



LOW CARBON LIVING
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RP 3035 Final Report

Modelling Uptake of Water Conservation and Efficiency Measures in Sydney



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The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

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- conclusions against results
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and provided constructive feedback which was considered and addressed by the author(s).

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Executive Summary

This report provides a summary of many of the activities in the LCL CRC project “RP3035 Modelling the uptake of water conservation and efficiency measures in Sydney” which is a collaboration between the CSIRO and Sydney Water, supported by the Low Carbon Living CRC.

The extended Millennium drought during the 2000s saw Australian cities have to move rapidly to implement water conservation measures and adopt alternative rainfall-independent water sources such as desalination, in order to ensure water supply security. The measures implemented during the drought have increased the energy and carbon intensity of water supply. There is the need to understand where future water conservation programs might be targeted during future droughts that can be most effective in reducing demand while minimising carbon footprint and economic costs.

To address this need the project developed a prototype decision support system simulating market diffusion to inform the following questions for water conservation/efficiency (and associated energy and carbon impacts) in the Sydney Water network:

- What factors influence consumer behaviour in changing patterns of water usage under a range of scenarios, including various levels of water restrictions, during drought conditions and outside of drought conditions?
- What types of interventions would be sufficient to motivate early adopters to implement new technology solutions? How long should these incentives remain to encourage wider market uptake?
- How can diffusion be accelerated via non-financial interventions – e.g. education, restrictions?
- What is the influence of drought conditions and awareness of consumers on behaviour?
- What population groups (by income, by group values etc.) will make changes that lead to the desired water savings?
- How can interventions to reduce water usage lead to energy and carbon reductions?

The following activities were undertaken:

Literature review – identification of the factors that influence the adoption of water conservation actions. The review highlighted the importance of considering water conservation actions through the ‘consumer decision journey’ which considers how to build awareness and familiarity, encourage adoption, and ensure the persistence of the behaviour.

Household survey – a survey of 547 households was undertaken to understand the relationship between residents and their complex responses to a set of interventions implemented by Sydney Water to promote the uptake of water conservation behaviours and technologies.

Statistical adoption modelling - Based on the survey data, several Multinomial regression models were fitted to the data to describe the likelihood of ‘stated intention’ to adopt various versions of Sydney Water’s WaterFix® program.

Willingness to pay analysis - This analysis ascertained how much Sydney Water Customers were willing to pay for various attributes of a rainwater tank or a smart meter. Findings from these studies shed light on the perceived benefits residents place on rainwater tanks or smart meters as measures to help conserve water and become more resilient to the drought in the future.

Agent-based Model – The ABM was developed as a decision support tool that can explore the uptake of water conservation actions under different policy scenarios and assumptions. The ABM simulates, based on the preceding activities, the complex social dynamics of customer behaviour drivers when making a decision on the potential adoption of water conservation actions.

The ABM model was validated against historical data on the adoption of water conservation programs in Sydney Water’s service area. This provided Sydney Water with greater confidence in the model outputs and has sparked interest in other water utilities looking to implement a similar approach in designing their water conservation programs.

Future research will attempt to develop a generic model for helping to understand the adoption of resource efficient behaviour in a range of contexts. Initial customer conversations have indicated the potential for this type of approach to be utilised more broadly across the utility sector (water and energy).

There is also an opportunity to further develop the water conservation model to be more all-encompassing and to explore all types of water demand behaviours in the context of drought, restrictions and various programs. The efficacy of the model in simulating water demand, for Sydney Water or other companies into the future, will require the ongoing collection of the specific data needed to populate and validate the model.

The project has demonstrated the benefits of ABM in understanding the implications of different policy setting in increasing the adoption of water conservation actions. In comparison to more traditional water demand models, the ABM can explore system leverage points and scenarios, as well as describing the complex behavioural responses across the community. The ABM approach is not as data intensive as other water demand modelling approaches so it can allow for rapid prototyping to assess water conservation policy options.

The approach demonstrated in this project can provide a useful approach for the water sector in targeting investment in their water conservation programs by improving institutional capacity to evaluate likely impacts of different policy options. The emergence of big data, from the widespread uptake of smart meters and the ‘internet-of-things’, creates an opportunity to develop ABMs that simulate individual responses to water conservation programs.

Introduction

This report provides a summary of many of the activities in the LCL CRC project “RP3035 Modelling the uptake of water conservation and efficiency measures in Sydney” which is a collaboration between the CSIRO and Sydney Water, supported by the Low Carbon Living CRC.

The project has delivered a prototype decision support system simulating market diffusion to inform the following questions for water conservation/efficiency (and associated energy and carbon impacts) in the Sydney Water network:

- What factors influence consumer behaviour in changing patterns of water usage under a range of scenarios, including various levels of water restrictions, during drought conditions and outside of drought conditions?
- What types of interventions would be sufficient to motivate early adopters to implement new technology solutions? How long should these incentives remain to encourage wider market uptake?
- How can diffusion be accelerated via non-financial interventions – e.g. education, restrictions?
- The influence of drought conditions and awareness of consumers on behaviour?
- What population groups (by income, by group values etc.) will make changes that lead to the desired water savings?
- How can interventions to reduce water usage lead to energy and carbon reductions?

There are many reasons why there is a need to boost the capacity for cities to ramp up water conservation efforts, i.e. to be more resource efficient, to improve supply-demand balance and thereby delay the need for supply augmentation and thereby save a lot of dollars (in the context of cities with growing population and demand) and to improve the resilience of urban water supplies. Australian cities face regular droughts which compound their common dilemma of ongoing population growth, whilst concurrently having very few easy or cheap options for supply augmentation.

During the last major drought, Australian cities invested in both new supplies, such as desalination which is costly and energy intensive to operate, as well as water conservation which requires ongoing investment but aims to do more with less. The success of water conservation during the Millennium drought shows its potential to reduce the demand for water and deliver longer term benefits well beyond drought periods. Currently in cities such as Sydney per capita, residential demand is nearly 30% higher than that of Melbourne. This shows that there is considerable potential in Sydney to adopt water conservation programs.

This project builds on the work undertaken in CRC project “A Framework for Low Carbon Living Community Policy & Program Development” RP3002 and “A “virtual market” for analysing the uptake of energy efficiency measures in residential and commercial sectors” RP3028. These projects used core Diffusion uptake algorithms developed over a number of years.

Activities of the project have involved:

- Undertaking a couple of household surveys.
- Statistical modelling to describe which factors have the greatest influence on adoption rates.
- Embedding data and models into an Agent-Based Modelling framework.

Here we outline some of the data collection and analysis that we have undertaken; with the main output, an Agent-Based Model (ABM) applied to one particular intervention WaterFix. This doesn't mean that we are particularly concerned about WaterFix as the main driver of water conservation behaviour, but rather WaterFix was chosen in order to validate the capacity of the model to replicate historical adoption rates. We have clearly demonstrated that the model can do this, but in doing so we have also uncovered some bigger questions and information gaps that may need to be explored for the next round of water conservation programs.

An ABM is a type of model which explores how groups of individuals create emergent patterns and how they interact with each other when they make decisions. It does this by simulating how agents make decisions, and also simulate how agents interact with each other in a computational environment. In other words, it is a software representation of agents and their decision making in interaction with each other and their environment. Ultimately, the agent-based model has been shown to be quite capable of describing adoption and diffusion of water conservation behaviour under a range of circumstances. There is particular capabilities to exploring hypothetical policy scenarios, drought scenarios, investment scenarios or outcomes in targeting segments of the population. Overall, the model can enable the optimisation of water conservation investment to maximise the benefits and support business cases for water conservation.

For the model to be expanded to other behaviours, all that is needed is some data collection and/or analysis. To apply this model to other behaviours or water conservation programs, all that is needed is some more data collection and/or analysis.

The report describes in order:

- A brief review of water conservation behaviour
- The survey that we have undertaken
- Statistical modelling
- Willingness to pay analysis
- The Agent-Based Model, including application to WaterFix

There are also some final reflections on these results.

Understanding water conservation behaviour: a brief review

The longer associated review is in the journal article ‘Promoting water conservation: where to from here?’ (Moglia et al., 2018a). We structure the understanding of the adoption of water conservation behaviour through the lens of the “consumer decision journey” (Court et al., 2009) which focuses on three key issues (adapted from Moglia et al., 2018a):

- *Awareness and familiarity*: how can you make people be aware of and familiar with water conservation practices? To what extent does this translate into consideration of water conservation behaviours? The consideration here is the active choice whether to undertake a particular behaviour.
- *Adoption*: once water conservation practices are “on the radar”, what makes people consider and adopt them?
- *Persisting*: once people have adopted water conservation practices, to what extent will they persist with this behaviour?

Awareness and familiarity

Before even making a decision about whether to conserve water or not, an important precursor is the knowledge of what could be done, an awareness of the reasons why water conservation may be important, and when people are busy and have multiple requests for their time and resources, importantly a level of engagement with the topic, to put it among the priority issues that may need to be addressed.

It is therefore not surprising that even just broadcasting the need for water conservation through media or other channels has an impact on water demand. In their review of experiences, Inman and Jeffrey (2006) found that media broadcasts tend to reduce demand by 2-5% and the effectiveness of awareness-raising campaigns is more unclear and with a broader range of 0-8%.

It was found that, as may perhaps be expected, when awareness and priority-raising campaigns are combined with individualised information about how to reduce water use, a 16% reduction of water demand could be achieved (Fielding et al., 2013). However, it is also noted by a number of authors that the impact of these types of campaigns need to be monitored over the long term.

Adoption

Whether a householder chooses to adopt or not adopt water conservation behaviour is dependent on two linked processes. Firstly, a householder needs to be actively making a decision. Whilst householder may make such decisions on a regular basis, there are a number of things that may speed up the rate of the decisions being made, i.e. by prompting action such as through media or direct communication, or generally through water conservation being a priority topic within the community

and therefore indirectly being prompted by friends or neighbours.

Once people make a decision however, the choice process is also a complex process that depends contextual factors such as urban design, and climate, price and restriction levels, household characteristics, as well as the perceived effort and inconvenience of behaviour, attitudes and social norms. All these factors have been explored during this project through the survey and subsequent statistical analysis.

