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Reprint of: The potential role of desalination in managing flood risks from dam overflows: the case of Sydney, Australia

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ABSTRACT

Shifting climate patterns are causing extreme drought and flooding across the globe. This combined with the world's burgeoning population and insatiable thirst for water requires water service providers to think differently about the limited resources they manage. In Australia, the severe drought at the beginning of the century caused dams to fall to record levels. In response, many state governments invested heavily in rain-independent supplies such as desalination to augment and diversify traditional sources. However, extreme rainfall soon followed the drought, filled reservoirs and caused flooding in many locations leaving billions of dollars worth of damage and new water infrastructure standing idle. This is the case in Sydney, where the new desalination plant is still not used and the potential for major flooding has raised concerns over the safety of the large population downstream of the dam. This paper explores the growing need to understand the relationship between drought, flooding and infrastructure optimisation. The paper focuses on Sydney to illustrate the application of a system dynamics model. The new model explores options for raising the dam wall, offering airspace to assist flood protection, in contrast to options to lower the dam full supply level and utilise idle desalination capacity to fill the water security gap created. The illustrative results, using publicly available data, find that by lowering the dam water levels and operating desalination, significant flood protection can be achieved at a similar cost to raising the dam wall. The paper demonstrates the importance of optimising existing and new water resources for multiple purposes and how system dynamics modelling can assist water service providers in these complex investigations.

1. Introduction

In recent years, areas including Australia (Turner et al., 2016), California within the US (Griffin and Anchukaitis, 2014; MWD, 2015), Sao Paulo in Brazil (Carvalho, 2015), many least developed countries in Asia (Miyan, 2015) and parts of China (Zhang and Zhou, 2015), have experienced severe drought. As we look to the future, the long-term effects of climate change are likely to result in a greater frequency of extreme droughts in many regions (IPCC, 2012, 2014). This in combination with significant population rise will put additional pressure on the world's already limited water resources (McDonald et al., 2011). With these increasing pressures on our limited water resources, there is a need for greater use of alternative water supply sources (Gurung and Sharma, 2014).

At the same time more extreme flooding is being observed in many parts of the world and is likely to increase (Huber and Gulledge, 2011; Pittock, 2012; IPCC, 2014). Such flooding has had a significant impact with flood damage constituting approximately a third of the economic losses inflicted by natural hazards worldwide over the past few decades (Berz, 2005).

These extremes have had a significant impact in many countries, with Australia being a prime example of where drought was experienced for over a decade and quickly followed by significant flooding causing loss of life and severe damage (Turner et al., 2016). This combination of extreme droughts and floods and the trend towards increased urbanisation requires water service providers to think differently and to utilise infrastructure in a more productive, efficient and resilient way. Thus moving away from a fragmented

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Table 1
Key statistics for the main desalination plants in Australia (ATSE, 2012).

Plants	Built	Initial capacity (1×10^6 m^3/a)	Capacity as a % of annual demand in 2009/10	Cost (1×10^6 A$)
Perth I (Kwinana)	2006	45	18	387
Gold Coast[a] (Tugun)	2009	49	25	1200
Sydney[a] (Kurnell)	2010	90	18	1890
Melbourne[a] (Wonthaggi)	2012	150	43	3500
Adelaide[b] (Port Stanvac)	2012	100	80	1830
Perth II[c] (Binningup)	2012	100	40	1400

[a] Standby as at Jan 2015.
[b] Planned standby 2015.
[c] Currently being expanded.

and myopic perspective of water planning and management to a more integrated multi-dimensional systems perspective (Pandit et al., 2017; Turner et al., 2010; Kondili et al., 2010; Fane, 2005).

