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CURRENT ISSUES IN WATER DEMAND MODELS BEING USED IN AUSTRALIA: A SURVEY

Reviewing the current demand forecasting models used by water authorities and agencies in Australia

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ABSTRACT

Water demand modelling is traditionally based on population growth and standards based on historical records of water consumption. Climate change, drought, increasing growth in population, agriculture and economy resulted in competing uses of an already scarce water resource and to implementation of water conservation programs and water restrictions.

This led to changed water consumption patterns and the need to determine if the current water demand models are still adequate to handle these changes. An anonymous survey targeting relevant stakeholders involved in water supply and demand planning, modelling and management was undertaken to obtain their opinions on the adequacy of their current water demand models.

The results of the survey revealed that a number of respondents found their models to be adequate as these are being used only for financial and water accounting needs and could not see the impact of factors mentioned in the modelling process.

The other respondents recognised the effect of these changes and have already incorporated in their water demand models one or two of: end-use analysis, climatic variables, water conservation programs, alternative sources of water and water restrictions. However, none of the respondents reported that all of these factors were considered in their current water demand models.

The recommendations of some respondents in the survey included: (i) integrating demand model with a supply model, (ii) incorporating climate variability and impact of rainwater use, (iii) linking network data and demand models, (iv) using population growth within acceptable confidence limits and (v) simplification and better user interface to make the models user-friendly.

INTRODUCTION

Traditional water demand models calculate demand based mainly on population in a specific region. Climate change, drought, growth in population, economy and agriculture, along with environmental and social changes trigger changes in water use. As a consequence, alternative sources of water supply are identified to cope with the change.

Given these changes both in supply and demand, are the current models adequate enough to take into account climate change; water restrictions; and water conservation? Do all these drivers need to be incorporated into the current models used by entities in Australia? What are the limitations of the current models? What are the issues that should be addressed or incorporated to improve these water demand models to meet the needs of stakeholders?

To address these questions, an anonymous survey of urban and regional water authorities, agencies and consulting firms in Australia was conducted using a survey tool 'Opinio'. The survey outcomes can benefit water resource planners and policy makers and other stakeholders involved in water modelling.

LITERATURE REVIEW

Population growth, climate change and limited water resources exacerbated by the recent drought (late 1996-mid 2010, the Millennium Drought in Australia; BOM 2015) placed enormous pressure on traditional sources of water supply.

As water plays a crucial role in the location, function, and growth of communities (Marshall 1879), fresh water has become the source of increasing controversy, as supplies fail to meet demand in many areas (Arbués et al. 2003).

The effective supply of water is essential in geographical regions where the demand is increasing due to the growing population, and an improved living standard (Jacobs and Haarhoff 2002; Worthington and Hoffman 2008) along with economic growth and social and environmental changes.

Australia is moving towards more sustainable water management with rapid advances in the use of recycled water, greywater, rainwater and stormwater as alternatives to the use of traditional water supply augmentation approaches. Demand management is another technique to optimise the uses of limited water.

Modelling becomes an important part of demand management in the current climate of water restrictions and water conservation, e.g. in Melbourne, Australia. Many factors are involved in demand behaviour and can influence the water demand directly or indirectly (Herrera et al. 2010).

Water demand modelling has been undertaken by various researchers considering factors (Fox et al. 2009) that affect water demand, such as rainfall and temperature (Martinez-Espineira 2002; Zhou et al. 2002; Arbués et al. 2003; Neto et al. 2005; Gato et al. 2007a,b, Sarker et al. 2013); evapo-transpiration (Aly and Wanakule 2004; Syme et al. 2004; Taylor 2012); population (Koo et al. 2005; Rao 2005); income (Liu et al. 2003); household size (Martinez-Espineira 2002; Liu et al. 2003; Bradley 2004); dwelling or housing type (Troy and Holloway 2004; Kowalski and Marshalsay 2005); and water price (Agthe and Billings 2002; Martinez-Espineira 2002; Liu et al. 2003; Neto et al. 2005; Rinaudo et al. 2012; Yoo et al. 2014).

