 © IWA Publishing 2015 Water Science & Technology | 71.4 | 2015

Developing a demand model integrating end uses of water (DMEUW): structure and process of integration

R. C. Sarker and S. Gato-Trinidad

ABSTRACT

The process of developing an integrated water demand model integrating end uses of water has been presented. The model estimates and forecasts average daily water demand based on the end-use pattern and trend of residential water consumption, daily rainfall and temperature, water restrictions and water conservation programmes. The end-use model uses the latest end-use data set collected from Yarra Valley Water, Australia. A computer interface has also been developed using hypertext markup language and hypertext pre-processor. The developed model can be used by water authorities and water resource planners in forecasting water demand and by household owners in determining household water consumption.

Key words | end uses of water, integrated water demand model, water demand forecasting

R. C. Sarker (corresponding author)
S. Gato-Trinidad
Faculty of Science, Engineering and Technology,
Swinburne University of Technology,
PO Box 218,
Hawthorn,
Victoria 3122,
Australia
E-mail: *rcsarker@swin.edu.au*

INTRODUCTION

Water demand management is not only an important issue warranting careful attention, but also a well-recognised tool within water supply industries in Australia and overseas. However, there is a great challenge in quantifying the impact of water conservation programmes on reducing water demand. In addition, considerable efforts are essential to evaluate the effectiveness of these options since these options have distinguishable and discernible sets of economic, social and environmental consequences. Recently, residential water demand modelling has been undertaken by various researchers (e.g. Jacobs & Haarhoff 2002; Gato *et al.* 2005, 2007a, 2007b; Blokker *et al.* 2010). However, there is a lack of integration of end uses of water, climatic factors (e.g. rainfall and temperature), water restrictions and water conservation programmes in total water demand modelling in the context of current climate and for sustainable water management.

End-use modelling is an approach or strategy for quantifying and forecasting water demand of individual end uses such as shower, toilet, tap, bath, dishwashing, laundry, garden watering, etc. (Rathnayaka *et al.* 2011). However, integrating output of these end-use models in forecasting water demand is currently not undertaken. There is also the issue of drought, possible effect of climate change and growing population which led to water authorities and government worldwide to enforce water restrictions and to implement water conservation programmes. Again these parameters are not included in the current water demand forecasting models; therefore, it is necessary to develop a new integrated water demand model which will incorporate end uses of water, climatic factors (e.g. rainfall and temperature), water restrictions and water conservation programmes. The integration of these parameters is a complex process and the question is how these parameters can be integrated in total water demand modelling.

The objective of this paper is to illustrate the process of integration of a proposed integrated water demand model integrating end uses of water (DMEUW) to overcome the limitations in current water demand models. Garden watering is not included in end-use components in this study because garden watering is considered as seasonal use not base use.

BRIEF LITERATURE REVIEW

Historical demand forecasting methods have considered relationships obtained from regression analysis, but have not considered the demand at the end-use level, or at different sectors, which may change over time. Gato *et al.* (2005) used simple time series analysis and multiple regression analysis to forecast short-term residential water use for East Doncaster, Victoria, Australia considering climatic variables such as temperature and rainfall and also rainfall

doi: 10.2166/wst.2015.002

Downloaded from https://iwaponline.com/wst/article-pdf/71/4/529/469617/wst071040529.pdf
by guest

threshold and temperature threshold (Gato *et al.* 2007b), but did not consider water restrictions. Sarker *et al.* (2013) also analysed temperature and rainfall thresholds of water uses from mixed areas (i.e. residential, industrial, and commercial) for Greater Melbourne, Australia. Since regression analysis cannot be used to determine how and which factors have affected the historical demand analysis, the end-use method could be extremely useful as it enables a far more refined analysis (Turner *et al.* 2008). Gato-Trinidad *et al.* (2011) also noted that understanding the end use of water will assist water planners, water authorities and household owners in discovering where, how much, and how often water is used/wasted.

The integration of a custom-built regression model for forecasting total customer water demand and end-use based water projections using the integrated supply demand planning model will result in a better forecast. This is because the regression model component allows future changes in climate or periods of restrictions to be modelled although it does not show where water demand increases post-drought (e.g. longer showers and greater garden irrigation). Conversely, the end-use model offers the ability to construct future scenarios (Giurco *et al.* 2013). For this reason, integration of end uses of water into total demand forecasting is necessary for long-term sustainable water management. There are already some end-use studies such as the domestic water end-use study of Gold Coast, Australia (Willis *et al.* 2009) and simulating residential water demand with a Stochastic End-Use Model (Blokker *et al.* 2010), but these only cover the end-use modelling and do not include estimates or forecasts of total water demand.

