Proceedings of the ASME Power Conference
SAND2013-3688C
ASMEPOWER
July 29-August 1, 2013, Boston, Massachusetts, USA

Power2013-98319

INTEGRATED ENERGY-WATER PLANNING IN THE WESTERN AND TEXAS INTERCONNECTIONS

Vincent Tidwell
Sandia National Laboratories
Albuquerque, NM, USA

John Gasper
Argonne National Laboratory
Washington, DC, USA

Robert Goldstein
Electric Power Research Institute
Palo Alto, CA, USA

Jordan Macknick
National Renewable Energy Laboratory
Golden, CO, USA

Gerald Sehlke
Idaho National Laboratory
Idaho Falls, ID, USA

Michael Webber
University of Texas
Austin, TX, USA

Mark Wigmosta
Pacific Northwest National Laboratory
Richland, WA, USA

ABSTRACT

While long-term regional electricity transmission planning has traditionally focused on cost, infrastructure utilization, and reliability, issues concerning the availability of water represent an emerging issue. Thermoelectric expansion must be considered in the context of competing demands from other water use sectors balanced with fresh and non-fresh water supplies subject to climate variability. An integrated Energy-Water Decision Support System (DSS) is being developed that will enable planners in the Western and Texas Interconnections to analyze the potential implications of water availability and cost for long-range transmission planning. The project brings together electric transmission planners (Western Electricity Coordinating Council and Electric Reliability Council of Texas) with western water planners (Western Governors' Association and the Western States Water Council). This paper lays out the basic framework for this integrated Energy-Water DSS.

INTRODUCTION

In 2005 thermoelectric power production accounted for withdrawals of 140 billion gallons per day (BGD) representing 41% of total freshwater withdrawals, making it the largest user of water in the U.S., slightly ahead of irrigated agriculture [1]. In contrast thermoelectric water consumption is projected at 3.7 BGD or about 3% of total U.S. consumption [2]. Thermoelectric water consumption is roughly equivalent to that of all other industrial demands and represents one of the fastest growing sectors since 1980. In fact thermoelectric consumption is projected to increase by 42 to 63% between 2005 and 2030 [2]. This projected range in growth is a function of many factors including the fuel mix of the future power plant fleet, cooling technology, and greenhouse gas emission controls.

While thermoelectric water use only represents about 3% of total U.S. consumptions, there is keen concern over future development in this sector. This is because irrigated agriculture and mining water use have stayed relatively constant over the past 40 years while the thermoelectric and municipal sectors have grown rapidly [1]. Additionally, many regions in the western U.S. can ill afford any new growth given that current water demands are challenging available supplies [3,4]. Water availability and quality concerns are not only limited to the West as plant effluent temperatures have caused plants to cease operations in times of drought in the East [5-8]. As such, water for power plant cooling is an important consideration in the siting of any new facility.

The Department of Energy's (DOE) Office of Electricity has embarked on a comprehensive program to assist our Nation's three primary electric interconnections with long term transmission planning. Given the growing concern over water resources in the western U.S. the Western Electricity Coordinating Council (WECC) and the Electric Reliability Council of Texas (ERCOT) requested assistance with integrating water resource considerations into their broader electric transmission planning. This resulted in a project with three overarching objectives:

1. Develop an integrated Energy-Water Decision Support System (DSS) that will enable planners in the Western and Texas Interconnections to analyze the potential implications of water stress for transmission and resource planning.
2. Pursue the formulation and development of the Energy-Water DSS through a strongly collaborative process between WECC, ERCOT, Western Governors' Association (WGA), Western States Water Council (WSWC) and their associated stakeholder teams.
3. Exercise the Energy-Water DSS to investigate water stress implications of transmission planning scenarios put forward by WECC, ERCOT, WGA, and WSWC.

The lead for this effort is Sandia National Laboratories supported by other national laboratories, a university, and an industrial research institute. Specific participants include Argonne National Laboratory, Idaho National Laboratory, the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory, the University of Texas, and the Electric Power Research Institute.

The purpose of this paper is to outline the basic elements of this project. Specifically, an overview of the proposed research, data collection, data assimilation, and analysis products to be produced by this effort.