METHODOLOGY

Selection of Respondents

The anonymous survey targeted managers of a total of 100 organisations both urban and regional water authorities, agencies and consulting firms in Australia, involved in water supply planning, demand modelling and management.

ANONYMOUS SURVEY QUESTIONNAIRE

The survey questions relate to the demand models currently being used, issues with these models, and appropriateness of the models; considering the effect of climate change, water restrictions, and water conservation practices. In this survey 'climate change' refers to consideration of climatic variables (rainfall, temperature and evapotranspiration).

A survey tool (Opinio) was used for the design of the questionnaire and for the implementation of the project.

A total of 100 representatives (managers) of both urban and rural water authorities, agencies and consulting firms in Australia, involved in water supply planning, demand modelling and management, were invited to respond to this anonymous survey through emails from December 1, 2014 to July 3, 2015. The email addresses of relevant representatives (managers) were collected from the corresponding websites of the organisations and from the Australian Water Directory published by Australian Water Association (AWA 2013).

The respondents were directed to "Opinio" by these emails and they completed the instrument online by ticking boxes and by inserting comments as required

The questionnaire was composed of five questions (Appendix A) and took approximately fifteen minutes to complete. Participants responded voluntarily and were free to withdraw.

Data Collection and Analysis

Responses of the survey were downloaded from Opinio and then analysed. All data is kept confidential according to Swinburne University's Human Research Ethics Committee (SUHREC).

SURVEY RESULT AND DISCUSSION

A total of 16 responses out of 100 invitations were received from the anonymous survey and owing to the anonymity, the breakdown of respondents is not known. The models in use were:

- End Use Model (EUM) - four respondents (includes two for iSDP model - one type of end use model)
- Resource Allocation Model (REALM) - two
- Demand Side Management Decision Support System (DSM DSS) - two.
- In-house – two.

The other six respondents use other types of model such as: (i) Projection of historic demands, (ii) State water supply-demand model, (iii) Bespoke demand forecast model (partnership with bulk water supplier), (iv) Statistical analysis in-house, (v) Spreadsheets, and (vi) Customised. The suitability and constraints of the models currently being used by the respondents have been collated in Table 1, taking into account climate change (climatic variables: rainfall, temperature and evapotranspiration), water conservation, rainwater tank supplies and end use of water. Table 1 also includes descriptions of the models and some recommendations received from the respondents.

