abstracters.</u>*

It goes beyond the scope of this paper to discuss national data gathering structures, but data collection is always difficult/expensive, especially for sectors where water is self-abstracted. However, some attempt at quantification should be made to account for these sectors, since their water consumption affects downstream users and river gauge measuring station. To provide a point of reference, cooling water is the largest water withdrawal, accounting for over 50% of national water withdrawals in several developed countries (Eurostat, 2010). Additionally, power companies provide a public good, and therefore their water requirements must be taken into consideration by river basin administrators to prevent power shortages during dry periods. Lastly, using accurate water requirements allows policymakers to better manage incentives or pricing structures to maximize the utility of water. The efficiency of pricing structures and the controls against dry seasons might outweigh the cost of data collection.

3) *Some Industries also use cooling water, and since industry and thermoelectric power plants are both self-abstracters, they are both aggregated into industrial water withdrawal.*

Due to the magnitude and specific properties of thermoelectric cooling water withdrawals, specific requirements should be taken into consideration. Also, given that development requires additional energy plants, thermoelectric water withdrawals should be an important component of water utilization policies. Whether this thermoelectric water extraction later gets reported as an industrial water withdrawal or not is left to the prerogative of local policymakers. AQUASTAT does keep track of thermoelectric water withdrawals where they may be present, but unfortunately not enough is known yet at a global scale to disaggregate this fraction systematically.

4) *Thermoelectric and hydroelectric water withdrawals are combined into 'electricity generation'.*

Hydroelectric water withdrawal is an in-stream water use, therefore the water is not withdrawn. Due to this, it is not correct to combine hydroelectric with thermoelectric water withdrawals. Regarding water consumption, hydropower generation might have reservoirs associated to dams which also increase evaporation, whereas thermoelectric installations do not have a reservoir but also increase evaporation through different mechanisms. To provide a point of comparison, in 1995 in the United States of America thermoelectric water withdrawals were responsible for approximately 182 km^3 of which 4.5 km^3 evaporated (NREL, 2003). Instead, AQUASTAT estimates that almost 50 km^3 were consumed from artificial lakes and reservoirs for the same year and country.

Thermoelectric water extractions and rising energy requirements

It is well known that population and urbanization will continue to increase in the coming years. Both of these imply an increase in energy requirements (Kemp and Rudden, 2009), although the specific increase depends on several factors that make prediction difficult. To further complicate matters, the rise in electricity demand does not necessarily imply a rise in water requirements, as designing new power plants using renewable technologies, or thermoelectric plants using ocean water, closed-loop cooling, or other technologies would substantially reduce the water withdrawal per MWhr.

In the case of most industrialized countries, a slow trend towards designing closed-loop power plants (or hybrid systems combining water cooling with dry cooling, which is an expensive and niche technology in which air instead of water is used to cool process water) has resulted in no clear global increases in cooling water withdrawals. This results in significantly lower water withdrawal requirements per KWhr of energy generated than what would be expected, although the statistics on types of cooling used and plant efficiencies are not generally collected. In low income countries where there is no physical water scarcity, it is probably most common to see once-through cooling, due to the decreased power plant capital costs, and lack of environmental regulation regarding thermal pollution (once-through cooling technologies discharge water at a higher temperature then when it was withdraw). Of course, if physical water scarcity is an issue, the water consumption might be more of a consideration than water withdrawal requirements, which in turn might affect design priorities.

TABLE 1
Approximate withdrawals and consumptions, not accounting for ambient temperature or plant efficiency (rounded and adapted from EPRI 2002)

Plant and Cooling System Type Water	**Withdrawal** (liters/MWh)	**Consumption** (liters/MWh)
Fossil fuel/biomass/waste | once-through cooling	76 000 – 190 000	1 000
Fossil fuel/biomass/waste | closed-loop cooling	2 000 – 2 300	2 000
Nuclear steam | once-through cooling	95 000 – 230 000	1 500
Nuclear steam | closed-loop cooling	3 000 – 4 000	3 000

Conclusions

Energy generation requires cooling, which intimately ties the energy sector to the water sector. Thermoelectric water withdrawal constitutes the biggest water withdrawal in several industrialized countries, and may become as important in as low-income countries develop. Business-as-usual scenarios in which more energy plants cooled with once-through systems are installed to meet demand might prove problematic for water planners. At a river basin level, dry periods can be responsible for rolling blackouts, not only due to hydropower plants operating at dangerously low levels, but also due to the unmet significant water requirements of thermoelectric plants. This is another reason why inter-ministerial coordination is crucial.

In the era of competing water uses, gathering disaggregated statistics on the water usage by thermoelectric power plants is paramount to adequate planning.

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