NEXT GENERATION WATER EFFICIENCY: LOOKING OVER THE HORIZON

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ABSTRACT

After major investment during the Millennium drought, many Australian cities have become more resilient by diversifying their water supplies with desalination, water recycling, rain tanks, and importantly, increased water efficiency through both programs and regulations. The achievements in efficiency such as reduced per capita demand and success of large-scale demand management programs, are internationally recognised. However, with both Sydney and Melbourne heading towards mega-city status by mid-century, further increases in efficiency must be considered. This paper explores the technologies, behavioural interfaces and programs that could aid Australia's next generation of water efficiency.

INTRODUCTION

Cities such as Sydney and Melbourne are undergoing significant population growth and urban densification. By 2050 both cities are forecast to reach a population size of 8 million and likely to be classed as mega-cities in the decades following.

Australian urban water systems have already undergone major transformation, from rain-fed systems to diverse supplies (i.e. desalination, water recycling, rain tanks, stormwater harvesting) and increased water efficiency, due to major investment during the Millennium drought. However, we will need to continue to invest to cope with the sheer scale of population growth in the coming decades. Such growth provides significant challenges but also enormous opportunities to incorporate new efficient technology in all new and refurbished properties, with efficiency not only providing savings in water but associated energy for transport, treatment and heating.

Whilst there may be a perception that we reached the limits of efficiency during the drought, and that it would be uneconomical to reduce demand further, investigations indicate a next generation of efficiency is already available and at hand. This includes new efficient technologies, behavioural interfaces, data driven programs and regulatory instruments. "Looking over the horizon" transformative technologies also exist. These technologies, including waterless or near waterless appliances, if fully developed and commercialised could dramatically alter potable water demand in our cities.

This paper reflects on some of the major achievements Australia has made in water efficiency in recent years. It identifies some of the new technologies and behavioural interfaces that have entered the market and also those technologies that are emerging. It then considerers how rapidly changing digital technologies could shift what is considered best practice in demand management program design. Finally, the paper explores the conservation potential of current best practice water efficiency through a hypothetical case study and considers the implications for the future of urban water provision in Australia.

WHAT HAS BEEN ACHIEVED?

Australia is recognised internationally for its achievements in water efficiency. These include: reduction in per capita demand achieved and maintained since the peak of the mid 1980s; roll out of national and state regulations on efficiency products and building requirements; and extensive demand management programs taken-up by millions of people across the nation during the Millennium drought (Turner et al, 2016). The impact on per capita demand has been dramatic as illustrated by the example of Sydney in Figure 1.

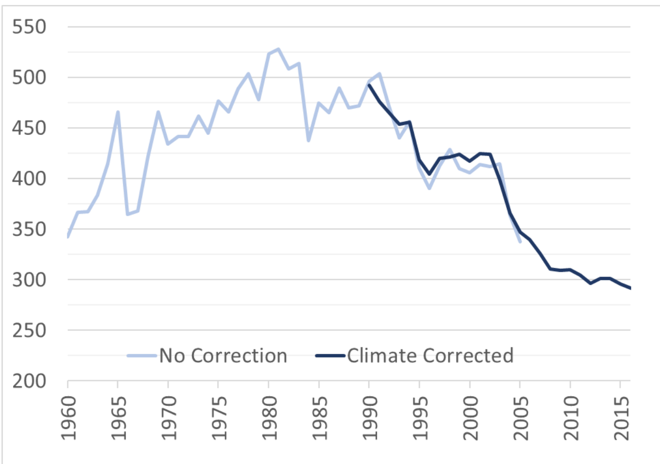

Figure 1: Sydney per capita demand – litres per capita per day (LCD)

Bulk water demand peaked in Sydney during the 1980s and has decreased in steps since then.

Significant reductions occurred during the core period of the Millennium drought (2000-2008). This was partly due to the shifting economic structure of the city away from heavy industry and single dwellings on large blocks. The increased use of alternative sources, in particular rain tanks, was another factor. However much of the decrease is due to major changes in water using appliances and fixtures. A similar story played out in the other major cities across the country (Turner et al 2016; Diringer et al 2018).

The major shifts in water efficiency were as a result of multiple measures acting together.