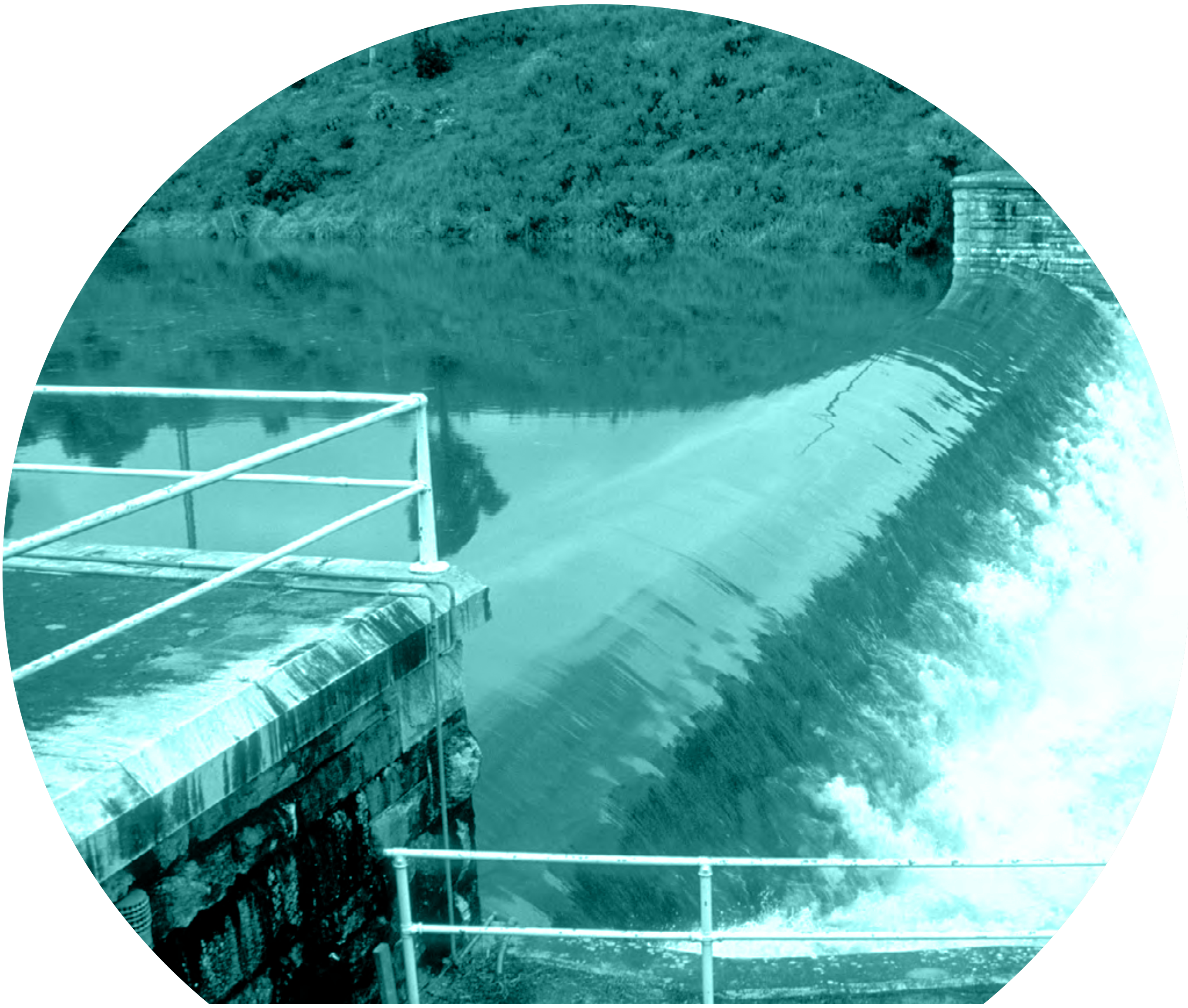

TABLE 1: Description and result of the surveyed models

Model Particulars				Analysed Responses		
Description of the model	**Input**	**Output**	**Assumptions**	**Constraints/ limitations/ disadvantages**	**Capabilities/ suitability/ advantages**	**Recommendations**
EUM (2*): In general, end uses of water refer to the water consumption by different sectors such as residential, industrial, agricultural, etc. For residential water demand modelling, Rathnayaka et al. (2011) define EUM as an approach or strategy for quantifying and forecasting of water demand of individual end uses (shower, toilet, bath, tap, clothes washers, dishwasher, garden watering) using household consumption data . The relationship between household size and some end uses of water is non-linear (Roberts 2004).	Volume (or flow rate and duration) and frequency of individual end uses of water. Household size (number of person/ house) and/or number of houses in a specific region or population.	Residential water demand of individual end uses, a house and a specific region. Water savings through adoption of efficient water appliances.	Average or mean value of frequency and volume (or flow rate and duration of use) of individual end uses. Average household size for a region. Linear relationship between household size and end uses of water.	Data-hungry model. Requires considerable cost and time to populate, run and maintain the model. For this reason, one respondent uses metered water volume of potable water for the calibration of the end-use model. Lack of homogeneity of non-residential water consumption data and difficult to model at the end-use level. Does not account for the impact of climate change or alternative sources of water.	Robustness in taking into account the ongoing significant effect of change in efficiency of water appliances. Suitable and relatively effective for estimating the impact of various water savings or recycling initiatives. Provides rich information to the customers, helps in managing their optimal water uses and to practice water conservation programs.	Incorporate climate variability. Difficulties of non-residential modelling can be addressed by modelling the end-uses of water in key sectors, including manufacturing, shopping centres, and hospitals.
iSDP (2*): An integrated supply demand planning (iSDP) is an end-use model first developed by the Institute for Sustainable Futures (ISF), University of Technology Sydney in the late 1990s to assist Sydney Water Corporation (SWC) in integrated water resource planning (ISF 2011).	Volume (or flow rate and duration) and frequency of individual residential end uses of water. Penetration rate of efficient appliances. Population or household statistics.	Residential water demand at individual end use level. Water savings. Water demand of subsectors (e.g.: manufacturing, shopping centers, and hospitals).	Average or mean value of frequency and volume (or flow rate and duration of use) of individual end uses. Average household size for a region.	Complex model from the user perspective. Limited user interface capability as incorporates complex Visual Basic for Applications (VBA) code/ macros in the background. Does not account for the impact of price on demand, climate change, and alternative sources of water uses such as rainwater tanks.	Capable of quantifying and forecasting demands of individual end uses. Capable of quantifying the amount of water savings from the water conservation program. Easy to explain to the general public.	Incorporate the impact of rainwater use. Integrate demand model into water resources allocation model Better Interface. Reduce the complexity of the model, making user friendly.

