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Water security through scarcity pricing and reverse osmosis: a system dynamics approach

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A B S T R A C T

Water supply and demand planning is often conducted independently of social and economic strategies. There are presently no comprehensive life-cycle approaches to modelling urban water balances that incorporate economic feedbacks, such as tariff adjustment, which can in turn create a financing capacity for investment responses to low reservoir levels. This paper addresses this gap, and presents a system dynamics model that augments the usual water utility representation of the physical linkages of water grids, by adding inter-connected feedback loops in tariff structures, demand levels and financing capacity. The model, applied in the south-east Queensland region in Australia, enables simulation of alternatives and analysis of stocks and flows around a grid or portfolio of bulk supplies including an increasing proportion of rain-independent desalination plants. Such rain-independent water production plants complement the rain-dependent sources in the region and can potentially offer indefinite water security at a price. The study also shows how an alternative temporary drought pricing regime not only defers costly bulk supply infrastructure but actually generates greater price stability than traditional pricing approaches. The model has implications for water supply planners seeking to pro-actively plan, justify and finance portfolios of rain-dependent and rain-independent bulk water supply infrastructure. Interestingly, the modelling showed that a temporary drought pricing regime not only lowers the frequency and severity of water insecurity events but also reduces the long-run marginal cost of water supply for the region when compared to traditional reactive planning approaches that focus on restrictions to affect demand in scarcity periods.

1. Background

The need for effective planning regarding potable water infrastructure is of growing concern in major cities, as population increases and development places stress on existing systems for augmenting our sources of supply. In policy terms the water supply "market" such as it is, calls for variations in pricing, trading, pipelines and now the use of desalinated seawater as mechanisms for balancing the aggregates of water supplied and demanded. While many of the water "shortages" reflect a shortage of sound governance and price incentives, the concern over changing rainfall patterns and reduced inflows makes increased water security through desalinated water highly attractive. While desalination options may have a higher capital cost than some rain-dependent schemes, they provide a greater degree of water security to a region, which in turn decreases planning risks for water-intensive industries as well as residential and commercial customers.

Australia is characterised by extreme climatic and annual rainfall variability, and therefore water supply and demand should be assessed in this context (ABS, 2012b). Not surprisingly, the large number and size of water storages is a function of both Australia's aridity and the variable rainfall, and yet many urban centres are reliant on rain-dependent supply sources such as dams and groundwater (ABS, 2010, 2012a). Consequently, Australia stores more water per capita than any other country in the world. The cities are often very dependent on normal rainfall patterns to replenish supply sources, making them highly exposed to extended drought conditions.

In this paper, the term water security refers to a water supply guarantee as defined in the South-east Queensland (SEQ) water strategy report (QWC, 2010). That is, there will be sufficient water to support a comfortable, sustainable and prosperous lifestyle

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while meeting the needs of urban, industrial and rural growth and the environment. In order to provide water security and prepare for future extreme conditions, the QWC considered potential droughts with a severity of between a one in 1000 and one in 10,000 year occurrence, which is worse than what was experienced during the recent drought that ran nearly eight years from between 2001 and 2009. As the availability of water has influenced the pattern of economic development throughout history in Australia (Roberts et al., 2006), so water is a critical input to almost every industry. Expanded and secure water supplies are clearly vital for Australia's socio-economic wellbeing as the Australian population grows, perhaps more than tripling to 70 million by 2100 (ABS, 2013). Regardless of the exact numbers, secure and expandable water supply is integral to dynamic industrial and commercial sectors, which can be can now for the first time be enhanced by secure water supply with desalination options (WSAA, 2010).

Water security is one of Australia's greatest issues of concern (Beal et al., 2013). Population and economic growth all add to the competition for water resources, with droughts exacerbating concerns at the level of security of existing water resources. During the recent "Millennium Drought" (from 2002 onwards) in most parts of Australia, water shortages have been dramatic, with inflows reduced by 70% or more in extreme years (Pittock and Connell, 2010). For example, according to Willis et al. (2013), during the recent drought, many water supply reservoirs in SEQ dropped below 20%. Consequently, the high variability in rainfall resulted in mandatory restrictions in response to drought as observed in many part of Australia since 2002. The problem of securing enough water for urban requirements in Australia is not really an issue of insufficient water resources, but rather an issue of local and regional water balance and costs of moving and treating water including salt water. More accurately stated, dealing with water imbalance (NCEDA, 2010) is all about sound water governance including pricing, financing and regulation.

