Water Policy 20 (2018) 617–630

An unexpected decrease in urban water demand: making discoveries possible by taking a long-term view

David Ebbs[a,*], Peter Dahlhaus[a], Andrew Barton[a] and Harpreet Kandra[b]

[a]*Federation University Australia, Mt. Helen, PO Box 663, Ballarat, VIC 3353, Australia*
**Corresponding author. E-mail: d.ebbs@federation.edu.au*
[b]*Federation University Australia, Churchill, PO Box 3191, Gippsland Mail Centre, Morwell, VIC 3841, Australia*

Abstract

Forecasting supply and demand is fundamental to the sustainability of the water system. Demand for urban water seems on an ever-upward trajectory, with use increasing twice as quickly as population throughout the 20th century. However, data from Ballarat, a city in south-eastern Australia, show that despite this conventionally held wisdom, total water usage actually peaked over 30 years ago. While the 1997–2009 'Millennium Drought' had some effect, the decline commenced many years before. Initially, this was due to a reduction in external domestic water use, which correlates well with an increase in water price. However, the effect was found to not be purely economic as the price was not volumetric-based. Internal water use seems more affected by technological advances and regulatory controls. Interestingly, there was no relationship found between rainfall and water demand. The role of price, water-reduction education programmes, water-efficient technology and regulation supports previous research that a multifaceted approach is required when developing demand-reduction policies and strategies. This finding emphasises the importance of understanding the component of consumptive behaviour being targeted, and ensuring that policies being implemented are appropriate for the desired behavioural change.

Keywords: Domestic water use; External water use; Internal water use; Urban water demand; Water policy; Water price; Water price elasticity

Introduction

Forecasting supply and demand is fundamental to the sustainability of the water system. The demand for water increased dramatically during the 20th century, with worldwide domestic water use increasing sixfold, compared to a threefold increase in population (Cosgrove & Rijsberman, 2000). The increases in living standards represented by the introduction of hot water availability, flushing toilets, showers and

doi: 10.2166/wp.2018.096

washing machines all contributed to increasing personal indoor use, with garden watering also impacting total domestic demand.

There has been a long-term interest in what drives consumptive water demand. Cochran & Cotton (1985) developed a model for Oklahoma, taking water price, per capita income, rainfall, temperature and people per household into consideration. This model compared favourably with the estimates by water utilities, which until then had simply used population as the indicator of water use. Studies such as those by Hamilton (1983) and Berk *et al*. (1993) examined factors that induce water-saving behaviours in households and include education, income and technological improvement, while Aitken *et al*. (1994) also included attitudes, habits and values. Jorgensen *et al*. (2009) investigated 27 previous studies into behavioural models of water consumption and concluded that trust in the water authority and other consumers to undertake water savings is an important factor in changing behaviour. As the driest inhabited continent with increasing population and water use, Australia has been grappling with these problems since the 1970s with continued focus until the present day (PMSEIC, 2007; Morgan, 2011; Ward *et al*., 2012; Marlow *et al*., 2013).

In the context of the above observations, this study reviewed the progress of a city in relation to changes in the water use over time and identified which strategies correlate with these changes. Rainfall, water availability, outdoor garden use, allotment size, water price and tariff structure are considered. Identifying which of these correlate to changes in use, using a long-term, community-wide analysis, may assist other cities that are similarly attempting to manage the balance between water supply and demand. Water use data were studied for 135 years for Ballarat, an inland city in south-eastern Australia with a current population of 102,490 people (ABS, 2014). Anecdotal observations, supported by studies into water behaviour (Coombes *et al*., 2014; Lowe *et al*., 2014), suggested that water use increased in Ballarat throughout the 20th century until the impact of the Millennium Drought, a 14-year period from 1997 to 2010 of below-average rainfall in south-eastern Australia (BOM, 2015). Severe restrictions then forced technological and behavioural change to reduce usage. The long-term drought was considered to last adequate time for behaviour change to become embedded, a critical mass of people to be involved, so that water-saving behaviour became normalised, and technological changes locked in. However, the longer record of water use data shows that usage peaked 20 years prior to the implementation of restrictions and had declined significantly prior to the drought.

The surprising result of long-term sustained water use reductions was analysed in relation to the factors that drove this. The study demonstrates the value of analysing long-term data, and the pitfalls of assuming that demand is simply driven by population, availability or price. Further, the longer record shows the factors responsible for water demand to be complicated, with social, economic and environmental factors all influencing urban water usage.

Ballarat – a case-study city

Ballarat is an inland, regional city in south-eastern Australia, 110 km from the Victorian capital, Melbourne. It is facing a range of water supply and demand issues typical of many cities throughout the world. The population has been constantly growing, from 40,000 in 1945 (ABS, 2014) to its current level, and is forecast to continue growing, reaching 140,000 people by 2035 (profile id, 2015). Ballarat was established and grew primarily due to the discovery of gold in the 1850s. As with other towns sited near a mineral resource, this meant that it was not primarily established due to convenient water availability. Indeed, it is located on the intersection and at the upper reaches of four catchments, which limits the available upstream harvesting area. Inter-basin transfers have been part of the water management system since its establishment.

The city is in a temperate climate zone, with average temperatures predicted to increase due to climate change, and average annual rainfall expected to decrease and become more variable (Ricketts & Hennessey, 2009). Over 80% of the urban water supply since 1974 has come from the Moorabool River, located in a catchment adjacent to Ballarat (CHW, 2016). This is now rated as being in very poor to moderate condition along various reaches (DEPI, 2014). During the Millennium Drought, the surface water supply was supplemented by using groundwater and the commissioning and use of the Goldfields Superpipe for inter-basin transfers from remote catchments (CHW, 2016). As Victoria's largest inland city, and third in size overall, water use in Ballarat has been the subject of interest in that it can be considered a developmental site for potential changes in the broader community.

