Desalination 358 (2015) 61–68

Contents lists available at ScienceDirect

Desalination

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

Long-term water supply planning in an Australian coastal city: Dams or desalination?

Helen Scarborough [a,*], Oz Sahin [b], Michael Porter [c], Rodney Stewart [b]

[a] School of Accounting, Economics and Finance, Deakin University, PO Box 423, Warrnambool 3280, Australia
[b] Griffith School of Engineering, Gold Coast Campus, Griffith University, QLD 4222, Australia
[c] School of Accounting, Economics and Finance, Deakin University, Burwood 3125, Australia

HIGHLIGHTS

- Interdisciplinary analysis of long term water supply planning incorporating economic, social and environmental variables.
- Comparison of dam and desalination costs
- Sensitivity of planning to social discount rate, water security index, population growth and scale of capital investment
- Over long term, desalination is a more cost effective supply augmentation alternative.

ARTICLE INFO

Article history:
Received 21 August 2014
Received in revised form 11 December 2014
Accepted 12 December 2014
Available online 18 December 2014

Keywords:
Water planning
Desalination
Social discount rate
System dynamics
Water security

ABSTRACT

Water resource managers and planners are continually involved in defining and evaluating alternative policies to better meet changing water supply conditions and the expectations of society. To undertake such long-term water supply planning, this study developed a novel integrated system dynamics model to combine economic, social and scientific variables and considerations within the planning horizon. Extensive sensitivity analysis for these variables was considered in this long term water resource planning process. The analysis suggests that over a longer time horizon, desalination provides a more viable, cost effective and secure bulk water supply alternative when compared to building large rain-dependent dams.

1. Introduction

Security of water for urban cities is an increasingly complex issue for water planners. Water management and optimisation is considered to be one of the most important issues to be resolved as water demand and availability vary significantly from year to year [22]. Resulting from declining and increasingly variable surface water supply and growing water demand, many urban water utilities are contemplating or have already made additional investments in less rain dependent supply sources [14]. This paper addresses the research question of determining the combination of rain dependent and rain independent water sources that most efficiently provides water security for a growing urban city. A system dynamics modelling approach which combines economic, social and environmental variables has been used to explore the sensitivity of water planning to specific variables. The system dynamics model provides a robust platform for demonstrating interactions between various factors over time [28,29].

A strength of this modelling approach is that the sensitivity of the model to the baseline assumptions can be explored. Our aim in this paper is to explore the sensitivity of the model to key assumptions, particularly those regarding economic variables such as the *social discount rate* and water supply variables such as the *water security index*. The water security index is an index of the ratio of water storage to annual usage. This measures the storage buffer available as a contingency for low rainfall years. The combination of economic and environmental variables in the model reflects the interdisciplinary nature of the research. The aim of the sensitivity analysis is to provide policy-makers with in-depth analysis on the life cycle influence of key economic and environmental parameters on the performance of water infrastructure alternatives. The system's modelling incorporating sensitivity analysis ensures that more informed water infrastructure decisions are made in the context of long term water planning.

The question being addressed is the most efficient means of attaining long term water security that is at minimum average cost. Incorporated

* Corresponding author.
E-mail addresses: helen.scarborough@deakin.edu.au (H. Scarborough), o.sahin@griffith.edu.au (O. Sahin), michael.porter@deakin.edu.au (M. Porter), r.stewart@griffith.edu.au (R. Stewart).

http://dx.doi.org/10.1016/j.desal.2014.12.013
0011-9164/

in the analysis is the question of the *preferred mix or trade-off* of cost and security that planners feel meets the needs of the community, given uncertainty of water supply due to rainfall. Economic theory suggests that in long term water projections, the pricing of water should be equivalent to the long run marginal cost of the provision of water. Hence, the aim of planning has generally been to secure water at lowest long run marginal cost. A limitation in striving to achieve this goal is the imperfect knowledge which is a feature of the preferences and the constraints of buyers and producers of urban water as well as policy-makers [13]. As discussed by Ghaffour et al. [15] there is a need to develop a structured and transparent procedure for water supply modelling which illustrates the sensitivity of results to economic parameter estimates. The modelling approach of this research builds on this literature by enhancing the information available to policy-makers with the aim of facilitating welfare maximising decisions when determining water infrastructure requirements and planning.

The paper is structured as follows. Section 2 provides the background to the case study. The modelling is outlined in Section 3, which includes, the underlying assumptions, results and sensitivity to particular variables. Section four discusses these findings and their implications for future water planning and section five concludes the paper.