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REALM (2*): Resource Allocation Model (REALM) is a generalised computer simulation software package and modelling tool which can be applied to develop specific water allocation models. It is used in modelling the harvesting and bulk distribution of water resources within a water supply system (Perera et al. 2005). REALM takes demand as an input in the program.	Unrestricted demands of each demand zone (urban, rural or irrigation demands) of the water supply system, demand restrictions (for demand nodes), streamflow (for stream junction nodes), climatic data (temperature and rainfall) (for reservoir nodes), and pipe size (for pipe junction nodes) (Perera et al. 2005).	Restricted demands of each sectors/ zone in the water supply system. River or carrier (pipe) flows (including minimum flows, maximum capacities, and transmission losses). Reservoir storage volume (including maximum capacity, dead storage, evaporation and reservoir inflows).	Assumes reduction in stream flows under various climate scenarios.	Requires considerable amount of spreadsheet data to estimate consumptions by sectors. One of the two respondents stated that the adoption of a wider range of population growth rate (1.3 to 1.96%) made the model less reliable. Not able to provide reasonable demand forecast considering factors like impact of water restrictions, decline in demand of customers using water savings devices, change in water-use behavior affected by social awareness, waterless gardens, financial influences, and impact of using alternative sources of water.	Assesses the reliability of supply using forecasted future demand and historical streamflow records and has adopted it as a State-owned model. Capable of allocating water for a supply system from a bulk water resource combining the demand criteria of all segments/sectors of the system network.	Use population growth rate within an acceptable confidence limit. While the respondent did not specify what would be an acceptable limit, it implies that deciding on what population growth rate to use in water demand modelling must be considered carefully, taking into account housing development, and government policy on migration at a particular time (for example the surge in population growth in the last five years in the west of Melbourne is due to opening of lands for housing developments, but will this continue for the next 20 years and how does this compare with a long-term average growth rate?). Focus on the influence of marketing on demand, compare new houses with older ones to identify changes in behaviour, and use more than one model to reach a balanced average water demand.

TABLE 1: Description and result of the surveyed models

Model particulars				Analysed responses		
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DSM –DSS (2*): The Demand Side Management Decision Support System (DSM DSS) model was developed by the Department of Energy, Utilities and Sustainability (DEUS) to enable NSW water utilities to prepare more accurate demand forecasts and to estimate the financial benefits for the organisation from conservation program (DEUS 2006). Assumes internal/indoor residential consumption with individual end use breakdown data from the 'domestic water use study for Perth' (Loh and Coghlan 2003; DEUS 2006) and public sector and commercial end use data from the 'commercial and institutional end uses of water' study by AWWARF (Dziegielewski et al. 2000; DEUS 2006).	Population with expected growth rate, household size statistics, total water use, number of accounts, system losses, percentage of water consumed in each customer category, and percentage of each category connected to sewerage, and current and previous year's water price rate.	Water demand of a region or city under the organisation. Water savings (water conservation).	Have significant in-built data assumptions related to the impact of water conservation programs.	Complex model. Does not address climate change implications.	Capable of incorporating end use of water, water conservation programs and alternative sources of supply such as rainwater tanks. Appliance and stock modelling are included to identify changes in behaviour considering the impact of different levels of efficiency of appliances. Provides a methodical and recognised approach to prepare demand forecasts for planning and economic regulatory activities, provided that appropriate input data can be obtained.	Simplify the model. Need additional research on data collection and assessment to provide more robust input data to the models.