A water supply in the form of a standpipe was first provided to Ballarat in 1858, with usage data recorded from 1882. Metered domestic supplies and tariffs were introduced in 1915 with the sewerage system commencing in the 1920s. During the next 60 years, expansion of the system and economies of scale resulted in the water price reducing. From 1980, with increasing concern about the viability of supplying ever-increasing quantities, the water price began to increase. In 1996, volumetric-based tariffs were introduced, with restrictions in place from 2000 until 2008 due to a sustained drought.

While Ballarat is a small, rural city and therefore not all observations regarding water management will be directly applicable to larger urban places, the issues of population growth, supply constraints, and increasing climatic and environmental pressures are common. The lessons from this case study using a long-term view and community-wide usage data can inform water management in other cities with similar issues.

Methods

Data sources

The amount of water supplied in the Ballarat region is recorded in the water utility annual reports. These are available in the Central Highlands Region Water Corporation (CHW) archives from 1882 until the present day (CHW, 2016). The annual reports have also been the source of information on reservoir levels, water-restriction implementation, domestic and non-domestic use, sewer flow and revenue, including fixed and variable water charges.

Population data for Ballarat are available from census reports (Victorian, 1857; ABS, 2014; profile id, 2015). Rainfall data have been sourced from the Australian Bureau of Meteorology (BOM, n.d.), information on groundwater wells (bores) from Southern Rural Water, and allotment sizes from the Department of Environment, Land, Water and Planning, while the websites of the major Victorian urban water authorities, Melbourne Water, Yarra Valley Water, South East Water and City West Water, were used to identify relevant legislative and policy changes, along with the Building Standards and the Victorian Legislation archives.

Data management

As additional regions have been merged into what is now CHW, care has been taken to only include connections and water use that are currently covered by that reported as 'Ballarat and District' in the most recent annual reports. The number of connections shows no significant discontinuities that would represent data being suddenly included or excluded.

From 1882 until 1955, the water supplied was calculated by a summation of all metered water, including unpaid water. In 1956, metering was installed at the discharge of reservoirs, which resulted in a step increase in the reported water use due to the inclusion of previously unmetered water, system losses and improved accuracy. A correction for this difference could be made by increasing all usage data prior to 1956 by 60%; however, for the sake of veracity and transparency, and as the change does not significantly impact any conclusions, the raw data are reported here.

While domestic and non-domestic water use have been reported for much of the time in question, this has not always been the case. Between 1956 and 1997, the revenue ($) and rate ($/litre) for each were used to calculate the volume such that:

$$\textit{Non-domestic water use}(\textit{litres}) = \frac{\textit{Non-domestic volumetric water revenue}(\$)}{\textit{Non-domestic water rate}(\$/\textit{litre})}$$

The conversion factor of 4.54 litres per UK gallon has been applied to all volumetric data from 1882 until 1974.

As few people were connected to the reticulated supply during the early years, total population does not give an accurate comparative water use per head. Therefore, the number of connections to the water supply system and the number of people per house were used to determine water use per connected person. This technique has been used in other jurisdictions, such as Melbourne's water supply, to determine the estimated population served by the water authority (MMBW, 1934).

The per person water use is calculated by:

$$\textit{Domestic water use per person} = \frac{\textit{Domestic water use}}{(\textit{Domestic connections} \times \textit{People per household})}$$

The vast majority of water used inside the home (bathroom, laundry, kitchen and toilet) goes to the sewerage system, and most of the water used outside the home is lost to evaporation, transpiration, soil infiltration, groundwater recharge or stormwater runoff. Therefore, in places where there are separate sewerage and stormwater systems, as there are in Ballarat, the ratio of sewage flow to total water supplied gives an indication of the percentage of water use within the home. While there will be variation between years due to rainfall, which inevitably affects the annual volume of sewage treated due to spillage and infiltration, trends over time will demonstrate changes in inside and outside water use. While no other published studies have been identified that use sewage volume as an indicator of internal water use, the process followed in this study is similar to the sewage discharge factor that water authorities apply when charging volumetric sewage rates to unmetered flows (e.g. CHW, 2016; CityWestWater, 2017). Other studies on water use behaviour, using individual household information, gain understanding from surveys and direct data collection (e.g. Aitken *et al*., 1994; Syme *et al*., 2004; Grafton *et al*., 2011; Wolters, 2014). While this provides a level of accuracy, there are the issues of observer influence and a relatively small sample size, and individual sewer flow is generally not available to confirm results. Prior to 1970, as areas of the city were not sewered, the ratio of the sewer flow to supply does not reflect the percentage of water used inside the home. Therefore, only data from 1970 onwards are used in this section of the analysis. An assumption is made that the percentage of non-domestic water that flows to the sewerage remains constant over time at 80%, using the same factor that CHW use for determining the waste-water rates for commercial customers (CHW, 2016). The results are not sensitive to this percentage, with a 10% difference having less than a 1% impact on the estimate of internal water use, and no detectable change in the trend. The amount of non-domestic sewage flow is then calculated and, by difference, the domestic sewage flow. The ratio of domestic sewage flow to domestic water use is then used to calculate the percentage of domestic indoor and outdoor water use, and the outdoor water use per person.

The total water revenue (fixed and variable) was divided by the total water supplied (excluding charitable, free or non-revenue water) to calculate a price per kilolitre, which was then converted to 2015 AUD ($) using the Consumer Price Index data (ABS, 2016) and decimal currency conversion rate when appropriate. While there were many variable water rates for different users, this method gave a value that coincided with the most commonly applied domestic rate.

