End-use forecasting in the context of building adaptive water services

Pierre MUKHEIBIR, Thomas BOYLE, Cynthia MITCHELL
Institute for Sustainable Futures, University of Technology Sydney, Sydney, Australia. e-mail: pierre.mukheibir@uts.edu.au

Abstract: Water resource managers are faced with planning for an uncertain future constrained by limited knowledge of how demands will change in future and what supplies will be available to match them. By adopting an adaptive management approach, flexible and robust responses can be developed as new information comes to hand. A transparent approach has been developed that avoids complicated probabilistic approaches and encourages planners to consider investment policies to accommodate a range of potential scenarios. Integrated resource planning (IRP) principles are key to this approach and requires that both supply and demand side options are considered. Whilst much focus has been on the supply side, end–user interventions have received less attention as a longer term approach. Restrictions have to date been the fall back option to deal with impending droughts, but this is not likely to be acceptable under reduced trending supplies.

By focusing on end-use planning, savings through suppressed customer demand can “free up” further water thereby delaying the introduction of large expensive supply options. By disaggregating the end uses by residential customers into for example, showers, toilets, baths, washing machines, outdoor use, etc., a richer understanding of where residential water actually gets used and therefore where the potential for demand reduction lie.

This paper firstly presents a framework for adaptive planning for urban water supplies and secondly, introduces the notion of end-use modelling and planning as a means to reduce consumption. Real examples from work conducted in Australia will be used to illustrate these approaches.

Key words: adaptive management, water, end-use, forecasting, uncertainty

1 INTRODUCTION

Water planners in Australia have always had a good appreciation of the variability in rainfall, and have responded by having one of the highest per capita water storage volumes in the world (World Bank, 2005). More recently however, many urban and rural regions have faced severe droughts after years of continued lower than average rainfall. The focus during the recent drought period was demand reduction through various end-use water saving programs and restrictions across the residential, commercial and industrial sectors. Towards the end of the last drought period, all of the state capitals along the eastern seaboard have constructed desalination plants to provide drought proofing reserve supplies. These options have been proven to be more costly than demand management options (Schlunke, Lewis, & Fane, 2008).

The urban water industry faces significant challenges in meeting growing and changing demands that threaten urban water supply security, especially under changing future pressures, such as climate change, population growth or decline, energy supplies and pricing, and changing water use demands. In addition to these challenges, new drivers that broaden the objectives that a water system should meet need to also be considered by the industry, such as supporting livable cities and protecting the natural water systems (LVMAC, 2011).

Whilst reserve supplies and water restrictions have been the default strategy, more recently some water service providers have sought to provide improved water security and resilience through flexible strategies and diversified portfolios, at reduced costs. The emergence of this new way of thinking represents a challenge to existing conceptual and analytical models underlying resource planning decisions and requires a shift from deterministic approaches to ones that offer adaptive management and planning opportunities.

Demand side management (DSM) options are a key component in the suite of available options that affords the water utility the flexibility and robustness needed to withstand the shocks and changing trends which confront it currently, and will do so in future. DSM options are effective in two ways, firstly they can often delay the investment in larger supply side options by reducing the overall demand for potable water, and secondly, some DSM options (such as restrictions) can afford some flexibility when responding to a short term drought or disruption in supply.

In Australia, and internationally, the combination of rebate programmes for water efficient appliances and rainwater tanks, and enforced water restrictions have resulted in large reductions in household water use (Arbués, Villanúa, & Barberán, 2010; Beal, Stewart, & Fielding, 2011). However, the approach by many regulating authorities to reduce water demand has often been reactionary. A proactive approach requires an improved understanding of how customers use water. The disaggregation of residential end-use is a crucial step in developing a proactive water strategy that responds to changing situations. Empirical end-use data is therefore essential for validating water use forecasting models (Blokker, Vreeburg, & Van Dijk, 2010; Druckman, Sinclair, & Jackson, 2008).

This paper focuses firstly on the approach developed to understand the impact of potential uncertain drivers and pressures, and how the water industry may respond to these. The second part of the paper focuses specifically on residential demand forecasting using end-use modelling and where the potential for DSM exists.

2 INTEGRATED RESOURCES PLANNING

Integrated Resources Planning (IRP) has been used as a planning framework to varying degrees by the water industry across Australia since the early 1990s and is considered best practice internationally (Turner et al., 2010). The IRP framework is aimed at long term urban water planning to ensure that available supply can meet demand, by evaluating both supply augmentation and demand reduction options on an equal basis.