At a national level, and under-pinning many state based and local initiatives was the Water Efficiency Labelling and Standards (WELS) scheme, launched in 2003[1] .The scheme introduced minimum standards for water efficiency of toilets and later clothes washers. It also mandated water efficiency labelling for indoor water using appliances and fixtures. This provided a common language (in relation to star ratings) and nomenclature for individual utilities and state governments to point to when promoting efficiency or defining programs.

In New South Wales (NSW) the Building and Sustainability Index (BASIX), first introduced in 2004, has been a successful regulation requiring all new residential buildings and refurbished homes to achieve sustainability targets for water and energy as well as minimum performance levels for thermal comfort[2]. Its mandatory targets driving water efficiency in the products installed in new homes

Also in NSW, a world leading demand management program in Sydney covered the residential, non-residential and non-revenue water sectors. It included the residential WaterFix program implemented on 0.5 million homes, rebate programs for washing machines, toilets and rain tanks, a garden program, an extensive and highly successful business program and sub-sectoral programs targeting commercial properties such as clubs and hotels or specific end uses such as water-cooled woks and dishwashers. Refer to Turner et al 2016 and Liu et al 2017 for details of Australia-wide water efficiency regulations and programs implemented during the drought.

NEW AND EMERGING TECHNOLOGY

Following the end of the drought, in 2012, water utilities began to dramatically wind back demand management efforts. Innovation in water efficient technologies, however, has continued. This can be seen in new fixtures and appliance coming onto the market. There have also been a plethora of new digital metering, monitoring and feedback systems brought to market. Again, refer to Liu et al, 2017, for details of these technologies.

In whitegoods such as dishwashers and clothes washers significant gains in efficiency have been made. A shift in dishwasher efficiency was seen over the period of the drought. In 2006, less than 25% of models registered in the WELS database used less than 14 L/wash. By 2013 around 90% of models did (Fyfe et al 2015; Liu et al 2017). Currently the most efficient machines available are 6 star models which use 6.5 L/wash (0.5 L/place setting)[3]. These use 20% less water than the commonly purchased 4 and 4.5 star models.

For clothes washers, historically, machines typically used 140 L/wash, whereas the 5 star machines now available use as little as 50 L/wash for a 7 kg machine (or 7 L/kg). However, the shift in efficiency has predominantly been in the mid to high consumption end of the market. For example, in 2006, 60% of clothes washers registered on the market used 100 L/wash or less. Less than 10 years later, by 2013, this had increased to 90%. At the low consumption/high efficiency end there has been less change with the number of machines available using 60 L/wash or less hardly changing. In sales almost all occur in the 3 star to 4.5 star range (Fyfe et al, 2015). If customers where to shift from 4.5 to 5 star machines this would see a water saving of around 17% per wash. A shift from a 4 star to 5 star machine would see water savings of 29% for each wash.

Looking over the horizon to technologies not yet in the Australian market, commercial clothes washer manufacturers using bead technology are investigating release of similar machines in the US domestic market[4]. Waterless super critical machines using either CO_2 or NO_2 are also in development. These technologies are also currently used in the commercial market but it is still unknown if they will be released in the domestic market[5]. Such new types of technology offer not just new levels of water efficiency but are potentially transformative in removing some end uses' reliance on water supply. They may also divert problematic waste streams currently going to sewage systems such as micro fibres and phosphate detergents.

Toilets provide a similar if no less dramatic story. Average toilet flush volumes decreased from approximately 11 L/flush in the 1980s to an average flush of 4.5 L at the end of the 1990s when the 6/3 L dual flush toilet was introduced. Now 4.5/3 L/flush dual flush toilets, introduced later in the 2000s, have dominance in the market and new 6 star 3/2 L/flush

[1] http://www.waterrating.gov.au (accessed 23/02/18)
[2] https://www.planningportal.nsw.gov.au/planning-tools/basix (accessed 23/02/18)
[3] https://wels.agriculture.gov.au/wels-public/action/search-product-load?src=menu (accessed 23/02/18)
[4] http://www.9news.com/article/news/nation-world/this-new-washing-machine-doesnt-rely-on-water-to-wash-your-clothes/507-507777231 (accessed 23/02/18)
[5] http://e3tnw.org/ItemDetail.aspx?id=512 (accessed 23/02/18)

dual flush toilets have recently become available. 6 star include macerating 3/1.8 L/flush dual flush toilets[6] which are not common but are available in Australia.