Examples of known correlations between such factors and water demand and water conservation behaviour are (Fielding et al., 2012, Yu et al., 2015):

- Higher income is generally associated with higher per capita water use.
- Larger households generally use more water.
- Households with older residents tend to use more water.

The amount of effort and inconvenience of water conservation efforts has been shown to influence the chances of adopting water conservation behaviour (Ramsey et al., 2017, Dolnicar and Hurlimann, 2010, Tapsuwan et al., 2017). In addition, demographic, psychosocial, behavioural, variables all are important in influencing the choice (Fielding et al., 2012).

Persistence

Whilst ideally one would hope that householders would persist with their water conservation behaviour once the drought has ended, that appears to be only partially true. Bounce back effects have been demonstrated in many jurisdictions such as California (Maddaus, 2001), Melbourne (Melbourne Water, 2016) as shown in Figure 1. We do note that the trend in nearly all cases is that some part of the decline is maintained.

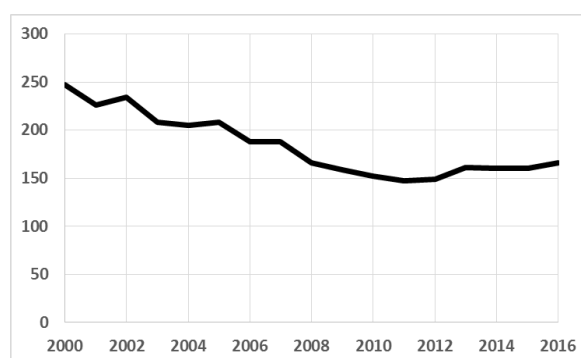


Figure 1: Residential water use in Melbourne, 2000-2016. X-axis: years. Y-axis: Per capita residential water use in litres per person per day. Sourced from Melbourne Water (2016).

Of particular relevance for this project is to explore the persistence of behaviours in the context of Sydney. For this purpose, we explore the case of Sydney, as shown in Table 1. Whilst there is not enough data to draw too

many conclusions, we note a few implications of the data:

- There is a close correlation between stated intention in 2005 and the self-reported behaviour in 2017, beyond what we would have expected. We interpret this to mean that stated intentions take time to be realised due to limits on resources - time, effort, knowledge and capacity etc. However, over time, if motivational drivers remain, the stated intentions will largely be translated into long term behaviours through a process of diffusion.
- We do however also note that two types of behaviour where there appears to have been a bounce back effect, i.e. only using washing machines when they are full, and turning the tap off whilst brushing teeth – which are the two behaviours showing decline since the peak in 2005 as per Table 1. We interpret this to mean that when opting out is easy, and when there is an effort and/or cost involved with persisting with the behaviour, some of the households will opt out over time.
- We also note that the appliance stock has changed significantly over the time period, with front-loading washing machines (often considered a proxy for water efficient appliances in Australia) increasing their proportion of the stock from 16% to 37%. This uptake of more water efficient appliance stock will definitely lead to reduced water demand

All considered, the data in Table 1 is quite consistent with the per-capita water demand over time. The majority of households will persist with most of the behaviours even after motivational drivers are removed, except in some cases when the effort and/or cost triggers householders to opt out of the behaviours. This shows that further longitudinal research is required in order to explore the persistence of water conserving behaviours, as well as changes in appliance stocks, in reducing water demand.

Table 1: Rates of self-reported water conservation behaviours in Sydney 2005 and 2017. First two data columns are from Randolph and Troy (Randolph and Troy, 2008). The last data column is based on a survey of 406 households in Sydney by the authors in 2017.

	Self-reported behaviour 2005	Stated intention 2005	Self-reported behaviour 2017
Use half flush button on toilet	13%	62%	62%
Use washing machine only when full	21%	86%	56%
Take shorter showers	29%	58%	57%
Reduce garden watering	13%	44%	50%
Turn tap off whilst brushing teeth	18%	92%	72%
Front loading washing machine (proxy for water efficient appliance)	16%	N/A	37%

Sydney Water User Survey

Methodology

The survey was designed to understand the relationship between residents and their complex responses to set of interventions implemented by Sydney Water to promote the uptake of water conservation behaviours and technologies.

There were two household surveys undertaken for this project. The second survey was conducted in June 2018. A total of 547 respondents completed the second survey, which is reported in more detail in this section.

The first survey was conducted in November 2017. A total 406 participants completed the survey. The purpose of this survey was to pilot the survey approach in understanding household decision triggers to adopt water conservation approaches, and also to apply the choice experiment that was used to develop the willingness to pay model (reported in subsequent section of this report).

Households were recruited via an online research panel. Participants on the panel who lived within the list of postcodes of our study region (i.e. Sydney Water service area) were sent an email from the online research company with an invitation to complete the online survey. In compliance with the CSIRO Research Ethics Guideline, participants were required to provide their consent to take part in the survey by checking the consent box before proceeding further with the survey. A follow-up email reminder was sent out to respondents who did not respond to the first invitation, to ensure that anyone who wished to participate had the chance to do so. Participants who complete the survey have their respondents ID entered into a draw to win a prize, as an incentive to complete the survey. This research study received ethical clearance from the relevant Human Research Ethics committee (Approval Reference 120/17 Water Conservation Modelling). Informed consent was obtained from the participants prior to the study.

Demographics

Figure 2 depicts the age and gender profile of the survey respondents. There was a reasonably balanced representation of males and females in survey respondents, but there was skew toward females in younger respondents and males in older respondents. Figure 3 shows the highest level of education reported by respondents, and annual gross household income. Slightly more than 50% of respondents reported having completed post-secondary school qualification (trade certificate, undergraduate or postgraduate degree). The level of education was reflected in annual gross household income, with 27% of the cohort with post-secondary qualifications having a household income of more than \$130,000 compared to only 14% of households where the respondent hadn't completed post school qualifications.

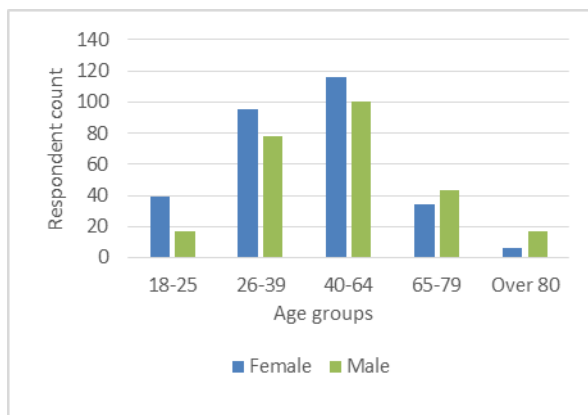


Figure 2: Age and gender profile of survey respondents

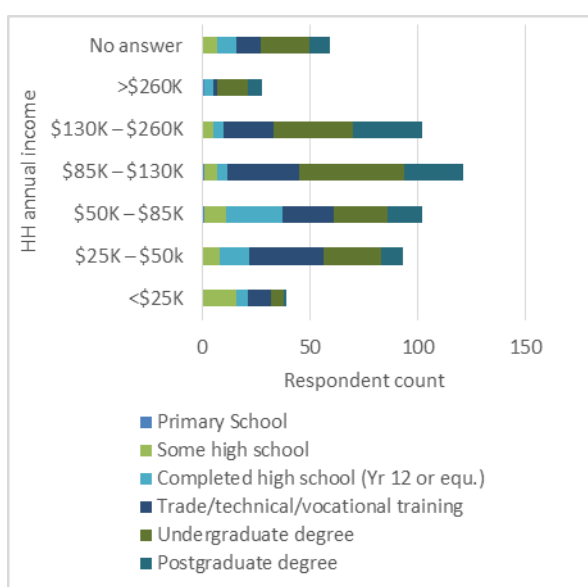


Figure 3: Household income and highest level of education completed

The average household size across respondents was 2.9 persons. One third of households had a child under the age of 15. Figure 4 shows that the majority of respondents owned their home or were paying it off. Respondents that were renting were more likely to live in medium density dwellings. 67% of respondents reported they paid their water bill directly, while the respondents who reported they paid for water charges indirectly (through rent or body corporate charges) were predominately renters.

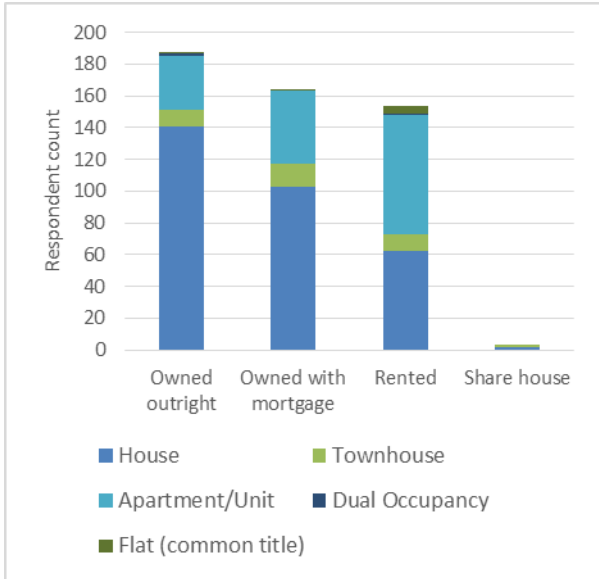


Figure 4: Dwelling type and tenure

Self-reported behaviours

Figure 5 shows the reported indoor water conservation behaviours reported by respondents. Actions that are simple to implement such as turning off taps while brushing teeth and only running appliances when full were the most popular reported actions – perhaps this is the reason why there is a bounce back. While actions that require more effort on behalf of the household, such as the reuse of greywater, or a greater behavioural change from the norm, such as turning off the shower while soaping, were reported by fewer respondents.

Figure 6 shows that while 50% of all respondents reported adhering to permanent water restrictions for outdoor use (water wise rules), such as not watering plants between 10 AM and 4 PM. Only 67% of all respondents report any watering of their garden. However, there was less adoption of other water conservation actions such as installing drip irrigation.