WATER WITHDRAWAL AND CONSUMPTION

This effort supports the development of a model to calculate water withdrawal and consumption (e.g., Figure 1) at the *power plant level*. Estimates will leverage work identifying the water use requirements of power plants for a variety of fuel types, generation technologies, and cooling types, which is more comprehensive and process-detailed than existing research. Both emerging and mature technologies will be considered. The primary focus of this effort will be to develop water use factors associated with individual power plant specifications that are projected to be built. Further refinement of water use factors will be needed to address the variation in power plant efficiencies associated with differences in microclimates (e.g., elevation, temperature, humidity).

Another factor affecting power plant efficiencies relates to the cooling system employed. Dry cooling and hybrid cooling systems can be used to mitigate water requirements, but can impose additional energy requirements [9,10]. The focus of this particular activity will be to identify and evaluate these parasitic energy requirements and associated reduced efficiencies related to choice of cooling technology. This effort will leverage existing work on renewables being conducted by NREL and will also require collaboration with the National Energy Technology Laboratory (NETL) and other institutions to develop parasitic requirements for conventional technologies [2].

Ultimately water withdrawal/consumption factors along with parasitic energy losses will be consolidated according to fuel type, power plant technology (e.g. Rankine cycle, Brayton cycle or combined cycle, etc.), and cooling technology, then integrated into the decision support system to estimate water demands for the thermoelectric sector.

This calculator will simulate water withdrawal and consumption for current and planned electric power generation (according to individual plants) based on the scenarios developed by WECC and ERCOT. These analyses will consider both potential impacts of carbon capture and sequestration and use of alternative power plant cooling strategies. In particular, parasitic energy loss due to CCS and implementation of hybrid or dry cooling technologies will be estimated. Ultimately, future thermoelectric water use scenarios can be compared in terms of total water withdrawal and consumption. Additionally, these estimates can be compared against other water use demands and water availability metrics to assess suitability of different locations for siting of new power plants.

NON-THERMOELECTRIC WATER DEMAND

The non-thermoelectric water demand projection model provides a basis for estimating future water demand for sectors competing with thermoelectric power generation. These estimates are calculated at the interconnection, state, county and watershed levels. Through interactions with the WSWC, which is comprised of water managers from each western state, access will be gained to each state's water data and reports. This information will be used to update and develop alternative growth scenarios of future water demand. Current water use profiles will be developed by combining data directly from the states (e.g., Figure 2) with that recently published in the 2005 U.S. Geological Survey (USGS) Water Use Report [1] and

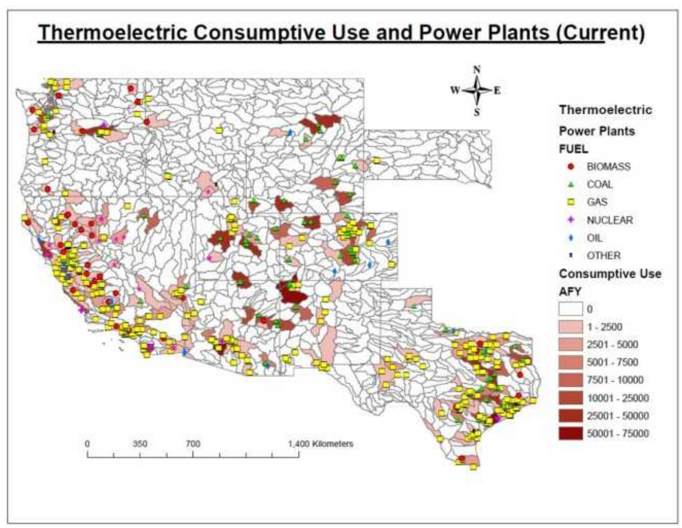

Figure 1. Consumptive water use by thermoelectric power plants in the western U.S.

ongoing efforts by the USGS relative to their National Water Census.

The water demand model will also consider irrigation and fuels processing requirements for biofuels. GIS-coverage maps for known and projected locations of biofuel crops in the U.S. will be gathered. According to these projected coverages current and potential biofuel water demands will be developed utilizing national/west-wide data collected/currently being collected by DOE, U.S. Department of Agriculture (USDA) and other researchers and utilizing the life cycle assessment and water footprint tools being developed at NREL [11]. These climatic- and geographic-specific water requirements for energy crops will consider unique crop attributes, soil type, and climatic conditions and general western crop growth factors (e.g., growing season, temperature, precipitation and soil data).