Again, over the horizon there are 1.5 L/flush air jet assisted toilets which are available in the UK[7]. More transformative are 0.8 L/flush vacuum systems[8] which require separate plumbing systems but can also allow for separate collection of toilet wastes and possible food wastes for anaerobic digestion and associated energy generation and nutrient recovery from the digestate (Turner and White 2017).

For showers, 3 star 9 L/min "efficient" showerheads became ubiquitous during the drought. These have now been eclipsed by an array of efficient devices entering the Australian market. High quality, high end 7 L/min showerheads are now easily found, if not commonly purchased due to price. New technologies (>4.5 star) that go as low as 5 L/min have been registered for sale. At the lowest end are atomizer showers using only 3 L/min. Alternatively, various companies retail recycling shower units that for example return the water back to the user after an initial short cleansing phase (Liu et al 2017).

The ongoing innovations in water efficient products have been accommodated with higher star bands within the WELS scheme. This work of keeping the scheme up to date and giving customers the information needed to buy the most water efficient products has been an important contribution by the Commonwealth. It also provides the basis for a new round of demand management programs by State Governments and local water utilities (if or when these occur).

EMERGING BEHAVIOUR/INTERFACES & PROGRAMS

When considering water efficiency and maximising efficiency in our water systems, technology cannot be considered in isolation. The behavioural aspects and human interaction with each appliance (i.e. duration of shower, deciding on how full and the number of loads of washing done in a household per week) is equally important (Beal et al 2013). New emerging devices may be efficient but the human element must be carefully considered and potentially influenced. For example, some new efficient showers have timers and recirculating "options". The use of these more water efficient options can be "encouraged" through "default" settings. This is also true in the case of clothes washers where the most efficient setting is set as the default and in many modern higher quality machines water use automatically linked to the weight of clothes in the machine on any given wash.

With advances in smart meters, data analytics and behavioural interfaces we are on the cusp of an exciting new era in which enormous amounts of data can be used by water utilities to better understand water using customers and interact with them.[9]. This new "Intelligent metering" is comprised of four main processes: measurement; data transfer; processing and analysis; and a mechanism for feedback to the customer (Boyle et al 2013). The data should provide dual benefits to the supplier and customer in identifying water use patterns and opportunities for cost savings and consumption adjustments.

In 2017, ISF conducted a review of 25 customer water use information feedback studies undertaken worldwide in order to identify impacts on water consumption of digital metering and associated feedback to customers (Liu, and Mukheibir, 2017). From the limited data available for analysis, it appeared that feedback programs could generate average water savings of 5.5%, within a range of 3-8%. No single intervention approach could be clearly identified as "best practice" from the studies conducted to date and further research is warranted.

Examples of the use of smart meters that both inform the utility and customer include for example Mackay Regional Council in Queensland. This includes an internal utility management portal, MyWater, which provides a suite of functions for the utility to access from the one hour interval meter reads from their 40,000 metered properties. It also includes MyH20 online portal accessible to individual customers by smartphone App and computer, which highlights anomalous water usage such as leaks.[10]

Further examples of more detailed behavioural interfaces include for example Home Water Updates that provide detailed end use level feedback to customers on their water usage, (Liu 2016). Other examples use innovative incentive schemes to promote water savings. For example, the Thames Water Greenredeem pilot of 3,000 homes in the UK. The program uses smart meters to inform an individual customer web portal that promotes water savings by rewarding residents with redeemable points (for local cafés and services) for engaging with the portal and saving water (Liu et al 2017).

Advances in smart meter technology, data transfer, associated analytics and behavioural interfaces are advancing rapidly. Consideration of how these new advances can translate in demand management program design and implementation has only just started. However, this already includes the realms of multi-utility approaches of data collection, analysis and program design (Stewart et al 2017).

[6] http://www.saniflo.com.au/professionals/Saniflo-product-line/sanicompact-43-description/ (accessed 23/02/18)
[7] http://www.propelair.com/homepage/ (accessed 23/02/18)
[8] https://www.vacuumtoiletsaustralia.com.au (accessed 23/02/18)
[9] https://utilitymagazine.com.au/the-key-ingredient-for-a-truly-smart-water-metering-system/ (accessed 23/02/18)
[10] https://utilitymagazine.com.au/transforming-a-water-business-using-iot/ (accessed 23/02/18)

WHAT IS THE NEXT GENERATION OF BEST PRACTICE?