The IRP framework includes the consideration of the planning objectives for the urban water system. With these objectives in mind, the demand forecast and available supplies can be assessed for any short fall. A range of demand reduction measures and supply options are then developed to meet the planning objectives at least cost, while accounting for sustainability impacts and future uncertainties. This is followed by the implementation of the suite of options and the monitoring of their effectiveness (Fane & Turner, 2010).

Recent work by the Institute for Sustainable Futures (ISF), augments this framework in two ways. Firstly, by introducing a decision making process created to develop long term adaptive water supply and demand policies and measures to respond to future contextual uncertainties, such as climate change and urbanisation (Mukheibir et al., 2012). The vision of the water businesses and the multiple values of water are incorporated into the decision making process by setting clear objectives to ensure that the investment strategies contribute to a sustainable, liveable, prosperous and healthy city. The aim is to provides a clear and transparent process that clearly communicates to key decision makers the outcomes and basis of the assessment.

And secondly, by disaggregating the demand forecast into discrete end-uses, such as industrial, commercial and residential sectors. Specifically, end-use analysis of the residential sector provides an improved understanding of how frequently and where water is used in homes (Giurco et al., 2008).

These two augmentations are discussed further in the following sections.

3 DECISION MAKING UNDER UNCERTAINTY

Approaches to managing uncertainty range from a qualitative understanding of potential risks through to a full quantitative assessment of uncertainty by assigning the probability of occurrence to all potential scenarios to produce a probability distribution of potential outcomes. The most appropriate approach will depend upon the degree to which the uncertainties can be quantified and the perceived risk associated with not quantifying uncertainties (Erlanger & Neal, 2005).

A lack of quantifiable information pertaining to the uncertainties, together with the complexity in implementation and the lack of transparency associated with the advanced methods from decision theory, has meant that water service businesses have not adequately considered future uncertainty. As such, an adaptive planning approach was designed to provide a guide for the strategic planning process, and to support operational decisions, in order that a portfolio of investments deliver a resilient water system over the long term - see Figure 1 (Mukheibir et al., 2012).

Figure 1: Strategy planning under uncertainty

In broad terms, this approach comprises bringing together three steps for thinking about, and planning for, uncertainty. The first is to characterise the uncertain pressures and drivers that may affect the water supply system as trends or shocks in order to distinguish and better respond to their impacts. The changing pressures and drivers that impact on the system and the global environment within which water businesses operate affect the performance of the supply and demand options. They can manifest in one of three ways: as trends that change over the longer term(such as reduced run-off or demand growth), as shocks that lead to new norms (such as unexpected step changes in the trends), or as extreme variability in the short term. Separating and characterising how the pressures and drivers occur is important because different supply and demand options will respond differently to trends and shocks. Adaptive management through flexible responses deals well with changing trends. Together with flexible responses, robust responses deal well with shocks. Therefore, responses that are both flexible and robust deliver resilience.

Since it is not practical to assess the impact of all the possible trends and shocks in combination, the most significant trends and shocks need to be identified. Using a risk matrix as shown in Figure 2, the trends and shocks can be ranked according to their relative uncertainty and the sensitivity of the existing system to that trend. Trends and shocks that fall into the top right-hand quadrant should be considered as significant. Those that fall into the top left-hand quadrant should be included in all scenarios since they have relatively low significant uncertainty. Those falling into quadrants three and four need only be considered if time and budget allow since they have relatively low significance.

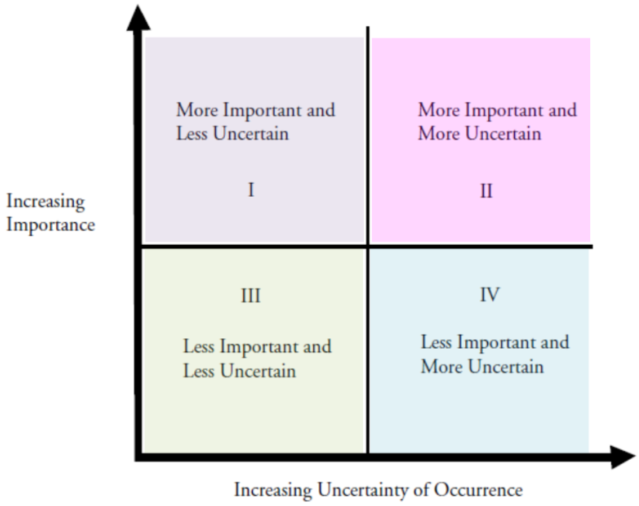

Figure 2: Risk assessment matrix for uncertainty

The second step is to bring together specific combinations of trends or drivers (in this case usually more than two) to form future scenarios, and consider the impact of that combination on the supply-demand balance i.e. whether or not a shortfall exists. This approach draws on the richness of traditional scenario analysis methods, however the water sector has to contend with multiple trends in various combinations. Increasing the number and combinations of potential trends has an exponential effect on the number of scenarios and analyses required, which generally leads to numerical optimisation, such as probabilistic approaches. However, by firstly selecting the combination of trends using qualitative approaches and then analysing the outcome for a reduced number of future scenarios, the response to a potential shortfall can be assessed, using traditional modelling techniques.

