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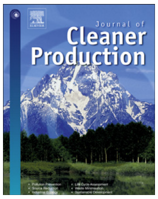

Examining the potential for energy-positive bulk-water infrastructure to provide long-term urban water security: A systems approach

Oz Sahin [a], [b], [*], Raymond Siems [a], [b], Russell G. Richards [b], [c], Fernanda Helfer [a], Rodney A. Stewart [a]

[a] *Griffith School of Engineering, Griffith University, QLD, Australia*
[b] *Griffith Climate Change Response Program, Systems Modelling Group, Griffith University, QLD, Australia*
[c] *School of Agriculture and Food Sciences, University of Queensland, QLD, Australia*

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ABSTRACT

Urban centres are increasingly requiring more water than existing groundwater and surface water sources can supply. Water authorities must consider energy intensive supply alternatives such as recycling and desalination, leading to a water-energy-climate conundrum. In this study, a systems perspective of the water-energy-climate nexus is applied to South-East Queensland (SEQ), Australia. Under a changing climate, SEQ is predicted to experience reduced reservoir inflows and increased evaporation rates, which will consequently lead to reduced water availability. To exacerbate this issue, anticipated high population growth in SEQ will increase water demand, putting even more stress on the traditional water supply sources. Clearly, there is a strong incentive to pursue solutions that increase water security without contributing to anthropogenic climate change. Using a system dynamics model, the water balance of the bulk water supply system is evaluated over a 100-year life cycle. The outputs of the model are used to investigate potential management and infrastructure options available to SEQ for adapting to increased water scarcity. The historical rainfall patterns of SEQ requires significant contingency to be built into surface water capacity in order to mitigate low rainfall years, and provide adequate water security. In contrast, reverse osmosis (RO) desalination plants do not require this excess capacity because they are rain-independent. However, RO has high energy consumption and associated greenhouse gas emissions when operating and their potential long periods of redundancy due to periods of sufficient surface water supplies remain unresolved issues. The model demonstrates that dual purpose pressure retarded osmosis desalination plants offer a potential solution, by providing water security at a lower cost than surface water reservoir augmentation, while offsetting energy use through renewable energy generation when RO plants would otherwise be sitting idle. Potentially this technology represents a future sustainable solution to overcome water security concerns.

1. Introduction

1.1. Global Context

Global demand for energy and water is ever increasing, yet an era is beginning where water and energy consumption must decrease to avoid worsening anthropogenic climate change, unless renewable energy sources comprise a greatly increased share of energy production. The impacts of climate change will be channelled primarily through the water cycle, with consequences that could be large and uneven across the globe (World Bank, 2016). Water-related climate risks cascade through food, energy, urban, and environmental systems (World Bank, 2016). Without a fundamental shift in production processes, a projected 55% more water (WWAP, 2014) and 40% more energy (IEA, 2014) would be required to support future food demands by 2050 (UNDESA, 2013).

Population and standard of living trends indicate that global energy demand will triple from 2011 levels to approximately 1500 EJ in 2050 (Siirola, 2014). Similarly, global water demand is expected to approximately double by 2050, even with significant efficiency gains (Hejazi et al., 2014). Freshwater supply is already

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[*] Corresponding author. Griffith School of Engineering, Griffith University, QLD, Australia.
E-mail address: o.sahin@griffith.edu.au (O. Sahin).

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unable to meet demand for at least part of the year for more than 33% of the world (WWAP, 2015). Similarly, in its latest report, the World Bank predicts that, within the next three decades, demand for water from agriculture could increase by 50%, and for urban uses by between 50% and 70%. Meanwhile, water consumption of energy sector by 2035 is estimated to increase by 85% (World Bank, 2016). While the world is expected to experience a surge in demand for water, under changing climate it will also face a less reliable water supply. Satisfying the concurrent increases in demand for water for food production, energy generation, urban growth, and ecosystem services would be impossible unless these sources are managed more effectively. Clearly, as water demand increases, it will likely become necessary to employ desalination in regions that currently derive most supply from natural sources, especially with current groundwater abstraction rates being unsustainable (UNESCO, 2012). Already there are more than 18,000 desalination plants installed worldwide, in over 150 countries, with more than 300 M people relying on desalination for their daily water needs (IDA, 2015). Reverse osmosis (RO) is the dominant technology for new installations (IDA, 2015). Water desalination with RO could significantly increase projected global energy demand beyond the aforementioned projections (Siirola, 2014); the energy intensity of removing soluble salts from water is a major issue (Elimelech and Phillip, 2011; Schallenberg-Rodríguez et al., 2014). However, the challenge of meeting future water demands whilst also dealing with, and reducing contributions to, climate change is very complex, akin to what has been described as a super wicked problem (Lazarus, 2009).