Also considered is the potential growth in the withdrawal and consumption of water for energy resource extraction and processing throughout the western U.S. This will include conventional oil, gas and coal extraction as well as other potentially important energy sources such as gas shales, tar sands and others. This analysis will also support development of alternative scenarios that differ in terms of future fuel utilization and extraction/processing technologies.

WATER AVAILABILITY

The water availability model provides a regional measure of water supply for surface water, groundwater, and non-potable resources. The model has two principle components, "wet" and "paper" water. Wet water provides a measure of the physical water available in a basin for use, while paper water addresses the institutional controls (policies) that define access to the water. These data are collected and assimilated through interactions with the WSWC, using each state's water data and reports. As necessary, data from the National Water Census and the WGA's Water Needs and Strategies for a Sustainable Future Program [12] are used to augment the available state data.

Mapping of groundwater availability was initiated by consolidating existing groundwater information within a standardized GIS coverage. The USGS base map of aquifers in the western U.S. is used to collect and consolidate available information on general aquifer type (e.g., freshwater, brackish water), and more specific information on the classification and use of economically viable aquifers. Additional groundwater availability information includes USGS and/or state saltwater intrusion and groundwater depletion maps [3].

With increasing competition for and restrictions on withdrawals from freshwater resources [13], it is becoming more commonplace for electric utilities to evaluate alternate or degraded water sources to meet power plant water needs. Potential alternate sources include reclaimed municipal wastewater and brackish groundwater. Key issues that are addressed in evaluating the availability of alternate water supplies for power plant use, include: quantity, quality, treatment requirements, discharge requirements, transport, acquisition, and regulations [14].

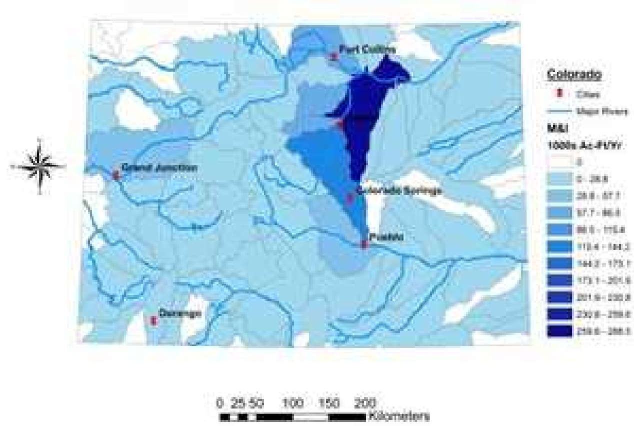

Figure 2. Current municipal and industrial water use in Colorado.

Working closely with the WSWC, WGA and state water managers major institutional controls that govern state water rights in the west are mapped. For any given location, the mapping tool will identify what state-level water rights regimes are in place for surface water and groundwater, the extent to which the water rights have been adjudicated, and what additional controls may apply, such as those relating to Tribal lands, acequias, irrigation districts, or special water districts. The tool identifies which basins are closed to future appropriation and indicate what rules are in place for water transfers. The tool also identifies basins where some or all water use is subject to interstate compact limitations.

WATER COST

Associated with the availability of water is the need to understand the cost related to the utilization of that water. In any given basin there are likely to be multiple potential sources of water for development. First, there is unappropriated water that simply requires the securing of a water right or permit from the State Engineer. Second, water can be transferred from an existing use to a new use, thus requiring payment for the water right transfer (similar to the selling of a property right). Third, a non-potable water source can be utilized, which requires the development, operation and maintenance of infrastructure to capture, convey, and treat the water for use. Finally, the choice to utilize a dry cooling system could alleviate the need for water; however, there are associated costs with adopting such technology as well as related production efficiency penalties.

The first component of the cost calculator projects historic payments for water rights transfers. Data on historic payments utilize water transactions reported in the monthly trade journals the *Water Strategist* and its predecessor the *Water Intelligence Monthly* [15]. The database lists, by state, water transfers including: the year of a water transfer; the acquirer of the water; the supplier; the amount of water transferred; the proposed use of the water; the price of the trade; and the terms of the contract.

Costing of brackish groundwater and municipal waste water consider both capital and operating and maintenance (O&M) expenses. Capital costs capture the purchase of water rights as well as the construction of groundwater wells, conveyance pipelines, and water treatment facilities, as necessary. All capital costs are amortized over a 30-yr horizon and assume a discount rate of 6%. O&M costs include expendables (e.g., chemicals, membranes), labor, waste disposal as well as the energy to lift, move or treat the water.