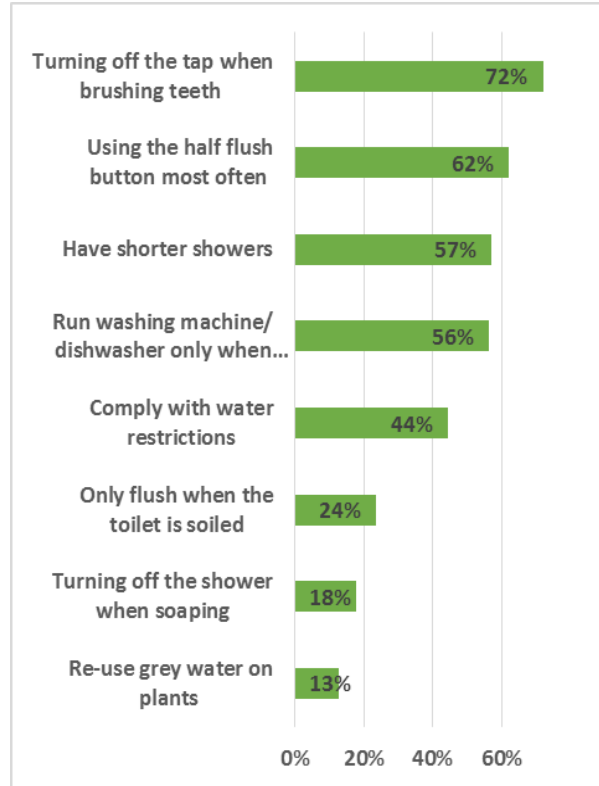


Figure 5: Reported indoor water saving actions

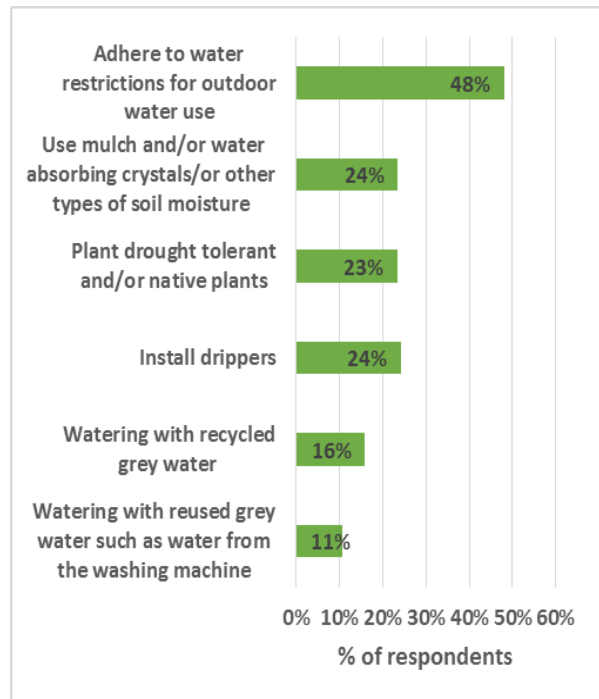


Figure 6: Reported outdoor water saving actions

Stated intentions for water conservation actions

Sydney Water offers customers the WaterFix® program, where qualified plumbers check a home for leaks and opportunities to save water. Customers are offered fixed priced installation of water efficient appliances. Figure 7 depicts the likelihood that a customer intends to use the WaterFix service based on different payment options. This shows that respondents were most receptive to WaterFix when they could spread payments as a part of their regular water bills over a five year period with a discount of 30% from the proposed \$430 fee. The majority of participants were not intending to book a WaterFix program regardless of the incentives that were offered.

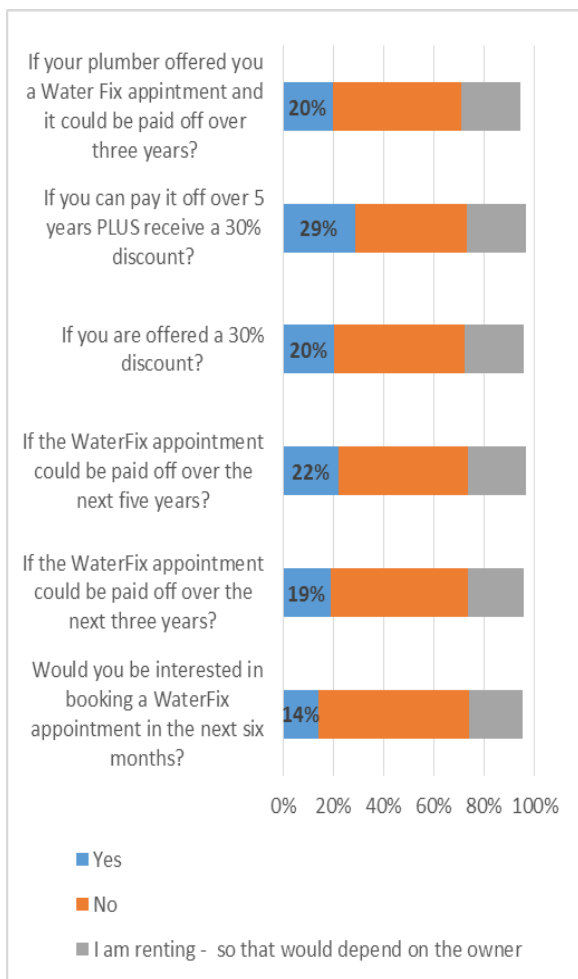


Figure 7: Stated intentions for WaterFix

Figure 8 shows the stated likelihood that different triggers would result in a respondent adopting water conservation actions. This shows that a higher than anticipated water bill was the factor most often stated as extremely likely to shift respondents' intentions in adopting a water conservation action.

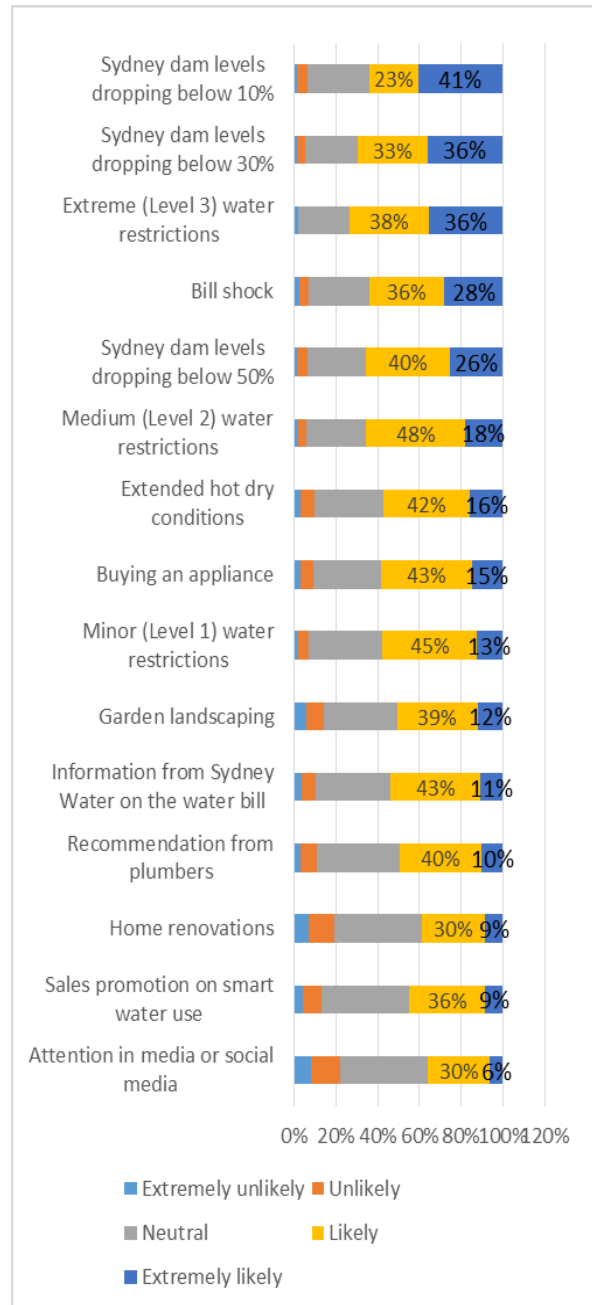


Figure 8: Likelihood of triggers prompting water conservation action

Householder priorities

Figure 9 shows how survey respondents rated the priority of different aspects of their life. This showed that the aspects most often considered an essential priority were related to health, financial security, comfort and social context. In considering the potential adoption of water conservation action households are likely to evaluate the potential for the action to adversely impact or add value to the priorities they consider essential. There is likely to be thresholds for these essential priorities, where householders would be unwilling to adopt a water conservation action if there were potential adverse impacts, such as increased health risks, regardless of the potential water savings. However, for lesser priorities householders might be more willing to trade-off against these to achieve a water saving.

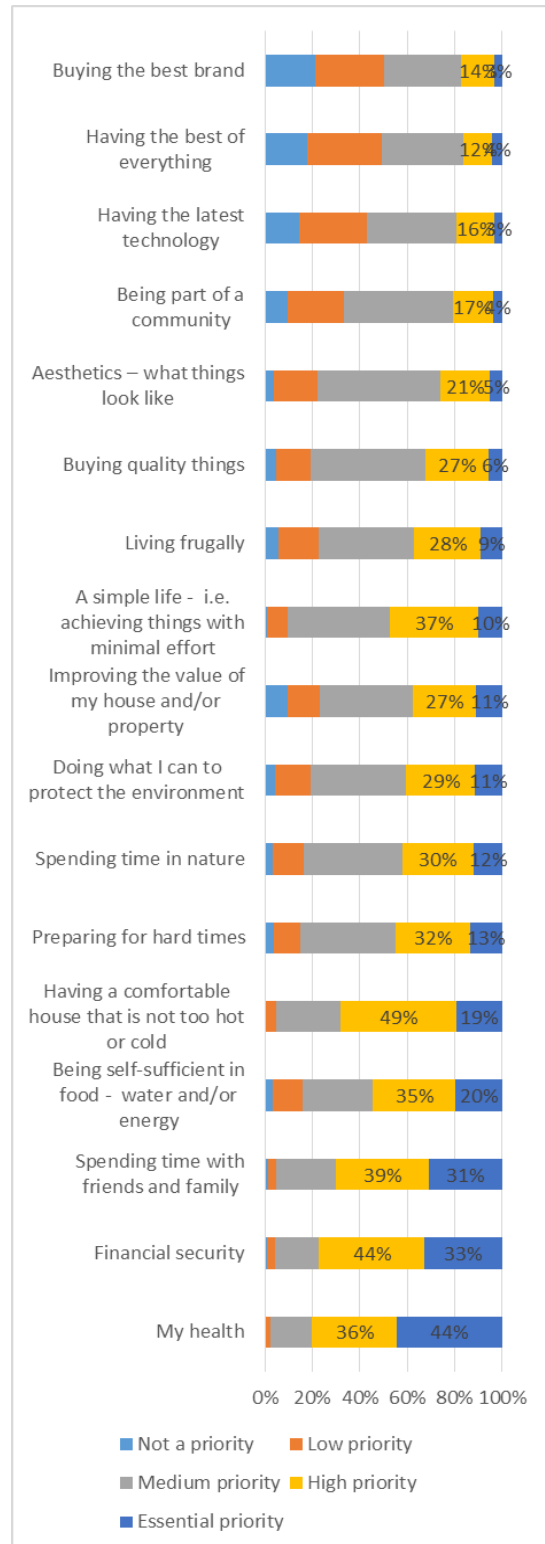


Figure 9: Household priorities

Social psychology factors

There are attitudinal variables that come into play when people make a decision about water conservation and the adoption of new water conservation technology.