TABLE 1: Description and result of the surveyed models						
Model particulars				Analysed responses		
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In-house (2*): The survey responses obtained from the respondents does not cover how the 'in-house demand model' estimates the water demand. One of the two respondents uses the in-house model to generate the demand data as an input to the REALM model. The other user employs the forecast demand of the 'In-house' model as an input into: (i) financial and water pricing models, which set customers charges, and (ii) supply and drought management models, which may trigger supply augmentation based on current Strategic Water Plan and Contingent Supply Strategy, and/or restrictions to contracting with new customers.				Relies on customer-provided information.	The output (water demand) of in-house model is used as an input of supply models.	Carry out good monitoring on demand and on all relevant parameters to analyse what factors are influencing water consumption.
Statistical analysis in house (1*): According to the respondents, 'Statistical analysis in house' is a low cost model and is effective enough for small systems. This model uses past usage patterns and does not account for source of water demand. The survey response does not explain what sort of statistical analyses are used.				Does not account for source of water demand.	Being low cost the model is adequate for small system.	No recommendation is obtained from the respondent.
Projection of Historic Demands (1*): According to the respondent, this is a simple model that simulates historical trends of water consumption. Rainwater tanks are included in this model.				The user does not take into account climate change and end-uses of water.	Simplicity of the model.	No recommendation is obtained from the respondent as no other driver (such as climate variability or end uses of water) needs to be incorporated at this point in time, which would make the model more complex.
State water supply-demand model (1*): The 'State water supply-demand model' user uses GoldSim software to forecast three water demand scenarios using economic and population growth for a number of sectors. This model is used for state, regional and local water resources. It helps in identifying the trigger points for water resource investigations, for various levels of planning, investment and infrastructure development.				The user is not currently using climate data in this model to forecast change in water demand.	The model has scenario tools to forecast change in water demand resulting from efficiency programs or other policy mechanisms.	Account for impacts of climate on water demand. Improve the capturing and recording of actual metered water use.
Bespoke Demand Forecast Model (1*): Bespoke Demand Forecast Model (in partnership with Bulk Water Supplier) user forecasts demand at a fairly high level at the gate rather than peak demand requirements. High level of base data is required to get down to a real low level which at this stage the business does not require.				The existing model has been pulled back from specific end uses to higher level consumption at the gate.	The uses of this model relate to revenue forecasts, water accounting, and water resource requirement growth in areas.	Integrate demand models with network data to enable water accounting and network specific improvement opportunities.

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Bespoke Demand Forecast Model (1*): Bespoke Demand Forecast Model (in partnership with Bulk Water Supplier) user forecasts demand at a fairly high level at the gate rather than peak demand requirements. High level of base data is required to get down to a real low level which at this stage the business does not require.				The existing model has been pulled back from specific end uses to higher level consumption at the gate.	The uses of this model relate to revenue forecasts, water accounting, and water resource requirement growth in areas.	Integrate demand models with network data to enable water accounting and network specific improvement opportunities.
Customised (1*): The respondent uses 'Customised' model for forecasting short-term future water demand (less than ten years). The model is updated annually with the current statistics such as customer numbers, customer types, water production volumes and end-user water consumption. This customised computer model estimates water consumption on a whole-of-city basis using a location map and demand rates of all existing and projected future users.				-	Highly effective in forecasting short-term future water demand (less than 10 years).	No recommendation is obtained from the respondent.
Spreadsheets (1*): According to the respondent, 'Spreadsheets' are being used in water demand projections taking into account population and household projections (Victoria 2008) and historical data on the number of connections and the corresponding water use.				-	The organisation was close to achieving a target of a 10% reduction in per capita use by 2015 from 2010. A leak reduction program is included as a part of 'demand management'.	No recommendation is obtained from the respondent as end-uses of water and rainwater tanks are considered to be not relevant to their projections of water demand.

