A systems approach for assessing water conservation potential through demand-based water tariffs

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Abstract: Sustainable and responsive water management policies are essential to provide high-quality, reasonably priced drinking water to consumers at any time, while simultaneously ensuring a profit for the water utility. Such goal can be typically achieved through two different types of policy, namely increasing water supply, or managing water demand; the latter can be performed, among others, through water pricing. Pricing, especially when demand-based, can lead to a behavioural change in customer water use, but it is arduous to introduce for a number of political and social reasons; it is essential to engage with relevant stakeholders to clearly recognise pros and cons of implementing a new water tariff. As a consequence, in this paper, economic and social implications of demand-based tariff structures, and their potential for greater water conservation, are assessed through a participatory approach. The variation of residential water demand and revenue outcomes were simulated through an integrated participatory systems approach by assuming that an inclining block tariff was introduced on the Gold Coast region, Australia. Such connection between price, demand, and revenue is highly complex and the choice of System Dynamics for this modelling exercise is considered ideal as it can explicitly handle the non-linearity, feedbacks and interconnections of such system. The simulation model was developed by collaborating with relevant stakeholders, thus ensuring the logical inclusion of all the relevant inputs and connections. Such model integrates three components, namely revenue forecasting; water billing; and demand feedback sub-model. The results show that: a) the inclining block tariff can effectively lead to behavioural change and water consumption reduction, especially within the high water users group, although the predicted water savings would be lower than when adopting water restrictions; b) customers' feedback to an increased cost can be used to achieve revenue neutrality; c) based on customer feedback and modelling simulations, the ideal proportion of customers to be charged with the second block tariff is 20%, however this can be recalculated and varied during wet seasons or dry seasons to optimise water availability. The developed model allows water planners to explore a wide range of policy alternatives (e.g. alternative pricing scenarios to influence demand) over medium to long-term periods and to optimise best-practice decision making for urban water conservation and management.

Keywords: *Water conservation, demand-based tariff modelling, participatory modelling, system dynamics, stakeholder engagement*

Word count: 6998

1. INTRODUCTION

The sustainable and responsive management of water resources has become over time an increasingly delicate issue, as it is influenced by continuously increasing population, as well as by climate extremes and decreasing water availability. In particular, during the Australian Millennium Drought (1997-2009), the worst drought in recorded history (CSIRO, 2010), local institutions inevitably increased their efforts towards reducing water scarcity risks, with most of the state governments committing to increase their water availability through the construction of large-scale desalination plants and other infrastructure investments, as well as the introduction of a range of demand management measures such as, for example, restrictions on water use (Porter et al., 2015), water-efficient technologies, and water recycling options both in residential and industrial sectors (Beal et al., 2012; Giurco et al., 2011). Especially in an urban context, a proportion of the water supplied is dedicated to end-uses that would not require high-quality drinking water, such as toilet flushing or irrigation (Beal and Stewart, 2011), hence attention has been given to the use of water of different qualities, including recycled water and rain water, with several studies trying to optimise and integrate these systems in the same water supply network (Bertone and Stewart, 2011; Gao et al., 2014). In general, there are two distinct types of policy that can be deployed by water utilities: management of water demand (such as through water restrictions or pricing) and augmentation of water supply. These are interconnected, since better demand management (e.g. optimised water pricing) can lead to a reduced need for supply augmentation (Grafton et al., 2015). This strategy in turn can enhance the resilience against the effects that climate change, extreme events and increased human activity may have on a number of water sources, both in terms of quantity and quality (Bertone et al., 2016a; Bertone et al., 2014; Haddeland et al., 2014; Schewe et al., 2014). Numerous studies have recently been undertaken, especially in the Australian context such as Grafton et al. (2015), in order to optimise water tariffs, and in turn water demand and water supply augmentation. Although urban water consumption accounts for only about 10% of the total water use in Australia (ABS, 2016), it is generally recognised that better planning and regulation, through instruments including pricing, can help optimise water use and create climate-resilient water suppliers in an urban context.

A water tariff (i.e. pricing) provides a potential management solution to deal with the delicate challenge of supplying affordable water to all consumers while at the same time conserving water resources. Water tariffs can be estimated in a way to keep supply and demand into balance; it has been asserted that if water use is allocated based on such price, several issues associated with climate and socio-economic scarcity could be overcome (WB, 2016). However, pricing water services is controversial. The main challenge when setting a water tariff is to make sure householders pay a reasonable price based on the available water that can be supplied, but additionally the price should be high enough to guarantee a realistic profit for the water utility and to optimally postpone water supply augmentation. Crucially, water pricing should also have the goal of promoting efficient water-use behaviour, in order to help achieve the sustainability of the water resources over the medium to long term. The process of water and sewage pricing involves several stakeholders at different political and regulatory levels, but also within water utilities, bulk water suppliers, and, of course, customers. Each of these stakeholders would have different aims and views on water pricing, thus reaching unanimous agreement on water pricing-related issues is often a challenge. In fact, there is typically disagreement over the water pricing objectives in the first place, as well as on the actual effects of the introduction of such water tariff (Whittington, 2003).

In Australia, typically the implementation of urban water prices lasts three to five years and the actual price is set by independent pricing authorities which differ from state to state. Such period is called ‘price determination period’, during which water tariffs are usually fixed, and thus cannot vary in case of drastic changes in water availability such as during drought periods (Grafton et al., 2015). As a consequence of such limitation, in recent time there has been a shift towards urban two-part water tariffs consisting of a fixed access charge and a water consumption- related charge, with the aim of leading to more efficient water consumption (NWC, 2011). In 2012, the

Independent Pricing and Regulatory Tribunal (IPART) predicted that in 2015-16 the volumetric charges would account for a large part (80%) of a total water bill, with only 20% related to fixed charges. However, in this case such as in many others, there is no inclusion of a "scarcity price" thus, in situations such as during a drought, the price (and thus consumption behaviour) does not change; this implies unaltered water demand despite decreased water supply, leading to potential water scarcity and likelihood of anticipated water supply augmentation projects (Grafton et al., 2015; Grafton et al., 2014; Sahin et al., 2016; Sahin et al., 2015b).

Inclining block tariffs (IBT) have been now adopted by all the main Australian cities. An IBT scheme applies an increase in the volumetric charge when a predetermined water consumption threshold is exceeded; thus, consumers using a lower amount of water pay proportionally less, while householders in the high-consuming block have to deal with a higher marginal cost for using much larger quantities of water (Crase et al., 2007). IBTs can be set up with two steps only (such as in NSW and South Australia), or with multiple steps such as in all other Australian jurisdictions; the extreme case is given by Busselton Water in Western Australia with an IBT incorporating eight steps (Frontier Economics., 2008). In general, at least in developed countries, IBT are considered a fair pricing method, since they target only consumers using an excessive amount of water, but at the same time they help achieve a target urban water consumption (Sibly and Tooth, 2014). Despite the growing acceptance and deployment of IBT for urban water pricing, certain IBT features such as thresholds and thus pricing blocks seem to be often poorly designed, without the use of a robust, rigorous scientific approach; as a consequence, the effectiveness of such tariffs is limited as the wasteful use of water is not fully discouraged (Crase et al., 2007).

The link between a water tariff, water demand fluctuations and change in revenue is highly intricate and defined by a number of interconnected factors. The deployment of an integrated modelling approach allows the integration of empirical data with qualitative expert inputs, as well as combining a number of different methods under the same framework. System Dynamics Modelling (SDM) was selected for this modelling framework to assess the water tariff-demand-revenue nexus given its ability of accounting for the feedbacks, interdependencies, and non-linear correlations characterising such system. SD is a powerful computer-aided modelling approach, initially developed and applied in the fields of engineering and management (Forrester, 1961). Gradually, the improvements and evolution of such SD approach lead to its application in other fields (e.g. chemical, biological, social, ecological, physical) to represent the behaviour of complex systems (Bertone et al., 2016b; Fiddaman, 2002; Ford, 1999; Sahin and Mohamed, 2013; Sahin et al., 2015b; Scarborough et al., 2015; Sterman, 2000; Sterman, 2008). In the specific field of water resources, SDM has been used in relation to irrigation systems and water quality (Gharib, 2008; Zhang, 2008), as well as in the climate-energy-water nexus context (Newell et al., 2011). Also, Dawadi and Ahmad (2013) utilised SDM to investigate the influence of growing population and climatic conditions on the water resources. Rehan et al. (2013) used SDM to examine the distinctive features and feedback loops for financially self-sustaining water distribution networks interactions among system variables over time.