Perception of how severe the next drought is going to be, and how concerned people are about how water shortages could affect their well-being has been found to have an effect on the willingness to pay (see e.g. Tapsuwan et al., 2014) and the acceptance and adoption of decentralised water technology (see e.g. Tapsuwan et al., 2015, Mankad and Tapsuwan, 2011).

Social normative influences also play an important role, as people who want to conform with others are more likely to 'do the right thing' and conserve more water (see e.g. Corral-Verdugo and Frías-Armenta, 2006; Lapinski et al., 2007; Bernedo et al., 2014).

The level of difficulty in making an informed choice influences the strategies for making a choice, either by delaying a choice, by simplifying choice and use heuristics, Broniarczyk and Griffin (2014) or even by people having a greater preference for options that are easier to analyse (Garbarino and Edell, 1997). Furthermore, the now well-established theory of social comparison (Festinger, 1954) states that, depending on personality, people to a lesser or greater degree compare themselves against others on an ongoing basis, for a number of reasons such as seeking social status or to seek self-enhancement by being competitive (Corcoran et al., 2011). All these factors can be explored using various instruments and survey questions (see e.g. Tigges, 2009, Gibbons and Buunk, 1999).

To capture the attitudinal and behavioural aspect of individuals relating to water conservation behaviour, and adoption of new water technology, we employed psycho-social constructs and statements from the psychology literature. Table 2 presents the attitudinal and behavioural variables that are expected to have an effect on people's decision to adopt water conservation technology.

Statements in Table 2 were presented to respondents, and respondents were asked to respond on a 5-point Likert scale how strongly they agree or disagree with the statements (1 = strongly disagree; 5 = strongly agree).

To analyse the constructs (in Table 2), exploratory factor analysis was used as a data reduction technique to group statements into constructs, and eliminate statements that were not strongly correlated to a particular psychological construct.

Afterwards, confirmatory factor analysis was used to generate a composite variable for each construct. In the end, each respondent has a normalised score for each of the attitudinal and behavioural variable.

The current study utilises the method specified in the equation below to calculate the composite score for coping behaviour. The composite score is specified as:

$$\widehat{AttBeh}_a = \omega_1 X_{1a} + \omega_2 X_{2a} + \dots + \omega_n X_{na}$$

, where \widehat{AttBeh}_a is the estimated composite score for selected attitudinal and behavioural variables of each individual, ω_n are the factor score regression weights and X_{na} are the observed score for each indicator of each attitudinal and behavioural variable.

Table 2: Attitudinal and behavioural variables, and associated observed indicators

Variable (Construct)	Statements of observed indicators (measures)	Confirmatory factor analysis
Statements/measures relating to uncertainty		
Tendency towards conformity	<ul style="list-style-type: none"> It is expected of me that I should install a rainwater tank on my property. It is expected of me that I should install water efficient/saving devices around the home. I feel pressured by others (for example, friends, family, neighbours) to install a rainwater tank. I feel pressured by others (for example, friends, family, neighbours) to install water-efficient/saving devices around the home. 	Fully saturated model
Outcome uncertainty	<ul style="list-style-type: none"> The ability for us as a society to conserve water is beyond my control 	
Cognitive effort	<ul style="list-style-type: none"> I spend the time required to choose an alternative that is satisfactory for me. I spend the time required to choose solutions that meet my needs. Whenever I am faced with a choice, I try to imagine what all the other possibilities are, even ones that are not present at the moment. I tend to choose solutions that guarantee satisfactory results for me. 	Chi-square (9,n=405)=0.04, p>0.98
Confidence	<ul style="list-style-type: none"> I know what to do to reduce my household leakage I know what to do, in order to purchase a more water efficient toilet I know how to purchase a more water efficient appliance (washing machine, dishwasher, etc.) I am able to purchase and install a more water efficient showerhead I know how to reduce how much water I need for my garden I know what behaviours to put in practice to reduce water use (e.g. shorter shower) 	Chi-square (7,n=405)=13.43, p>0.06
Statements/measures relating to motivations		
Monetary	<ul style="list-style-type: none"> I use less water around the house to save money I choose what I really need at the lowest price I seek only the cheapest products I look around to find lower-priced products, even if they are an off-brand 	Chi-square (9,n=405)=0.26, p>0.61
Environmental	<ul style="list-style-type: none"> I use less water around the house to reduce pressure on the environment I use less water around the house to reduce my greenhouse gas emissions I use less water around the house to contribute to Sydney's water supply security 	Fully saturated model
Hassle & Effort	<ul style="list-style-type: none"> I am not willing to waste much time and energy to buy water saving devices I am not willing to waste much and time and energy to save water around the home 	Not enough degrees of freedom
Vulnerability	<ul style="list-style-type: none"> I am concerned that Sydney will experience water shortages in the future. I worry about how water shortages will affect my way of life. I worry about how water shortages will affect my water bill. I am worried about how water shortages will affect others in my community. My friends and family are worried about future water shortages. I don't think other people in my community are concerned about future water shortages. 	Chi-square (3,n=405)=1.68, p>0.64
Perceived behavioural control	<ul style="list-style-type: none"> The decision to install water saving devices is not entirely up to me The decision to use less water around the household is not entirely up to me 	Not enough degrees of freedom
Statements/measures relating to ambition and tendency for comparison		
Tendency towards comparison	<ul style="list-style-type: none"> I often compare myself with others with respect to what I have accomplished in life. I always pay a lot of attention to how I do things compared with how others do things. I always like to know what others in a similar situation would do. I am not the type of person who compares often with others. I often try to find out what others think who face similar problems as I face. I never consider my situation in life relative to that of other people. I often compare how I am doing socially (e.g., social skills, popularity) with other people. 	Chi-square (9,n=405)=15.76, p>0.07
Tendency towards satisficing	<ul style="list-style-type: none"> I set targets to be achieved with minimal effort I am okay with any choice that yields the minimum result I choose the option that meets the absolute minimum I always set the highest targets I set the highest standards for household No matter how satisfied I am with what I currently have, it is only right for me to be on the lookout for better ones 	Chi-square (5,n=405)=3.27, p>0.66
Tendency towards superiority	<ul style="list-style-type: none"> I never settle for second best 	Single statement
<p>Confirmatory factor analysis means a statistical test to evaluate whether a set of measures (i.e. question results) can be grouped into a single construct (i.e. variable), i.e. if they all measure approximately the same thing and that not too much information is lost by grouping the measures into a construct. Here, the p-value indicates the likelihood of getting these results under the Null Hypothesis, i.e. that all measures describe the same thing. Thus a higher p-value is preferable.</p> <p>Not enough degrees of freedom means that there was not enough degrees of freedom to perform a confirmatory factor analysis, however, exploratory factor analysis confirms that the statements form one factor.</p> <p>Single statement means that exploratory factor analysis suggest that only one statement is sufficient to explain the construct.</p> <p>Fully saturated model means the items explain the construct perfectly.</p>		

Statistical Adoption Modelling

Based on the survey data previously described, several Multinomial regression models have been fitted to the data to describe the likelihood of 'stated intention' to adopt various versions of the WaterFix program.

We have adopted a standard multinomial regression model described by the following equations.

$$P(Y_k = Yes) = \frac{\exp(Z_{k,Yes})}{1 + \exp(Z_{k,Yes}) + \exp(Z_{k,N/A})} \quad (1)$$

$$P(Y = N/A) = \frac{\exp(Z_{k,N/A})}{1 + \exp(Z_{k,Yes}) + \exp(Z_{k,N/A})} \quad (2)$$

$$P(Y = No) = \frac{1}{1 + \exp(Z_{k,Yes}) + \exp(Z_{k,N/A})} \quad (3)$$

$$Z_{k,Yes} = \alpha_{Yes} + \sum_{i=1}^N x_{i,k} \cdot \beta_{i,Yes} \quad (4)$$

$$Z_{k,N/A} = \alpha_{N/A} + \sum_{i=1}^N x_{i,k} \cdot \beta_{i,N/A} \quad (5)$$

Here, x_i is the dependent variable i for the householder k . P is a probability, and Z is an intermediate mathematical variable which forms part of the multinomial regression model. There can be three possible values for the stated intention, i.e. Yes, No or N/A meaning it's not feasible to adopt for the particular householder. α are the intercept parameters of the model. The statistical estimation algorithm, using the R statistical software, establishes the α and β parameters. As part of the statistical estimation of parameters, a very large number of covariates were explored. The variables that remain statistically significant in explaining the data are the following:

- A. Tenure category (i.e. owning or renting, etc.)
- B. Number of children
- C. Time poverty (~having limited available time)
- D. Employment
- E. Prioritising being in nature
- F. Prioritising having quality things
- G. Prioritising protecting environmental values
- H. Prioritising reducing greenhouse gas emissions
- I. Prioritising the amount of effort involved
- J. Being concerned about water supply security

Furthermore, there are seven versions of the WaterFix program that we explore. All of these options are not necessarily cost efficient for the home owner and the

choice to opt in therefore goes beyond cost optimisation. The options are:

1. WaterFix #1: The current version of the WaterFix, i.e. price \$430 and a licensed plumber can repair toilet, tap and pipe leaks, replace toilets, replace indoor and outdoor taps, replace shower heads, and install flow control devices.
2. WaterFix #2: Same as #1 except it can be paid off over 3 years which after accounting for water savings would be approximately \$93 per year for three years.
3. WaterFix #3: Same as #1 except it can be paid off over 5 years which after accounting for water savings would be approximately \$36 per year for five years.
4. WaterFix #4: Same as #1 except with a 30% subsidy so would cost \$300.
5. WaterFix #5: Same as #4 except paid over five years, i.e. after accounting for water savings an average cost of \$10 per year for five years.
6. WaterFix #6: Same as #2 except would be offered by a plumber when he/she would be on site anyway.
7. WaterFix #7: A more basic version of WaterFix would include fixing tap leaks, changing shower heads, etc., but would not include the replacement of toilets. This is, therefore, a much cheaper service. This is also offered with an 80% discount. After accounting for water savings, the estimated cost of this offer is \$22.