Results and discussion

Potable water use

A continual increase in total potable water use (with a step change in 1956 as discussed) is seen from the 1920s, consistent with growing population and higher living standards. As described in the introduction, this was expected to continue until the end of the century; however, the increasing trend ends in the mid-1970s (Figure 1) with the peak usage occurring in 1980. As demand is so multi-variant, it is unsurprising that it is difficult to define a clear-cut time when the decrease commenced, but it certainly

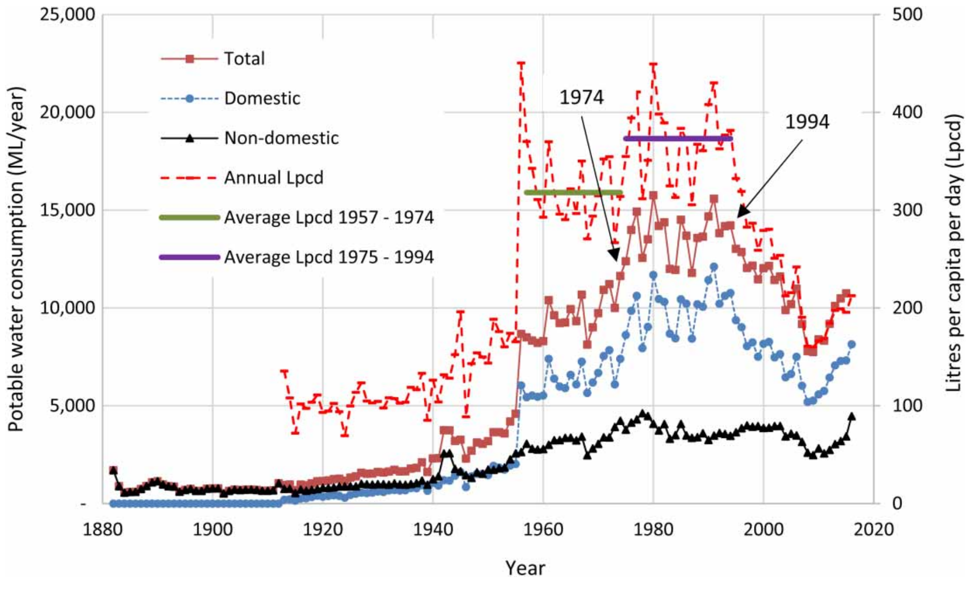

Fig. 1. Ballarat water use 1882–2016.

stopped increasing sometime between 1976 and 1980. There is no detectable change in overall water use between 1980 and 1994, and then a significant reduction occurs during the 6 years prior to 2000, when restrictions commenced due to drought, and this decreasing trend continues until restrictions are lifted in 2008.

Domestic and non-domestic use

Non-domestic water use is a target for alternative water supplies as there can be businesses using high volumes, often with lower-quality requirements. This, along with changes to the industrial and commercial landscape, can lead to higher volatility in demand. While the non-domestic water use for Ballarat peaked in the 1980s and then declined (Figure 1), similarly to the overall consumption, it was not the driver of reduced usage. Since domestic usage is almost entirely the cause of overall reduction, it is the focus of this paper.

Factors in driving domestic demand identified in previous studies (Cochran & Cotton, 1985; Aitken *et al*., 1994; Cary, 2008; Grafton *et al*., 2011) include outdoor water use, rainfall and water availability, price, environmental awareness and water policy, which are explored more fully in the following sections.

Water use per person

Managing total use and balancing supply and demand are the main objectives for water utilities. However, when trying to understand demand and consumer behaviour, water use per person is a more appropriate measure. The water use per person per day shows a steady increase, as expected, until 1955 (Figure 1). The measurement changes and the 1956 peak attributable to increased water use in filling Lake Wendouree, the rowing venue for the Melbourne Olympic Games, create a discontinuity in the data at this time. From 1957 until 1994 there is an overall increase, although linear lines of best fit and testing of means between low and high periods show no statistically significant change between 1957 and 1974. Similarly, there is no change from 1974 to 1994. It is therefore best characterised as a step change from an average 318 litres per capita per day (Lpcd) to 373 Lpcd. There is a strong decline in water use from 1994, although it could also be observed as having declined from earlier peaks in 1980 or 1991, with a few higher years against the per capita water use trend. Potential causes for the reduction in use, including a tariff structure change in 1996, are discussed further in this paper.

By the time water use restrictions commenced in Ballarat in 2000 as a result of the Millennium Drought, water use had already reduced from 400 Lpcd in 1980 to approximately 270 Lpcd. A further reduction to 200 Lpcd occurred between 2000 and 2008 with restrictions in place during the drought. In Melbourne, the capital city of Victoria with a population of approximately four million people and 110 km from Ballarat, the annual water consumption increased until 1998. From then until 2010 water use declined, before stabilising over the past few years (MelbourneWater, 2015). The domestic water use is currently 166 litres per person per day or 17% less than that of Ballarat.

The decline in water use in Ballarat and Melbourne is similar from 2000 onwards and could be attributed to similar climate influences that were being experienced. However, the decline in water use in Ballarat between 1980 and 2000 is incongruent, confirming the potential for lessons to be drawn from the analysis of the drivers of demand.

Rainfall, water availability and restrictions

If water is not available, it cannot be consumed and, conversely, as water supplies increase in size and distribution becomes more common, use also tends to increase. An increase in ability to supply to Ballarat came with the commissioning of the Lal Lal reservoir in 1973 and this corresponds to a consumption increase at this time. Lack of rainfall and any subsequent implementation of restrictions will result in demand reductions, and restrictions in 1982 may be considered to have contributed to the reduction in use at that time. However, restrictions were used in Ballarat in 1946 and 1967, and while they had the desired impact of temporarily reducing demand in those years, they had no long-term impact, leading to the assumption that restrictions during 1982 would not have been the reason for the longer-term reduction in use. Restrictions were again in place between 2001 and 2008, and generally increased in severity (DEPI, 2015), until water diverted from northern Victoria (via the Goldfields Superpipe) became available. The restriction schedule initially limited, and later banned, external household water use. The length of time for which these restrictions were in place has been considered to be significant enough to permanently change people's water use behaviour (Lowe *et al*., 2014), to the extent where water demand would not recover to pre-restriction levels, even after all restrictions were lifted.

