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Planning for the Electricity-Water Nexus

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Introduction

Energy production requires water, while the conveyance, storage, and treatment of water requires energy—this is the energy-water nexus. The importance of this nexus has recently been highlighted by droughts reducing hydropower production, heat waves impacting stream water temperatures forcing nuclear and coal-fired power plants to suspend operations, floods and hurricanes damaging energy infrastructure, and the denial of new power plant permits due to limited water availability. All this while the energy intensity of the water sector is increasing as water is moved from more distant locations and increasing water treatment is required. Tackling this energy-water nexus will require significant coordination between water and energy managers from the local to the federal level. Coordination is necessary for:

- Quantifying use of water by the energy sector and placing it in context of other water use sectors,
- Identifying energy system vulnerabilities to water related shocks,
- Planning for energy system expansion while recognizing competing demands, and
- Quantifying energy use by water services and its relations to the changing water sector.

To help close this gap efforts have recently been made to incorporate water related considerations into the long-range transmission planning of the Western Interconnection.[1] This effort brought both state-level water managers represented by the Western Governors' Association and Western States Water Council, together with regional energy managers represented by the Western Electricity Coordinating Council (WECC). Technical support was provided by Sandia National Laboratories, Argonne National Laboratory, Electric Power Research Institute, Idaho National Laboratory, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and the University of Texas. The purpose of this paper is to highlight some of the benefits and insights gained from this integrated planning (organized according to the four needs for coordination identified above). Given the focus of this study, our analysis is limited to the electricity-water nexus.

Water for Electricity

You can't manage what you don't measure. Data on thermoelectric water use has traditionally been problematic. Coverage has been spotty and, where collected, data quality has suffered from a variety of issues. Recently the U.S. Geological Survey (USGS) teamed with the Energy Information Administration to improve the collection of water related data from our nation's thermoelectric power plants. The result was a publication by the USGS estimating water use at each of the nation's 1290 thermoelectric power plants (http://pubs.usgs.gov/sir/2014/5184/). Total estimated withdrawal in the U.S. in 2010 was 144 million acre-feet (MAF) of water or 45% of total withdrawals and 38% of freshwater withdrawals making it the largest user of water. The picture in the WECC is very different where total withdrawals measure 5.7 MAF or only 5% of total withdrawals and less than 1% of fresh water withdrawals. This big difference reflects the choice in cooling systems (e.g., Macknick et al. 2012).[1] In the eastern U.S. where water is

[1] See our project website: http://energy.sandia.gov/climate-environment/water-security-program/energy-and-water-in-the-western-and-texas-interconnects/

plentiful, it is common to have open-loop systems in which large quantities of water are directed through a condenser and then largely returned to the original source at an elevated temperature. The West is predominated by closed-loop systems that withdraw much smaller quantities of water, most of which is consumed through evaporative cooling processes.

A map of the WECC region, including all the water-using power plants, is given in Figure 1. The type of power plant is also provided, along with a relative measure of its associated water withdrawal. Sixty-one percent of all installed capacity in the WECC is thermoelectric, while an additional 28% is hydroelectric. Thermoelectric power production taps a number of sources in the West, including fresh surface water (47%), fresh groundwater (23%), municipally supplied (7%), sea water (10%) and wastewater (13%). The largest user of water in the West is the agricultural sector, accounting for over 80% of all withdrawals. Total withdrawals across the West are also mapped by county in Figure 1 to help provide some indication of the competition between electric power generation and other water use sectors.

Energy System Vulnerabilities

Both the electricity and water sectors are subject to a variable and changing climate. Energy managers need to understand infrastructural vulnerabilities to heat waves and drought, while water managers must weigh energy sector needs among other competing water demands when allocating drought-compromised water supplies. Electric generation and transmission infrastructure are vulnerable to climate in a number of ways: rising temperatures increase the demand for electricity, particularly with peak loads; increasing temperatures decrease the capacity of power lines, transformers, and substations to transmit electricity to customers; higher temperatures reduce power plant efficiencies and thus the power they produce; drought reduces stream flows reducing hydropower production; lower stream flows could cause thermoelectric power plants to reduce production due to lack of cooling water; while sea level rise and increasing wildfire threaten transmission and generation assets. The water sector will likewise realize increased demand for water across all sectors, but with more variable or reduced streamflow. Stresses on the water sector are likely to result in increased electricity demand for water pumping and treatment.

