Journal of Environmental Management 215 (2018) 79–90

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Evaluating a novel tiered scarcity adjusted water budget and pricing structure using a holistic systems modelling approach

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ARTICLE INFO

Article history:
Received 29 December 2017
Received in revised form
28 February 2018
Accepted 10 March 2018

Keywords:
Water demand management
Water conservation
Scarcity pricing
Water restrictions
System dynamics

ABSTRACT

Population growth, coupled with declining water availability and changes in climatic conditions underline the need for sustainable and responsive water management instruments. Supply augmentation and demand management are the two main strategies used by water utilities. Water demand management has long been acknowledged as a least-cost strategy to maintain water security. This can be achieved in a variety of ways, including: i) educating consumers to limit their water use; ii) imposing restrictions/penalties; iii) using smart and/or efficient technologies; and iv) pricing mechanisms. Changing water consumption behaviours through pricing or restrictions is challenging as it introduces more social and political issues into the already complex water resources management process. This paper employs a participatory systems modelling approach for: (1) evaluating various forms of a proposed tiered scarcity adjusted water budget and pricing structure, and (2) comparing scenario outcomes against the traditional restriction policy regime. System dynamics modelling was applied since it can explicitly account for the feedbacks, interdependencies, and non-linear relations that inherently characterise the water tariff (price)-demand-revenue system. A combination of empirical water use data, billing data and customer feedback on future projected water bills facilitated the assessment of the suitability and likelihood of the adoption of scarcity-driven tariff options for a medium-sized city within Queensland, Australia. Results showed that the tiered scarcity adjusted water budget and pricing structure presented was preferable to restrictions since it could maintain water security more equitably with the lowest overall long-run marginal cost.

1. Introduction

1.1. *Demand management strategies*

The urban water utilities in Australia and around the world are struggling to meet the increasing demand for water as they are confronted by a number of challenges including severe droughts, increasing population, highly variable rainfall, and ageing infrastructure. Supply augmentation and demand management are two main strategies used by water utilities. In order to guarantee long-term water security, the water utilities need to diversify water supply investments while improving the efficiency of water use through implementing a range of demand management strategies.

To provide water security under a range of uncertainties, utilities undertake long term planning with forecast cycles of 20–30 years (Cole et al., 2012). Complex decisions are made on how to balance the need to augment the water supply capacity, while ensuring the financial sustainability of expensive infrastructure and water services through cost recovery as well as implementing effective demand management strategies (DMS). DMS are considered to be the lowest-cost water security measure and have the potential to significantly reduce consumption of a region in terms of system leakage (Girard and Stewart, 2007), household leakage (Britton et al., 2013), water efficient appliance retrofits (Beal et al., 2012), real-time water consumption monitoring (Nguyen et al., 2013), water consumption behavioural change communication (Fielding et al., 2013) and technologies (Stewart et al., 2013). A key question is: to what extent could the water utilities satisfy the

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https://doi.org/10.1016/j.jenvman.2018.03.037
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water demand of a rapidly growing population? This issue was extensively debated during the Millennium drought between 1997 and 2009 in Australia (Pittock and Connell, 2010). Substantial water supply investment decisions are usually prompted during a water security crisis; however, as observed during the Millennium drought, often they do not deliver the desired outcomes when needed (Sahin et al., 2015). This is usually due to limited knowledge about future conditions, inadequate capabilities to handle uncertainties, and short political timeframes.

In Australia, supply augmentations, solutions, such as constructing new dams, are typically used as one of the main strategies to meet a long-term demand growth. However, in recent years, water utilities have begun considering a more reliable supply of water alternatives due to limited availability of suitable dam sites and potential impacts of changing climate, e.g.: climate-independent water supply systems. Further, many water utilities have also engaged in water efficiency initiatives with rebate schemes, while exploring the concept of Time of Use Tariffs (e.g. Wide Bay Water Corporation in Queensland, Australia) to target high water users in order to reduce their demand on the system by utilising smart meter technologies across their city (Cole et al., 2012). Although these new options are more reliable, they also require significantly higher capital and operating costs (Hughes et al., 2009). Thus, if water utilities continue building new infrastructure without managing the demand, the capital investments, as well as the operational and maintenance costs of these assets will increase the financial burden upon the utilities and jeopardise the services over time. Therefore, water utilities have been increasingly exploring the benefit of implementing demand management measures to reduce peak water demand. DMS is another key policy instrument for water utilities for planning and managing water resources (Beal et al., 2016). DMS includes: i) educating consumers to limit their consumption and incentivising improvements in water use efficiency; ii) imposing water use restrictions or/penalties for high use; iii) use of smart technologies; and iv) pricing mechanisms. Key objectives of DMS are to reduce the consumption to the level of available water supply capacity and to defer the new expensive capital infrastructure investments.