From the initial stages of trying to model urban water demand (Cochran & Cotton, 1985), rainfall has been identified as a factor that may negatively correlate with water use. It seems logical that with higher rainfall, less water use is required for lawns and gardens. However, rainfall anomaly versus water use data from 1957 until 2016 (Figure 2) shows that there is no correlation ($R^2 = 0.03$) and, even when outliers are removed, which correspond to the transition from drought years with restrictions to high rainfall (1967, 1982, 2010 and 2011 as shown), there is a slight positive correlation, but the R^2 value of 0.11 is

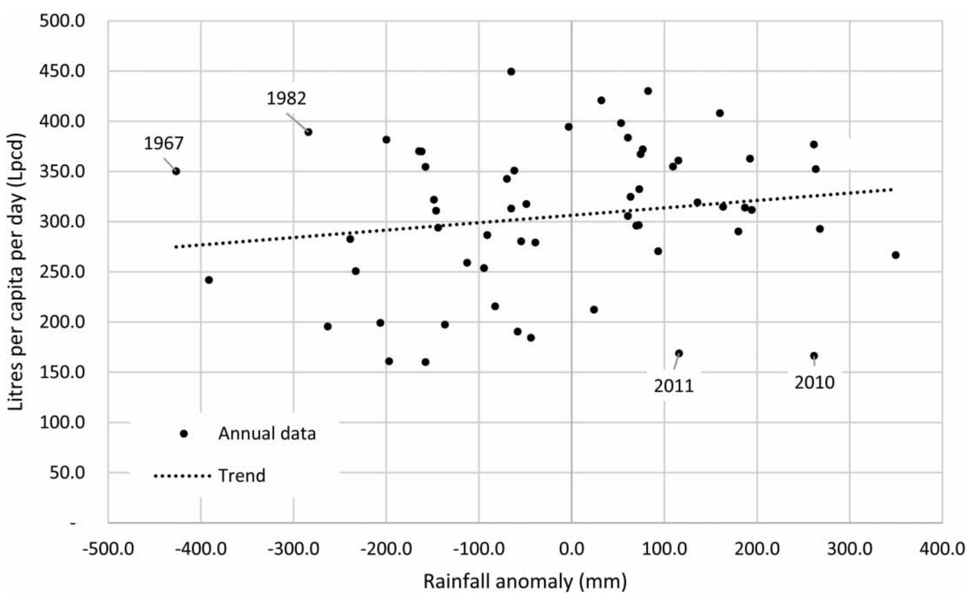

Fig. 2. Ballarat water use per person versus rainfall anomaly.

still very low. A positive relationship between rainfall and use may be related to consumer behaviour whereby there is a level of comfort with high use when there is plenty of water available.

The reduction in water use throughout the 1980s and 1990s cannot be conclusively attributed to either less external water being required due to high rainfall, or the impact of a low rainfall period with restrictions. Despite the expectation of a relationship between rainfall and usage, no correlation was found, which is consistent with studies over 6 years in Phoenix, Arizona (Campbell *et al.*, 2004) and Germany (Schleich & Hillenbrand, 2009). Over the period of this study, changes in technology and community behaviour have resulted in much larger changes than any that can be attributed to rainfall variation. While it may seem counter-intuitive, the data for Ballarat suggest that rainfall was not a particularly important factor in the change in annual water use.

Outdoor water use versus total water use

External water use is often considered more discretionary than internal use (Sadalla *et al.*, 2014), although Syme *et al.* (2004) argue that the amenity achieved through maintaining a garden is important for many in the community. As such, it has been regularly included in domestic demand models (e.g. Aitken *et al.*, 1994; Syme *et al.*, 2004; Jorgensen *et al.*, 2009; Sadalla *et al.*, 2014). Comparing the total sewer flow to the total water supplied to Ballarat shows a steady increase (Figure 3), which is considered to reflect the higher percentage of total water being used inside the home. The external domestic use per person shows a decrease from 1980, corresponding to the timing of the overall decrease in water use in the city.

Allotment size is intuitively related to outdoor water demand and has been shown to be a significant variable (Syme *et al.*, 2004), although those with smaller lawns have been shown to be less efficient