Furthermore, we have two different models for each WaterFix, i.e. for those engaged with water conservation (through awareness of water conservation programs as a proxy) and those who are not. The estimated parameter values, based on multinomial regression analysis, i.e. the β s and α s are shown in Tables 4-7. These parameters can be used either independently in multinomial regression models to describe adoption of WaterFix alternatives, but here in this project we embed these parameters into our ABM.

When interpreting Tables 4-7, a value higher than zero means a positive influence on adoption likelihoods, and similarly negative number means negative influence. Sometimes counter-intuitive results occur, but these are generally because of the combined influence of all information taken altogether. We can also see that those who are unaware of WaterFix are likely to be concerned about the effort of getting involved, whilst those who are aware of the program are generally not so concerned about this issue. This shows the potential benefit of communicating how easy it is to sign up to WaterFix to the wider community.

Table 3: Parameter values for those "engaged with water conservation" and for Yes

	α	Tenure category	N children	Time poverty	Employment	Nature priority	Quality-things priority	Environment priority	GHG priority	Effort priority	Supply concern
1	-21.48	8.93	3.12	-7.91	7.23	13.79	12.17	0.30	-0.02	13.90	-3.93
2	-3.63	-1.45	0.60	-0.84	0.22	-1.43	3.83	-6.25	8.77	2.57	-0.45
3	-8.51	1.73	0.74	-1.93	3.71	1.73	-0.90	-1.80	4.53	3.13	2.66
4	-7.12	1.54	1.25	-1.09	1.70	3.27	-0.05	-2.65	4.43	1.62	3.55
5	-5.12	0.13	0.09	-0.97	3.28	-2.03	4.63	0.28	4.25	1.89	-3.55
6	-12.13	3.12	0.11	-1.77	6.24	-0.30	5.57	5.90	-1.71	1.57	0.18
7	-2.33	-1.25	-0.78	-1.33	1.02	3.46	5.29	-2.95	0.82	3.45	-4.20

Table 4: Parameter values for those "engaged with water conservation" and for N/A

	α	Tenure category	N children	Time poverty	Employment	Nature priority	Quality-things priority	Environment priority	GHG priority	Effort priority	Supply concern
1	-82.41	48.50	-30.33	22.62	20.16	83.18	-76.86	69.58	-2.18	17.86	-35.35
2	-97.80	138.77	21.41	22.58	-57.76	109.45	-93.79	94.31	6.74	-174.03	-12.67
3	-135.35	103.32	54.51	-38.08	-15.92	103.65	-194.10	267.86	-66.43	-80.28	5.37
4	-3.94	6.95	6.44	-0.57	-2.83	3.43	-9.12	2.09	0.77	-6.15	6.89
5	-195.19	159.27	92.64	-120.92	-3.35	-76.31	-150.66	417.22	2.87	-85.40	-44.69
6	-4.99	16.20	11.59	-17.34	-9.15	2.34	1.66	11.41	-2.02	-19.55	3.28
7	-4.45	4.66	2.48	-3.78	-0.38	0.11	-2.20	4.94	2.07	-3.10	-0.50

Table 5: Parameter values for those "not engaged with water conservation" and for Yes

	α	Tenure category	N children	Time poverty	Employment	Nature priority	Quality-things priority	Environment priority	GHG priority	Effort priority	Supply concern
1	-4.92	-0.22	0.68	-2.21	1.09	0.76	1.31	-2.18	2.97	0.98	1.65
2	-4.15	-0.61	0.46	-0.36	0.39	0.63	0.88	1.39	0.53	-0.09	0.83
3	-3.88	-0.36	0.74	-0.30	0.52	0.33	0.53	1.75	0.49	-0.21	0.86
4	-4.28	-0.46	0.72	-0.77	0.93	0.71	0.47	1.37	0.79	0.08	0.77
5	-3.00	-0.63	0.58	-0.42	0.60	-0.10	0.33	1.82	0.33	0.26	0.62
6	-3.68	-0.16	0.23	-0.85	0.64	0.51	0.06	1.38	1.51	0.14	0.01
7	-2.77	-0.23	0.06	0.24	0.71	0.24	0.56	1.20	-0.19	-0.04	0.70

Table 6: Parameter values for those "not engaged with water conservation" and for N/A

	α	Tenure category	N children	Time poverty	Employment	Nature priority	Quality-things priority	Environment priority	GHG priority	Effort priority	Supply concern
1	-3.59	3.49	-0.35	-0.73	-0.75	1.21	0.94	1.35	-0.27	-1.29	0.57
2	-3.46	3.55	-0.04	0.39	-1.21	0.49	1.10	1.26	0.30	-1.67	0.25
3	-3.37	3.83	0.08	0.01	-0.81	-0.07	0.79	1.71	0.13	-2.15	0.65
4	-3.55	3.71	0.15	0.17	-0.58	-0.27	1.12	1.46	0.90	-2.15	0.17
5	-4.15	4.05	0.22	0.50	-0.86	0.28	0.73	2.06	0.57	-1.96	0.22
6	-4.19	4.05	-0.08	0.67	-0.87	0.85	0.87	1.42	1.14	-1.60	-0.61
7	-3.53	3.87	0.07	0.49	-0.70	-0.10	1.47	1.41	-0.12	-2.29	0.94

The Willingness to Pay Model

Water conservation can take many forms, but two important methods are rainwater harvesting, and the use of smart meters to provide near real-time updates on water use, and which tend to help householders reduce their water usage. However, to what extent are water customers prepared to pay for these types of items? As part of a study into behavioural aspects of water conservation, and to gain a better understanding of household preferences, and willingness to pay for features of rainwater tanks and smart meters, two choice experiment surveys were conducted in November 2017.

The objective of the willingness to pay studies was to ascertain how much Sydney Water customers are willing to pay for various attributes of a rainwater tank or a smart meter. Findings from these studies shed light on the perceived benefits residents place on rainwater tanks or smart meters as measures to help conserve water and become more resilient to the drought in the future. This can be used to design future water demand management programs that ensure interventions (e.g. advertising, financial incentives, etc.) are structured to encourage adoption.

This report presents a summary of findings from the two willingness to pay studies – for features of a rainwater tank and for features of a smart meter.

Method

The studies applied the choice experiment (CE) method. The choice experiment (CE) method, is a type of stated preference method using a survey instrument to ascertain how much people are willing to pay for attributes of a good. Empirical literature in the environment and health domains have provided evidence that CE surveys show external validity, in other words, results can be generalised to other populations, settings and circumstances (see e.g. Carlsson & Martinsson, 2001 and Telser & Zweifel 2007).

In a CE survey, goods are described in terms of their attributes, and the attributes have varying levels. In the case of willingness to pay for interventions that may help customers reduce their water demand, CE allowed for a flexible approach to structuring the evaluation of rainwater tanks and smart meters that included a range of attributes with different levels. This approach allowed for an efficient approach getting respondents to evaluate a large number of combinations within the one survey (Gordon et al. 2001). By including the price (cost) as one of the attributes, willingness to pay for each attribute separately and as a package can be indirectly recovered from the people's choices (see Hanley et al., 2001 for a more comprehensive explanation).

Figure 10 and Figure 11 show example screenshots of the rainwater tank and smart meter choice cards, respectively.

Figure 10 Example of a choice card to ascertain the willingness to pay for features of a rainwater tank

Storage volume	2,000 L	5,000 L
Tank material	Fibreglass	Concrete
Rainwater tank uses	Outdoor only	Toilet only
Rainwater tank design	Round	Underground
Rainwater system total cost (purchase and installation)	\$1,000	\$1,500
	Select	Select
	NONE: I wouldn't choose any of these.	
	Select	

Figure 11 Example of a choice card to ascertain the willingness to pay for features of a smart meter

Provides leak detection and alert	No	Yes
Water use report can be viewed on smart devices (e.g. phone, tablet)	Yes	Yes
Reports on energy demand associated with water use	Yes	No
Cost	\$300	\$500
	Select	Select
	NONE: I wouldn't choose any of these.	
	Select	

Respondents were directed to the rainwater tank willingness to pay survey if they stated that they do not currently own a rainwater tank and were directed to the smart meter willingness to pay survey otherwise (i.e. if they stated that they already own a rainwater tank).

Each respondent evaluated six choice cards. Each choice card varied slightly in terms of the attributes of a rainwater tank or a smart meter. Respondents are then asked to choose the option they most prefer, or choose neither one of the options presented to them.

To capture preference heterogeneity, the surveys also collected information on various socio-economic variables, household characteristics, water use behaviour, and attitude towards water conservation.

Households were recruited via an online research panel. Participants on the panel who live within the list of postcodes of our study region (i.e. Sydney Water service area) were sent an email from the online research company with an invitation to complete the online

survey. Participants who complete the survey have their respondents ID entered into a draw to win a prize, as an incentive to complete the survey. This research study received ethical clearance from the relevant Human Research Ethics committee (Approval Reference 120/17 Water Conservation Modelling). Informed consent was obtained from the participants prior to the study.