The third step of the approach is to establish a set of investment policy rules and instructions that control the sequence in which the types of options are chosen, the thresholds and triggers for new options, predecessors for some options and the constraints of the system. More than one set of policy rules can be analysed to determine which would be most resilient under the future scenarios.

The suite of options (as defined by the policy rules) that best cope with the future scenarios, should then be tested against the future potential shocks, using sensitivity analysis.

In implementing this approach for the Melbourne water businesses, two investment policies were applied to future scenarios, with varying climate change impacts and population growths, viz. (Mukheibir et al., 2012):

Policy A: Large scale potable supply options are the first choice;

Policy B: Small scale non-potable and DSM options are considered first before introducing the large scale potable supply options.

The investment strategies were further tested for sensitivity to a number of shocks. These included energy price increases, sudden increases in demand and sudden drops in supply.

It was found that Policy B was better able to cope with more extreme circumstances and was better able to absorb future shocks and respond to changing objectives (WSDS team, 2012). Under a drier climate and higher demand scenario, Policy B accrued net present cost benefits through the deferment of large scale supply options. This resilience however, comes at the price of potential over investment under a more mild future scenario. Significantly, the cost variability for Policy B was considerably less than that for Policy A when tested under shock sensitivity (see Figure 3). This is because under Policy B options are not triggered by a supply/demand imbalance but rather by urban growth.

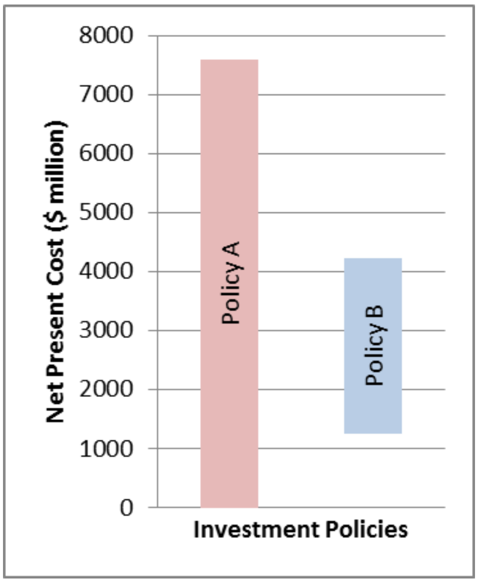

Figure 3: Range of NPC under combinations of water supply and demand scenarios (WSDS team, 2012)

Policy B makes specific use of DSM options to improve both its robustness and flexibility, through firstly reducing the overall demand on the system, thereby building robustness and deferring the need for capital intensive supply side investments, and secondly, to have flexible options, such as outdoor use restrictions, that can be implemented during a drought period, and then removed again when the situation returns to normal.

In order to develop appropriate DSM strategies and programs, it is necessary to better understand the end-uses of potable water, and where potential opportunities exist for further demand reduction.

4 END-USE ANALYSIS

Rather than use broad trends for demand, the end-use analysis approach is based a series of disaggregated end uses, each representing individual sectors (e.g. commercial, industrial) or residential activities (e.g. showering, toilet flushing). The residential end-use volumes are based on the combination of the characteristics of the installed appliance stocks and the users consumption behaviour, together with assumptions relating to the mix of housing types (Institute for Sustainable Futures, 2009). Accurate end-use data is of particular relevance to developing accurate end-use-based demand forecasting models, to option design and to the on-going monitoring and evaluation of implemented options (Turner et al., 2008). In most cases however, assumptions based on a number of household surveys have been used (Athuraliya, Gan, & Roberts, 2008; Beal, Stewart, Huang, & Rey, 2011; Roberts, 2012). By aggregating up these end-uses, a baseline forecast can be constructed.