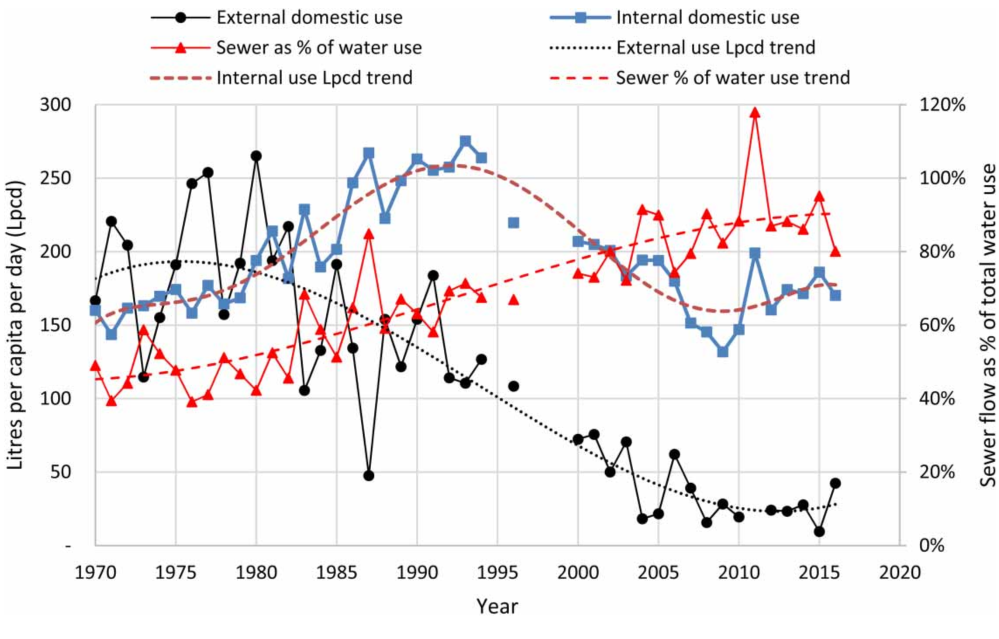

Fig. 3. External and internal domestic water use in Ballarat.

(Landon *et al*., 2016). Comparing allotment size in Ballarat from 1956 to 2016 to water use produces a weak linear correlation ($R^2 = 0.33$). However, this simply demonstrates that both variables increased and then reduced at the same time, without establishing causation. The average number of people per home reduced linearly over this period, unlike water use, which increased and then decreased.

The impact of other potential causes of reduced external water use such as garden aesthetics, drought-resistant plants and water-efficient design cannot be identified using these data. Given these constraints, it is not possible to quantify the effect of block size and separate its effect on water use with these data, while recognising the large impact that external water use had on the overall water use reduction.

Outdoor water use is generally non-potable, leading to the possibility that alternative water supplies have been increasingly used rather than there being an actual reduction in water use. However, the use of rainwater tanks in the 1980s was still discouraged and it is unlikely that they had a significant impact at this time (Gardner & Vieritz, 2010), and the number of domestic groundwater supply wells also showed no increase. Grey water reuse systems, such as laundry water to the garden, would have a similar effect in reducing external use of potable water; however, this would result in a simultaneous reduction in both sewer flow and water supply, with little change in the relationship, counter to the data. There is, therefore, no indication that non-potable water use was the cause of water use reductions prior to the Millennium Drought.

The data on internal and external water use over time demonstrate a major shift in the consumption pattern, with external use accounting for more than half of all use in the 1970s but reducing to typically 10% since 2005, after which it remains relatively constant. While some of the difference may be attributed to restrictions from 2001 to 2008, there has been a long-term and sustained change in consumer behaviour.

While external use decreased from 1980, as did the overall water use, internal domestic use per person continued to increase throughout the 1980s, with the voluntary programmes in place at that time having little effect on non-discretionary use. Internal use peaks and declines from the mid-1990s (Figure 3), suggesting that the restrictions imposed, technological changes and general awareness during the protracted Millennium Drought period had more impact on the internal, less-discretionary, water use as may be expected.

Water price

Demand for water has generally been considered inelastic with regard to price, although this does not mean that price does not affect usage, only that the percentage change in use will be less than the percentage change in price (Olmstead & Stavins, 2009). The price for water in Ballarat has been calculated by dividing the total water revenue, made up of fixed and volumetric charges, by the total quantity of water supplied. From 1915 to 1996, the fixed component of the water price was 95% of total domestic revenue, and the variable domestic portion never exceeded 11% of the total domestic charge in any year. Up until 1980, network expansions and economies of scale enabled the price to be reduced and then maintained in real terms allowing for inflation (Figure 4). The resulting relationship between price and usage is therefore a result of higher volumes rather than a driver of increased use. From 1981, increases in real price correlate with a decrease in water use (Figure 4). While this trend appears continuous between 1981 and 2006, there was a significant change to the tariff structure in 1996. The fixed price component of the tariff was reduced to 25% of the total, with a volumetric charge making up the

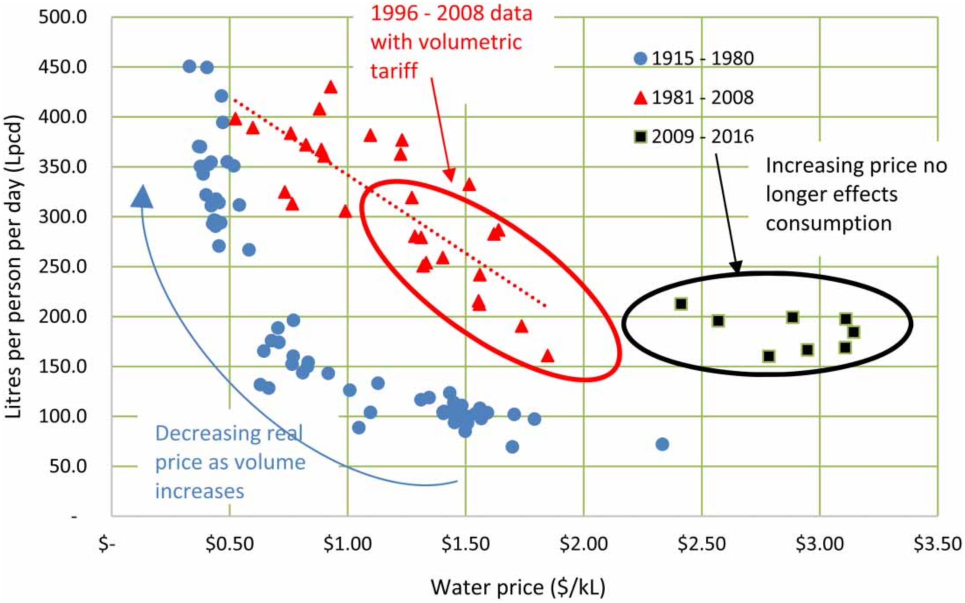

Fig. 4. Ballarat water consumption versus price.

remainder. Despite the change in tariff structure, the data from 1996 to 2008 produce the same usage versus price slope as the period from 1981 to 2008.