Results

A total of 127 households responded to the rainwater tank survey, and 151 to the smart meter survey. Regression parameters from the conditional logit analysis of the willingness to pay survey results are presented in Appendix A.

Rainwater Tanks

On average households are willing to pay \$2,300 for a round polyethylene tank with an average volume 4,400 litres. However, households are willing to pay an extra 11 cents for every additional litre of tank volume they gain. Households also show a strong preference for a slimline tank over a round tank. On average, they are willing to pay \$770 more to obtain a slimline tank over a round tank. There is also a strong willingness to pay to use tank water for outdoor water use rather than for toilet flushing or for washing clothes. Households are somewhat indifferent to the material used to make the tank (i.e. households are indifferent whether the tank is made from fibreglass, galvanised steel or polyethylene).

Table 7 provides a summary of the willingness to pay levels on average for a rainwater tank and its features.

Table 7 Willingness to pay for rainwater tank features

Willingness to pay	Mean	Min	Max
For a tank	2,361.81*	759.36	3,964.25
For an additional litre (above 4,400ltr)	0.11*	0.06	0.16
For a fibreglass tank (as compared to polyethylene)	252.14	-137.73	642.01
For a galvanized tank (as compared to polyethylene)	12.99	-365.35	391.34
For outdoor water use (as compared to toilet use only)	679.24*	199.58	1,158.90
For washing machine use (as compared to toilet use only)	332.99	-131.34	797.31
For washing machine and toilet use (as compared to toilet use only)	428.64	-33.86	891.13
For a slimline tank (as compared to a round tank)	778.78*	432.22	1,125.34

*Statistically significant (i.e. hypothesis test $X > 0$)

Smart meters

Households that already own a rainwater tank were asked whether they were willing to pay for a smart meter and its features. Unlike the willingness to pay for rainwater tanks, the willingness to pay for smart meters is not as encouraging. Households are willing to pay \$120 for a smart meter that is able to detect leaks only but are not willing to pay for other features (mobile phone reports and energy use report). If the smart meter does not have a leak detection feature, households would not be willing to pay anything for a smart meter. In fact, the willingness to pay estimate showed a negative coefficient for an average smart meter. The interpretation is that households would need to be compensated in order to consider installing a smart meter in their homes.

Discussion

The strong preference demonstrated for slimline rainwater tanks indicates the importance of the aesthetics for homeowners. Also the importance of practicality in homes with limited space for a tank. The

preference for less obtrusive slimline tanks may continue to strengthen with the increasing trend for smaller lot sizes with larger homes and increased medium density development (townhouses and units). While, the greater willingness to pay for a rainwater tank connected to outdoor uses compared to indoor uses may be related to perceptions that outdoor water uses, such as garden watering, are more sensitive to the impacts of water restrictions. Water restrictions during the Millennium drought mostly targeted outdoor uses as these are seen as more discretionary, with fewer risks to public health, than limiting supply to indoor uses. People who highly value their garden or washing their car at home might be more willing to pay for a rainwater tank during a drought.

Leak detection was the only smart meter feature that households demonstrated a willingness to pay for. This could be related to the fact that smart meters are relatively novel so it was difficult for households to evaluate the benefits of attributes that were unfamiliar. For example, households might be more willing to pay for a smart meter that provided an integrated display of water use with associated energy if they were more aware of how water efficiency for different appliances can significantly influence household energy bills and

greenhouse gas emissions. A consumer barrier to pay for a smart meter is likely to be related lack of awareness of benefits, and the paucity of water meters in the community means households are not able to evaluate and validate these benefits by discussing or observing their peer network.

In addition to technology attributes of rainwater tanks and smart meters, various socio-economic and household characteristics variables (e.g. household size, household water use behaviour) were modelled to test for their correlation with willingness to pay. A number of variables were significant, which suggests a degree of preference heterogeneity among households.

Rainwater Tanks

Consistent with economic theory, households with higher income are willing to pay more for a rainwater tank than households with lower income. Respondents who live in a house, state that they have space on their property for a rainwater tank, or are actively conserving outdoor water use are willing to pay more for rainwater tanks than other respondents. Respondents who stated that they have a fulltime job are willing to pay less for a rainwater tank. This could be explained by the time involved in maintaining a tank, which those with full-time jobs may have less time to do.

Those who own their own homes (outright or paying a mortgage) are not as enthusiastic about paying for a rainwater tank as compared to those who do not own their home. The latter group (primarily renters) are less likely to pay for the installation, while still reaping the benefits. This may explain why only 30% of homeowners currently own a rainwater tank.

Households with a washing machine are less willing to pay for a rainwater tank than the 3% of households without one (i.e. 18 respondents). This is also echoed in the zero willingness to pay for a connection from the rainwater tank for washing machine use.

Respondents who have a tendency to compare themselves with others, who like to conform, and who spend effort at making decisions are willing to pay more for a rainwater tank than respondents who rate lower on each of these three attitudinal and behavioural tendencies. However, respondents who are more concerned about water shortages in the future are less likely to pay for rainwater tanks. The reason for this is unclear but may be because they simply don't think that rainwater tanks are the solution to water shortages.

Smart meters

Male respondents are more likely to pay for a smart meter than female respondents. Younger respondents are willing to pay more than older respondents. Unlike rainwater tanks, respondents who work full-time are more likely to pay for a smart meter than respondents

who do not work full-time. Hence, promotion of smart meter technology may be more successful if targeted towards younger male respondents with a full-time job. Respondents who also rate higher on the 'tendency to compare with others' scale are also willing to pay more. Households that rate highly on indoor water conservation behaviour are less willing to pay for smart meters than households that are less active at conserving indoor water use. Counter to expectation, households with higher income or own a home are less willing to pay. It is possible that households with higher income or own their own homes are implementing other water conservation measures, or have invested in other water conservation measures, or who simply feel it's not their role to monitor their own usage, and thus feel less inclined to pay for a smart meter. Lastly, households with more showers or who water their gardens and lawn more often have a higher willingness to pay than households with fewer showers or do not water their gardens and lawn as often.

Conclusion

The results from the survey of Sydney Water residents show encouraging evidence for adoption of rainwater tanks among households who currently do not own one. Given insights from this study around preference heterogeneity, specific attention could be given to particular groups of customers for targeting rainwater tank adoption messages. These people have a tendency to compare themselves with others, like to conform, spend effort at making decisions when buying products, and are already actively conserving water outdoor. Space for a rainwater tank is also important.

Less encouraging results are on the adoption of smart meters. Households are keen to consider smart meters that could detect and report leaks, and were willing to pay up to \$120 to acquire such a smart meter. However, households were not particularly interested in other features that are on offer, including reports onto mobile devices and the amount of carbon produced as a result of their water use. There might need to be more effort expended in raising customer awareness of the benefits of smart meters that extend beyond reducing their direct costs associated with water use. Also, to enable initial adoption there might need to be incentives, such as rebates, which allow for early adopters to influence uptake in the broader community as the benefits and risks are normalised.

The Agent-Based Model (ABM)

Here we describe the Agent-Based Model that has been developed for describing the uptake of the WaterFix program. There are some minor changes to the model for describing other behaviours.

Purpose

The purpose is to describe the 'uptake of the WaterFix program, or similar behaviours, under different policy/program interventions'. Furthermore, the ABM sets out to achieve this in a way that incorporates a more complete set of behavioural drivers and processes for decision making as per previous discussions, modelling activities and reviews (Moglia et al., 2017, Moglia et al., 2018b, Moglia et al., 2018c).

Implementation

The model has been implemented in the NetLogo 5.3.1 software environment.

State variables and scales

There are three types of agents in the model:

- Households, who make decisions whether or not to participate in the program.
- Sales agents, if relevant, who prompt households to make decisions about whether to participate in the program.
- Information agents, who provide recommendations for or against participation in the program – in the inquiry decision mode.

Attributes of the household agents are shown in Table 8.

Table 8: Attributes of households

Attribute	Description
ID	A unique identifier for each household
property-size	Representing the size of the property
dwelling-type	One of the two categories, "Apartment/Unit/Flat" or "House/Townhouse"
tenure-category	Whether renting or not renting
household-size	Number of people in the household
age	Representing the age of the household

employment	Whether employed or unemployed
nchildren	Number of children in household
education	Education level
post-code	Post code
income	The income level of household
wGHG	Value between 0 and 1 representing the extent by which the household prioritize reducing greenhouse gas emissions
wNature	Value between 0 and 1 representing the extent by which the household prioritize being in nature
wQuality	Value between 0 and 1 representing the extent by which the household prioritize having high quality things
wEnv	Value between 0 and 1 representing the extent by which the household prioritize protecting environmental values
wEffort	Value between 0 and 1 representing the extent by which the household prioritize minimising effort
wSupplyConcern	Value between 0 and 1 representing the extent by which the household is concerned about water supply shortages
time-poverty	Value between 0 and 1 representing the level of time poverty
awareness	Representing the awareness of the WaterFix program
participation	Representing the participation in the WaterFix program
feasible	Whether it is even feasible to adopt to WaterFix program
plumber-prob	The frequency by which the household has a plumber visit
plumber-trust	The extent by which the householder trust the plumbers' advice

Information agents represent different types of information sources that householders report having consulted, and have attributes that indicate their likelihood of recommending the WaterFix program.

Sales agents are indirectly represented based on the likelihood of a householder 'making a decision' – which in this case in turn is based on two types of activities, i.e. Sydney Water activities, as well as the hypothetical case of plumbers' promoting the program.

Process overview and scheduling

An ABM is an engine for simulating the actions and interactions of agents within their environment. Agents are software representation of either individuals or organisations/groups of people. The environment is the context in which the agents operate, for example in ecosystem modelling an agent may be an animal and the environment is a software representation of the ecosystem that it lives in. A simulation needs a schedule for the events and actions along the timeline, in this case as per Figure 12.

