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Evaluating options for Balancing the Water-Electricity Nexus in California: Part 1 – Securing Water Availability

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HIGHLIGHTS

- A spatially and temporally resolved model of California's major surface reservoirs is presented.
- The sensitivity to urban water conservation, desalination, and water reuse is examined.
- Under baseline hydrology conditions, individual options secure water availability alone.
- Water savings from individual options other than desalination are insufficient.
- Seawater desalination alone requires extreme capacity installations.

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ABSTRACT

The technical potential and effectiveness of different water supply options for securing water availability in a large-scale, interconnected water supply system under historical and climate-change augmented inflow and demand conditions were compared. Part 1 of the study focused on determining the scale of the options required to secure water availability and compared the effectiveness of different options. A spatially and temporally resolved model of California's major surface reservoirs was developed, and its sensitivity to urban water conservation, desalination, and water reuse was examined. Potential capacities of the different options were determined. Under historical (baseline) hydrology conditions, many individual options were found to be capable of securing water availability alone. Under climate change augment conditions, a portfolio approach was necessary. The water savings from many individual options other than desalination were insufficient in the latter, however, relying on seawater desalination alone requires extreme capacity installations which have energy, brine disposal, management, and cost implications. The importance of identifying and utilizing points of leverage in the system for choosing where to deploy different options is also demonstrated.

1. Introduction and background

Concerns over climate effects on water availability combined with increasing demands in various regions are driving interest in diversifying the water supply portfolio. Many regions in the world are expected to face decreased water availability due to the impacts of climate change on regional hydrology and weather patterns (Boithias et al., 2014; Charlton and Arnell, 2011; Li et al., 2010; López-Moreno et al., 2013; Olmstead, 2013; Pingale et al., 2014; Vairavamoorthy et al., 2008; Cayan et al., 2010; Hao and AghaKouchak, 2013; Schubert and Lim, 2013; Trenberth, 2001; Wehner, 2013). A number of relevant studies have been performed for the water supply system of California in particular, due to its particular susceptibility to climate change impacts on water supply availability. Connell-Buck et al. (2011), Zhu et al. (2005), Tanaka et al. (2006), and Lund et al. (2003) investigated the effects of warmer and drier climates on water supply using the CALVIN model and outlined potential adaptation measures. More studies have predicted a warmer and drier climate with less snow pack in the future in southwestern United States (Cayan et al., 2010; Seager et al., 2007) that could affect both the water availability and energy production (Madani and Lund, 2010). Coupled with population growth and projected increases in demand in many regions, the need for more prudent water management strategies and alternative options for usable water supply has been identified. Many alternative options for water supply are currently available. The accessibility of these options varies significantly by region, however, reliance on the historical paradigm of precipitation-based surface and groundwater supplies may not be enough to meet increasing demands.

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Water conservation is one option that is encouraged in many sectors and regions. Conservation is considered as the most direct and immediate method for stabilizing the water supply. For example, regions such as California have managed to maintain per-capita water usage at steady levels through improvements in urban and agriculture water use efficiency measures (Hanak et al., 2009; Gleick et al., 2005), offsetting the increase due to population growth. Certain studies have estimated that water conservation measures may be enough to negate the impacts of climate change in particular regions (Boland, 1997). It has also demonstrated beneficial economic impacts by reducing the cost of water and increasing the value of related commodities such as food (Ward, 2014; Smart Savings: Water Conservation Measures that Make Cents, 2008).

Desalination is another option that has been implemented or is being considered as part of the water supply portfolio to combat water shortages in arid regions. As of 2011, a worldwide capacity of about 72 Mm^3/d has been installed, with the largest share of this capacity being located in the Persian Gulf countries in the Middle East region for seawater desalination, and the second largest total capacity in North America, mostly focused on brackish water desalination (Desalination.com: Market data, 2012; Lattemann et al., 2010). Middle Eastern regions have historically relied on thermal desalination, whereas new plants in North America and Australia have relied on membrane technology for large scale operations. For example, a membrane desalination plant was installed in Sydney, Australia as a contingency measure after the effects of the Millennium Drought which impacted the region from 1995 to 2010, with the capability to provide up to 15% of the city's water supply (Review of Operating Regime for Sydney's Water Desalination Plant, 2010). High energy demand is the biggest challenge in desalination installation and operation. Many research efforts in this area focus on reducing the energy and greenhouse gas impacts of this measure (Al-Karaghouli and Kazmerski, 2013; Al-Zahrani et al., 2012) or comparing it with other options (Shrestha et al., 2011; Ghaffour et al., 2013). The use of desalination, however, is limited to coastal regions with access to seawater or inland regions with access to large brackish groundwater reservoirs.