Environmental systems in particular, are characterised by highly non-linear behaviours, feedbacks and interdependencies (Patten and Sven, 1995); similarly, several interconnected components pertaining to different specific fields (e.g. economic, social, environmental, ecological) also define water resources systems (Loucks et al., 2005). As a result, traditional modelling approaches seem to be inadequate in representing such a wide category of systems, including the assessment of urban water policy options (Barker, 2010); this is due to a rigid supply side modelling approach (Hughes et al., 2009), in contrast to more appropriate dynamic approaches incorporating the response of the demand side given a change in price. SDM is therefore an appropriate modelling technique for such complex, nonlinear system. It also has the benefit of being considered a hybrid methodology able to combine the advantages of both continuous and discrete concepts of time.

SDM was therefore applied to estimate the effects of the introduction of an IBT to residential customers on water demand and utility revenue within the City of Gold Coast (COGC), Australia. A Project Reference Group comprising several stakeholders including COGC council staff, community representatives and academics were engaged in the model development phase of the project.

2. APPROACH

As illustrated in Figure 1, three research activities were concurrently undertaken for this project: 1) social survey, which not only helps engaging residential water consumers but also provides information on their water pricing preferences and drivers for water conservation; 2) water consumption analysis for assessing and comparing the average and peak flows from a number of residential water end-uses, taking in account the socio-demographics of different households; and 3) tariff modelling. The participatory modelling approach adopted in this study requires not only empirical data collection through smart water meters (second research component), but also consultation with experts from different backgrounds, and evaluation of customers' responses to current and proposed tariff scenarios (first research component). Stakeholders' consultation helped in identifying that the primary objectives for the COGC, when designing an alternative tariff system, were to ensure that the new tariff is:

1. *Financially effective*, cost reflective with an acceptable risk and influencing appropriate customer behaviour. The main goal would be not to increase revenue, but to be revenue-neutral while leading to increased water conservation behaviours of the consumers;
2. *Customer friendly* and simple to understand while also administratively straightforward; and
3. *Socially equitable* thus leading to an appropriate, realistic share of the costs of service.

Moreover, the analysis of the outcomes of the undertaken social survey helped in identifying thresholds of feasible IBT scenarios, while retracting tariff options which received a negative feedback. The inclusion of social aspects in this modelling exercise is deemed crucial, since raising awareness to achieve behavioural changes is as important as technical design and calculations when aiming at water conservation and minimisation (Barrington et al., 2013). It is important to highlight how this study focuses solely on water delivered by the water utility to the households. It does not consider whether the consumers can access different sources of water (e.g. via a rainwater tank). Throughout the manuscript, when we refer to water use or water consumption, this does not reflect the total amount of urban water used by the consumers, but the proportion of consumed water which is supplied by the urban water utility and therefore is paid by the households (i.e. billed water).

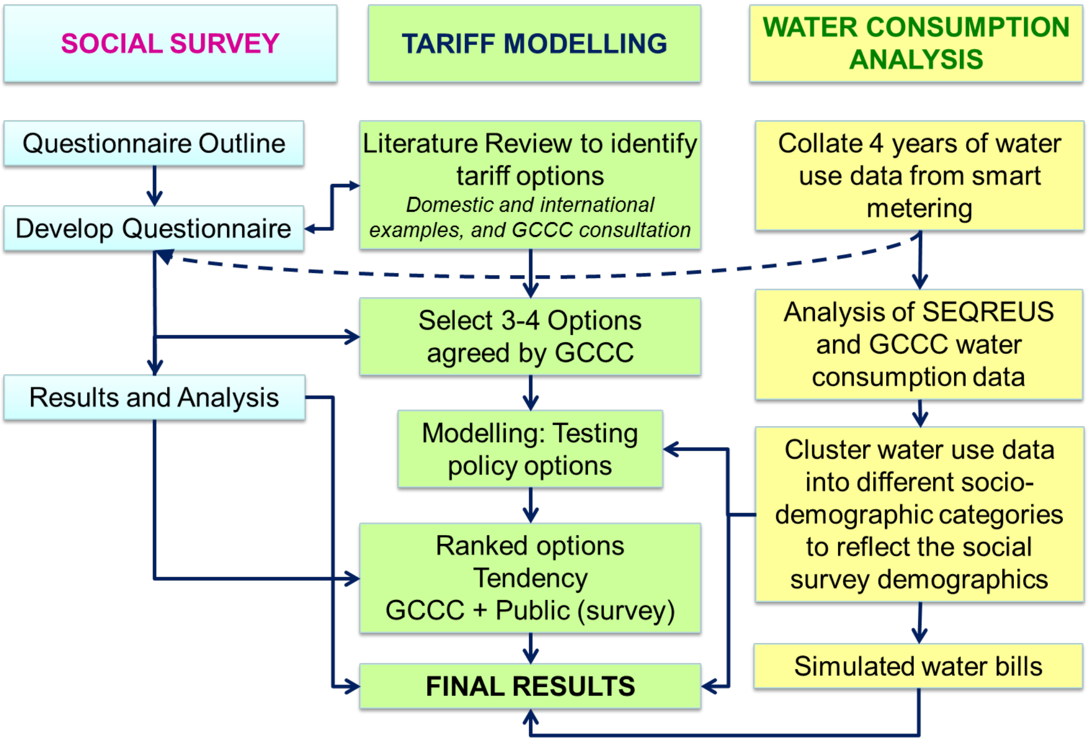

Figure 1. The three research components
Note: GCCC = Gold Coast City Council and SEQREUS = South East Queensland Residential End Use Study

2.1 Social Survey

A number (approximately 800) of Gold Coast householders, randomly selected, were interviewed by using individual computer assisted telephone interviews. Relevant COGC experts and stakeholders were initially consulted to ensure that the survey could collect all the relevant data/information required for this study. The detailed survey methodology and results are currently being prepared for publication in a concurrent manuscript (Beal et al, in preparation).

The outcome of this component provided a systematic assessment of inclinations and dislikes of customers towards water pricing, and their drivers for water conservation. The social survey was found to be beneficial in increasing customers' engagement and guiding future policy directions, as the results helped benchmark the current customers' satisfaction and identify the most valuable means of communication which can improve their water use management. These insights were fed back into the SD model to provide for certain feedback mechanisms and likely adopted tariff options.

2.2 Water Consumption Analysis

This component was applied to quantify the water consumption (both average and peak) associated with a number of residential water end-uses and for different social and demographical household characteristics. For this purpose, it was possible to access four-year water consumption data for 252 South East Queensland dwellings collected as part of the South East Queensland Residential End Use Study (SEQREUS) (Beal and Stewart, 2011). In this study, data were collected from different sources including audits on water appliances and customer-filled water use diaries, as well as high resolution smart meters connected to data transfer loggers. Such smart meters could measure the amount of water delivered to each households by the water utility through the mains (i.e. billed water consumption). Smart meters data were disaggregated to a water end-use level through the deployment of a flow trace characterisation software (Beal and Stewart, 2011). This level of detail can provide valuable data on the peak water demand and the degree of discretionary water end-uses that may drive consumers into the higher use block tariffs (Beal and Stewart, 2013). Thus a key outcome of this component was the ability to estimate the potential for peak demand reduction using this database as input to test different water tariff options in the tariff model developed through SDM.

2.3 Tariff Modelling

SDM was built in order to predict the effects of different tariff policy options. A participatory modelling approach methodology, as described in (Langsdale et al., 2009; Sahin et al., 2016; Van den Belt et al., 2004), was applied to build the SDM. Such approach allows for logically developing the structure of the system, while the numerical simulations of the final model can predict less intuitive behaviours which by definition would be unlikely to be expected by the stakeholders.