2. Background to the case study

The millennium drought in south east Australia between 1997 and 2009 led to investment in rain independent water infrastructure in five Australian states [12]. In Melbourne, which is a rapidly expanding city and the capital of the state of Victoria, the drought led to the decision to invest in a 150 GL per annum desalination plant. The investment was part of a $A4.9 billion plan to secure water supplies in Victoria [11]. With a population of over 4.2 million and current population growth of over 2% per annum, community pressure for security of water supply intensified. Hence, a critical aspect of this infrastructure decision was the desire for security of the water supply for the urban population. During much of this period the urban population experienced restrictions on the availability and use of water. The volatility of the water supply is evidenced by the fact that the standard deviation of the annual inflow for Melbourne reservoirs is about 45% of the average annual inflow [13].

The nature of this volatility of inflows in the model highlights the importance of including the water security index in the analysis and incorporating the significant difference between the two water options in terms of the degree of water security associated with different infrastructure decisions.

Given that this investment has now been undertaken, there is a period of time before further water augmentation decisions need to be made. This provides the opportunity for reflection of past decisions and planning for the future by examining the issues associated with future water augmentation infrastructure decisions. A comprehensive analysis of future water augmentation decisions needs to include demand management, portfolio choice of additional investment in infrastructure, and the timing and scale of investment in additional supply. These issues are addressed in the following model.

With current projections, particularly regarding population growth and climate variability, there is a looming gap between increasing water consumption and declining water supply in Melbourne. Hence the question arises as to the least cost, most achievable means of meeting these forecast future supply and security constraints.

Rain dependent alternatives to supply augmentation generally come under two headings; the construction of dams to meet water requirements or extraction from groundwater and/or river water supplies. In the case of Melbourne, the latter option is not currently a realistic alternative, given constraints, including political, on using the new pipelines for inter-basin transfers. Thus we have only canvassed the building of dams as a viable rain dependent future water supply for Melbourne. The viability of future dams raises issues such as site availability and environmental impacts and costs and these issues are discussed in section four.

There are two main rain independent alternatives to supply augmentation; investment in desalination and demand management policies such as water restrictions. Research into the willingness of consumers to pay for security of supply suggests that households have significant preferences and willingness to pay to have security of water supply and to avoid the imposition of water restrictions [6,9,17,18,19]. Willingness to pay to avoid restrictions is shown to increase with the severity and duration of restrictions and may be as high as half the current water bill and, as expected, varies considerably between households. In terms of long term water demand and supply, restrictions are not a viable long term alternative for meeting impending water shortages as it is not feasible that demand could be sufficiently reduced to meet constrained supply levels. Similarly, the price elasticity of demand for water is too low for price mechanisms to be applied to reduce demand by the required magnitudes. Hence, this paper focuses on comparison of the predominate rain dependent long term water supply option for Melbourne — the construction of dams and, the viable rain independent alternative — the construction of desalination capacity. The limitations associated with this approach are discussed in Section 4.

3. Modelling

3.1. Baseline assumptions

The Systems Dynamics Modelling used in this study provides a robust platform for analysing the interactions between variables influencing water demand and supply, and for exploring the sensitivity of the results to the economic, social and environmental assumptions. It is a powerful tool for informing policy-makers seeking to undertake long term planning of water supply augmentation decisions and has been used for long term planning in a range of fields. (For a summary see [28,29].)

Systems Dynamic Modelling is a powerful methodology and computer simulation modelling approach which can be used for exploration of different options and understanding the long-term implications of management decisions. The system diagram used in this project for analysing the water resource planning situational context for Melbourne is illustrated in Fig. 1. The systems dynamic model simulates current and future water supply and demand by considering the effects of factors such as population growth, climate triggered variability in water supply and the potential portfolio mix of rain-dependent dams and rain-independent desalinated water supply. For this analysis, the systems dynamic model was built using Vensim® DSS [34] with assumptions for parameters and responses drawn from available literature and a range of experts from academia, private consulting firms and government water agencies. The status quo model parameter inputs for the case study city of Melbourne are summarised in Table 1.

The population estimate of 4.25 million is based on Australian Bureau of Statistics estimates of Melbourne's population as at June 30, 2012 [3]. A default conservative rate of population growth of 1.25% has been used based on estimates from the Victorian government [32] . Based on historical usage patterns water use is assumed to be 250 L per person per day, with 150 L being based on residential use and 100 L based on non-residential use [24]. The current dam water supply capacity is 1812 GL [2] and the current Wonthaggi desalination plant capacity is 150 GL per annum. Although the major dams supplying Melbourne are near full capacity as a result of a few consecutive years of normal rainfall, in the last decade it reached a low of approximately 30% of full capacity.

Construction and operation of desalination plants require substantial investments and vary region to region [10]. Accordingly, the cost of desalinated water depends upon many factors such as desalination method, the energy source, the water salinity and the size of desalination plant [21]. From a cost perspective, in this paper, the capital cost