Hydrologic Impacts of Energy Production

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REFERENCE: *Proceedings of the 2011 Georgia Water Resources Conference*, held April 11–13, 2011, at the University of Georgia.

Abstract. Global future energy requirements will likely require substantial investments in power production facilities. Both hydro- and thermo-electric power production require water as part of their operations, some of which is water consumptive (i.e., water is lost by evaporation as part of the cooling or storage process), while other water use is non-consumptive (i.e., water is returned to the source). Both consumptive and non-consumptive water uses may affect water quantity and quality, such as increased thermal load, decreased hydrologic connectivity, and alteration of natural flow regimes. This presentation discusses the main features of the water-energy nexus with the goal of establishing a framework for evaluating the hydrologic impacts of energy production.

INTRODUCTION

National energy consumption has grown steadily over time, with occasional reductions due to slowdowns in economic activity (Figure 1). While renewable and nuclear sources has increased over time, reliance on fossil fuels still dominates the U.S. energy portfolio.

Renewable energy from wind and solar sources is likely to continue to increase, while hydroelectric production is likely to remain at current – or perhaps lower - levels due to limits on new facilities and continued droughts. The nation's arsenal of approximately 103 nuclear production facilities is approaching design lifetimes, and will eventually be retired. Thus, the nuclear sector's contribution to energy production will decline unless replaced or upgraded in the near future. Fossil energy production is largely dependent on imported petroleum and domestic coal sources, but the impacts on global carbon stocks will make new production problematic.

Against this backdrop of current energy production is the need to address future water requirements for both hydro- and thermo-electric power production. This is because water is an integral component of both energy sectors (i.e., for direct power production by hydro-electric facilities, and for cooling purposes for thermo-electric facilities). This manuscript attempts to summarize the energy production impacts on water resources so that we are adequately prepared to manage this finite resource.

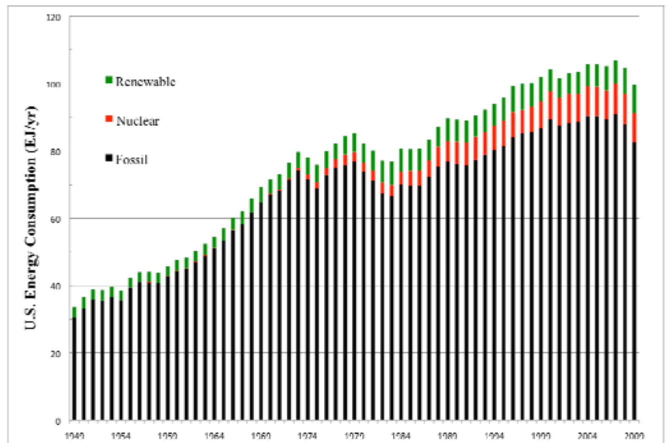

Figure 1. National energy consumption, 1949-2009. (U DOE, 2009)

HYDROLOGIC IMPACTS

Hydroelectric production. Hydroelectricity is produced using the volume and elevation drop of rivers to drive generators that convert the mechanical force of falling water to electricity that can be transmitted to distant users. Either an off-channel diversion or a reservoir are required to generate a sufficient drop for power production.

Off-channel diversions and reservoirs can both interfere with fish migration by interrupting the natural continuity of stream channels. In addition, substantial water may be lost by evaporation from reservoir water surfaces, especially during warm, dry weather. Reservoirs can also affect downstream hydrologic regimes by intra-daily, inter-seasonal, and multi-year alterations in natural flows. Loss of continuity and changes in flow regimes are important causes of impairments to aquatic ecosystems.

Water quality can be altered because of longer residence (holding) times in reservoirs. Algal productivity increases in slow moving waters. Eutrophic conditions can lead to increased water treatment costs due to the presence of algal flavors, as well as increased metals in hypolimentic waters. Natural sediment transport can also be affected, resulting in sediment starvation or accumulation below reservoirs.

Thermoelectric production. Both nuclear and fossil fuel power production facilities utilize water as their primary coolant. The fuel (either uranium, coal, oil, or natural gas) is "burned" to produce heat that is used to produce steam that drives electrical generators. Like hydroelectric power, this electrical energy can be distributed to distant users.