The cost and performance implications of dry/hybrid cooling technologies are summarized according to primary fuel technologies and geographic location. Cost data include installed capital costs, retrofit costs, and O&M costs. Performance data include annual generation and peak capacity changes to a power plant. Existing literature from peer-reviewed, government, and industry sources are reviewed to determine reported cost and performance implications of alternative cooling technologies.

ENVIRONMENTAL RISK

The purpose of this task is to develop a set of tools (collectively termed the Environmental Risk Calculator) for the identification of aquatic habitats and biota that have the greatest potential to be adversely affected by water extraction for future energy development. Efforts begin by focusing on identifying and collecting data for ESA-listed threatened, endangered, and candidate species, as well as ESA-designated critical habitat for freshwater ecoregions in the western United States (Figure 3). The focus is on currently listed riparian and aquatic biota.

Next, a model is developed for quantifying environmental risks associated with specific environmental resources and for estimating an overall risk level of a proposed energy development scenario. The model will focus initially on identification and visualization of environmental risk based on single indicators such as presence of selected endangered species. The initial model will then be enhanced to incorporate a framework for identification and visualization of more comprehensive measures of environmental risk.

Environmental risk is directly related to the types of ecological resources occurring in a watershed (i.e., hydrologic unit) located at and downstream of the extraction point, the relative significance of those resources in terms of regulatory requirements, and the impact on those resources from changes in water availability. A numerical weighting factor of relative importance is assigned to each environmental resource within in a scenario-impacted river basin. The value of this weighting factor is a function of the regulatory requirements associated with the resource (e.g., Endangered Species Act protection), the nature of the effect that an energy scenario may have on the resource (e.g., temporary habitat disruption, long term displacement of biota, injury, or mortality), and the sensitivity of the resource to changes in water availability. To provide an overall relative risk level for a proposed scenario, the relative importance of each ecological resource in the location of interest is combined. For equally important resources, the more

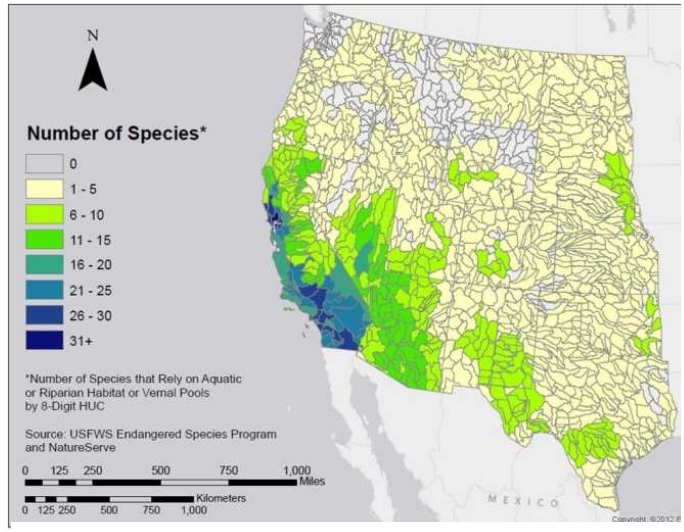

Figure 3. Number of threatened and endangered species by 8-digit HUC.

resources overlapped at a specific project location, the higher the relative environmental risk level [16].

CLIMATE VARIABILITY ANALYSIS

The purpose of this study is to examine the potential impacts of climate variability on electricity generation in the Western and Texas Interconnections. Specifically, the task assesses the vulnerability of U.S. thermoelectric and hydroelectric power plants in three water resource regions (or major river basins), Pacific Northwest, Texas-Gulf, and California, due to future adverse climate conditions. These three regions are selected based on results of our first-year drought impact study, which shows that these basins (1) have the highest potential losses of electricity generation under drought scenarios and (2) own 72% of generation capacity among all power plants in eight regions using surface water that is more sensitive to climate change [17].

A detailed analysis of hydrologic effects from the past records and future projections using finer-scale watershed modeling under climate scenarios is conducted for three major river basins at a resolution of the 8-digit Hydrologic Unit Code (HUC) watershed. Specifically, the study includes: (1) identification of basin-specific, extremely low and high stream flow events based on available historic stream flow data, (2) projection of future 2030 year stream flows and extreme flow events using finer-scale hydrologic modeling that incorporates downscaled climate forcing data under future climate scenarios, future water uses from various sectors, stream routing, as well as reservoirs along the major rivers, (3) determination of projected change in intensity, duration, and frequency of extreme flow events at the basin level, (4) estimation of stream water elevation for impacted plants and watersheds under extreme flow events, and (5) development of water availability index at the HUC digit-8 basin level by combining drought intensity and duration and water usage.

