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Research article

# Comparison of water-energy trajectories of two major regions experiencing water shortage

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ABSTRACT

Water shortage, increased demand and rising energy costs are major challenges for the water sector worldwide. Here we use a comparative case study to explore the long-term changes in the system-wide water and associated energy use in two different regions that encountered water shortage. In Australia, South East Queensland (SEQ) encountered a drought from 2001 to 2009, while Perth has experienced a decline in rainfall since the 1970s. This novel longitudinal study quantifies and compares the urban water consumption and the energy use of the water supply systems in SEQ and Perth during the period 2002 to 2014. Unlike hypothetical and long-term scenario studies, this comparative study quantifies actual changes in regional water consumption and associated energy, and explores the lessons learned from the two regions. In 2002, Perth had a similar per capita water consumption rate to SEQ and 48% higher per capita energy use in the water supply system. From 2002 to 2014, a strong effort of water conservation can be seen in SEQ during the drought, while Perth has been increasingly relying on seawater desalination. By 2014, even though the drought in SEQ had ended and the drying climate in Perth was continuing, the per capita water consumption in SEQ (266 L/p/d) was still 28% lower than that of Perth (368 L/p/d), while the per capita energy use in Perth (247 kWh/p/yr) had increased to almost five times that of SEQ (53 kWh/p/yr). This comparative study shows that within one decade, major changes in water and associated energy use occurred in regions that were similar historically. The very different "water-energy" trajectories in the two regions arose partly due to the type of water management options implemented, particularly the different emphasis on supply versus demand side management. This study also highlights the significant energy saving benefit of water conservation strategies (i.e. in SEQ, the energy saving was sufficient to offset the total energy use for seawater desalination and water recycling during the period.). The water-energy trajectory diagram provides a new way to illustrate and compare longitudinal water consumption and associated energy use within and between cities.



## 1. Introduction

This study quantifies the urban water consumption and the energy use of the urban water supply system in South East Queensland (SEQ) and Perth from 2002 (the early period of the Millennium Drought) to 2014 (the post drought period). It then explores the difference in the long-term water and energy use for water provision pathways of the two regions.

The water sector worldwide is facing a range of challenges including increasing water demand from population growth, droughts, groundwater depletion, surface water pollution, rising energy use from increasing uptake of energy-intensive alternative water sources, rapidly increasing energy cost, and the need for climate change mitigation and adaptation. For example, the combination of ongoing population growth and lower than average rainfall has generated significant water shortage/stress in many parts of Australia over the past two decades. From late 1996 to mid-2010, a prolonged dry period was experienced in much of the southern part of Australia (Bureau of Meteorology, 2015; Grant et al., 2013). It is known as the Millennium Drought and was particularly severe in densely populated south-eastern Australia and south-western Australia.

Both south-eastern Australia (where SEQ is located) and south-western Australia (where Perth is located) experienced a dry period during the Millennium Drought. South-eastern Australia had uninterrupted below median rainfall from 2001 to 2009 and entered a

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wet period afterwards as a result of La Niña-Southern Oscillation (Van Dijk et al., 2013). On the other hand, south-western Australia has encountered a "stepping down" decline in rainfall since 1975 with several major short-term meteorological droughts in 2001, 2002, 2004, 2006 and 2010 (State of the Environment 2011 Committee, 2011), and the drying climate (attributed considerably to human-induced climate change (State of the Environment 2011 Committee, 2011)) has continued after 2010.

In response to their water stress situations, both regions implemented some water management options on both the supply-side and demand-side. In SEQ, the water shortage crisis (the combined dam storage dropped to 16% (Laves et al., 2014)) was addressed by some adaptive responses from the water sector on the demand-side, commencing in the earlier stage of the drought (e.g. water restrictions, water conservation campaigns), and followed by building new-supply sources in the later stage of the drought (i.e. seawater desalination, water recycling). In Perth, water stress was concurrently tackled by outdoor water restrictions, water conservation campaigns and augmenting the system with new supply sources (e.g. desalination). The adopted supply-side and demand-side options in the two regions have significant long-term urban water consumption implications and energy implications to the water supply systems, which have not been well studied.