Accordingly, the model was developed by following a number of stage processes, in order to achieve a shared, consistent level of understanding and thus produce a logical simulation model. Such steps are the following:

1. Preliminary investigation
2. Problem scoping and model conceptualisation through Project Reference Group (PRG) meetings and consultation with experts;
3. SDM development; and
4. Model calibration and validation through Project Management Group (PMG) meetings and expert consultation.

The PRG refers to the Project Reference Group that advised the research team throughout the project including input parameter for the modelling, appropriate tariff scenarios and data quality assurance. The PRG included members from different key sectors such as academia, the local water utility and a number of agencies (e.g.: Queensland Council of Social Services, Queensland Competition Authority, Gold Coast Chamber of Commerce). Both local and international literature review was conducted in order to identify generic and specific model inputs; these were then further reviewed and refined following stakeholders consultation. Additionally, the data and information obtained from the other two research components (i.e. social survey and water consumption analysis) were used to develop the final SDM. For instance, an important input from the social survey was the identification of the ideal IBT cut-off point between low/high water user groups; such cut-off point was 80%, meaning 80% of the customers to be charged with Block 1 tariff and 20% high water consumers to be charged with Block 2 tariff. Nevertheless, for scenario modelling purposes, other cut-offs (70% and 90%) were hypothesised in the final model.

The tariff model is composed by three distinct sub-models, but which interact with each other. The model was developed using the Vensim DSS v6.3 software package (Ventana). These three components are:

1. Revenue forecasting sub-model;
2. Water bill sub-model; and
3. Demand feedback sub-model.

1. *Revenue forecasting sub-model*; the aim of this component (Figure 2) is the estimation of the water utility's revenue and profit variations when the cut-off point between the two water users groups (i.e. Block 1 and 2), and thus the price, is changed. Such revenue is affected by charges (both fixed and volumetric, for both water and sewerage) and the number of customers, and therefore will vary based on the price and also the water use behaviour. The sub-model components are linked and interact with each other due to the interdependencies between these components.

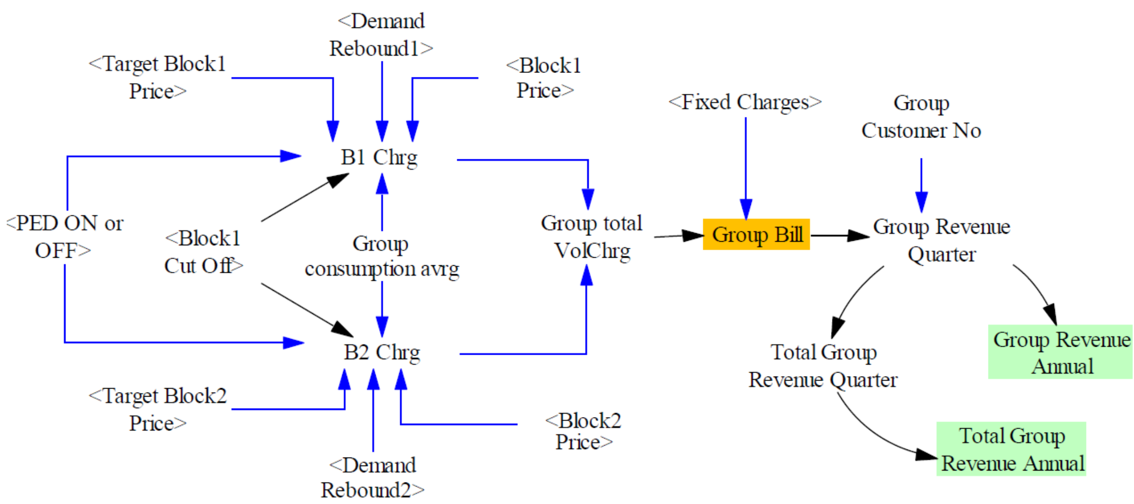

Figure 2. Revenue forecasting sub-model

Notes: PED = Price Elasticity on Demand; VolChrg = Volumetric Charges

2. *Water bill sub-model;* this component's goal is, instead, to estimate how the average water bill for Block 1 and 2 households is affected by a price change (Figure 3). Such bill is a function of both fixed and volumetric charges, which are affected by Block 1 and Block 2 prices. The fluctuations in water consumption following the application of Block 2 pricing are calculated based on estimated elasticity. Different tariff scenarios can be analysed and model outputs (i.e. water consumption, water bills) estimated.

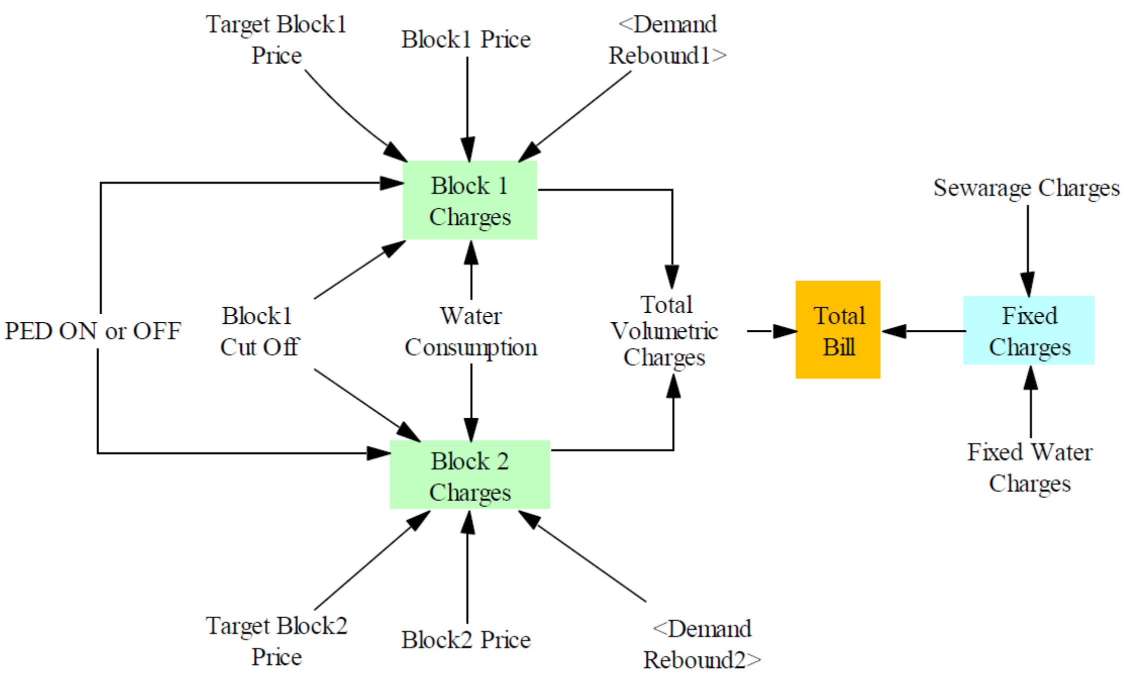

Figure 3 – Water bill (Block 1 and 2 charges) sub-model

Notes: PED = Price Elasticity on Demand

3. *Demand feedback sub-model:* finally this component assesses, based on different scenarios for Block 1 and 2 prices, cut-off point, demand elasticity and rebound time, how different customers adjust their water consumption in response to such variations (Figure 4).