***The number of respondents whose organisation(s) use the model**

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be drawn from the analysis of the anonymous survey results:

1. The EUM and iSDP models are suitable and relatively effective for estimating the impact of various water savings or recycling initiatives, although they are data-hungry and expensive to maintain. They do not account for the impact of climate change or alternative sources of water uses such as rainwater tanks. The relationship between household size and some end uses of water is non-linear (Roberts 2004), which is not adopted in the EUM.
2. DSM DSS integrates end-uses of water, alternative sources of water uses such as rainwater tanks, water restrictions and water conservation. The DSM DSS model includes appliance and stock modelling to identify change in behaviour considering the impact of different levels of efficiency of water appliances. However, it is a complex model and does not incorporate climate change implications.
3. The REALM model does not include end-use modelling; rather, it uses in-house demand models to generate the demand data as input. REALM is capable of modelling catchment yield and bulk distribution of water resources within a water supply system but is not able to provide reasonable forecasts considering the impact of water restrictions, water conservation (decline in consumption of customers using water savings devices and change in water-use behaviour affected by social awareness) and alternative sources of water. REALM is beneficial for allocating water for a supply system from a bulk water resource combining the demand criteria of all segments/ sectors of the system network. One of the two respondents (REALM users) uses its own growth figures of population, sourced from a variety of organisations, and estimates water demand from the extrapolated trends of historical average population ranging from 1.3 to 1.96%. This wide range of population growth makes it difficult to determine water demand with confidence and hence the model can be less reliable. It is therefore necessary to determine the factors affecting the varying population growth rates (land opening for more housing developments or government policy on migration) and the longevity of these growth rates. Are these growth rates temporary, short term or long-term? The uncertainty in population forecasting/water demand modelling would therefore require different modelling scenarios to cater for these varying growth rates.
4. Although some respondents deemed their models to be adequate in relation to their financial and water accounting requirements, the others acknowledged the impact of end-use analysis, climatic variables, water conservation programs, alternative sources of water and water restrictions in the demand modelling process and have already incorporated one or two of these factors separately in their water demand models. However, none of the respondents considered all these factors together in their current water demand models.
   The suggestions of other respondents include:
   - **(i)** integrating demand model with a supply model;
   - **(ii)** incorporating climate variability and impact of rainwater use;
   - **(iii)** linking network data and demand models;
   - **(iv)** improving the capture and recording of metered water use;
   - **(v)** good monitoring of demand and all relevant parameters to analyse what factors are influencing water consumption;
   - **(vi)** using population growth within acceptable confidence limits; focussing on the influence of marketing on demand; comparing new houses with older ones to identify changes in behaviour, and using more than one model to reach a balanced average water demand as an input to a resource allocation model;
   - **(vi)** simplifying the iSDP, REALM and DSM DSS models and;
   - **(viii)** better user interface to make the models user-friendly.

   Considering all these suggestions it can be argued that, for long term sustainable water management, there is a need for an improved water model, which can be accomplished through integration of end-use analysis, climatic variables, water conservation, water restrictions and alternative sources of water in total water demand modelling and forecasting.
5. It is recommended that the following be undertaken to improve water demand forecasting and for sustainable water management:
   - **a.** The population forecasting in water demand modelling needs to be accurate at least within an acceptable confidence limit to determine water demand with confidence.

b. The non-linear relationship between some end-uses and household size(s) should be considered in EUM.

c. Demand models (such as EUM, iSDP and DSM DSS) can be integrated into supply models (such as REALM).

d. Climatic variables and rainwater tanks need to be incorporated in the water demand model.

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APPENDIX A: QUESTIONNAIRE

1. What are the current water demand models that are being used by your organisation?
2. Describe the effectiveness/appropriateness of the current water demand model being used by your organisation in terms of taking into account climate change, water conservation, rainwater tank and end-use of water?
3. Why does your Water Authority use these models? What are the advantages of using these models at present?
4. What are the limitations/disadvantages in using these models at present?
5. Do you have any recommendation to improve the model or to address the limitations and disadvantages of the model?

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