End-use modelling has its origins in the energy sector, where it was recognised in the early 1980’s that the traditional planning methods focused only on the construction of electricity supply infrastructure and ignored opportunities to make existing networks more productive (Turner et al., 2008). This led to the consideration of the full range of both supply-side and demand-side options are assessed against a common set of planning objectives or criteria (Tellus Institute, 2000). This approach was later introduced into the water sector by the California Urban Water Conservation Council (CUWCC) and the American Water Works Association (AWWA), who developed methodologies to better forecast water demand and design and assess water conservation options (Turner et al., 2010). The Institute for Sustainable Futures (ISF) developed an integrated Supply Demand Planning (iSDP) tool for the Sydney Water Corporation in the late 1990s. This included both the development of a detailed demand forecast and the development of a broad range of options. The tool was further developed by ISF and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and is currently used as a planning tool by various large water service providers in Australia.

Residential end-use measurement is concerned with understanding where and how water is used by the domestic customer to determine what proportion of the total water consumed by a household should be attributed to individual end-uses (Giurco et al., 2008). The end-use approach requires that the residential demand is “build up” using a “bottom-up” approach (see Figure 4).

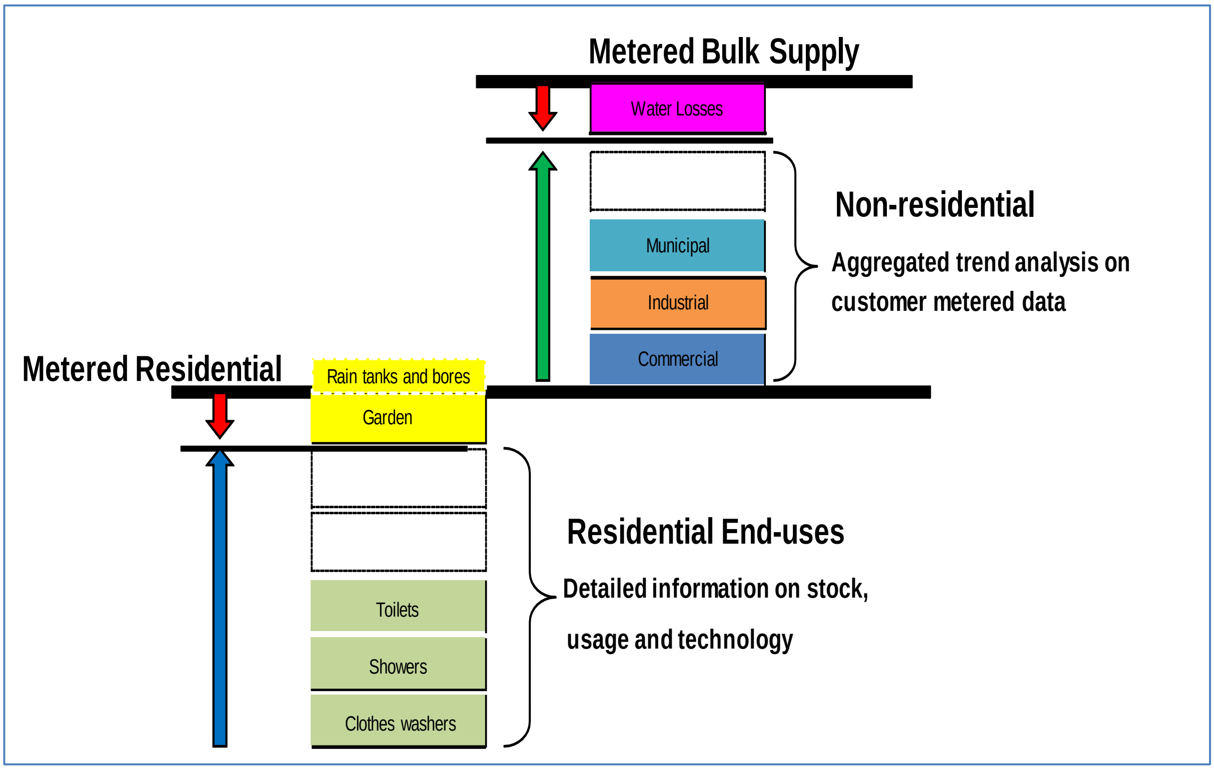

Figure 4: Bottom-Up and Top-Down Approach diagram (Mukheibir et al., 2013)

This approach provides an improved understanding of how potable water is used in the residential sector, and hence how to identify the potential opportunities for demand side management and water loss reduction. The method for determining each of the residential end-uses in the forecast model is similar in that they rely on a stock/ownership model of appliances or fixtures and assumptions about the household behavior as it relates to each end-use. For most end-use categories, the annual appliance ownership is estimated using data on appliance sales in each year in combination with assumptions about the average duration of time that appliances will remain in service prior to being replaced.

Parameters for the frequency and intensity of usage are based on assumptions determined from available literature (Athuraliya et al., 2008; Beal, Stewart, Huang, et al., 2011; Roberts, 2012). It is important that, as new research becomes available, these assumptions are updated, as well as being validated for local conditions.