In reviewing best practice demand management programs implemented in Australia over the last decade and a half (Turner et al 2013; Turner et al 2016; Liu et al 2017) it is apparent that what was considered best practice in the past would shift today with moves towards new behavioural interfaces, digital technologies and digital utilities. This means there is potential for a new leading practice approach to demand management programs to be developed. Such an approach would take learnings from what Australian utilities did to develop world "best practice" programs during the drought and combine these with advances in behavioural interfaces, digital metering and data analytics. The new digital technologies could shift the design, development and implementation of programs as well as recast the role of program evaluation from being something that was done after the program, historically in part due to the time needed to collect adequate data (Turner et al 2014) to an integrated element throughout the program evolutionary cycle (i.e. design, development, implementation and review) due to the ongoing accessibility of data (Turner 2015).

Some of the key characteristics of "historical" best practice that the "next generation" of leading programs should take forward include:

- targeting of market segments, sub-segments and end uses;
- using piloting for both program testing and data collection; and
- using evaluation - now considered throughout the lifecycle of a program.

During the peak of the Millennium drought many large-scale programs were implemented. However, towards the end of the drought, the need to be more sophistication in the design and targeting of demand management programs became apparent. The best non-residential programs sought to target particular sub-sectors and particular high water using end uses (i.e. glass washers and water cooled woks). Some utilities conducted detailed surveys to target high water users in both the residential and non-residential sectors. Coming out of the drought, there has been a need to continue with a market segmentation approach with programs targeted on equity grounds to disadvantaged customers.

Across the water industry, organisations are embarking on major investments in becoming digital utilities. Depending on how these investments are implemented, the next generation of demand management programs could see a revolution in the sophistication of targeting, customer segmentation and customer interaction. Data analytics can be expected to become central in program design and development. The role of targeting customer segments and end uses will be particularly relevant in cities that conducted extensive programs in the Millennium drought. With new more efficient technologies on the market and new data analytics available to distinguish various market segments retargeting of customer groups and customer groups missed in the last drought may now be differentiated. So too will the way in which utilities can communicate with such customers, that is, through on-line Apps and websites with sophisticated tailored programs enabled by data analytics (Liu et al 2017; Turner and White 2017).

The role of pilots in the design and development of best practice demand management programs has also been evident in recent review of best practice and a key learning from Australia's response to the Millennium drought (Turner et al 2016). Again, the increasing ubiquity of digital technologies can significantly increase the information collected in pilots. This is true for programs involving plumbers or water auditors being present on customer sites or actually doing work in homes or on-site. It is also true if pilot programs are twinned with smart meter roll outs and on-line data collection and analysis. In particular pilots might now be designed to both test interventions and collect data. This could mean that as well as identifying potential water savings and implementation issues, the piloting process could collect data on other aspects. This might be water usage by other end uses, appliances and fixtures or behavioural aspects and information critical to program design such as socio demographics, "take-back" rates by customers choosing high levels of service (such as taking longer showers with more water efficient shower heads installed) and problems with new technologies.

That programs should be fully evaluated after their implementation is an accepted element of best practice (Turner et al 2010; Turner et al 2014). With growing access to data the potential for on-going evaluation increases. This could see programs evaluated initially and then re-evaluated a number of times as they are implemented. Preliminary evaluations could be conducted on pilots and the initial stages of programs. Previously best practice, taking into consideration the limitations of data accessibility, indicated that once a program has been running for a period of approximately 1 to 2 years they should be evaluated and consideration given to adjusting the program or redesign. With new smart metering and data analytics evaluations might become embedded and on-going and potentially instantaneous (Turner 2015).

Initial evaluation includes assessment of participation rates, savings, costs and implementation issues for a program. Later this may shift to assess on-going effectiveness of the program and market saturation in the segment or end use targeted. Some successful programs may achieve transformation of market sectors, such as the shift to front loading clothes washers driven by rebate programs observed during the Millennium drought (Turner et al 2016). Indicators of market shift (such as an increasing proportion of free riders) should become part of evaluations with more sophisticated data and associated analytics.