To help combat water scarcity, the vast opportunities of using desalinated seawater as a resilient rain independent urban water source are now being explored globally, with major focus in the Middle East, China, Australia and South America. This blending of ocean and rain-fed source water adds nuance to water planning and management and requires more sophisticated modelling of options to inform public debate given the major capital and operating costs incurred. There are currently over 18,000 desalination plants worldwide, with a production capacity of over 86 million m^3/day. These plants are located in over 150 countries and supply more than 300 million people.[1] Until recently, the key drawback of desalination plants has been their high energy intensity and associated unit cost (A$/kL) to produce potable water when compared to other available water supply source options. However, recent development in desalination technologies, notably reverse osmosis, has meant that new plants are less energy intensive and have a lower production unit cost, making them viable bulk supply options in large coastal cities.[2]

Water security is one of Australia's greatest issues of concern (Beal et al., 2013). Australia has a vast coastline of 69,000 km (Galloway and Bahr, 1979). Over 85% of the population live in coastal urban areas, with about 50% of the population currently located within 7 km of the shore and as many as 30% within 2 km of the coast (Chen and McAneney, 2006). Desalination has therefore been seen as a huge untapped opportunity for urban water planning over the last decade whilst more traditional water sources (e.g. dams, groundwater and river abstraction) which are often rain-dependent, have fallen short during the worst national drought in Australian recorded history, the "Millennium" drought (Turner et al., 2016). Table 1 identifies the main desalination plants built in Australia since 2006, their capacity and costs.

These assets represent total sunk capital costs in excess of A$10 billion. This high capital outlay places significant pressure on water pricing, which reflects infrastructure investment, and is recognised as being a major contributor to the rapid rise in water supply costs in Australia in recent years (PC, 2011).

Because unusually high rainfall has followed the investment in desalination, all of the desalination plants except Perth are currently on standby (as at 2015). Whilst some plants have been used for a limited time (i.e. Tugun in the Gold Coast predominantly as a backup source during flood events that caused water quality issues), such infrastructure now represents significant stranded assets that are not realising their full potential.[3]

The high rainfall experienced after the drought has caused severe flooding in several areas such as South East Queensland and Sydney. This has caused loss of life and billions of dollars worth of damage resulting in the need for State level inquiries (Queensland Floods Commission of Inquiry, 2012). Similar to the drought situation, much of the discourse on flooding currently focuses on major infrastructure solutions, that is, raising of dam walls to provide airspace to assist in flood protection (DPI, 2014). Whist this does provide a solution this comes at a high cost and does not make best use of the assets at hand, such as idle desalination.

This paper aims to provide an illustrative example of how such desalination plants can be utilised more effectively and assist in optimising the water infrastructure systems we have now. The analysis is based on a system dynamics model (SDM), developed and applied to other water planning illustrative examples in:

- South East Queensland (Sahin et al., 2014a) to explore scarcity pricing; and
- Melbourne (Porter et al., 2014; Sahin et al., 2014b; Scarborough et al., 2015) to explore rain-independent desalination versus more traditional rain-dependent dams in long term planning.

The analysis summarised in this paper focuses on examining how desalination could be used to ensure water security whilst other existing water infrastructure is used to increase flood protection. That is, a desalination plant is used to substitute supply lost if the full supply level (FSL) in the dam is dropped to such an extent that the dam provides both water security and capacity to hold a proportion of flows from flood events, thus reducing the risk of flood damage and assisting in improving evacuation timing. In this illustrative example the SDM uses publicly available information from Sydney and makes a constructive contribution to a contemporary policy problem, that is, exploring the merits (or otherwise) and costs of raising the dam wall to assist with flood mitigation arising from dam overflows due to heavy rain within the catchment versus other options. More broadly the illustrative example helps demonstrate the importance of optimising existing and new water resources for multiple purposes and how system dynamics modelling can assist water service providers in these complex investigations with multiple objectives.

The following sections provide a summary of the Sydney water supply system, current flooding issues and potential options where desalination could be considered to mitigate such flooding. It

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[1] http://idadesal.org/desalination-101/desalination-by-the-numbers/ (accessed 29/04/2016).

[2] Desalination power costs have been inflated in public estimates by using expensive wind and solar energy cost estimates, rather than optimised power from the grid. Thus reported Australian desalination unit costs relative to the Middle East raise questions of comparable cost definition, since typically the energy efficiency of Australian plants has been as good as or better than other plants.

[3] Assets are often described as "stranded" when total revenues fail to cover total (fixed and variable) costs. However this does not mean plants should be idle, since marginal costs per ML can and frequently are lower than other sources, creating a need for sound asset optimisation based on marginal cost pricing and revenue generation.