In addition, there is a need for climate variables to be considered since climate change poses a significant or moderate risk to the sustainable management of water (AWA/Deloitte State of the Water Sector Survey 2012). Water conservation should also be included in an integrated end-use model to analyse the cost effectiveness of the programmes (Maddaus & Maddaus 2004). So far, no known model has considered all these factors and this could be attributed to the complexities in smaller known models let alone integrating these complex models.

In the context of the current situation in Australia and worldwide and for more precise and accurate demand forecasting, this paper tries to develop a framework and structure of an integrated water demand model capable of incorporating: (i) end-use analysis, (ii) water conservation programmes, (iii) climate factors, (iv) population, and (v) water restrictions.

PROPOSED METHODOLOGY FOR DEVELOPING THE MODEL

This section illustrates the process of integrating end uses of water, climate factors (rainfall and temperature), water restrictions and water conservation programme in developing the structure of the integrated water demand model DMEUW.

Data set

The required data for this model include:

(i) daily residential water consumption data (water end-use data, e.g. toilet flushing, clothes washing, dish washing, bath, shower, tap, and garden irrigation);
(ii) climatic data (daily rainfall and temperature);
(iii) water storage level.

Residential water consumption data can be collected from Yarra Valley Water, Australia, and the climatic data are from Bureau of Meteorology, Australia.

Algorithm/mathematical structure of the model

Water demand models are based on the premise that total water use can be divided into base use and seasonal use, where base use is characterised by the water use during winter months, and seasonal use is dependent upon climatic conditions (e.g. rainfall) (Maidment & Miaou 1985). Most of the previous end-use models were developed based on monthly billing data (Mayer & DeOreo 1999; Jacobs & Haarhoff 2002; Worthington *et al.* 2009). The DMEUW model is based on a daily total water demand (W_{TD}) and consists of two components: (i) base use, W_{BU} (daily), and (ii) seasonal use, W_{SU} (daily).

Base use, W_{BU}

The estimation of daily base use of total water demand depends on end-use modelling. Base use equations were developed for both a household and a region as follows:

- The base use of daily water demand of a residential household is

$$W_{BU} = \sum_{e=1}^{e=e} B_e .\, Q_e . F_e . N_e \qquad (1)$$

where W_{BU} = base use of the daily water demand (litre/day), B = absence (0) or presence (1) of an end use, Q = volume (litre/event), F = frequency of the event

Downloaded from https://iwaponline.com/wst/article-pdf/71/4/529/469617/wst071040529.pdf
by guest

(events/person/day), N = household size, e = end-use components.

- The total base use of daily water demand of a region is

$$W_{BU} = \sum_{h=1,\, n=1}^{h=h,\, n=n} (\sum_{e=1}^{e=e} B_e.Q_e\, F_e\, .N_e)_h \tag{2}$$

where h = household size (may vary from 1 to 6, or more), n = number of households with household size h. If 'n' is unavailable, the total base use of daily water demand of a region containing population p is estimated as

$$W_{BU} = \sum_{p=1}^{p=p} (\sum_{e=1}^{e=e} B_e.Q_e\, F_e\, .N_e)_p \tag{3}$$

Water conservation programme in base use

The model estimates the water consumption of a household at every end-use level. The water savings of a water conservation programme, such as retrofitting an efficient showerhead, can be estimated through changing the volume parameter of this model.

Seasonal use, W_{SU}

Seasonal use (W_{SU}) is calculated by deducting the estimated base use from observed total water consumption, i.e. $W_{SU} = W_{TD} - W_{BU}$ (modelled). The variations in seasonal water consumption depend on several factors such as air temperature, rainfall, evapotranspiration, wind speed, etc. Among these factors, rainfall and temperature play a key role in determining the variations of seasonal water use (Gato *et al.* 2005). Therefore, in this model W_{SU} is dependent on climatic variables such as rainfall and temperature. W_{SU} has two components: (i) potential seasonal water use (W_{PU}), which varies depending on the variation in surface air temperature; and (ii) the short memory use (W_{SM}) which has the effect of rainfall, air temperature and random errors which represents the quick response of people to weather changes (Maidment & Miaou 1985).