It is imperative that water supply is increased in line with demand whilst also reducing the contribution of feedback pathways that exacerbate energy use and climate change. Under the existing water-energy-climate system, increased water extraction leads to “more greenhouse gas (GHG) emissions”. Conversely, the goals and targets of sustainable development broadly demand that more water means “no more GHG emissions”. Of the United Nations 17 Sustainable Development Goals, six relate directly to the water-energy-climate nexus (UN, 2015). New technology, policy and optimised infrastructure portfolios must be developed to meet these goals, which is the focus of this exploratory research. Consequently the aspiration of sustainability requires a transformation in system behaviour from one where increased water use currently drives energy use and climate change (reinforcing loop) to one that mitigates energy use and climate change (balancing loop).

1.2. *Australian context*

Australia is characterised by climatic extremes. It is the driest inhabited continent and has the highest per capita surface water storage capacity of any country in the world (ABS, 2012). At a glance, it may appear to have ample water supply, only utilising roughly 5% of its total freshwater resources (OECD, 2015a). However, due to its vast size and extensive expanses of desert, there is uneven spatial distribution of population, with high concentrations in coastal areas extracting more than 50% of total renewable supply annually (Hatton et al., 2011). Until recently, Australia's water supply relied solely on precipitation and surface runoff storage. However, possessing a large storage capacity that is dependent on rainfall patterns does not provide water security. This has been observed during recent droughts, such as the Millennium drought which shaved at least 1% off the country's GDP in 2006/2007 (World Economic Forum Water Initiative, 2011). During this time, unprecedented water scarcity was experienced with inflows reduced by 70% (Pittock and Connell, 2010). In South-East Queensland (SEQ) in 2007, the result of six consecutive years of decline in the total storage level due to low rainfall caused the accessible volume in the region to fall below 40% of capacity. The primary supply reservoir for SEQ's capital city Brisbane fell to 15% capacity (SEQ Water, 2016). Subsequently, more than two M people in the region were subject to the highest level of water restrictions available, reducing residential consumption from approximately 450 L per person per day to 140 L per person per day in 2007 (QWC, 2010).

Pressure on water supply availability is expected to increase over time, led by a changing climate and high population and economic growth in Australia. Annual surface runoff, currently the main source of surface water storage systems, is expected to decrease in all Australian capital cities under an increase of 1 °C in global average temperatures, which is expected to occur by 2030 (IPCC, 2014a). In SEQ, annual surface runoff is predicted to decrease by between 5 and 30% in this scenario, depending on location. Under 2 °C global average warming, these decreases will approximately double (Post et al., 2011). In addition, open water evaporation is expected to increase in the SEQ region, reducing the availability of surface water. Evaporation rates from reservoirs are expected to be 8% higher in 2040, and 15% higher in 2080 in comparison with the baseline long-term average evaporation rates observed in the SEQ region (Helfer et al., 2012). The main driver of these increases in evaporation is the increased air temperatures. Warmer air temperatures will also see an increase in water demand. In SEQ it is well established that higher temperatures lead to increased household water demand (QWC, 2010, 2012; Willis et al., 2013).

With these factors considered, the Intergovernmental Panel on Climate Change (IPCC, 2014a) lists constraints on water resources in southern Australia as one of eight key risks facing Australasia due to climate change. However, it also lists this risk as one that ‘can be reduced substantially by globally effective mitigation combined with adaptation’ (IPCC, 2014a, 1375).

With the objective of achieving water security through water resources policy and management, adaptation began in earnest following the aforementioned drought affecting South-Eastern Australia. Water authorities have increasingly sought rain-independent supply alternatives such as large-scale recycling and seawater desalination for both base load supply and rapid drought response. SEQ was the second Australian region to invest in a reverse osmosis (RO) desalination plant, in 2009. There are now six large-scale RO desalination plants across Australia representing total capital costs in excess of A$10 billion (Turner et al., 2016).

According to El Saliby et al. (2009), the predominant desalination technology in Australia is RO desalination (68%), followed by vapour compression distillation (23%) and by multi-stage flash distillation (7%). RO desalination is responsible for 90% of the desalinated water in Queensland – the state where this study was conducted. Even though RO desalination remains as an energy-intensive process with high installation and operation costs, through significant technological improvements in the last decade, the costs have been considerable. Factors that contributed to the reduced costs were the development of membranes that can operate for a longer duration, the use of renewable energy to supply part of the energy requirements, and the development of energy recovery devices to reduce power consumption (Wilf, 2014). The economics of seawater desalination and its potential application in Australia were studied by Winter et al. (2002), who found that RO is the most economical technology to be used in Australia due to its lower energy consumption, leading to lower unit water costs, when compared to the other desalination technologies.

While rain-independent bulk supply sources such as RO desalination significantly enhance the resilience of the SEQ water supply to higher climate variability, they also adversely contribute to

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