Droughts reduce streamflow and reservoir storage, which threatens power plant operation due to the physical lack of water for cooling or lack of administrative access to water due to junior water rights priority. Thermoelectric power plants that depend on fresh surface water which account for about 29% of electricity production in the WECC, are at greatest risk. This risk increases where water resources are highly appropriated for municipal and agricultural use; specifically, the Colorado River, San Juan River in New Mexico, and the Arkansas/South Platte in Colorado. Plants utilizing open-loop cooling are further challenged by the temperature of discharged cooling water exceeding permit standards (e.g., Harto and Yan 2011). In the WECC there are only two power plants that utilize open-loop cooling and that depend on fresh surface water; thus such vulnerabilities are of limited concern in the West.

Drought also impacts hydropower production. Hydropower is important in the WECC, accounting for roughly 25% of annual electricity production. However, production is variable, as in some years it can account for 40% of the region's electricity generation and in some basins the annual hydropower production can differ by a factor of 5. Studies exploring the potential impacts of climate change on hydropower production in the West suggest similar ranges in variability are to be expected over the next 20-30 years, while extreme water years, both wet and dry, should be anticipated (Sale and Kao 2012). Also important is a likely shift in the timing of spring runoff associated with mountain snowpack which could impact managed reservoir releases for hydropower production.

System Expansion
Another challenge to both the water and electricity sectors is growth. More people will require more water and more electricity. These new demands will also require more water for electricity generation and more electricity for water services. Clearly, the electricity-water nexus is an important consideration to both water and energy managers in planning future infrastructure expansion projects. In this section we address water for electricity production, while electricity for water services is addressed in the next section.

To assist WECC in their long-term transmission planning water availability, cost, and projected future use were mapped for the western U.S.[1] to identify those regions where siting of new thermoelectric power generation might be challenged by limited water supplies (Tidwell et al. 2014a). Working directly with state water managers, the availability of water for five different sources (fresh surface water, fresh groundwater, appropriated water [water likely to be sold and transferred to another use], wastewater and brackish groundwater) was mapped for 960 watersheds in the WECC. Recognizing that some sources require more effort to access and treat, relative costs (both capital and operating) were also calculated for each source and watershed. Projected new uses for water in other sectors (e.g., public, agriculture) were similarly estimated to help map out competing uses with new thermoelectric power. Finally, potential environmental constraints posed by aquatic and riparian communities were mapped to identify ecologically sensitive areas that should be avoided by new development.[1] These data were then used by WECC to help geographically constrain planning toward transmission and generation expansion.

Electric transmission planning considered other factors beyond water: future peak and base electric loads; transmission network capacity; fuel prices; technology evolution; state and federal policies; and others. Uncertainty was associated with each of these; thus WECC's long-range transmission planning was organized by a series of scenarios intended to bracket the expanded range in the future state. Each scenario resulted in a different water for electricity footprint. Regardless of the scenario, new generation choices favored low water intensity renewables and natural gas. In all cases a modest decrease in total thermoelectric water withdrawal was projected, largely due to the retirement of old inefficient generation. In contrast, water consumption generally increased by 20-30% over the next 20 years. However, in cases where strong air quality standards were assumed, consumption dropped by 30-40% due to the displacement of coal-fired generation, thus freeing water up for other uses.

Electricity for Water
Electricity is integral to moving and treating water. Efforts have recently been made to estimate electricity use in providing water services; specifically, electricity for large-scale conveyance, agricultural pumping, delivery of drinking water, and wastewater treatment (Tidwell et al. 2014b). Results indicate that drinking and wastewater account for roughly 2% of total West-wide electricity use, while an additional 1.2% is consumed by large-scale conveyance projects and

2.6% is consumed by agricultural pumping. The percent of electricity use for water services varies strongly by state, with some as high as 34% while other states expend less than 1% (average is a little over 5%). These results suggest that electricity use by the water sector is non-trivial and thus is an important considered for transmission planning.