The major contributions of this work are the use of rare comparative time-series case studies, and the development of a water-energy trajectory diagram to explore the changes in the long-term water consumption and associated energy use in two major regions encountering water stress. A considerable amount of work has quantified and evaluated the energy implications of different water management options, ranging from centralised water sources (Lundie et al., 2004; Shrestha et al., 2011; Stokes and Horvath, 2006) to alternative decentralised water sources (Anand and Apul, 2011; Devkota et al., 2013; Lee and Tansel, 2012; Racoviceanu and Karney, 2010) and to demand management (Bartos and Chester, 2014; DeMonsabert and Liner, 1998; Racoviceanu and Karney, 2010; Willis et al., 2010). Most of these studies focus on long-term projections of energy use of individual systems through scenario analysis (Bartos and Chester, 2014; Hall et al., 2011; Lundie et al., 2004; Shrestha et al., 2011; Stokes and Horvath, 2006) or on quantifying energy use with hypothetical cases (Anand and Apul, 2011; DeMonsabert and Liner, 1998; Racoviceanu and Karney, 2010). In addition, it is well documented how SEQ (Head, 2014; Laves et al., 2014; Poussade et al., 2011) and Perth (Morgan, 2015; Newman, 2014) responded to their water stress situation, but relatively little is known about the energy implications of the drought and the implemented options on the urban water systems. A retrospective comparative study based on the experiences of the two regions can demonstrate how cities perform in practice and provides insights into managing energy use in urban water systems. This work is particularly relevant to urban areas that are facing water stress and increasing energy costs, and starting to utilise more energy-intensive water sources.

In the context of urban water supply management, there are a wide range of factors that influence both the water supply system operation and water demand, which in turn have energy implications (Fig. 1). This work focuses on the long-term impacts of changes in supply system operation and water demand on the energy use of centralised water supply systems (enclosed by the dashed line). This study examines the collective water and energy consequences of the implemented water management options and specifically, addresses the following research questions.

1. What have been the long-term changes in water consumption and associated energy use for two major urban areas (i.e. SEQ, Perth) encountering water stress?
2. How much can water management options influence long-term water consumption and associated energy use in cities? And what are the lessons learned from the two regions?

## 2. The water situation in South East Queensland

South East Queensland (SEQ) is the most urbanised and populated region of the Australian state of Queensland. It consists of ten local government areas (LGAs) – Brisbane, Gold Coast, Sunshine Coast, Redland, Logan, Ipswich, Moreton Bay, Lockyer Valley, Scenic Rim and Somerset. This work focuses on the first seven LGAs which accounted for approximately 97% of SEQ population of over three million in 2013 (Australian Bureau of Statistics, 2014b) and are connected to the SEQ bulk water supply network (Seqwater, 2013). The region obtains water from its main water source, Lake Wivenhoe and Lake Somerset (together contributing to approximately 60% of the total storage capacity of 26 dams managed by Seqwater (Seqwater, 2014a)), in addition to some smaller reservoirs such as the Hinze Dam situated in the Gold Coast region and the North Pine Dam located north-west of Brisbane. During the Millennium Drought, the main water supplies dropped to 16% of capacity (Laves et al., 2014), seriously jeopardising the regions water supply. A diagram of the bulk water supply system can be found in the Supplementary Material. The water context of SEQ is summarised in Table 1.

In SEQ, the water shortage crisis caused by the Millennium Drought triggered major changes in the configuration of the urban water supply system, the structure of urban water services and the way that water resources were being managed (Table 1). The Queensland Government provided AUD$321 million for rebate schemes of water efficient devices and rainwater tanks to the region (Walton and Holmes, 2009). Approaching the end of the drought, two climate-independent sources – Gold Coast Desalination Plant and the Western Corridor Recycled Water Scheme were commissioned. Regional bulk water pipelines called the Southern Regional Water Pipeline (SRWP), Northern Pipeline Interconnector (NPI) and Eastern Pipeline Interconnector (EPI) were constructed to connect previously segregated regional water supply systems to form a bulk water supply network.

## 3. The water situation in Perth

Perth is the capital city of the state of Western Australia. The Greater Perth region had a population of approximately two million people in 2014, 79% of the state's total population (Australian Bureau of Statistics, 2015a). The water supply and wastewater treatment services of Western Australia are managed entirely by the Water Corporation. Unlike SEQ, Perth relies heavily on groundwater for water supply with less carry-over surface water capacity. The Gnangara Mound is a major groundwater source for Perth. The water context of Perth is summarised in Table 1.

In response to the drying climate and growing water demand, stage 4 water restrictions have been imposed since 2001, limiting the use of sprinklers by householders and businesses to only two days per week. In addition, some studies were conducted in the early 2000s for augmenting the system with new supply sources. Noticeably, one of them is the study of extracting water from South West Yarragadee aquifer (the largest freshwater aquifer in Western Australia) to supply Perth (Newman, 2014). In 2004, a decision was made to construct a seawater desalination plant instead because of reducing cost of desalination technology and a concern that long-term sustainable yields from groundwater may not be achieved. Two desalination plants, namely the Perth Seawater Desalination Plant (Engineers Australia, 2010) and the Southern Seawater