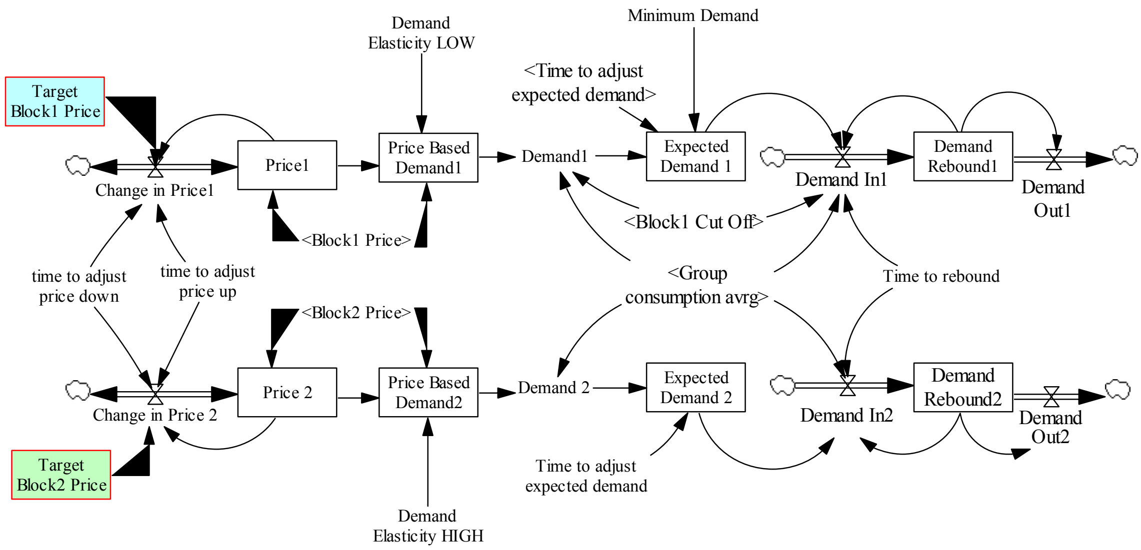

Figure 4. Demand feedback from IBT sub-model (from Sahin et al. (2015a))

There are a number of case studies providing data to calculate this response. In most cases, a change in a tariff structure or pricing is introduced to influence the consumers and reduce their water demand: consumers will have an incentive to save water so as to minimise their water bill. For instance, in Denmark the water price increased by 54% from 1993 to 2004, achieving an associated reduction in water consumption of 19.3% (WB, 2016). However, the price/water consumption relationship is not linear, and thus water utilities need to carefully estimate the price elasticity of demand (i.e. the sensitivity of water consumption to a price variation) for their particular context. An example of what demand elasticity is, and how it is calculated, is given by Figure 5. In this example, the price of water increases by 100%, resulting in a reduction in demand of 50%, then this would be expressed as:

$$E_d = {}^{-50}\!/_{100} = -0.5 \qquad (1)$$

where E_d is the elasticity of demand, representing the slope of the blue line linking the original demand-price balance (x=50, y=4) with the new one (x=25, y=8). In line with the economic fundamental of price and quantity moving in opposite directions on a demand curve, E_d is typically negative (i.e. as price increases demand will decrease), especially for outdoor uses.

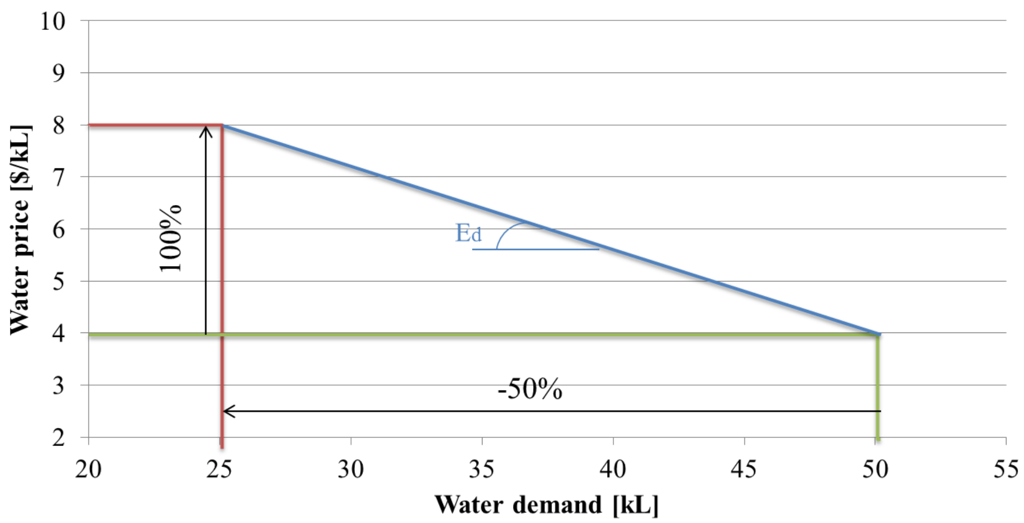

Figure 5 – Relationship between water demand, price, and elasticity.

According to the literature, water price is more elastic than one could expect. For instance, a study from 1997 (Espey et al., 1997), considering 162 previous separate estimations of the price elasticity of water made between 1963 and 1993, concluded that on an average, the price elasticity was -0.51. More recently, a lower average value of -0.41 was found, based on 300 studies undertaken over the previous two decades (Dalhuisen et al., 2003). In an even more recent study (Worthington and Hoffman, 2008) an elasticity in between -0.5 and 0 for the short run was estimated; however it was also calculated that this value increased to between -1 and -0.5 for the long run. Similar discrepancies between short (-0.66) and long (-1.01) run were calculated by Yoo et al. (2014).

As a result, the variations in water demand were dynamically computed in order to consider a time-dependant elasticity. Only Block 2 will be responsive to a change in water price as Block 1 elasticity is set to 0 (regardless, by definition they are not affected by water price changes in the IBT). The results showed in this paper are based on simulations run with a Block 2 elasticity value of -0.51, since it resulted to be the most suitable value after stakeholders' meetings and consultation, and review of the literature (Grafton and Ward, 2008; Hoffmann et al., 2006; Olmstead et al., 2007; Worthington and Hoffman, 2008) However this number can be changed in the model in the range from -0.3 to -0.8 to obtain a wider spectrum of potential outcomes.

The extent of the response of the Block 2 customers to a price change was calculated using the following demand elasticity equation:

$$\Delta D = RD \cdot \left(\frac{P}{RP}\right)^{E_d} \tag{2}$$

where:

ΔD = change in demand [kL];

RD = residential demand per household [kL];

P = new water price [$/kL];

RP = current water price [$/kL]; and

E_d = demand elasticity.

By combining the three separate sub-models, the SDM can run several scenarios where key-inputs (e.g. water price, IBT cut-off point, demand elasticity) can be simultaneously varied (and feedbacks/nonlinear behaviours considered), in order to assess how such changes would affect costs for both customers and water utility, as well as water consumption, and present the results in a visually clear, user-friendly manner so that policy makers and stakeholders (who helped in developing this model through our participatory approach) will be able to deploy such a tool.

2.4 Key assumptions and scenarios

The development and deployment of such SDM can help decision/policy makers to understand what would happen when a new policy is implemented, and thus assist them when taking decisions regarding a number of policy alternatives. However, as for any model, a number of assumptions were to be made. Table 1 summarises assumptions and input data sources:

Table 1 - Assumptions and source of main input data for SDM

Variable	Assumption	Source
Fixed sewerage charges	$ 725.12 household/year	COGC water bill in 2014
Fixed water charges	$ 212.08 household/year	COGC water bill in 2014
Volumetric water consumption charges	$3.53 per kL	COGC water bill in 2014
Elasticity	[-0.3;-0.8] and default value = -0.51	Olmstead et al. (2007); Scarborough et al. (2015)
Number of water consumption bands	16	COGC based on billing data

Although, as mentioned above, the SDM can consider several scenarios of input values, for this particular study we selected eight key-scenarios based on close consultation with COGC experts and outcomes of social survey and water consumption analysis components. The main features of these are listed in Table 2. Scenario 1 represents the current (baseline) situation, while the remaining seven scenarios explore different (but realistic) tariff structures.