The garden end-use is the only residential end-use that is determined using a “top-down” approach. Garden use is the difference between bottom up modelling results for other end-uses and the historical metered consumption for residential customers. It should be noted, that the full garden use would be the sum of this difference and any rainwater and bore water use, as illustrated in Figure 4.

The non-residential end-uses are structured differently to the residential end-uses, since there is greater diversity in this sector, with the result that it is difficult to obtain detailed information to disaggregate the uses, as was done for residential end-uses. The non-residential sector has been split into sub-sectors (e.g. commercial, industrial, municipal sub-sectors), and an aggregated trend analysis of historical customer metered data can be used, together with information about the likely future water requirements of key large users. The difference between the bulk metered supply data and the total customer metered data, reveals the non-revenue water volume (i.e. leakage, meter inaccuracies, and unbilled authorized consumption).

An analysis of the outputs from the model, shown in Figure 5, reveals that showers, clothes washers, gardens and toilets are in general the main end-uses that contribute to residential consumption. Dishwashing appliances make up a small contribution to the overall residential demand.

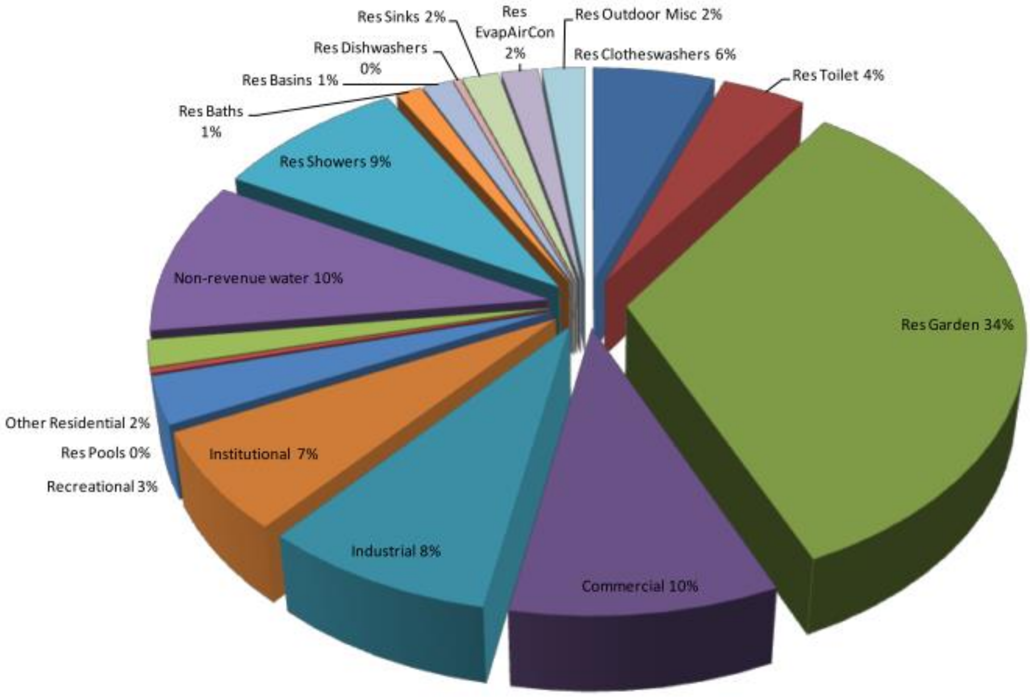

Figure 5: Example of the typical average annual end-use consumption for a water service provider (ISF, 2011)

Residential showers and gardens are the dominant areas of use and uncertainty when undertaking end-use analysis. Whilst toilets and clothes washers are also large users of water, the use in these appliances is heavily influenced by the efficiency in the technology choice. Usage durations and frequency of use do play a part in saving water and could relax following the lifting of restrictions (e.g. washing half loads of clothes resulting in an extra load per week), but this has a lesser impact on usage than do shower length and garden usage.

It has previously been assumed that residential water savings under water restrictions and education campaigns were from outdoor savings only i.e. reduced watering of gardens, however Beatty (2011) estimated that significant indoor savings of up to 44% where achieved in Sydney under restrictions. The extended length of time for which people stay in the shower or water the garden contributes significantly to increased residential water consumption i.e. “bounce-back”. To date, limited research has been published on bounce-back in Australia (Giurco et al., 2013).

The following subsections serve to illustrate specific characteristics of these key end-uses.