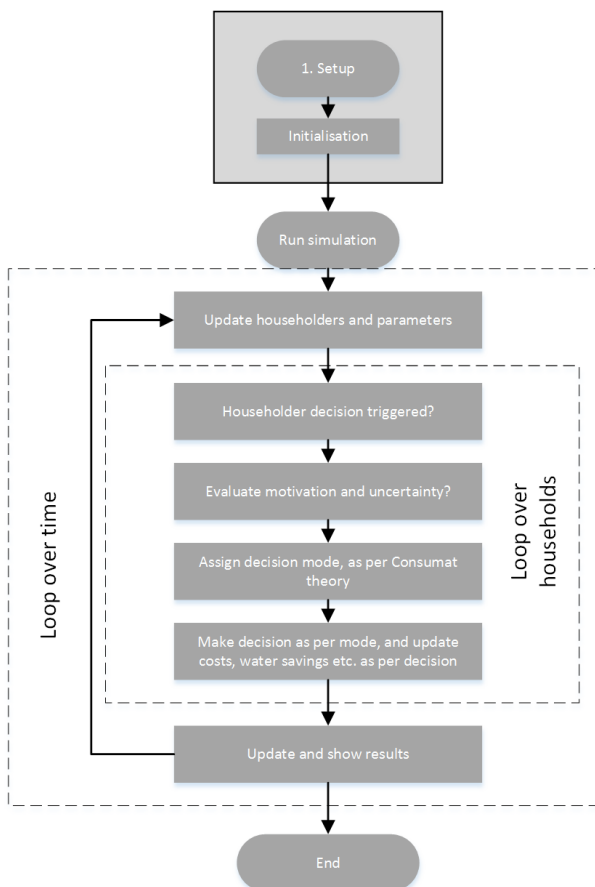


Figure 12: Process of our ABM

There is a reference to the *Consumat* theory here, which is a meta-theory based on social psychology and which dictates a software architecture to be implemented in an ABM (Jager and Janssen, 2012, Janssen and Vieck, 2001). It is based on an evaluation of high or low

motivation and high or low uncertainty, and an assignment of a decision mode based on this as per Figure 13.

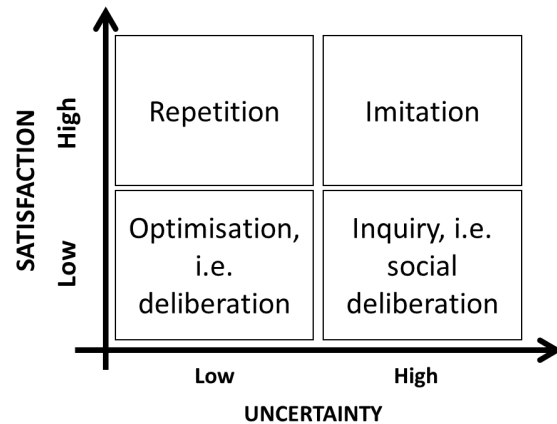


Figure 13: Overview of *Consumat* theory

The modes, in turn, are carried out according to the following instructions, adapted from (Moglia et al., 2018b).

Repetition: Satisfied and certain. The repetition decision mode involves repeating the behaviour of the past whether that is adoption or not adoption of WaterFix.

Imitation: Satisfied and uncertain. The imitation decision process involves copying the behaviour of a friend in the household agent's connections within the social network.

Optimisation: Unsatisfied and certain. The optimisation decision mode is very simple, i.e. it chooses the product that is associated with the highest overall motivation.

Inquiry: Unsatisfied and uncertain. The inquiry decision mode involves exploring recommendations from the information sources that the household agent will consider (i.e. based on the information preference attributes) and seek recommendations from each of these, and the householder will synthesize all recommendations to make a decision.

Evaluating motivation and uncertainty

This model is a simplification of our previous models in that it relies primarily on a multinomial logit model to evaluate motivation (as per the previous section), which has as an output a probability, p , of being motivated and the probability of 'being uncertain' is, in turn, a function of p as per:

$$q = P(\text{uncertainty is high}) = \exp(r \cdot p) \quad (1)$$

Here, r is a model parameter which can be explored through sensitivity analysis as well as varied in the user interface. The default value is -0.7.

Decision points

Water conservation is not always on people's mind, in fact in the theory of marketing, the concept of a purchase funnel is often used whereby potential customers are first aware of the product (in this case WaterFix), secondly they develop an interest in the product, thirdly they more actively consider a purchase by asking others about information or undertaking more formal research, this may lead to an intent to purchase the product, but this is only activated when the customer takes action.

The time of an active decision is what we refer to as 'a decision point'. In the simulation model, decision points are the points in time when a particular agent will either choose to opt into or opt out of the WaterFix program.

These may either be based on proactive customers who become aware of the program in one way or another, or based on reactive customers who are contacted by a sales person. The number of customers contacted by a sales person can be estimated relatively easily, but the number of proactive customers is hard to estimate and therefore we rely on calibration to estimate the rate of proactive customers as a function of promotional activity.

On the basis of this calibration, the number of decision points, i.e. times when a householder actively chooses to opt in or out of WaterFix, created for households has been estimated based on past performance during previous investments into promoting WaterFix as per the Table 9. Furthermore, there are ways for the user to provide inputs into investment levels and the type of promotional activity being carried out.

Table 9: Cost-effectiveness of different promotional activities

Type of promotional activity	Price per decision point
Targeted	\$37.62
Media & Targeted	\$58.62
Media only	\$92.71
The passive, i.e. website only	\$417.53

Setup and Initialisation

Initialising the model involves creating a number of agents that represent the population. The survey is representative of the population in Sydney so we used that as a template where individual householder's attributes are as per the survey responses (from the survey previously described in this report). When a household agent is created, it receives its attributes copied from one of the household survey responses. Further description of the process is found in related papers (Moglia et al., 2018c, Moglia et al., 2018b).

Accounting

Each household that adopts the WaterFix program is assumed to make a 21.9 kL water saving per annum. There is also an associated electricity use saving of 1.06 kWh/kL (Cook et al., 2012) from the reduced water for which there are associated emissions of 0.86 kg CO₂-e/kWh. Water savings and emissions reductions are aggregated over the time of simulation. There is also an accounting for costs to Sydney Water and costs to households in order to evaluate overall cost-effectiveness.

Model application: Water Fix adoption

Per capita urban water consumption in Sydney has seen a significant drop since early 2000 – from around 280 L to around 210 L per day by 2016/2017 (Sydney Water, 2017), and has remained at that level since. However, with the population of New South Wales predicted to grow from 7.95 million as of March 2018 (Department of Premier and Cabinet, 2018) to nearly 9.3 million by 2030, and where most of the growth is expected to occur in Sydney (Australian Bureau of Statistics, 2013), the growing demand for urban water is expected to be substantial. Despite the reduction in per capita water consumption to only 300 L per day, there is still room to reduce per capita consumption further.

Sydney Water's WaterFix program is one avenue that could help improve water use efficiency at the residential level, further reducing per capita consumption, and potentially delaying the need to augment supply. It is projected by Sydney Water that over the 5 year period between 2018 and 2022, the Residential WaterFix program could reduce water demand by around 136ML (Sydney Water, 2018). The objective of this case study is to demonstrate the modelling and predictive capability of the human behaviour model, at predicting the uptake of the residential WaterFix program. Information from this project can be used to inform Sydney Water's WaterFix program the best points of intervention, in other words, when and what kind of marketing programs are most effective, at increasing uptake.

Background

Sydney Water's Residential WaterFix program is a targeted program designed to improve water use efficiency in the home. It is a targeted program because each household can choose the type of water efficiency devices that is suited for their specific needs. The WaterFix program commenced in 1999, as a pilot programme to offer lower-income households, such as pensioners and health care card holders, retrofitting of their end use devices, to help improve water use efficiency. Households were targeted based on the local government area that they live in and were contacted via letters and brochures. At the time, the cost to participate in the WaterFix program was \$22 per household. A total of 36,000 households participated in this pilot program in the first year of its launch. The WaterFix program has been on-going ever since, and any household can participate. Today, the base fee is \$99, and households will have to pay additional costs to retrofit or replace their end use devices. Through this program, households can retrofit new AAA-rated showerheads, tap flow regulators, cistern replacement device or flush arrester for single flush cisterns. They can also get plumbers to come to their homes to check for leaks, make repairs, and provide advice on how to be more water efficient. In the past, Sydney Water promoted the WaterFix program using a variety of communication methods, including brochures inserted into people's bills, educational programs, information on Sydney Water's website, and media campaigns. Today, communication about the

WaterFix program is via Sydney Water's website only. The objective of the Program has also shifted from reducing water use during water shortages to detecting and repairing leakages.



Figure 14: Sydney Water's WaterFix program promotes fixing leaks and installing water efficient devices. Information about the WaterFix program can be found on the Sydney Water website: <http://www.sydneywater.com.au/SW/your-home/saving-water-at-home/bathroom/waterfix/index.htm>

Data

We used a combination of empirical survey data, expert judgment, calibration and sensitivity analysis to parameterise the model.

In order to validate, and to explore the past adoption rates of WaterFix we have used the following data:

- Stated intentions data for WaterFix where the stated intention is described using a multinomial regression model, as described in, survey data as described in Figure 7, household priorities shown in Figure 9, and applied at an individual household level as per Equations 1 to 7 and parameter values as per Table 3 to Table 6 . Thus, this model is based on empirical data, i.e. the household survey previously described and the associated statistical analysis.
- Number of decision triggers per marketing activity style, as per Table 9. This has been calibrated to help fit historical data.
- Investment rates into WaterFix per annum, as per data provided by Sydney Water, shown in Figure 15. This based on historical information provided by Sydney Water.
- R-parameter value of -0.7 (relatively low levels of uncertainty-based behaviours). This parameter has been chosen based on calibration and the impacts of this parameter value explored using sensitivity analysis. Sensitivity analysis shows that it has some impact on results, albeit relatively limited. There is currently no empirical data for this parameter. Sensitivity to this parameter is further explored in the next section on model stability and sensitivity analysis.
- Targeted program from 1999-2004; Media and targeted program from 2004-2007; Media program from 2008-2010; and Passive program from 2011-2018. This based on historical information provided by Sydney Water.
- WaterFix version 7 from 2001-2010; and WaterFix version 1 from 2011-2018. This based on historical information provided by Sydney Water.
- Annual water saving from WaterFix version 7 of 21.9 kL; and annual saving from WaterFix version 1 of 24 kL. This is based on estimates provided by Sydney Water.
- Estimated “engagement with water conservation” over the time frame as per Figure 16. This is based partially on three data points, with extrapolation in between these points based on expert judgment and knowledge of conditions during this time.