Table 2 - Eight tariff scenarios used in the SDM (modified from (Sahin et al., 2015a))

	Scn 1	**Scn 2**	**Scn 3**	**Scn 4**	**Scn 5**	**Scn 6**	**Scn 7**	**Scn 8**
B1 within residents	100%	90%	80%	70%	80%	80%	70%	70%
B2 within residents	0%	10%	20%	30%	20%	20%	30%	30%
Number of B1 residents	216,396	211,674	201,220	190,000	201,220	201,220	190,000	190,000
Number of B2 residents	0	4,722	15,176	26,396	15,176	15,176	26,396	26,396
B1 cut off [kL/hh/year]	n/a	360	295	240	295	295	240	240
B1 cut off [kL/hh/quarter]	n/a	90	73.75	60	73.75	73.75	60	60
B1 Elasticity	n/a	0	0	0	0	0	0	0
B2 Elasticity	n/a	-0.51	-0.51	-0.51	-0.51	-0.51	-0.51	-0.51
B1 Price [$/kL]	3.53	3.53	3.53	3.53	3.53	3.53	3.53	3.53
B2 Price [$/kL]	n/a	4.5	4.5	4.5	4	5	4	5

Notes: Scn=Scenario
hh=household

The simulation for each scenario is run over a period of 10 years, which corresponds to 40 quarterly billing cycles, enabling the analysis of the impact of a new tariff block (Block 2) on demand and revenue, as well as rebounding demand. Based on price elasticity (fixed to -0.51, as discussed before), a gradual decrease in demand is assumed to occur following an increase in water price; however, assuming no further price increase, the consumers would adjust their consumption back towards the original level. The time lag for adjusting demand is assumed to be 2 - 4 billing periods (6 - 12 months), while the rebounding time is assumed to be 6 - 8 billing periods (18 - 24 months).

2.5 Model calibration and validation

Although a number of authors asserted that it is very difficult, if not impossible, to validate numerical models of natural systems given the uniqueness of such systems (Orestes, 2004), a number of calibration/validation methods have been proposed. Some of the critical steps are to test the model against predefined standards and historical data, as well as the consultation of experts for sensitivity analysis of the system outputs to recognize potential pitfalls (Sojda, 2007). In this particular project, we followed a calibration and validation procedure previously adopted in similar systems modelling research projects (Sahin et al., 2016), which relies on a number of critical activities:

1. *Continuous stakeholder engagement*; as previously mentioned, several experts' workshops and consultations were organised in order to (1) clearly identify the modelling scope; (2) design, build, edit, refine the model structure; (3) collect data for model calibration; (4) discuss the logic behind model simulations' outputs to ensure the model is sensible and robust.
2. *Model calibration trough deployment of historical dataset*; the developed model was run using historical input data and compared the outputs with real observations. Once the model behaviour was close enough to historical patterns based on experts consultation during the PSG meetings, it was deemed appropriate for further deployment.
3. *Comparing model outputs with findings of existing reports;*

4. *Visual inspection*; the model outputs were visually analysed by the research team and stakeholders to check for illogical/unexpected patterns
5. *Sensitivity analysis*; following the visual inspection, in order to further validate the model the values of the constant variables of the system were gradually changed to examine the effects on the simulations' outputs. These were again checked to ensure that the simulations yield sensible and logical results.

2.6 Tariff optimisation for drought management

Given that, proportionally to the elasticity level, the water demand will decrease for 1 - 2 years following an increment in water price, there is opportunity to explore the potential of a water price increase for a drought management policy - as an alternative to water restrictions. Based on the developed SDM, a number of scenarios were run with different initial input values, such as:

- Volumetric water price for Block 2; and
- Threshold of water consumption for Block 2.

Once Scenarios 2 – 8 were run, each scenario was compared to the baseline (current) scenario for overall water demand reduction, and the optimal combination of volumetric water price and proportion of Block 2 users was identified accordingly. The sensitivity of the input variables (i.e. water price, Block 2 cut-off point) was investigated by equally varying their values (e.g. 10%) and assessing the corresponding variation in the output (i.e. water savings) value. The estimated hypothetical water savings were compared with typical water restrictions savings.

3. RESULTS AND DISCUSSION

3.1 Input parameters for SDM from social survey and water consumption analysis

Both social survey and smart-meter water consumption data provided critical input information for the SDM. With regards to the social survey, some of the outputs were:

- When asked how satisfied they were with the water and sewerage services provided by the City of Gold Coast, the majority of respondents with individual meters said they were satisfied or extremely satisfied, with less than a quarter being neutral and 20% not satisfied (Figure 6).
- However, the findings were different for respondents from Lot Entitlement (i.e. non-individually metered) properties. Less than 40% of them were satisfied, with more participants in fact feeling neutral towards it and about a quarter being dissatisfied.
- Since the respondents were also asked to provide any specific comments, it was found that a number of the Lot Entitlement properties group participants felt that group billing is unfair as they were not billed for their actual water use.
- In addition, a very common comment from both groups was that, despite being generally content with the provided service, the water price was perceived to be too high.
- These results suggest that people would like to have the option of using less water and thus paying less; 52 % of the respondents were supportive or extremely supportive of an IBT structure with two blocks, and 60% of respondent agreed that the largest water users cluster should be charged proportionally more for their excessive water consumption.

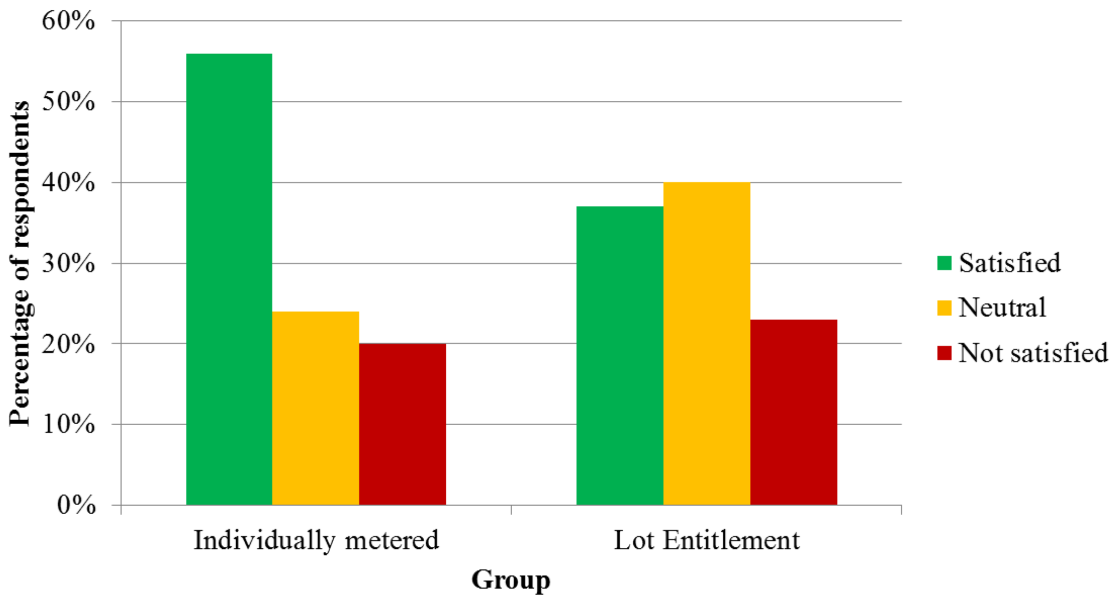

Figure 6 – Satisfaction with water and sewerage services

The outcomes of the SEQREUS project (Beal and Stewart 2011) were also important inputs for the tariff modelling exercise performed with SDM. Some of the results were:

- Winter water consumption (145.7 L/p/d) was higher than summer water consumption (125.3 L/p/d). This however was partially due to a wet summer which limited the need for irrigation.
- The three indoor end uses responsible for the highest water consumptions were: shower, taps, and clothes washer. They represent approximately 70% of the total water consumption.
- A very weak rebound effect was noticed, with households only slowly increasing their consumption over time, thus showing that the regulations introduced during the Millennium Drought led to prolonged behavioural changes.
- The ratio peak day/average day ranged from 1.22 to 1.7. Peak hour ratios instead ranged from 1.3 to 3.0.
- Water retrofitting technologies (e.g. efficient shower heads, tap aerators, efficient clothes washers) can individually lead to water savings of up to 37% and energy savings up to 87% for a particular end-use (Beal et al., 2012), and help reduce daily peak demand. Calculated water savings were in line with more recent studies conducted elsewhere. Vieira and Ghisi (2016) estimated water savings of up to 20% by considering only water efficient taps and toilets in in Florianópolis, Brazil; by considering a university building, instead, Kalbusch and Ghisi (2016) found that water taps could lead to water savings of over 26%, despite slightly higher water and energy demand during the production phase. These findings are relevant since water price reforms have typically an accelerating effect in the adoption rate of water efficient technologies (WB, 2016).
- Among the households with higher water usage are families with young children. Interestingly, the proportion of this household type is projected to decline from 28% levels of 2001 to 20% only by 2026, while the proportion of lone person households and couples without children is expected to rise (GCCC, 2007).