The proposed next generation approach to demand management is likely to be heavily data-driven. The outcomes of many activities being both water savings and data collection. It will bring together the new digital technologies with the learnings from the highly successful programs conducted during the Millennium drought. Such an approach is likely to embed targeting of sub-sectors and end uses, piloting and evaluation as central elements.

CONSERVATION POTENTIAL; HYPOTHETICAL CASE STUDY

This hypothetical case study considers the current generation of water efficient appliances and fixtures that could impact potable water demand in our growing cities if there is a new drive for water efficiency to meet the needs of growth. The case study focuses on residential potable water in a city of one million with growth characteristic similar to Melbourne and Sydney. Residential potable water, in these cities, represents approximately 65% and 70% of demand respectively. The case study looks only at currently available technologies in the form of digital meters with behavioural interfaces and products that are available in the WELS scheme data base[11]

The "case study" seeks to illustrate the level of indoor residential water conservation potential possible that currently exists. It includes only the current generation of water efficient products and evaluates the impact of implementing through known mechanisms. The case study does not consider the range of ultra-efficiency technologies and waterless technologies that are over the horizon and described in the Liu et al (2017) report (and above). These might take efficiency to a new level, as discussed at the end of this paper.

Significantly the case study also does not consider the potential for outdoor efficiency nor alternative non-potable sources of supply for outdoor use.

The hypothetical case study has been modelled using a new residential end use demand forecasting model that ISF is current developing. The model for this paper draws the assumptions used in the previous integrated supply demand planning (iSDP) end use model as well as the stock and end use data used for the Fyfe et al 2015 study into the WELS scheme effectiveness.

The new model is constructed in a single excel workbook increasing potential for use by utilities in their own demand forecasting. In 2018, ISF will be updating the new model with the latest end use and stock sales data from around Australia. ISF also intends to create individual versions of the model with the latest water and energy data for each Australian State.

In the new model, a hypothetical city with a population of one million in 2018/19 was modelled which grows to 1.5 million in 2043/44. In 2018/19 70% of the dwellings are single residential homes but as reflects current planning in major cities in Australia, the new growth is predominantly multi-residential flats and units. It is assumed that 70% of new population live in multi-residential dwellings.

The "base case" forecast aims to reflect the current situation assuming no specific drivers for water efficiency beyond those that currently exist. This is a vastly different situation to the Millennium drought era. While average efficiency continues to slowly increase there are no drivers for substantial uptake of new water efficient product types. The base case does assume schemes such as WELS and BASIX continue and there is therefore no substantial eroding of efficiency in existing or new properties.

Whilst there have been moves to incorporate higher efficiency star bands within the labelling side of the WELS scheme, there has been less movement on minimum standards. The current minimum water efficiency standards for clothes washers and toilets have remained at similar levels for some time (Fyfe et al 2015). While rebates can promote some customers to buy more efficient products, to increase the efficiency of all sales, minimum standards would need to be strengthened. Both rebates and minimum standards are key measures that are included in the "efficient case" model.

The interventions in the efficient case are:
1) Digital metering with customer fed back introduced over five years from 2018/19
2) A showerhead minimum standard introduced at 9 L/min in 2018/19 with rebates for 7 L/min showers on 50% of sales. In 2028/29 (once the market has been shifted by the rebates) a new minimum standard of 7 L/min is introduced.
3) A toilet minimum standard introduced of 4.5/3 L/flush and BASIX like regulation requiring new multi-residential building to install 6 star 3/2 L/flush dual flush toilets.
4) A dishwasher minimum standard of 4.5 star with 50% of sales rebated to 6 star
5) A clothes washer minimum standard of 4 star with 50% of sales rebated to 5 star
6) A minimum standard for hand basin taps at 5 star. Kitchen and laundry taps are not affected.

[11] http://www.waterrating.gov.au/

The key assumptions for both the "base case" and "efficient case" are given in Table 1.