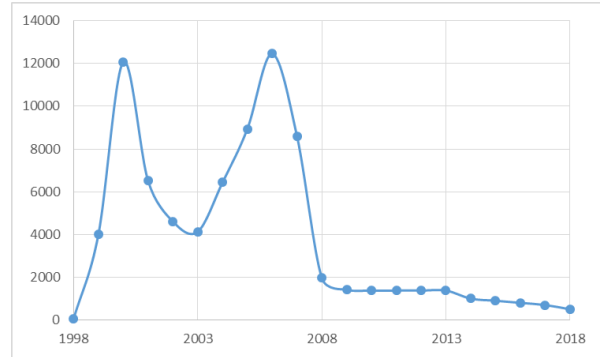


Figure 15: Investment in WaterFix program. X-axis: years. Y-axis: \$1000s spent.

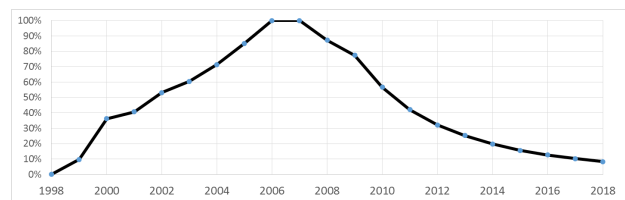


Figure 16: Proportion of the population "engaged with water conservation", i.e. who see water conservation as an important issue and who are aware of water conservation programs (knowledge of water conservation programs is seen as a proxy for being engaged).

Results

Based on the input data and settings, we are able to replicate past adoption rates of WaterFix, as shown in Figure 17.

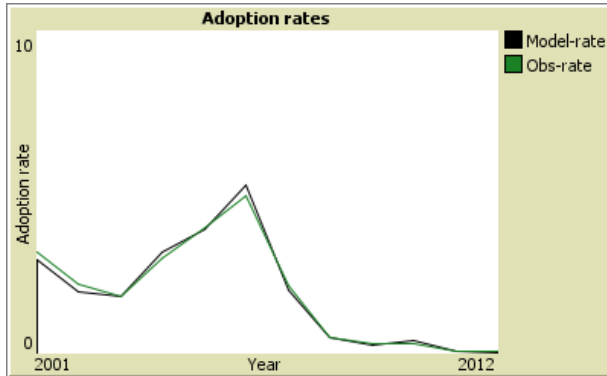


Figure 17: Modelled vs. Observed adoption rates of WaterFix

We can also establish a number of estimates on the basis of the simulation as per:

- Cost-effectiveness for householders (cost for households divided by household water savings): \$0.4 per kL
- Cost-effectiveness for Sydney Water (cost for Sydney Water divided by total water savings): \$1.25 per kL
- Combined cost-effectiveness: \$1.65 per kL
- Total emissions reductions: 62,537 tonnes of Carbon Dioxide Equivalent.
- Value of emissions reductions at \$15 per tonne: \$0.94Ms
- Cumulative water savings 68,601 ML
- Cumulative adoption rates: 22%

Variability of results

ABM is a simulation approach with stochastic components within the model. In other words it is not determined by equations, but through deciding on underlying decision rules of thousands of agents and their environments, and the results therefore emerge from these lower level interactions. Therefore, there is sometimes a high level of uncertainty associated with ABMs, and it is best practice to explore such uncertainty by means of sensitivity analysis. This sensitivity analysis has two purposes, 1) explore the level of variability of the modelling results, where variability is not negative per se, but is likely to indicate a high level of real world variability as well; 2) explore to what extent model results depend on variables that are difficult to empirically estimate (an ABM will nearly all have some parameters that either have not been estimated or which are philosophically difficult to measure).

To test the stability of our baseline model, we run the model multiple times with a baseline scenario, i.e. with no intervention, to check whether the model is able to produce repeatable results. Figure 18 provides an illustration of the predicted adoption rate over 500 simulation runs, which appears to provide relative consistent outcomes.

For each year, the plot indicates the median adoption rate with a line and then the 25% percentile, 75% percentile, in a box, as well as minimum and maximum values.

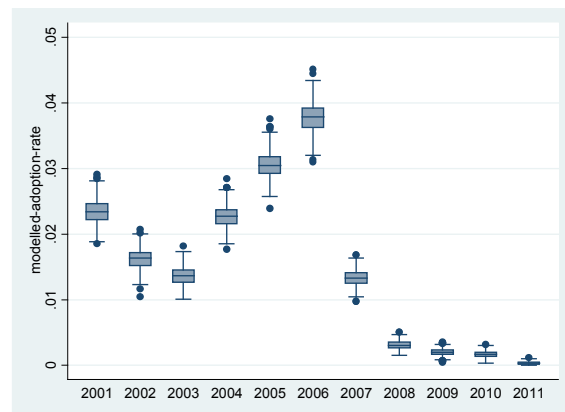


Figure 18 Box-Whiskers Plot of the baseline scenario based on 500 simulation runs. Y-axis is average rate of adoption per year.

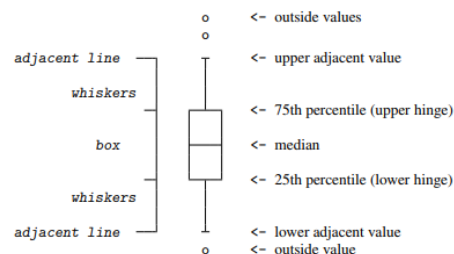


Figure 19: Guide for Box-Whiskers plot

Sensitivity to parameter values

A series of sensitivity analyses were conducted on key variables (i.e. parameter values and assumptions), to ensure that the human behaviour model is robust to changes in the parameter values. Figure 20 illustrates the impact of two parameters on modelled adoption rate 1) the participation of plumbers in promoting the WaterFix program (TRUE=plumbers participate, FALSE=plumbers do not participate), and 2) variation in the uncertainty parameter (high uncertainty=-0.1, low uncertainty=-0.9).

On inspection of Figure 20 we can see that the involvement of plumbers helps improve modelled adoption rate at any given level of uncertainty (i.e. the "TRUE" curve is well above the "FALSE" curve regardless of parameter value).

Note also that the involvement of plumbers seems to be particularly important when householders more often make choices based on the uncertain modes of decision making (i.e. when the uncertainty parameter is nearer -0.9), as per *Consumat* theory, i.e. imitation or inquiry. In those circumstances, plumber involvement boosts adoption rates.

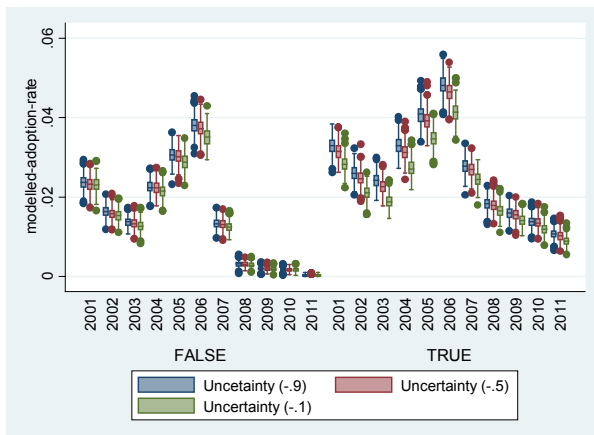


Figure 20: Sensitivity analysis showing the result of 500 simulation runs of modelled adoption rate for three levels (-0.9, -0.5, -0.1) of the uncertainty parameter, and whether the plumber parameter is switched on or off. Y-axis is average rate of adoption per year.

Reflections

Whilst the research team had previously developed ABMs for another context, such as energy efficiency, this project provided an opportunity to validate the model against historical data, to update the data collection approach and to standardise the model. The resulting ABM is, therefore, a simpler, but perhaps more powerful than previous versions of the model, and one that is quite easily translated to other contexts.

On the topic of other contexts, the data set we have collected will allow us to apply the model to as varied topics including other water conservation activities and also solar PVs, electric cars, home battery systems, public transport and active transport. This is because the survey we have collected includes stated intentions on these topics as well, so the same underlying models can be developed. Hopefully with only minor further changes to the model.

The main future direction for us is to develop the generic model for adoption of resource efficient behaviour and to apply it to the above-mentioned range of contexts. We will be continuing the conversations with potential stakeholders and customers to try and ensure that we can maintain a level of funding to support the capability.

There is also an opportunity to further develop the water conservation model to be more all relevant indoor and outdoor water saving behaviours especially in the context of drought, restrictions, heat waves as well as various water conservation programs.

If this is achieved, the model should be capable of modelling water demand for Sydney Water or other companies into the future, but this would depend on the commitment of those companies to the ongoing collection of required data. We propose to develop a roadmap for how this can happen. At the very least this would require the collection of longitudinal data of customer preferences, per capita water use, the level of community engagement with water conservation, stated intentions and self-reported behaviours, as well as information related to marketing and sales activities.

We believe that this type of model has many benefits ahead of more traditional statistics-based models, or more basic bottom-up models, because we can describe more leverage points, more hypotheticals, we can describe communication between community members and also other types of agents in the system, although currently with only limited data on their behaviour.

Overall we think that this is a worthwhile step for the water industry to take as it will interface well with smart city concepts, smart metering data, and what we believe the next generation of water conservation programs will look like, i.e. individually targeted water conservation programs based on smart metering data and audits.

We also note that if we were to undertake this modelling activity again for Sydney Water or similar organisation, we would like to focus more on how decision points are generated, so that more rigorous recommendations can

be made on the trade-off between providing incentives to potential adopters, and the marketing and sales activities.

Another feature we would like to develop is the capacity to be able to estimate peak demands and methods to reduce such demand, thereby reducing infrastructure requirements for water companies. This would help provide triple bottom line benefits of reducing household costs, reducing public infrastructure costs, as well as reducing water demand and thereby improving water security and environmental pressures.

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