Modelling potential seasonal water use

For modelling, the potential seasonal water use (W_{PU}), the regression of W_{PU} against a seasonal variable such as maximum temperature has been adopted (Maidment & Miaou 1985). While, it is recognised that there are other methods of modelling potential seasonal water use variations 'the regression of W_{PU}, against a seasonal variable' considers the change in water use if temperature and rainfall changes. A change in air temperature can increase or decrease water usage, but occurrence of rainfall only leads to reduction in water usage. This type of effect cannot be incorporated properly into a conventional method such as Fourier series model of historical seasonal water use (Maidment & Miaou 1985) because this model considers the effect of both rainfall and temperature, which is inconsistent with basic assumptions – when there is no rainfall there should be an increase in water usage. Potential seasonal water use is modelled using this heat function. Heat function is expressed as (Maidment & Miaou 1985)

$$H(T) = C_0 + C_1\ T \tag{4}$$

where C_0 and C_1 are coefficients to be estimated by applying iterative trial and error techniques of linear regression, $H(T)$ is the heat function of air temperature T. The daily W_{PU} is calculated by substituting the normal daily air temperature, T_N estimated from long-term records, into the heat function for each rainless day of the year.

$$W_{PU} = H(T_N) = C_0 + C_1 T_N \tag{5}$$

Modelling short-memory water use

The short-memory effects of rainfall, surface air temperature and random errors are calculated as

$$W_{SM} = W_{SU} - W_{PU}(\text{modelled}) \tag{6}$$

W_{SM} is calculated using the method transfer function noise model (Box & Jenkins 1976) as rainfall has dynamic effects on the variation of water consumption, and can be incorporated through the transfer function.

Transfer function noise model for DMEUW

Transfer function noise model for DMEUW is based on Box & Jenkins (1976), and considered for multiple input cases. The general form of this model is

$$\begin{aligned} W_{SM,\,t} &= \upsilon_T(B)T_t + \upsilon_R(B)R_t + n_t \\ &= \frac{\omega_T(B)}{\delta_T(B)} T_{t-b(T)} + \frac{\omega_R(B)}{\delta_R(B)} R_{t-b(R)} + n_t \end{aligned} \tag{7}$$

Downloaded from https://iwaponline.com/wst/article-pdf/71/4/529/469617/wst071040529.pdf
by guest

where $W_{SM,t}$ = short-memory water use; T_t = transformed daily temperature; R_t = rainfall; n_t = error or noise term; $b(T), b(R)$ = delay (b time units of delay between the response and the input); $v_T(B)$, $v_R(B)$ = transfer function for temperature and rainfall; v_T, v_R = transfer function weights for temperature and rainfall; $\omega_T, \omega_R, \delta_T, \delta_R$ = transfer function coefficients; B = backshift operator or time lag; t = no of day – time index (daily basis)

The general steps for developing the transfer function model involves (i) plotting the data, (ii) prewhitening, (iii) rational polynomial representation of the transfer function, (iv) fitting a model for the noise, (v) fitting the transfer function-noise model, and (vi) diagnostic checks (Bisgaard & Kulahci 2011).

For calculating short-memory effects of air temperature using the transfer function noise model, daily average air temperature is substituted by residual air temperature (T_i) as

$$T_i = T - T_N \quad (8)$$

Water restrictions in seasonal use

Water restrictions depend on water storage level. Figure 1 shows the relationship between water restriction stages in Greater Melbourne and their corresponding water storage levels on different seasons of the year.

Water storage level depends greatly on rainfall (Gupta 2010). There is no model reporting a direct relationship between water restrictions and rainfall. Therefore, in this model water restriction level (WRL) is a function of rainfall (R). Mathematically

$$\mathrm{WRL} = f(R) \quad (9)$$

One component of DMEUW investigates the effect of rainfall on storage level and on water restrictions which eventually determines the prospective WRL. Then, the model will incorporate the corresponding percentage reduction in seasonal use and total water demand based on determined WRL.

Parameters for consideration

Population growth, climatic variables (rainfall and temperature), water restrictions, water conservation, and residential water end use are incorporated in this model. End-use parameter values considered by Roberts (2005), Roberts *et al.* (2011), and Athuraliya *et al.* (2012) have been adopted as default values (see Table 1) in the initial development of DMEUW. The model is parameters can be changed depending on the region's water end-use trends and patterns.