Water managers must also be cognizant of the electricity footprint of planned infrastructure expansion projects. There are a number of large interbasin water transfer projects currently in the planning stage in California, New Mexico, Colorado, and Nevada. Groundwater levels are declining throughout the West, requiring increased electricity to lift the water for irrigation. Cities and industry are increasingly looking to saline, brackish, and reclaimed wastewater as new sources of water, each requiring extensive treatment before potable use. Cities are also faced with changing regulations requiring higher levels of treatment of drinking water, again with the result of increased electricity demand. One positive trend is the expanding capture and utilization of waste energy in municipal and industrial wastewater streams, which is often sufficient to power the wastewater facility and beyond.

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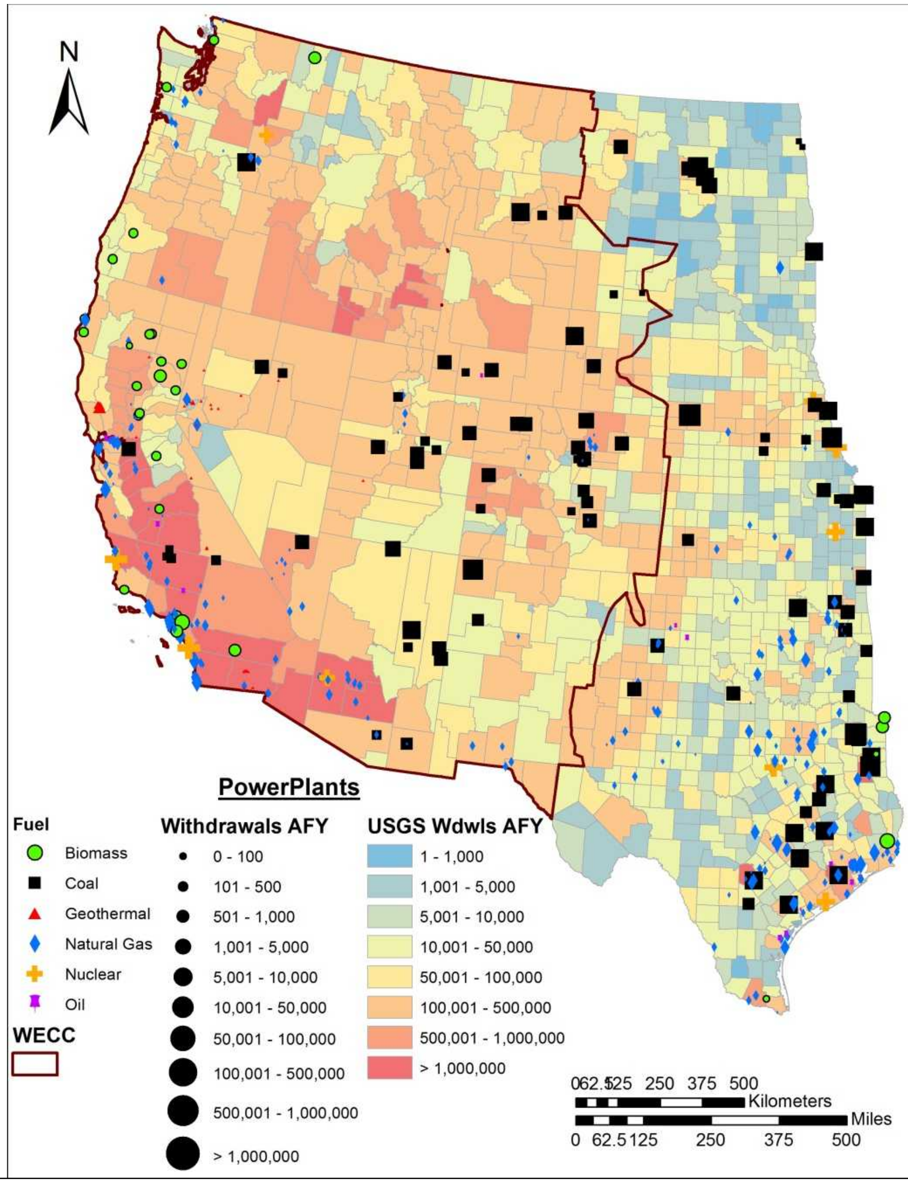

Figure 1: Map of thermoelectric power plants in the Western U.S. The icon shape designates the power plant fuel type, while the icon size indicates its water withdrawal. Total water withdrawal for all sectors is mapped at the county level.