1.2. Rethinking traditional water pricing and restriction policy

High demand triggers a need for additional supply and subsequent construction of water infrastructure. Interactions between demand, supply and infrastructure/assets are complex, interdependent and dynamic over time. Water pricing and water use restrictions are two key demand management mechanisms for water use efficiency and conservation resulting in differing outcomes (O'Dea and Cooper, 2008). Water pricing refers to a mechanism covering the costs of different water services by making the users pay a defined sum per unit of water they used (or discharged). With cost-reflective pricing of water services, the utilities can send clear price signals to customers, allowing them to alter the pattern of consumption. Previous research emphasises the importance of the pricing mechanism in maximising water conservations across users in an urban setting (Arbues et al., 2004; Sahin et al., 2017). For example; two-part tariffs play a key role in enabling water utilities to achieve economic efficiency and cost recovery goals (OECD, 2010). Two-part tariffs will best meet the objectives of efficient pricing, cost recovery and equity for most urban water businesses (QCA, 2000).

However, traditional two-part tariff arrangements have not been linked to the water scarcity level of a particular supply region, thereby targeting high water consumers in the same manner regardless of the abundance or scarcity of water supply. Ideally, the second (or third, fourth, etc.) part of the tariff should be adjusted based on water availability or water security level. Well-advanced communications to customers will inform them of situations when their second tariff will be adjusted to reflect the water security position of the city (i.e. 60% of full supply, 40% of full supply, etc.) at the current or near-term projected time. When a threshold has been exceeded, the second part of the tariff can be adjusted to reflect the true cost of building and operating the capital-intensive water supply options (e.g. desalination plant) necessary to shore up water security for a city. This type of approach will ensure that capital funding is secured closer to the requirement for new infrastructure. In comparison, the current decision making approach often means that significant water security investments are only triggered during severe water scarcity situations. This approach leads to capital outlays for bulk water supply infrastructure being funded through long-term debt, meaning that customers are burdened with long-term annual price increases many years after a drought period has ended and water security has been restored. In an attempt to better link water pricing to water scarcity and equitably place the cost burden of new required bulk water supply infrastructure to those consumers that can afford to pay for higher levels of water consumption, this paper presents a novel tiered scarcity adjusted water budget and pricing structure that is argued to be preferable to water restrictions when implemented appropriately.

In many locations in Australia, water storage volumes or percentage are used as thresholds for triggering different restriction stages (Chong et al., 2009). For example, in the urban populated South East Queensland (SEQ) region, which is predominately reliant on surface water for supply, a five level restrictions schedule triggered by the dam level was introduced during the Millennium drought. For the regions' combined dam levels being 40/35/30/25/20 percent, restriction levels 1/2/3/4/5 were introduced, respectively (SEQ Water, 2015). In SEQ, water restrictions target the non-essential uses in order to reduce demand, for example: Level 1 restrictions require voluntary saving measures such as watering time; Level 2 - watering three days per week at set times by hand-held hose only; Level 3 – hoses are banned with bucket watering only; Level 4 – timed bucket watering restricted to 4–8 am and 4–8 pm; and Level 5 - timed bucket watering only and vehicle washings are banned (SEQ Water, 2015).

1.3. Tiered scarcity adjusted water budget and pricing framework

The scarcity concept suggests that the price for a scarce good should fluctuate until reaching equilibrium between supply and demand. The concept is widely discussed/implemented by a range of industries including: online retailers (Aguirre-Rodriguez, 2013), electricity retailers (Potomac Economics, 2017) and water utilities (Denver Water, 2013). In Denver (CO, United States), water is charged progressively based on usage, with a progressive drought tariff also added when applicable per 1000 gallons. At the peak of severe drought in 2009, the Independent Pricing and Regulatory Tribunal in Australia expressed interest in developing a scarcity pricing strategy for potential implementation in 2012 (Frontier Economics, 2011). More recently (Lopez-Nicolas et al., 2018), have proposed a dynamic increasing block urban tariff, based on varying reservoir levels. The proposed method was designed in 2 blocks, with the first block remaining the same, while the rate of the second block varied depending on the storage level. However, this method didn't consider changing the block thresholds while also increasing the price of the second block.

Our work addresses this gap by taking a unified approach that combines the water consumption threshold and price, enabling upward and downward adjustment. This means that as the severity