Table 1 Residential conservation potential modelling assumptions

	Base case (BC)	Efficient case (EC)
Initial population	0.75 million in 1980 1 million in 2018/19 70% Single residential (SR)	
Population growth	1.6% per year 70% multi residential (MR)	
Showers	to 84% 3 star (9 L/min)	In 2019 min standard (std) at 3 star & rebate 50% to 7 L/min. In 2029 min std. of 7 L/min.
Toilets	to 30:70 split 6/3 L:4.5/3 L	In 2019 4.5/3 L/min std; new MR 3/2 L
Clothes washers	Recent sales data projected	In 2019 4 star min std. & rebate 50% to 5 star
Dish washers	As above	In 2019 4.5 star min std. & rebate 50% to 6 star
Customer Feedback	None	From 2019 to 2024 - all households save 5.5% and 50% of leakage
Basins and taps	As per Fyfe *et al* 2015	Min std for basin taps at 5 star
Outdoor	SR 175 L/dwelling/day MR 40 L/dwelling/day	
Customer leakage	2% of total	1% of total (minus feedback savings)

The residential demand projections are shown in Figures 2 and 3 below. Figure 2 shows the base case residential water demand forecast broken down by end use with residential demand at 99,341 ML per year in 2044. Figure 3 shows the efficient case also broken down by end use. The residential demand is forecast to be 79,950 ML in 2044. The difference in residential water use is 19,391 ML per year, a 20% saving. Looking only at the indoor component the saving is 23%.

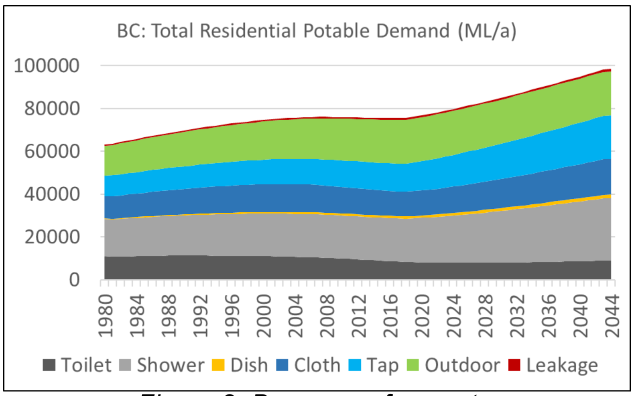

Figure 2: Base case forecast

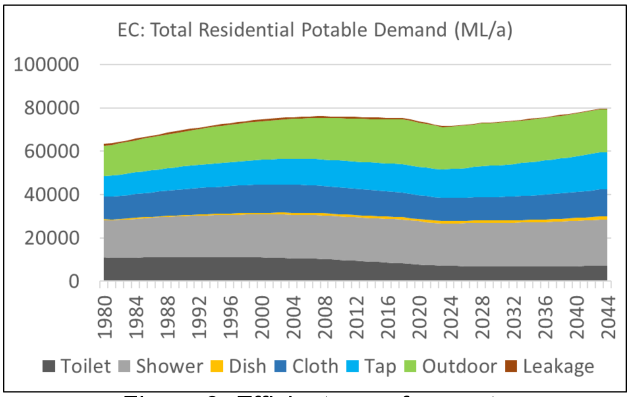

Figure 3: Efficient case forecast

Figures 4 and 5 below shows average per capita water use for the "base case" and "efficient case". In the base case the per capita demand for residential uses is 210 LCD in 2017 and decreases to 181 LCD by 2044. This reflects the assumption that even with no strong drivers towards further increasing efficiency in the base case LCD can be expected to decline.

In the efficient case the litres per person drops from the same level in 2017 to reach 145 LCD in 2044. The indoor component of this is an average LCD of 110 L. In the efficient case the LCD could be expected to continue to decrease after 2044 as the efficiency initiatives implemented would continue to have an impact on demand over future decades.

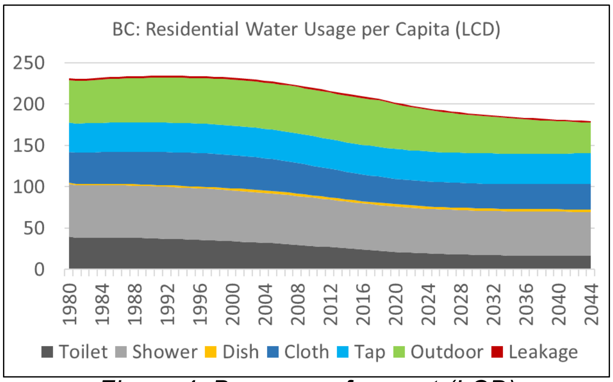

Figure 4: Base case forecast (LCD)