Disposing of waste heat from thermoelectric facilities can be accomplished in multiple ways:

- Sensible heat (i.e., an increase in water temperature) is transferred to local rivers or lakes by withdrawing cooler water and returning hot water to the receiving water body;
- Latent heat (i.e., an increase in water evaporation) is transferred to the atmosphere by withdrawing water from local sources and evaporating the water; and
- Power production facilities avoid the use of water by using gas combustion turbines or air-cooling.

Each of these strategies has their own impacts on water resources.

For sensible heat transfer, little water is used consumptively, but the impact of heated return flows may adversely affect the water quality of the receiving water body (Figure 2). For example, dissolved oxygen in water is dependent on temperature – warmer water has a lower concentration at saturation than cooler water. Thus, the impacts on aquatic systems may be due to oxygen starvation, which may be exacerbated by other discharges with high biochemical oxygen demands. Also, excessive discharges to lakes and reservoirs may result in elevated lake surface temperatures, causing biological impairments. Both examples lead to a consumptive use of water quality, which may affect TMDLs (Total Maximum Daily Loads).

For latent heat transfer, most water is used consumptively, which means most heat is transferred to the atmosphere and does not have such a large impact on stream systems. Yet residual return flows are still needed to dispose of dissolved solids present in the diverted water, which increases the dissolved solids concentration in the receiving waters (Figure 3). Also, the water supplies of downstream users may be adversely affected by these consumptive losses.

And finally, waterless cooling is employed in some cases where gas turbines or radiative heating to the atmosphere are used. The direct effect on water resources is reduced, yet the atmospheric heating that results may adversely affect the regional climate by increasing both daytime and nighttime temperatures.

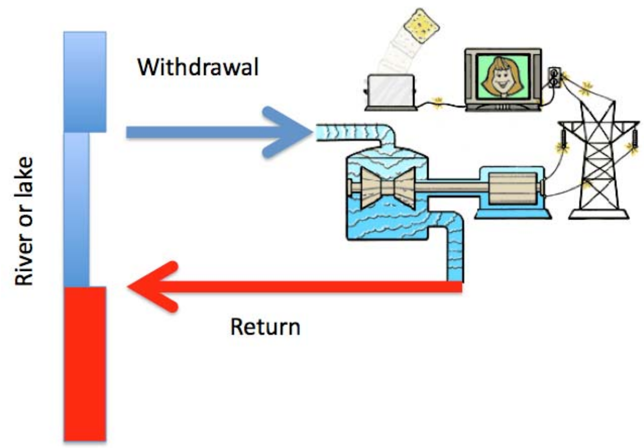

Figure 2. Thermoelectric power production facility with single-pass cooling water returned to stream. No consumptive use, but water quality is impaired.

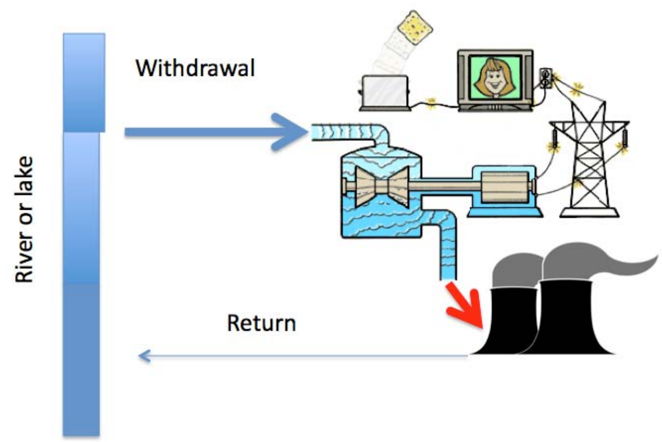

Figure 3 Thermoelectric power production facility with cooling towers. Most water is consumptively used, but water quality returned to stream is improved.

For each of these cases, the timing and magnitude of water quantity and quality alterations are important considerations for evaluating the impacts of energy production on water resources.

Impacts of water conservation. While great interest has been placed on reducing domestic, commercial, agricultural, and industrial water use, especially during periodic droughts, lesser attention is usually placed on the energy impacts of water conservation.

Clearly, reducing energy consumption has a direct impact on water conservation, in that a reduction in power demand results in less thermoelectric cooling requirements.

Yet, an important consideration is how a reduction in water use affects energy needs. Within the agricultural sector, it can be easily accepted that a reduction in water pumping for irrigation leads to a reduction in water use. This is also likely to be true for many industrial uses.