4.1 Showers

Efficient showers are expected to make up 80% of installed showers in Australia by 2022, based on interviews with plumbing product suppliers (Fane, Patterson, Kazaglis, & Fyfe, 2009), and household surveys conducted by Athuraliya et al. (2008). The rate of uptake past this date is likely to be slower due to preference and residual old stock still in use. The duration of a shower is a key variable in determining the volume of usage. During drought periods, customers responded well to public education and advertising campaigns about having shorter showers, with the average duration being 5 minutes (Athuraliya et al., 2008). Whilst an efficient shower head can reduce the amount of water used by almost half, lengthening the shower duration by a further 5 minutes would allow the usage to “bounce-back” to its original average volume.

The amount of savings from showerhead replacements is dependent on the flow rate which is governed by the pressure in the network system. A sensitivity analysis may be appropriate to assess the impact of varying pressures on the flow rate.

4.2 Toilets

The substitution of single flush toilets with dual flush toilets has the potential to save large volumes of water. Dual flush toilets have been introduced into the Australian market since 1989, progressing from 9/4.5 liters, 6/3 /liters to 4.5/3 liters per flush. It is expected that all three types will be still part of the sales mix until at least 2015 (ABS, 2010). The percentage of households using dual-flush toilets was used to fit a log-normal decay function of toilet lifetime and standard deviation to the residential stock of single-flush toilets Australia-wide (Fane et al 2009). Whilst the average life of a toilet is 35 years, it is expected that some non-4.5/3L toilets may still be in operation in 2060.

As is illustrated in Figure 6, the installation of more efficient flushing toilets results in the reduction in total water used by toilet flushing. This trend has been observed for all growing urban locations within Australia. However, the reduction in total water demand from toilets diminishes over time (assuming even more efficient devices aren’t developed and introduced) and usage is then projected to rise again in line with population growth from around 2025 (Mukheibir et al., 2013). A similar profile can be demonstrated for efficient showers.

The frequency of use has been determined by Roberts (2004) to be approximately 3.7 times per person per day.

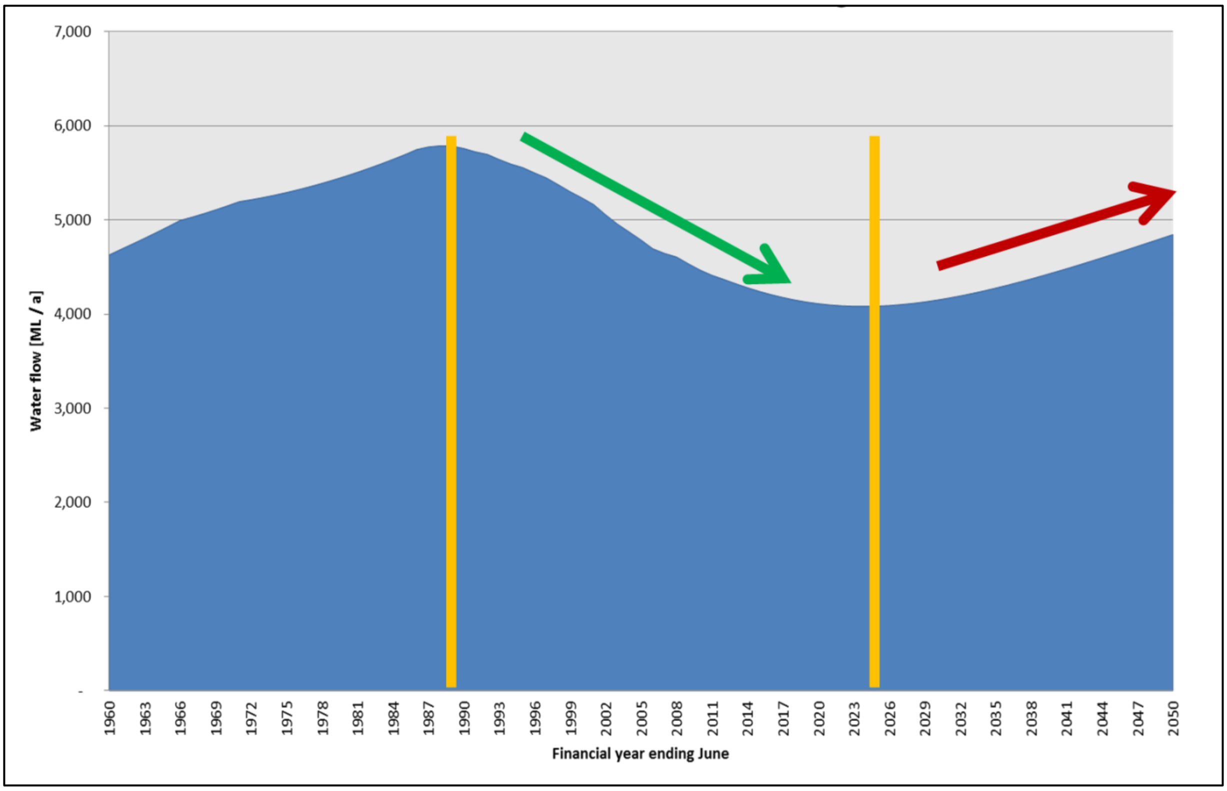

Figure 6: Water demand due to toilet use over time for an urban center in Australia