The 1981–2008 correlation between price and usage (Figure 4, $R^2 = 0.64$) shows a 200% price increase resulting in a 35% decrease in overall water consumption, a price elasticity of −0.17, which is a little higher than the result previously reported for Sydney, Australia of −0.11 (Abrams *et al.*, 2012). However, it has been demonstrated that external use is more price-sensitive than internal use (Thomas & Syme, 1988) and in Ballarat the decline during periods of price increase was heavily weighted to external use. Therefore, if external water use only is considered, the price elasticity is −0.4, which corresponds to two meta-analyses in the USA that found an average of −0.5 (Espey *et al.*, 1997) and −0.41 (Dalhuisen *et al.*, 2003), but the latter study also concluded this depended on the pricing structure. This supports the view that a price incentive will have the greatest effect on discretionary use, but much less effect on essential use. Post-2009, with external use being at an effective minimum, further price increases had no effect, demonstrating that there is a limit to reductions that can be achieved through price incentives.

Demonstrating the price sensitivity of water is not unexpected, with simple economics suggesting that a higher price would encourage less use. However, it may be expected that the change in pricing structure in 1996 from a 95% fixed rate to a 75% variable rate would alter the price versus usage sensitivity; however, this did not occur in Ballarat at the time.

Environmental awareness and water awareness programmes

The attitude of customers towards the environment has been found to impact the amount of water they consume in some studies (e.g. Grafton *et al.*, 2011). Awareness campaigns are used to increase public understanding, change attitudes and alter behaviour.

The Millennium Drought and the associated concerns about climate change and the long-term water supply resulted in many programmes aimed at water efficiency (WELS, 2005; SWEP, 2006; Australian Government, 2016). However, this was well after the reduction in Ballarat's water use commenced. While they do not correspond to the overall water use reduction that was initiated by reductions externally, these programmes do show an effect on internal water usage.

While attitude to the environment has been hypothesised to impact the water consumption of individual consumers, Nieswiadomy (1992) suggests that conservation attitudes do not significantly affect consumption at a community level, while Landon *et al*. (2016) state that the mechanism for it to have an effect is poorly understood. Wolters (2014) also shows that environmental concern is not a good indicator of environmental behaviour. As this study is historical, without comparative groups to determine what altered behaviour, it is not possible to categorically determine whether environmental attitudes were a contributor to reduced water consumption. However, we do know (from the water price analysis) that price alone is not the cause.

It is reasonable to consider that a level of environmental awareness is required for long-term behavioural change with respect to water, and that this combined with pricing produced change throughout Ballarat. The idea that incentives are required in conjunction with awareness campaigns is consistent with the review by Cary (2008). Awareness, campaigns for change and incentives are all required to produce a long-term effect – individually they can plant the seed for change, but unless the ground is fertile they will not grow.

Government and policy changes

Legislators can impact demand by ensuring higher water availability or imposing restrictions and pricing policy, enacting building regulations that target water-saving devices, providing incentives for water reuse programmes, and altering the structure of and interaction between water utilities. Significant governance changes in the water industry in Victoria in the 1990s may be both a reflection of and a reason for a significant focus on water supply and management.

In Ballarat, stormwater harvesting for public open-space watering and filling the city's main recreational lake has been implemented, although this commenced in 2006 and the total impact on usage was expected be less than 2% (Rossiter, 2013). The dual-flush toilet was invented in Australia in 1982 (PowerhouseMuseum, 2016) and became compulsory in all new homes in Victoria from 1984. However, this change would take years to have a significant impact, and other legislative changes were associated with the Millennium Drought years after the reduction in Ballarat water use commenced.

Conclusions

This research has highlighted that it is possible for a city to achieve sustained reductions in water use over a period of 35 years, seemingly irrespective of the changes in water availability during drought and relative water surplus. With water security and the impacts of urbanisation a major issue across many modern cities, this is an example that can be used to demonstrate what can be achieved, although larger cities with differing circumstances will need to develop their own methods for implementation.

The separation of internal and external domestic water use in a historical study, without access to any individual or household information, was possible by using sewage flow data as a proxy for internal water use. In a city where sewage and stormwater systems are separate, effectively no water used outside the home goes to the sewage system and the majority of internal water does; this is considered to be a robust approximation approach. Despite intuitively considering that external demand would be inversely correlated to rainfall, this study confirms the findings of others, showing a negligible relationship.

Initially, reductions in use were driven by changes in external water use and corresponded to price increase/tariff changes. However, the effect cannot be purely economic, as the price of water was not based upon the volume used. The effect of overall, rather than variable, price on water demand is not without precedent (Nieswiadomy, 1992), and it is surmised that price acted as a change agent, in conjunction with general awareness of water and environmental issues and policy changes. Consequently, the total price, rather than a price based on consumption, was the most important factor. Internal water use, considered to be much less discretionary, showed little sign of responding to price changes, as may be expected.

The combined impact of price and non-price policies has been studied by a number of authors (e.g. Renwick & Green, 2000; Barrett, 2004; Olmstead & Stavins, 2009; Reynaud, 2013), who conclude that mixed-policy implementation is effective in reducing water consumption. This would be supported by the results of this research on Ballarat. Pricing policies and awareness programmes combined to effectively minimise the water use outside the home, where reductions could be made relatively easily without compromising comfort and at minimal cost. The encouragement to use water-saving devices was then effective in reducing the internal water use. This supports a multifaceted approach to water demand reduction that requires economic incentives, awareness programmes and policy approaches encouraging the reduction of water use. It demonstrates the importance of understanding the behaviour being targeted, and ensuring that the incentives or policies being implemented are appropriate.