On the basis of changes in water availability resulting from climate variability and future water demand and an evaluation of power plant-specific climate vulnerability characteristics, the project team identifies vulnerable watersheds and associated plants in each of three study regions and quantify potential reduction or curtailment of power production as a result of the future adverse climate conditions.

ENERGY FOR WATER CALCULATOR

As water use expands, so too does the demand for electricity to pump, convey, treat (both primary and waste water), and distribute water [18]. Nationwide, about 4 percent of U.S. power generation is used for water supply and treatment, which, is comparable to several other electricity intensive industrial sectors. Additionally, electricity represents approximately 75 percent of the operational cost of municipal water processing and distribution [19].

The analysis of energy for water will address municipal primary/wastewater, large interbasin conveyance projects and agricultural pumping. Electricity demand for primary water supply is modeled according to an empirical relation developed by AWWArf [20] based on a regression of municipal water use versus energy consumption for a wide range of U.S. cities. In the case of the waste water system, electrical demand is modeled as a function of the water discharged to the waste treatment system, the type of treatment (trickling filter, activated sludge, advanced, advanced with nitrification), and the design capacity of the plant [21]. Wastewater plant specific data are available from EPA's Clean Watersheds Need Survey database.

Power use associated with large-scale interbasin transfers has been estimated for current and planned projects [22]. Energy use for agricultural irrigation is consistently tracked in the Census of Agriculture performed by the National Agricultural Statistics Service. This data will be used to extend the coverage of energy use for water to include agriculture.

DECISION SUPPORT SYSTEM INTERFACE

The final task is focused on integrating all of the acquired data into a self-consistent database and to develop a set of interfaces that allow different communities to interact with the data. Specifically, this task will develop the interface for the Energy-Water Decision Support System (EWDSS). And, it is the output from the EWDSS that will form the basis for interconnection wide planning.

This task will involve the development of a custom application built within the ESRI ArcGIS development environment. The custom interface will link the interactive dashboard with the EWDSS data set compiled in the tasks above. The dashboard is envisioned as providing an interactive, real-time environment comprised of tools for controlling the viewing, managing and analysis of the geospatial data. Specifically, the dashboard will facilitate the viewing of raw data (e.g., municipal water demand, location and type of existing thermoelectric power plants, thermoelectric water consumption) at a variety of different spatial scales, e.g. interconnection, state, county, HUC-8 watershed, or point level.

Another important function of the dashboard is in supporting the construction and evaluation of alternative measures of water availability. A review of the preceding tasks reveals the numerous metrics that contribute to the concept of water availability (e.g., water demand, gauged stream flow, institutional controls, water cost, environmental factors), for which there is no universally accepted measure. For this reason, a flexible means of engaging stakeholders in evaluating and approving an accepted measure of water availability is needed. The dashboard facilitates this process by supporting the construction of alternative measures of water availability and then interactively viewing them. In this way the EWDSS dashboard facilitates the development of water availability metrics that appeal to a particular stakeholder and that can be subsequently vetted with the broader community.

STATE OF THE PROJECT

Efforts on this project were initiated in the fall of 2010 and are scheduled for completion in September of 2013. Below a brief update on progress to date against each of the project's tasks is given.

Water withdrawal and consumption factors have been developed for electric power generation distinguished by fuel and cooling type [23]. Additional papers are in the review process discussing impacts of environmental factors on developed water use factors. Data supporting non-thermoelectric water demand and supply have been collected and associated water availability metric have been developed. These data/metrics are currently being vetted with state water managers and a journal paper is in review. Likewise water cost metrics have been developed and are currently under review. The environmental metric is still under development.

Climate analyses have been completed to support ERCOT planning [24]. Analyses are ongoing for the Pacific-Northwest and California regions. Work on the energy for water calculator was only recently initiated.

The EWDSS has been developed and is currently operational. It is being used to vet water demand/supply/metric data with state water managers. Once the vetting process is complete (target of July 2013) the EWDSS will be opened up for public use. When activated, the EWDSS will be accessible through the WSWC website.