Process of integration

The model's basic working steps and process of integration for estimating and forecasting total water demand is shown in Figure 2.

COMPUTER INTERFACE OF THE DMEUW MODEL

Operational feature of the model

Parameters required

The data required to run the model are: (i) household size (h), (ii) end-use data information about the old and new efficient water fixtures and appliances (e), (iii) rainfall and temperature data (daily) of a region or city (R, T), (iv)

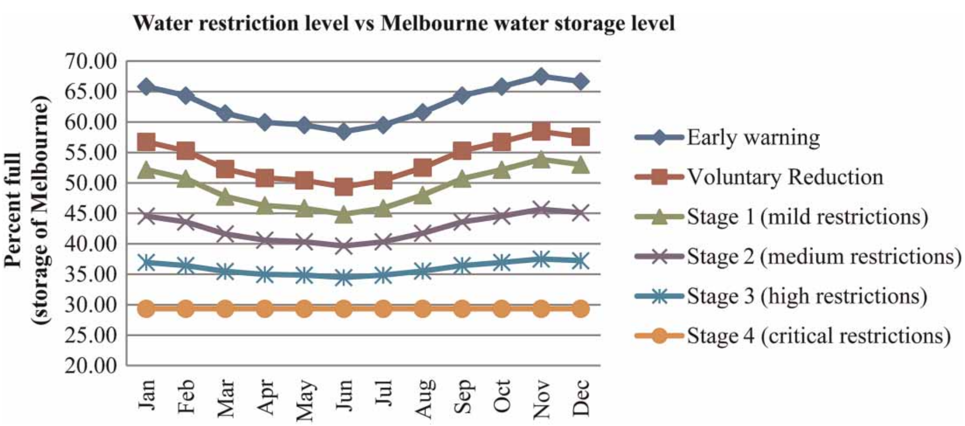

Figure 1 | Water restriction levels in Greater Melbourne and their corresponding water storage levels.

Downloaded from https://iwaponline.com/wst/article-pdf/71/4/529/469617/wst071040529.pdf
by guest

Table 1 | End-use components and parameters considered in DMEUW. *Sources:* Roberts (2005); Roberts *et al*. (2011); Athuraliya *et al*. (2012)

	Appliances		Parameter			Value			
End use	Type	Measurement	Notation	Description	Unit	2004	Winter 2010	Summer 2012	Combined 2010 & 2012
Shower	Standard	Flow rate	q	Volume	L/m	9.8	8.7	8.3	8.4
	3 Star	Flow rate	q	Volume	L/m	6.7	6.3	6.4	6.4
	All shower	Flow rate	q	Volume	L/m	9.5	7.3	7.2	7.2
	All shower	Average time of uses	t	Duration	Minutes/event	7.1	7.1	6.5	6.8
	Standard	Volume	Q	Volume	L/event	69.58	61.77	58.93	59.64
	3 Star	Volume	Q	Volume	L/event	47.57	44.73	45.44	45.44
	All shower	Volume	Q	Volume	L/event	67.45	51.83	51.12	51.12
	All shower	Frequency of use	F	Frequency	Events/person/day	0.76	0.73	0.73	0.73
Toilet	All type	Average flush volume	Q	Volume	L/flush	7.6	5.6	5.5	5.6
	All type	Flush frequency	F	Frequency	Events/person/day	4.2	3.9	3.9	3.9
Clothes washing	All type	Average load volume	Q	Volume	L/load	143	110	93	101
	Front loader	Average load volume	Q	Volume	L/load	75	64	58	61
	Top loader	Average load volume	Q	Volume	L/load	152	147	131	139
	All type – measured	Frequency of average load per week	F	Frequency	Events/house/week	6.4	4.5	5.2	4.8
	All type – modelled	Frequency of average load per week	F	Frequency	Events/house/week	5.7	4.4	4.9	4.6
		Household size = 2.6 persons. No. loads/week$_{CW}$ = 2.62 * ln(household size) + 1.87 [winter 2010]. No. loads/week$_{CW}$ = 2.28 * ln(household size) + 2.09 [combined 2010 & 2012]							
Dish washer	All type	Average load volume	Q	Volume	L/load	23.9	16	14	15
	All type – measured	Frequency of average load per week	F	Frequency	Events/house/week	3.4	3.5	3.5	3.5
	All type – modelled	Frequency of average load per week	F	Frequency	Events/house/week	3	3.2	3.3	3.2
		Household size = 2.6 persons. No. loads/week$_{DW}$ = 2.77 * ln(household size) + 0.64 [winter 2010]. No. loads/week$_{DW}$ = 1.896 × ln(household size) + 1.28 [combined 2010 & 2012]							
Tap	All type	Average flow rate	q	Volume	L/m	3.3	3	2.2	2.6
	All type	Time of uses	t	Duration	Min/event	0.39	0.33	0.45	0.38
	All type	Average volume per event	Q	Volume	L/event	1.3	1	1	1
	All type	Frequency per day	F	Frequency	Events/person/day	21	21	22	21
	All type	Average water use per capita per day	Q	Volume	L/person/day	27	21	22	21
	All type	Modelled – average water use per capita per day	Q	Volume	L/person/day	29	24	25	24
			Modelled – tap use/person = 33.8 – 10.2 × ln(household size) [combined 2010 & 2012]						