4.3 Clothes washers

The uptake of the more efficient front loading washing machines in recent times has resulted in an almost 50:50 split with top loading machines (Roberts, 2012). However, the split is less of a concern since front loaders have more recently been produced with larger capacities, whilst top loaders have been designed to be more water efficient. Frequency of use is the key parameter for this end-use. Survey work done in 2003 by Roberts (2004) revealed that the frequency of use for a family of four, for example, would do on average six loads of washing a week, whereas a household of two would wash on average 3.6 times a week.

4.4 Garden irrigation

As discussed earlier, garden irrigation is used to balance the difference between the sum of the actual metered residential consumption and the sum of all the other end-uses. The outdoor use should be climate corrected based on soil-moisture content. The use of climate corrected consumption data assists in determining the average baseline residential consumption.

When determining the average garden end-use, alternative sources of supply, such as rainwater tanks, should be ignored so that the true demand from gardens can be determined. Households with rain tanks or other alternative sources should not be used when determining the average garden demand using the top-down method. The suppression of demand for potable water through alternative sources should then be deducted from the total baseline demand at the end of the analysis. This is important, since it is not easy to establish which end-use the alternative water source is offsetting – toilets, washing machines, garden irrigation or other outdoor uses.

5 CONCLUSIONS

By undertaking end-use modelling, an improved appreciation of how the residential sector uses potable water. This will allow for improved planning of targeted demand management programs, such as rebates, appliance swaps and incentives, in order to reduce per capita demand, thereby potentially delaying large infrastructural investments over the medium term.

It has been shown that as the appliance stock becomes progressively more efficient, and usage patterns and behaviours remain fairly constant, the increased uptake of efficient appliances decreases specific residential uses of water (e.g. in toilets and showers), even though population continues to rise. The effect that this has is to delay any major supply side investments, thereby avoiding any increases in future service costs. The reduction in demand also ensures that the system can withstand the fluctuations due to the uncertainty associated with the trend scenarios. However, without additional significant shifts in the level of efficiency of these appliances over time, these major savings are likely to bottom out in the near future. The result of this is that the growth in residential water consumption will then follow population growth.

These estimates differ across the various regions of Australia, and can be attributed to differences in the social, environmental, economic and regulatory contexts, survey circumstances, and in the case of the modelled estimates, the assumptions used and how the iSDP model is calibrated. It is for this reason that Stewart (2011) suggests the need for location based research to overcome the dependency on end-use estimates and to verify the assumptions on which the forecasts are based, such as stock penetration, flow rates and volumes per use, and frequency and duration of use. It is likely that these will be progressively updated as smart metering studies expand. In addition, the commercial and industrial demand forecasts projections should be updated on an annual basis based on new information.

Besides playing a role in closing any projected supply-demand shortfall, water efficiency will also help achieve the objectives under future uncertainty scenarios. End-use efficiencies, through efficient appliances such as toilets and showers, can be expected to reduce “minimum levels of supply” that a community will require during an extreme supply shortage (Fane & Turner, 2010). The rapid roll out of demand management programs as a drought response measure can improve the flexibility of the adaptive management strategy of a water service provider.

By understanding the effect of education programs or restrictions on outdoor and indoor use provides great potential for flexible response options during periods of sudden change or system shocks. Determining the effect of restriction periods on urban water consumption is an important modeling exercise which can be used to more effectively manage scarce water resources. Not only is it important to determine the reduction of water consumption during periods of restrictions, it is also important to determine the longevity of reductions after the stages of restrictions are lifted i.e. “bounce-back”.

The shift in focus from long term deterministic planning to a more flexible adaptive planning and management approach, means that large scale centralised supply infrastructure will in future compete with small scale, decentralised and DSM options in order to address the uncertainty in the future while still maintaining water security. A diversity of supply enhancement and demand reduction options may in itself serve to reduce risk relative to relying on a single option.

By undertaking the planning process as described in this paper, uncertainty in the future can be accommodated by developing a suite of options through the application of proactive investment policies that delivers resilience and flexibility. By periodically reviewing the response of the investment policy to the drivers and pressures based on new information, the suite of supply- and demand-side options can be modified and if necessary strengthened through the options assessment process outlined in this paper.