The reduction in water consumption over such a long period was incongruent with the expectations. It demonstrates that water authorities and communities can respond to the pressures inherent in the water supply system in a timely manner. It shows that communities will respond to changes and constraints in the services provided, adjusting behaviour to meet a new paradigm, with no apparent loss in facility. It is also a reminder of the difficulties in forecasting resource demand, which is multivariate and complex; however, increasing water use that has been associated with a more affluent and urbanised society need not continue to inherently grow. While meeting water demand is a major, ongoing issue, it need not be an ever-increasing problem.

Acknowledgements

This work would not have been possible without the access readily given to the Central Highlands Water archive, particularly by Rosalie Poloski and Phil Anstis. Thanks also to Rick Pope and Arthur Dallas from Land Victoria, for producing a unique data set on allotment size by year for the municipality. The comments from three independent and anonymous reviewers are appreciated, and resulted in a more concise article. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Abrams, B., Kumaradevan, S., Sarafidis, V. & Spaninks, F. (2012). An econometric assessment of pricing Sydney's residential water use. *Economic Record 88*(280), 89–105.

ABS (2014). *3105.0.65.001 Australian Historical Population Statistics, 2014*. Available at: http://www.abs.gov.au/ausstats/abs@.nsf/mf/3105.0.65.001 (accessed 3 December 2015).

ABS (2016). *Consumer Price Index*. Canberra, Australia. Available at: http://www.abs.gov.au/ausstats/abs@.nsf/mf/6401.0 (accessed 14 February 2018).

Aitken, C. K., McMahon, T. A., Wearing, A. J. & Finlayson, B. L. (1994). Residential water use: predicting and reducing consumption. *Journal of Applied Social Psychology 24*(2), 136–158. doi:10.1111/j.1559-1816.1994.tb00562.x.

Australian Government (2016). *Your Home, Australia's Guide to Environmentally Sustainable Homes*. Available at: http://www.yourhome.gov.au/introduction (accessed 14 February 2018).

Barrett, G. (2004). Water conservation: the role of price and regulation in residential water consumption. *Economic Papers: A Journal of Applied Economics and Policy 23*(3), 271–285. doi:10.1111/j.1759-3441.2004.tb00371.x.

Berk, R. A., Schulman, D., McKeever, M. & Freeman, H. E. (1993). Measuring the impact of water conservation campaigns in California. *Climatic Change 24*(3), 233–248.

BOM (2015). *Recent Rainfall, Drought and Southern Australia's Long-Term Rainfall Decline*. Canberra, Australia. Available at: http://www.bom.gov.au/climate/updates/articles/a010-southern-rainfall-decline.shtml (accessed 14 February 2018).

BOM (n.d.). *Climate Data Online*. Available at: http://www.bom.gov.au/climate/data/ (accessed 14 February 2018).

Campbell, H. E., Johnson, R. M. & Larson, E. H. (2004). Prices, devices, people, or rules: the relative effectiveness of policy instruments in water conservation. *Review of Policy Research 21*(5), 637–662. doi:10.1111/j.1541-1338.2004.00099.x.

Cary, J. (2008). Influencing attitudes and changing consumers' household water consumption behaviour. *Water Science and Technology: Water Supply 8*(3), 325–330.

CHW (2016). *CHW Annual Reports*. Ballarat, Australia. 2008–2017. Available at: http://www.chw.net.au/about-us/annual-report (accessed 14 February 2018).

CityWestWater (2017). *How do you Calculate the Sewage Disposal Charge?* Available at: http://www.citywestwater.com.au/residents/charges_explained.aspx (accessed 14 February 2018).

Cochran, R. & Cotton, A. W. (1985). Municipal water demand study, Oklahoma city and Tulsa, Oklahoma. *Water Resources Research 21*(7), 941–943.

Coombes, P., Barry, M., Gay, Q., Rossiter, I., Clarke, B., Anstis, P. & Powell, R. (2014). *Analysis of Water Cycle Systems. Analysis of the Base Case Scenarios for the Ballarat Region*. Melbourne, Australia. Available at: https://urbanwatercyclesolutions.com/wp-content/uploads/2016/03/LivingBallaratSystemsAnalysis.pdf (accessed 14 February 2018).

Cosgrove, W. & Rijsberman, F. (2000). *The use of Water Today, Chapter 2. World Water Vision*. Available at: http://www.worldwatercouncil.org/fileadmin/wwc/Library/WWVision/Chapter2.pdf (accessed 14 February 2018).

Dalhuisen, J. M., Florax, R. J., De Groot, H. L. & Nijkamp, P. (2003). Price and income elasticities of residential water demand: a meta-analysis. *Land Economics 79*(2), 292–308.

DEPI (2014). *Index of Stream Condition The Third Benchmark of Victorian River Condition, ISC3*. Melbourne, Australia. Available at: https://www.water.vic.gov.au/water-reporting/third-index-of-stream-condition-report (accessed 14 February 2018).

DEPI (2015). *Water Restriction*. Available at: http://www.depi.vic.gov.au/water/using-water-wisely/water-restrictions/stage-1-water-restrictions (accessed 14 February 2018).

Espey, M., Espey, J. & Shaw, W. D. (1997). Price elasticity of residential demand for water: a meta-analysis. *Water Resources Research 33*(6), 1369–1374.

Gardner, T. & Vieritz, A. (2010). The role of rainwater tanks in Australia in the twenty first century. *Architectural Science Review 53*(1), 107–125.

Grafton, R. Q., Ward, M. B., To, H. & Kompas, T. (2011). Determinants of residential water consumption: evidence and analysis from a 10-country household survey. *Water Resources Research 47*, W08537. doi:10.1029/2010WR009685.

Hamilton, L. C. (1983). Saving water: a causal model of household conservation. *Sociological Perspectives 26*(4), 355–374.