current population (p), (v) rate of population increase (Rp), (vi) number of households with different household-size ($N{-}h$), and (vii) dataset of record of population ($p{-}R$).

Output

The expected output of the model for a household family or for a region includes: (i) daily base use (B_{SU}), (ii) daily water consumption of each major end use (W_{EU}), (iii) estimation of water savings in daily base use ($W_{SV\text{-}BU}$), (iv) seasonal water use (daily) (W_{SU}), and (v) total daily water demand (W_{TD}). The model users will be able to select the desired combination of output from this model and subsequently the model will automatically generate a display 'what combination or what set of data are required for input' as illustrated in Figure 3.

Compiling considerations and assumptions of the model

The compiling considerations and assumptions of the model are as follows:

- Population is the same throughout the year.
- If the rate of population increase data are unavailable, the model estimates the growth rate based on available

Downloaded from https://iwaponline.com/wst/article-pdf/71/4/529/469617/wst071040529.pdf
by guest

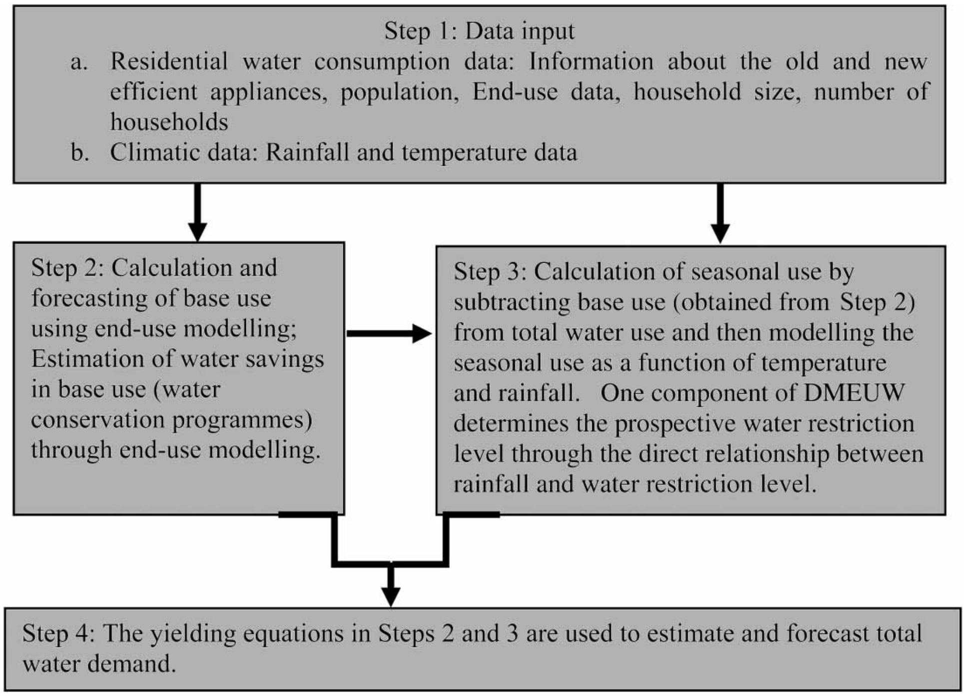

Figure 2 | Integration process of the model for estimating and forecasting total water demand.