6 REFERENCES

ABS. (2010). *Environmental Issues: Water Use and Conservation*. Cat. No. 4602.0.55.003, Australian Bureau of Statistics, Canberra.

Arbués, F., Villanúa, I., & Barberán, R. (2010). Household size and residential water demand: an empirical approach. *Australian Journal of Agricultural and Resource Economics*, *54*(1), 61–80. doi:10.1111/j.1467-8489.2009.00479.x

Athuraliya, A., Gan, K., & Roberts, P. (2008). *2007 Appliance Stock and Usage Patterns Survey*. Yarra Valley Water.

Beal, C., Stewart, R., & Fielding, K. (2011). A novel mixed method smart metering approach to reconciling differences between perceived and actual residential end use water consumption. *Journal of Cleaner Production*, *on-line*. doi:10.1016/j.jclepro.2011.09.007.A

Beal, C., Stewart, R., Huang, T., & Rey, E. (2011). SEQ residential end use study. *AWA Water*, (March), 80–84.

Beatty, K. (2011). Unsung water savings How people in Sydney saved water during drought restrictions. *AWA Water Efficiency*.

Blokker, E., Vreeburg, J., & Van Dijk, J. (2010). Simulating Residential Water Demand with a Stochastic End-Use Model. *Journal of Water Resources Planning and Management*, *136*(January/February), 19–26.

Druckman, A., Sinclair, P., & Jackson, T. (2008). A geographically and socio-economically disaggregated local household consumption model for the UK. *Journal of Cleaner Production*, *16*(7), 870–880.

Erlanger, P., & Neal, B. (2005). *Framework for Urban Water Resource Planning*.

Fane, S., Patterson, J., Kazaglis, A., & Fyfe, J. (2009). *Cost benefit analysis for minimum water efficiency standards and changes to the regulation of plumbing product quality.* Prepared for the Australian Government Department of the Environment, Water, Heritage and the Arts by the Institute for Sustainable Futures, University of Technology, Sydney.

Fane, S., & Turner, a. (2010). Integrated water resource planning in the context of climate uncertainty. *Water Science & Technology: Water Supply*, *10*(4), 487. doi:10.2166/ws.2010.120

Giurco, D., Carrard, N., McFallan, S., Nalbantoglu, M., Inman, M., Thornton, N., & White, S. (2008). *Residential end-use measurement guidebook: A guide to study design, sampling and technology*. Prepared by the Institute for Sustainable Futures, UTS and CSIRO for the Smart Water Fund, Victoria.

Giurco, D., Mohr, S., Fyfe, J., Rickwood, P., Teng, M., & Franklin, J. (2013). Modelling bounce-back in water consumption post-drought. *AWA Efficiency 2013 Sydney*.

Institute for Sustainable Futures. (2009). *Integrated Supply-Demand Planning (iSDP) Model User Manual*. Water Services Association of Australia.

LVMAC. (2011). *Living Melbourne, living Victoria roadmap*. Living Victoria Ministrial Advisory Council, Department of Sustainability and Environment, Victoria, Australia.

Mukheibir, P., Giurco, D., Turner, A., Franklin, J., Teng, M., & McClymont, T. (2013). Integrated resources planning: contemporary insights. *AWA Efficiency 2013 Sydney* (Vol. 2). Australian Water Association.

Mukheibir, P., Mitchell, C., Mckibbin, J., Ryan, H., Komatsu, R., & Fitzgerald, C. (2012). Adaptive planning for resilient urban water systems under an uncertain future. *OzWater12*. Sydney: Australian Water Association.

Roberts, P. (2012). *2011 Appliance stock and usage patterns survey - June 2012*. Yarra Valley Water, Victoria.

Schlunke, A., Lewis, J., & Fane, S. (2008). *Analysis of Australian opportunities for more water-efficient toilets*.

Stewart, R. (2011). *Verifying potable water savings by end use for contemporary residential water supply schemes*. Waterlines Report Series No. 61, October 2011.

Turner, A., Willetts, J., Fane, S., Giurco, D., Chong, J., Kazaglis, A., & White, S. (2010). *Guide to Demand Management and Integrated Resource Planning (update on original 2008 Guide)* (pp. 1–174). Association of Australia (WSAA), Sydney, Australia.

World Bank. (2005). *World Development Indicators (WDI). Washington. DC*.

WSDS team. (2012). *Draft Background Paper for Water Supply Demand Strategy: Options Assessment Framework (unpublished source)*. Melbourne Water, Australia.