Jorgensen, B., Graymore, M. & Toole, K. (2009). Household water use behavior: an integrated model. *Journal of Environmental Management 91*(1), 227–236.

Landon, A. C., Kyle, G. T. & Kaiser, R. A. (2016). Predicting compliance with an information-based residential outdoor water conservation program. *Journal of Hydrology 536*, 26–36. doi:10.1016/j.jhydrol.2016.02.024.

Lowe, B., Lynch, D. & Lowe, J. (2014). The role and application of social marketing in managing water consumption: a case study. *International Journal of Nonprofit and Voluntary Sector Marketing 19*(1), 14–26. doi:10.1002/nvsm.1484.

Marlow, D. R., Moglia, M., Cook, S. & Beale, D. J. (2013). Towards sustainable urban water management: a critical reassessment. *Water Research 47*(20), 7150–7161. doi:10.1016/j.watres.2013.07.046.
MelbourneWater (2015). *Enhancing Life and Liveability, Melbourne Water Annual Report 2014/15*. Available at: https://www.melbournewater.com.au/about-us/publications-and-policies/annual-report/annual-report-archive (accessed 18 February 2018).
MMBW (1934). *Report for the Year Ended June 30, 1934: Melbourne and Metropolitan Board of Works*. Available at: http://search.slv.vic.gov.au/primo_library/libweb/action/dlSearch.do?dscnt=1&onCampus=false&query = any%2Ccontains%2Cmmbw%20annual%20reports&bulkSize = 20&tab = default_tab&group = ALL&vid = MAIN&institution = SLVPRIMO&fromLogin = true&search_scope = Everything (accessed 18 February 2018).
Morgan, R. (2011). A thirsty city: an environmental history of water supply and demand in 1970s Perth, Western Australia. *Studies in Western Australian History 27*, 81–97.
Nieswiadomy, M. (1992). Estimating urban residential water demand: effects of price structure, conservation, and education. *Water Resources Research 28*(3), 609–615. doi:10.1029/91WR02852.
Olmstead, S. M. & Stavins, R. N. (2009). Comparing price and nonprice approaches to urban water conservation. *Water Resources Research 45*, W04301. doi:10.1029/2008WR007227.
PMSEIC (2007). *Water for our Cities: Building Resilience in a Climate of Uncertainty*. Available at: http://www.industry.gov.au/science/PMSEIC/Documents/WaterforOurCities.pdf (accessed 14 February 2018).
PowerhouseMuseum (2016). *A Century of Innovation Dual Flush Toilet*. Available at: http://archive.maas.museum/australia_innovates/index4dd3.html?behaviour=view_article&Section_id=1040&article_id=10044 (accessed 18 February 2018).
profile id (2015). *Estimated Resident Population – City of Ballarat*. Available at: http://forecast.id.com.au/ballarat/home (accessed 14 February 2018).
Renwick, M. E. & Green, R. D. (2000). Do residential water demand side management policies measure up? An analysis of eight California water agencies. *Journal of Environmental Economics and Management 40*(1), 37–55.
Reynaud, A. (2013). Assessing the impact of price and non-price policies on residential water demand: a case study in Wisconsin. *International Journal of Water Resources Development 29*(3), 415–433. doi:10.1080/07900627.2012.721670.
Ricketts, J. & Hennessey, K. (2009). *Climate Change in Southern South Australia and Western Victoria*. CSIRO. Available at: http://ccia2007.climatechangeinaustralia.gov.au/documents/resources/Climate%20change%20in%20southern%20South%20Australia%20and%20western%20Victoria.pdf (accessed 18 February 2018).
Rossiter, I. (2013). *Harnessing Ballarat's Stormwater Project, City of Ballarat, Final Report for the Department of Sustainability, Environment, Water, Population and Communities*. Available at: http://www.ballarat.vic.gov.au/media/1481865/hbsw_report_for_website.pdf (accessed 14 February 2018).
Sadalla, E., Berlin, A., Neel, R. & Ledlow, S. (2014). Priorities in residential water use: a trade-off analysis. *Environment and Behavior 46*(3), 303–328. doi:10.1177/0013916512456286.
Schleich, J. & Hillenbrand, T. (2009). Determinants of residential water demand in Germany. *Ecological Economics 68*(6), 1756–1769. doi:10.1016/j.ecolecon.2008.11.012.
SWEP (2006). *Schools Water Efficiency Program*. Victorian Government, Melbourne, Australia. Available at: https://www.myswep.com.au/ (accessed 14 February 2018).
Syme, G. J., Shao, Q., Po, M. & Campbell, E. (2004). Predicting and understanding home garden water use. *Landscape and Urban Planning 68*(1), 121–128. doi:10.1016/j.landurbplan.2003.08.002.
Thomas, J. & Syme, G. (1988). Estimating residential price elasticity for water in presence of private substitutes: a contingent valuation. *Water Resources Research 24*, 1847–1857.
Victorian (1857). *Census of Victoria, 1857: Population Tables*. John Ferres, Government Printer, Melbourne.
Ward, S., Lundy, L., Shaffer, P., Wong, T., Ashley, R., Arthur, S., Armitage, N. P., Walker, L., Brown, R., Deletic, A. & Butler, D. (2012). Water sensitive urban design in the city of the future. In: *7th International Conference on Water Sensitive Urban Design*, Melbourne, Australia.
WELS (2005). *Water Efficiency Labelling Standards*. Available at: http://www.waterrating.gov.au/label-display/requirements (accessed 18 February 2018).
Wolters, E. A. (2014). Attitude-behavior consistency in household water consumption. *Social Science Journal 51*(3), 455–463. doi:10.1016/j.soscij.2013.10.003.

Received 27 June 2017; accepted in revised form 4 January 2018. Available online 7 February 2018