Additional information, reports and presentation are available from the project website at: http://energy.sandia.gov/?page_id=1741.

ACKNOWLEDGMENTS

The work described in this article was funded by the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability through the American Recovery and Reinvestment Act of 2009 under Contract No. M610000581. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

REFERENCES

[1] Kenny, R.F., N.L. Barber, S.S. Hutson, K.S. Linsey, J.K. Lovelace and M.A. Maupin, 2009. Estimated use of water in the United States in 2005, U.S. Geological Survey Circular 1344, 52p.

[2] NETL, 2008. Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements, 2008 Update. DOE/NETL- 400/2008/1339, 2008.

[3] Reilly, T.E., Dennehy, K.F., Alley, W.M. and Cunningham, W.L., 2008, Ground-Water Availability in the United States, U.S. Geological Survey Circular 1323, 70 pages.

[4] U.S. Bureau of Reclamation, 2010, WATER 2025 Preventing Crises and Conflict in the West.

[5] Nuclear Regulatory Commission, 2010, Power reactor status reports, July–August. Online at *http://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status*.

[6] Nuclear Regulatory Commission, 2011, Power reactor status reports, July. Online at http://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status.

[7] Nuclear Regulatory Commission, 2007, Power reactor status reports, July. Online at http://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status.

[8] Nuclear Regulatory Commission, 2006, Power reactor status reports, July–August. Washington, DC. Online at http://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status.

[9] Clayton, M.E., Stillwell, A.S. and Webber, M.E., 2010, A Model of Implementing Advanced Power Plant Cooling Technologies to Mitigate Water Management Challenges in Texas River Basins, ASME International Mechanical Engineering Congress and Exposition, Vancouver, British Columbia, Canada.

[10] Stillwell, A.S., Clayton, M.E. Webber, M.E., 2010, A River Basin-Based Model of Advanced Power Plant Cooling Technologies for Mitigating Water Management Challenges, AIChE 20010 Annual Meeting, Salt Lake City, UT.

[11] Heath, G. A., Hsu, D. D., Inman, D., Aden, A., Mann, M. K., 2009, Life Cycle Assessment of the Energy Independence and Security Act of 2007: Ethanol – Global Warming Potential and Environmental Emissions. 9 pp.; NREL Report No. CP-6A2-45805.

[12] Western Governors' Association, 2010, Water Needs and Strategies for a Sustainable Future: 2010 Progress Report.

[13] Electric Power Research Institute, 2003, A Survey of Water Use and Sustainability in the United States with a Focus on Power Generation, Washington, DC: Electric Power Research Institute, EPRI Report No. 1005474.

[14] Electric Power Research Institute, 2008, Water Use for Electric Power Generation. EPRI, Palo Alto, CA. Report No. 1014026.

[15] Water Strategist, 2012. Published by Stratecon, Inc., PO Box 963, Claremont, CA, available at www.waterstrategist.com.

[16] McPherson, M., 2008, GIS-based Modeling of Environmental Risk Surfaces (ERS) for Conservation Planning in Jamaica. Journal of Conservation Planning. 4:60-89.

[17] Harto, C.B. and Yan, Y.E., 2011, Analysis of Drought Impacts on Electricity Production in the Western United States, ANL/EVS/R-11/14, Argonne National Laboratory, December.

[18] Electric Power Research Institute, 2008, Program on Technology Innovation: Research Opportunities for Efficient Water Treatment and Use, EPRI 1016460.

[19] Powicki, C., 2002. The Water Imperative, Electric Power Research Institute.

[20] American Water Works Association research foundation, 2007, Energy Index Development for Benchmarking Water and Wastewater Utilities. AWWArf, Denver, Colorado.

[21] Electric Power Research Institute, 2002, Water and Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply and Treatment – The Next Half Century, EPRI 1006787.

[22] Western Resource Advocates, 2010. Protecting the Lifeline of the West: How Climate and Clean Energy Policies can Safeguard Water

[23] Macknick, J.; Newmark, R.; Heath, G.; Hallett, K. C. Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature. Environmental Research Letters, 2012, 7(4), 045802.

[24] Yan, Y.E., Tidwell, V.C., King, C.W., and Cook M.A., 2013. Impact of Future Climte Variability on ERCOT Thermoelectric Power Generation, ANL/EVS/R-13/2, Argonne National Laboratory, Argonne, IL.