But the impacts of water conservation on energy use in the domestic and commercial sectors are more problematic. A major determinant in power use is the need to air condition, which is particularly true during droughts. Reducing air-conditioning demand is thus a major factor in reducing water consumption.

There are many factors that can affect air-conditioning demand, including the amount of structural insulation, external heat load, and internal heat production. The primary factors in the external heat load component are the outdoor temperature and direct solar insolation (direct sunlight on the structure). Outdoor irrigation can reduce outdoor temperatures by evaporative cooling. Water fountains can also reduce exterior temperatures, as do trees and shrubbery.

It is possible that restricting outdoor water use, while reducing individual water consumption, may result in a greater heat load to the structure, causing a larger air-conditioning demand, which requires greater electrical power generation, which consumes more water. Figures 4 and 5 illustrate this concept. This energy-related water demand may (or may not) exceed the water saved by individual consumption.

SUMMARY AND CONCLUSIONS

The interactions between water and energy use are complicated. Different methods for producing thermoelectric energy lead to widely different impacts on water resources. Sensible heat disposal increases water quality impacts, but reduces consumptive water use, while latent heat disposal effects increase consumptive uses but may have fewer impacts on aquatic resources. Analyses to evaluate alternative heat shedding are needed.

For hydroelectric energy, the advantages of storing large quantities of seasonal flows and stormwater may be offset by greater evaporative water losses. Also, the timing and magnitude of reservoir discharges may adversely affect aquatic habitats.

And finally, strategies to reduce both energy and water at domestic and commercial structures need to be examined in the context of total water use.

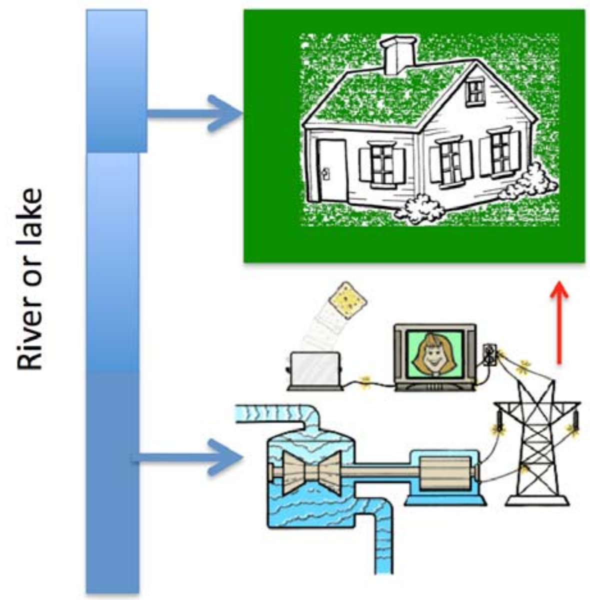

Figure 4. Water and energy use in home with outdoor irrigation. Evaporative cooling by landscape reduces heat load, reducing electrical demand and water consumed by power production.

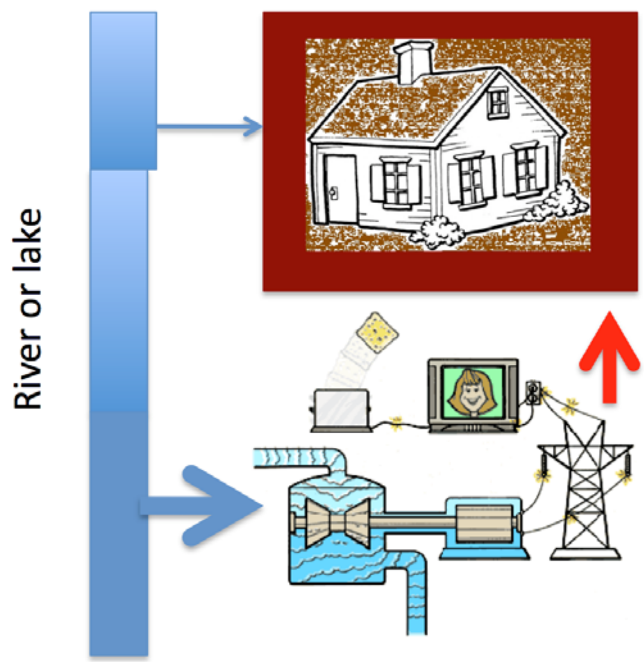

Figure 5. Water and energy use in a home without outdoor irrigation. Lack of landscaping increases residential heat load, increasing electrical demand and water consumed by power production.