Figure 8 illustrates the descriptive statistics of the Gold Coast residential water consumption in the period 2013-14, after water users were grouped under 16 water consumption bands. The average annual water use was found to be 163 kL. Understanding water consumption is critical not only for tariff modelling, but also because it is a crucial input variable when predicting water savings from water efficient technologies (Silva and Ghisi, 2016).

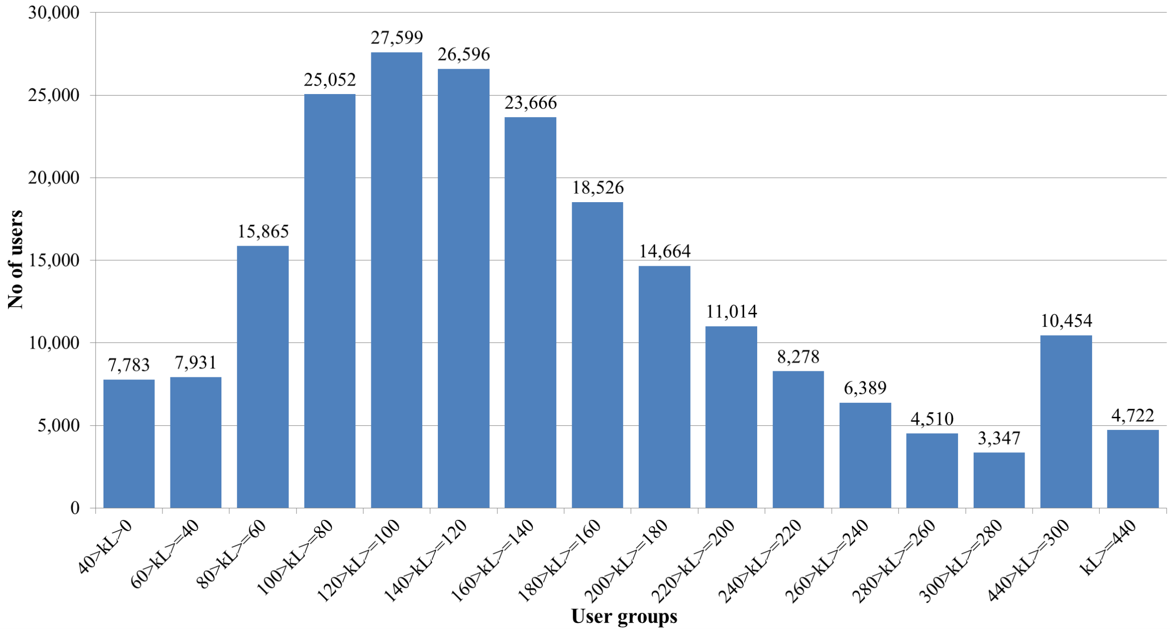

Figure 7 – City of Gold Coast residential water consumption by user groups, 2013-14

The individual household water consumptions were of particular importance for the SDM as this database allowed the consumers to be divided in different water use blocks in order to experiment the efficacy of different IBT features.

3.2 Tariff modelling

Figure 8 presents the expected revenue for the different scenarios as predicted by the tariff model

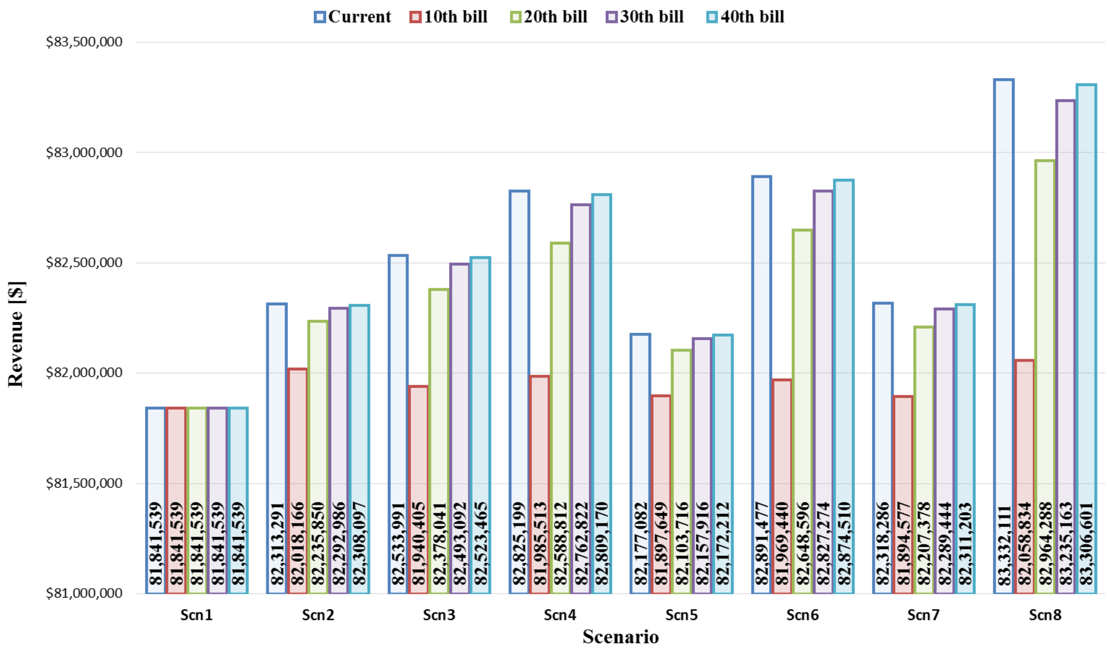

Figure 8. Quarterly revenue comparison over five decadal billing cycles for the eight scenarios (modified from Sahin et al. (2015a))

In Scenario1 there is no revenue variation over time as this represents the current tariff structure. Such tariff, also commonly used elsewhere in Australia, consists of two components, namely: (1) a volumetric charge representing the marginal cost of providing additional volumes of water to the customers; and (2) a fixed charge, independent of the quantity consumed, which ensures revenue neutrality for the water utility. The fixed cost is divided equally among the consumers; the variable, volumetric costs are also proportionally divided among each costumer, based on water consumption. Although this system would make sense in case of identical customer groups, in reality consumers differ in income, family size and water use behaviour. As a result of evenly sharing costs, the fixed charge is proportionally much larger for low water users, compared to high water users, as shown in Figure 9.