Water utilities across the world are struggling to satisfy the increasing demand for both potable and non-potable water whilst also improving the environmental profile of the urban water system (Amores et al., 2013). Clearly, with increasing pressure on existing water infrastructure from population growth and climate change, there is a need for alternative water supply sources (Gurung and Sharma, 2014). To complement traditional rain-dependent supply sources and maintain a more reliable supply of potable water to consumers, governments and water authorities, there are now a range of alternative rain-independent options such as desalination plants, advanced wastewater plants and even storm water recycling schemes. However, these capital intensive infrastructures are often planned and built only in crisis or drought periods when there may be no adequate existing funding pool for such significant expenses. As experienced in most Australian state capital cities in the recent drought, extensive debts were taken on by government and water businesses to build bulk supply infrastructure, creating on-going servicing costs on the capital raised.

When drought hits, the standard experience has been a sequence of level 1 to 5 restrictions, with increasingly severe bans on watering gardens, washing cars, and even using drip irrigation systems. Studies have estimated the costs per person of the restrictions as in excess of AUS$100 per household for each dry summer (Grafton and Ward, 2008). This means that any reform such as new desalination supply that avoids restrictions, say for 10 million people, enables in principle the self-funding of new investments at a cost of $1 billion per dry summer.

A sound and sustainable financing and economic approach to water supply and demand through a comprehensive tariff structure, as distinct from a restrictions approach, creates a capacity to fund required capital, and to optimise bulk water sources according to costs and risks. Rather than having politicians using water crises and pricing as a political platform through announcing new dams, subsidies, pipelines and desalination plants, the sound financing approach can consider the full portfolio of options, including rain-independent sources, and seek to achieve best value for money in achieving the required level of water security. Despite the potential welfare effects of household water restrictions there have been surprisingly few studies that have compared the use of volumetric prices versus water rationing (Grafton and Ward, 2008).

At the outset, it is imperative that most environmental systems are complex and highly dynamic with many feedbacks. These complex systems are characterised by feedbacks, interdependencies, and chaotic and discontinuous non-linear relations of their elements (Patten and Jørgensen, 1995). These systems have a large number of elements, which are in a series of dynamic interactions and driven by multi-causality. Effective environmental management requires an understanding of the interactions between policy choice and complex social, economic, technical and environmental processes and related aims (Kelly et al., 2013). Typically, water resources systems are highly dynamic and characterised by multiple interdependent components that together produce multiple economic, environmental, ecological and social impacts (Loucks and van Beek, 2005). Thus, as stated by Proust and Newell (2006), managing the water system optimally, and assessing its resilience and sustainability by considering possible changes in climate, population and patterns of consumption requires these systemic changes to be taken into account.

In the light of above discussion, the primary objective of this research was to develop a dynamic modelling framework for evaluating the water resource system for a number of bulk water supply source futures over a 100 year life cycle and addressing the following issues in SEQ, Australia:

- the impact of desalinated water supply in reducing the SEQ regions' vulnerability to urban water security;
- the role of desalination plants for providing water security to the SEQ region, particularly during times of drought; and
- the potential welfare gains from the use of desalination plants in combination with an alternative pricing regime (access, volume and seasonal or drought reflective tariffs) rather than restricting water use during periods of scarce supply.

To achieve the research objective, System Dynamics (SD) modelling is employed to investigate the water system in SEQ as well as conduct scenario analysis. SD modelling is a system approach and offers a suitable platform for exploring complex water systems. The following section provides more detail about the approach.

2. Approach

2.1. Provision of potable water in the study area: SEQ region, Australia

SEQ stretches from Noosa, south to the state border of New South Wales, and west to Toowoomba. In 2013, the SEQ region had an approximate population of 3.2 million people. Total urban water demand accounts for approximately 65% of SEQ's total water usage (QWC, 2010, 2012). The SEQ region, like many major cities in Australia, predominantly rely on surface water reservoirs (96%), with the exception of Perth, which relies on groundwater for 60% of its water needs (NCEDA, 2010). Such a high proportion of rain-dependent supply sources means that SEQ, like most Australian cities, requires a large storage buffer against low rainfall years (Marsden and Pickering, 2006). Dam inflow yields are particularly