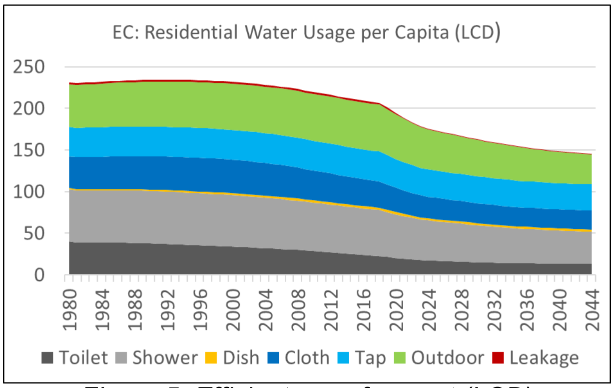

Figure 5: Efficient case forecast (LCD)

The hypothetical case study illustrates the conservation potential that may be seen within our growing cities if we were to take advantage of the current water efficient technologies with new regulations and demand management programs. Extrapolated up to a city with a population current at 5 million, as is the case for Sydney's water supply system which includes the Wollongong region, the savings in 2044 would be approximately 100 GL/a.

Significantly, the case study only shows a situation of promoting current available water efficiency and indoor efficiency. It does not consider transformative technologies and systems that may see functions currently performed by water no longer required or required with minimal water (i.e. vacuum toilets or waterless clothes washers).

DISCUSSIONS & CONCLUSIONS

This paper shows through the use of a hypothetical case study that there is significant water conservation potential available in the residential sector even by only exploiting current available technology. In the efficient case, high population growth is not reflected in rapidly increasing potable water demand.

Whilst many in the water industry consider it difficult to reduce water demand much further or that it is uneconomical to do so, new technology and customer behavioural interfaces are emerging that if employed at scale could further reduce our demand for potable water on a per capita basis. This would not only push out the need for increasingly expensive supply augmentation but simultaneously reduce other resource needs such as the energy used for heating water, and material and energy used in transportation and treatment.

As we head towards high populations and urban densification in our major cities it is imperative that we take advantage of the next generation of efficiency technology, customer behavioural interfaces and programs, as every new property built and existing property refurbished is an opportunity to reduce demand and ensure efficient use is at the foundation of the water security for our growing cities.

At the beginning of this century the Millennium drought acted as a significant driver for change as many of our existing water supply systems became precariously low. Without the dramatic shift in efficiency achieved through socio-technical measures and education, economic and regulatory instruments some large cities could have come very close to running out of water (Turner et al 2016).

Without such a clear driver currently front of mind during the current unprecedented levels of growth and urban densification it is necessary to "create" the required driver. The most obvious is the use of regulations in the form of minimum water efficiency standards for all key residential end uses. The use of such regulation would not only virtually eradicate poor performing technology but also drive efficiency innovation further. Complimenting this with the advances in behavioural interfaces and best practice demand management programs can significantly optimise the existing systems. As can be seen by the hypothetical case study this can make a dramatic difference in indoor residential water use and enable significant population growth without substantial growth in water demand.

The case study does not assess the potential of transformative technologies which could see ultra-efficient products or those where water is no longer needed for current end uses. These new technologies, which are currently over the horizon, could see demand for potable water continue to remain stable despite rising populations.

With further advances in socio-technical systems driven by investment in research, demonstration and evaluation over the coming years it is not inconceivable to create the necessary radical system changes that allow for significant population growth beyond 2050 without the associated growth in potable demand. This is important as a changing climate in this period is likely to mean significant investment in potable supplies are needed to meet existing levels of demand in many places.

Faced with population growth and climate change, whether our cities in the future will embrace ultra-efficiency and waterless technologies cannot be known now. What is known is that technologies such as vacuum systems, recirculation showers, waterless washing machines and ubiquitous digital metering/monitoring with associated feedback, if adopted at scale, would result in transformative changes to our water systems. These changes would have wide implications for the water industry more generally. The potential of water efficiency therefore needs to be a critical element in any conversation about looking over the horizon to alternative futures for urban water.

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