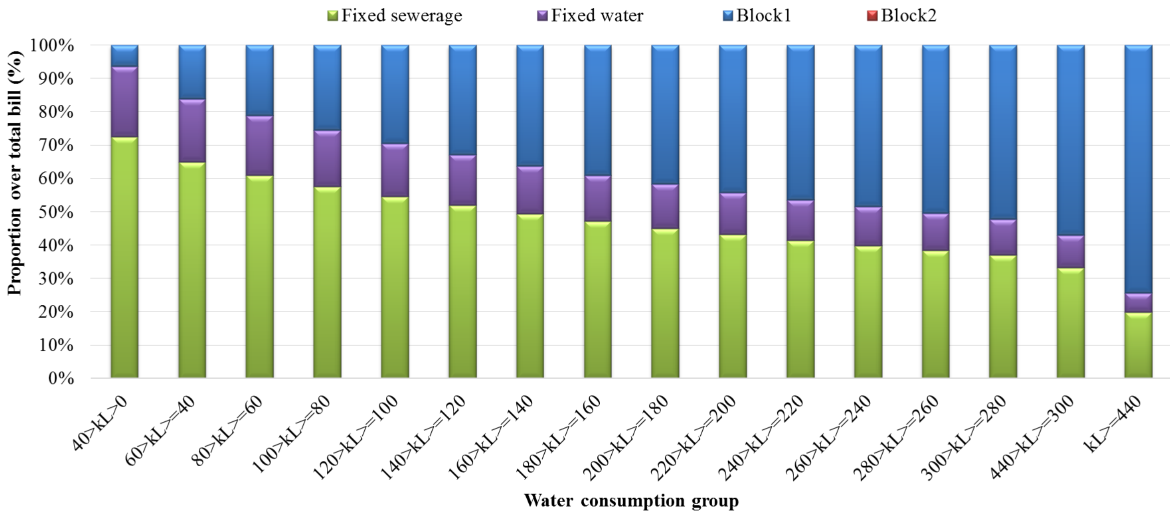

Figure 9 – Type and proportion of water and sewerage charges with current tariff structure

As mentioned before Scenarios 2 - 8 represent different potential IBT structures. With this approach combining an IBT with fixed charges, the higher tariff rate (Block 2 price) is applied once consumption increases above a threshold level (Block 1 cut off), meaning that only those who consume a large amount of water will be charged with the higher volumetric price. In these scenarios, the expected revenue, because of Block 2 charge, will change over time as Block 2 water demand will adjust according to the price change. The proportion of such change will directly affect the degree of change in revenues. It seems that Scenario 8 would lead to the highest revenue ($83,332,111); compared to the current structure (Scenario 1), this translates to an extra quarterly revenue of $1,490,572 which also means a 56.5 $/hh/quarter increase in a high water use customer's bill (26,396 high use households). Scenario 5 would instead generate the smallest revenue ($82,177,082), however it would still provide an additional quarterly revenue of $335,543 compared to the existing tariff structure, but however implying a quarterly water bill increase of 12.7 $/hh for the 15,176 Block 2 customers (Sahin et al., 2015a).

In Figure 10, the expected water use variations for four distinct water user groups across Blocks 1 and 2, based on the eight tested scenarios, are illustrated. Clearly, at least 70% of the COGC customers (i.e. lowest considered cut-off point for Block 2) will not change their water consumption if an IBT is introduced as this would not impact their water bills. Only the higher water user group (exceeding 250 kL/hh/y – green bars) will adjust their consumption due to an increase in price. Figure 10 shows in particular that customers exceeding 440 kL/hh per year could see their quarterly water bill increasing up to $195.50 in their worst case scenario (Scenario 8), compared their current bill (Scenario 1).

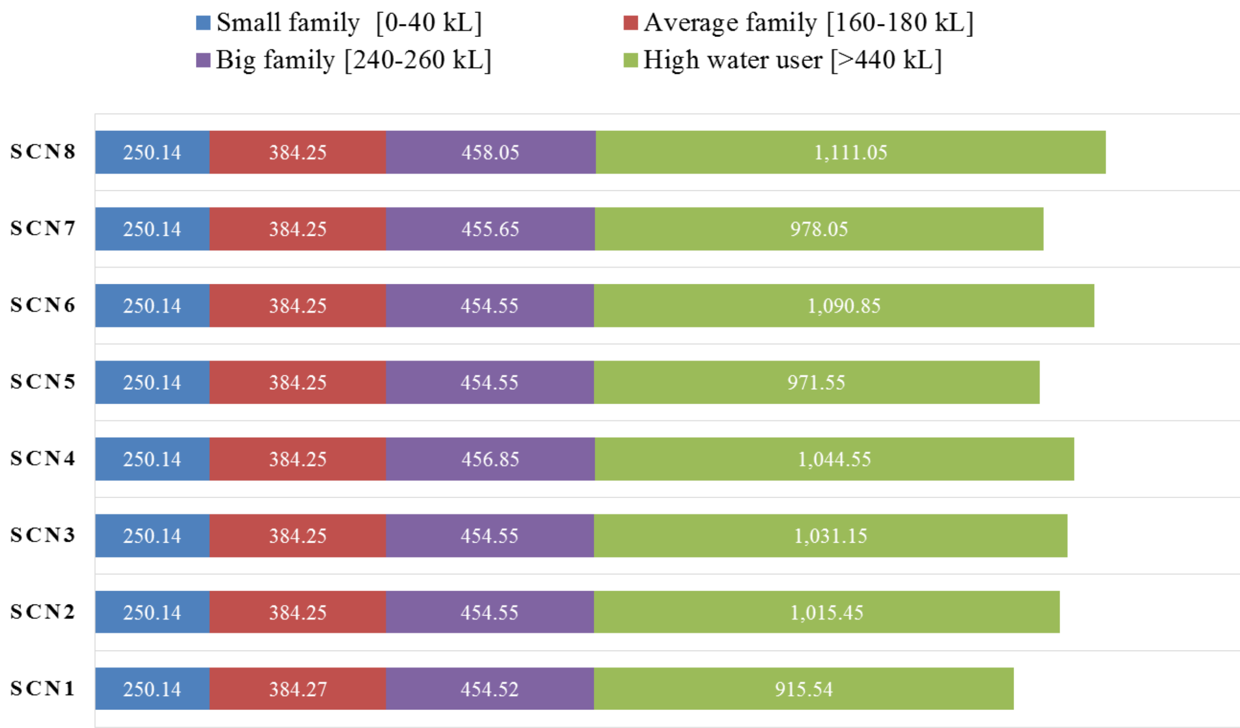

Figure 10. Comparison of expected quarterly water bills [$] for four customer groups: Current tariff (Scn1) versus seven simulated IBT (Scn2 – Scn8) (edited from Sahin et al. (2015a))

3.4 Tariff optimisation for drought management

In Figure 11, we summarised the expected water demand reduction after 10 quarterly bills, when considering the seven different IBT scenarios (Scenarios 2 – 8). Several more scenarios, with more combinations for Block 2 water use cut off point and volumetric price were run; however these final seven scenarios were selected following consultation with the stakeholders and social survey outcomes as being the most suitable and realistic ones.

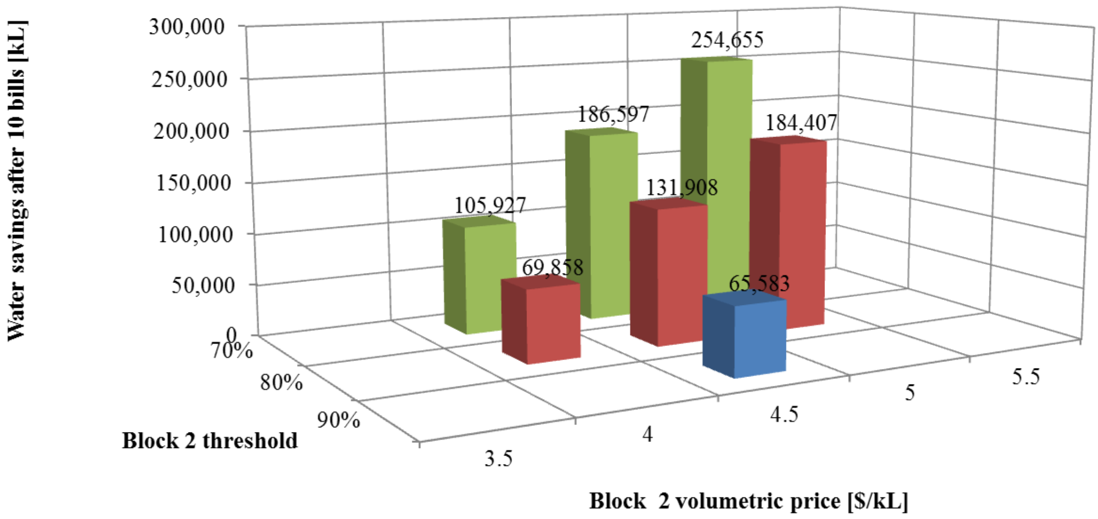

Figure 11 – Water demand reduction for the City of Gold Coast after 10 quarterly bills under different IBT conditions – SDM simulations

What is evident is that both an increase in price for Block 2 and the inclusion of a wider proportion of consumers into Block 2 have a positive effect in reducing the demand over the short term (10 quarterly bills = 2.5 years), before the consumption bounces back to initial values (Figure 8). An increase in volumetric price would reduce the water demand based on the elasticity value as described in Equation 2; the inclusion of a wider range of water consumers into Block 2 would imply a larger number of people affected by a volumetric water charge and thus a larger proportion of the population that will reduce their demand. Therefore, imposing a volumetric water price of 5 $/kL, affecting 30% of the population, would lead to the greatest savings (approximately 255 ML). Interestingly, the two factors seem to have a similar influence for the water demand reduction: thus, keeping the price at 5 $/kL but reducing the affected proportion of consumers to the top 20% only, would have the same effect of keeping the top 30% of the population affected, but decreasing the price to 4.5 $/kL. This means that the decision-makers, in response to a drought, can decide whether to increase the volumetric price, or to extend the Block 2 threshold, knowing that the effect would be proportionally similar; it may be that, for instance, affecting a larger percentage of water users could be more accepted than an increase in price, which is already perceived to be high according to the outcomes of the social survey.