Besides conventional resources, reclaimed wastewater effluent is another alternative resource option to help secure water supplies. Approximately 12 billion gallons (45.4 Mm^3) of municipal wastewater effluent is discharged each day to an ocean or estuary out of the 32 billion gallons per day (121.1 Mm^3/d) discharged in the United States. Reusing these coastal discharges would directly augment available water resources (equivalent to 6% of the estimated total U.S. water use or 27% of public supply) (Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater, 2012). About 5–6% of municipal wastewater effluent in the U.S. is reclaimed and beneficially reused. It is projected that water reuse level will increase from 1.92 BGD (7.27 Mm^3/d) in 2008 to 2.7 BGD (10.22 Mm^3/d) by 2015. In some countries with scarce water resources (e.g. Singapore) up to 30% of the wastewater is reused. In 2009, State of California reused 218 BG (825.2 Mm^3) reclaimed water (National Water Reuse Database, 2013). Among this volume, 36.5% was used for agricultural irrigation, 11.9% for groundwater recharge, 9.7% for industrial reuse, 11.7% for wetlands, and 12.6% for public access irrigation.

All of these available options also have strong implications for regional energy use, greenhouse gas emissions, and the ability to meet renewable energy targets in different regions, and the interface between water and energy is an ongoing research field of importance (California's Water-Energy Relationship, 2005; King et al., 2013; Stillwell et al., 2011). A variety of previous studies have examined particular aspects of interactions within the water–energy nexus. Madani et al. (2014) and Guégan et al. (2012) examined in detail the potential impacts of climate change hydrology on hydropower generation and operation, and implications for sustainable energy policy (Hadian and Madani, 2013). Blasing et al. (2013) investigated the response of hydropower electricity generation to changing temperatures under climate change scenarios.

Depending on the pathway taken and the portfolio composition of water supply measures that different regions use to stabilize their water supply, energy impacts can range from co-beneficial to detrimental to the metrics described previously. Before an evaluation of the interaction of different options with sustainable energy goals can be determined, however, the sense of the scale of these options required must be determined for a given system. Many efforts have characterized only the specific energy consumption of different options. Without an understanding of *how much* of these options would be required to stabilize the water supply of a given system, however, the strength of the synergies or interferences with the energy sector cannot be accurately determined. Additionally, there have been few studies which have holistically compared different available options for securing water availability on common criteria. This study aims to address these topics in two parts.

This paper is the first of two parts, aimed at determining the following for this system:

- The ability of individual options to contribute toward stabilizing the water supply.
- The scale (capacity) of individual and mixed option portfolios required to secure water availability under baseline and climate change augment hydrological conditions.

With a more accurate sense of scale, the strength of the interactions with the energy sector can then be determined. This is the focus of the second part of the study.

For both parts of this study, the system of the state of California is used. California provides a good example system for this type of analysis. The state includes a diverse array of climates. The northern and eastern mountain regions of the state have historically received large amounts of precipitation and provided natural storage in the form of snowpack that drive the flow of major in-state rivers. The northern coastal regions experience moderate temperatures and precipitation rates, and are at the center of the state's water system as most of the major in-state rivers flow into the Sacramento Delta, which is the major distribution point of water supply for the entire state. The highly-populated southern part of the state, however, typically exhibits an arid and desert climate with little natural precipitation, necessitating an extensive reservoir network and aqueduct system to import water from the wetter regions of the state and from out-of-state sources such as the Colorado River. Additionally, water demand in the state is very diverse. High populations give rise to high urban demands, while a thriving agricultural economy gives rise to high agriculture water demands. Finally, exhibiting high populations in addition to being situated on the coast allows the state access to a wide array of water supply options: conservation, desalination, and water reclamation. A recent study based on historical observations indicates a drying precipitation trend in most of the western United States including California (Damberg and AghaKouchak, 2013). Climate model simulations of future climate exhibit different wetting and drying patterns. However, most model simulations show a drier future for California (Seager et al., 2007). In addition, highly progressive energy policies for reducing greenhouse gas emissions and increasing renewable energy usage are also present in the state, as well as access to a diverse array of renewable resources. This allows many aspects of the interplay between energy and water to be examined.

2. Model description

To accomplish the objective of determining the scale of available options to stabilize major reservoir levels and therefore the water supply, an integrated modeling platform was developed. This includes two major classes of components: 1) a model of major surface reservoir behavior and their network and 2) modeling and characterization of the