From Figure 12 however, it can be observed that even in the most severe IBT scenario (Scenario 8), the total water consumption after 2 and a half years would be 8,570 ML, compared to a total of 8,825 ML if the current tariff is in place. This corresponds to water savings of less than 3%. Considering that water restrictions in other Australian metropolitan areas resulted in water savings in a range between 4% and 20%, depending on restriction severity and type of household (Haque et al., 2013), it seems that water pricing would be less effective than water restrictions as a water demand management strategy during dry periods. Similarly, in the Gold Coast it was demonstrated how the average water consumption during, and immediately after, a drought leading to water restrictions fell by 50% before slowly bouncing back (Beal et al., 2014). Interestingly, these calculations are in line with the social survey's findings, which indicate that water restrictions seem to be more welcome than extra water charges during drought.

In addition, both in Australia and internationally, there seems to be an increased awareness of the value of water (Jones et al., 2011), which may lead to behavioural changes and an inherently more efficient water use. Recent studies (Liu et al., 2016) also demonstrated that engaging households through surveys, water end-use monitoring (through smart meters) and reporting can help customers identify opportunities for water savings and behaviour changes, with lower necessity for mandatory restrictions.

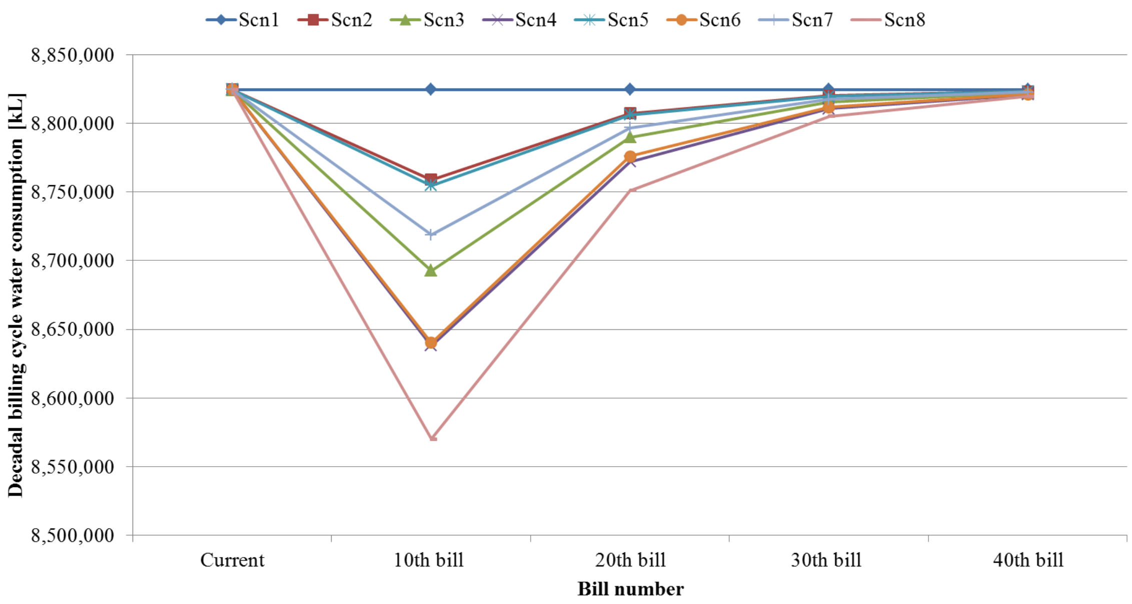

Figure 12 – Estimated water consumption for current tariff (Scn1) versus seven simulated IBT (Scn2 – Scn8) under four decadal billing cycles

4. CONCLUSIONS AND IMPLICATIONS

A modelling framework, based on SDM, was developed to test the social and economic feasibility of different IBT structures for the residential Gold Coast households. The IBT was tested using eight scenarios which considers three different possible cut-off points between Block 1 and Block 2: 70%, 80% and 90%. Based on the feedback of approximately 800 Gold Coast customers, resulting from the social survey component of this study, the 80% configuration (i.e. 80% of customers included in Block 1 and thus not impacted by an IBT, and 20% of "high water users" included in Block 2) seemed to be the most accepted one, and it was used as starting point for the modelling exercise.

The tariff model developed following with a SDM approach makes use of the collected COGC data, and demonstrated that householders using excessive volumes of water, which in this area is typically associated to outdoor end-uses such as irrigation (Beal and Stewart 2011), will be penalised. As a consequence, such high water consumers can either reduce their water usage, or pay remarkably more for preserving their water use habits. As a result, the IBT system can be successful in achieving increased water conservation by incentivising demand reduction and water efficiency through targeted price increase. Additional conclusions were also derived through tariff modelling:

- According to the results of the social survey on the ideal cut-off point, only 20% of residential COGC customers would be affected by the introduction of the IBT. The greater water conservation can be achieved by leaving 80% of the population with unchanged water price.
- As a consequence, based on such division (Scenario 3), following the introduction of IBT Block 2 customers would pay approximately an additional $100 on their first quarterly bill.
- Because of demand elasticity, water consumption and thus utility revenue would decrease at first; however, due to the rebounding effect, it has been simulated that Block 2 water demand would increase back to pre-IBT levels after two years from IBT introduction.
- If additional revenue can be actually achieved, the COGC council could consider using part of the additional profit for subsidies to those Block 2 customers that, for a number of

reasons (e.g. medical issues, home business, very large family), struggle to reduce their water use.

- Potentially, the selected cut-off point can be adjusted dynamically, based on new model simulations, according to long-term abnormal weather patterns and thus optimise available water supply.
- Increasing the billing frequency (e.g. from two to four per year) increases the reactiveness of customers to changes in price. Hence, with shorter billing cycles, the impact of variations in tariff structures on water consumption will be more immediate and easier do model.
- Overall, it seems that water restrictions are more socially accepted, and would lead to higher water savings than an increase in volumetric water price for B2 given an IBT tariff structure is in place.
- Future work may also focus on numerically quantifying the change in adoption rate of water efficient technologies based on a change in water price (e.g. based on a new social survey), and incorporating such component in the SDM.

Contemporary water management and planning for major cities is complex and decisions often have inadvertent long-term consequences across economic, social and environmental dimensions. Successful models for policy analysis aid combine a range of data sources, views and knowledge, and facilitate stakeholder participation in supporting decision making. The participation of stakeholders and a range of differing perspectives are crucial to improve our understanding of complex policy development and implementation issues. However, models often lack an adequate representation of stakeholders. As demonstrated herein, the proposed integrated participatory SDM approach can be utilised to explore a range of long-term water management and planning scenarios. Therefore, SDM allows water planners to explore thoroughly a range of policy alternatives (e.g.: alternative pricing scenarios to influence demand) over medium to long-term periods and potentially reveal optimal decisions that would not be expected using current water planning paradigms. The SDM approach is flexible and transferable therefore it enables the users to apply the model in new cases by slightly modifying the model and data to run a range of scenarios.

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