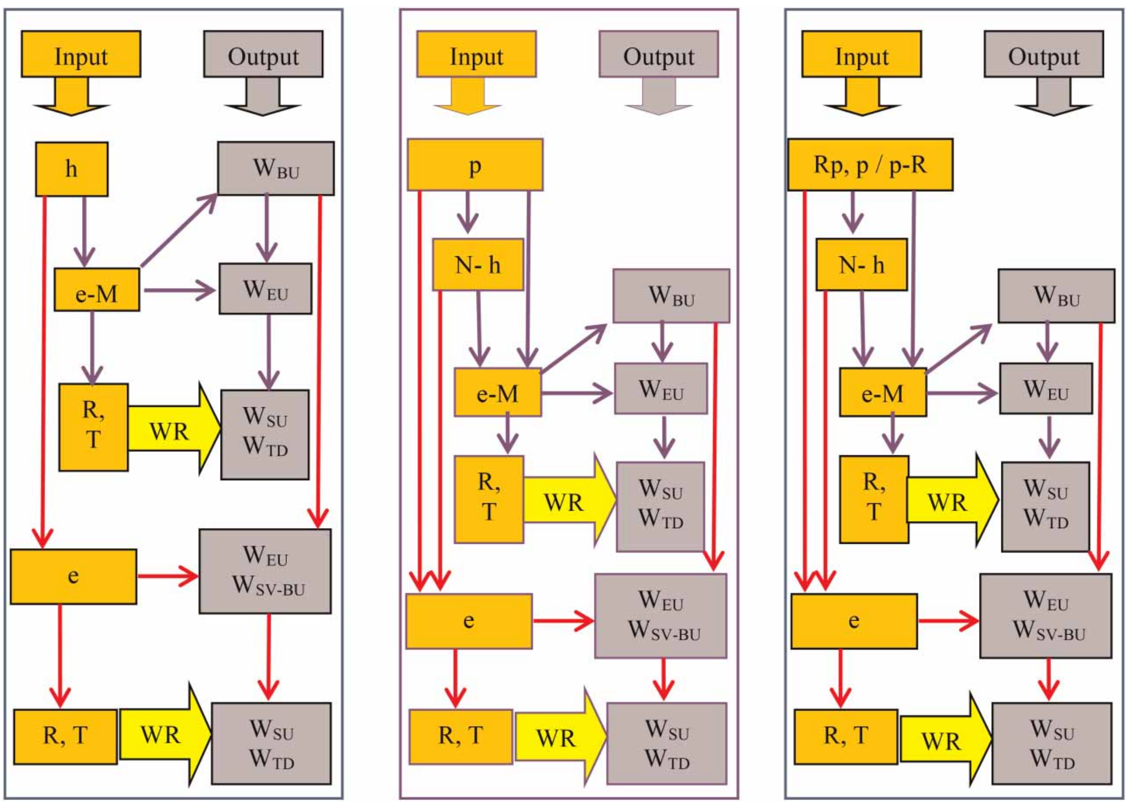

Figure 3 | Flowchart of required input corresponding to expected output: left: estimation – one house; middle: estimation – for a region or city; right: forecasting – for a region or city; WR: water restriction; e-M: default end-use data of the model.

Downloaded from https://iwaponline.com/wst/article-pdf/71/4/529/469617/wst071040529.pdf
by guest

population data, i.e. population is forecasted by extrapolating recorded information on the population.

- Number of households with different household-size (*N*–*h*) is preferred instead of population. The model does not convert population into corresponding *N*–*h*.
- No household size is forecasted. But, if the *N*–*h* data set for a number of years from a region is available, then the model considers the percentage of *N*–*h* and extrapolates it to make the forecast.
- If the *N*–*h* data set is unavailable, the model estimates water demand considering per capita water consumption for the given population.
- To calculate water consumption at major end-use level, the model considers the default end-use parameter values published by Yarra Valley Water; however, the model users can input their own end-use data and information about water fixtures and appliances for their customised assessment.
- To assess the water savings from conservation programmes, such as retrofitting water efficient appliances, the end-use data and information about the old and new efficient fixtures and appliances must be inputted.
- The model considers WRLs based on the relationship among storage level, restriction level, and rainfall.
- No climate factor is forecasted by this model. The model uses climatic data (rainfall and temperature) inputted by the model users. The model considers the present

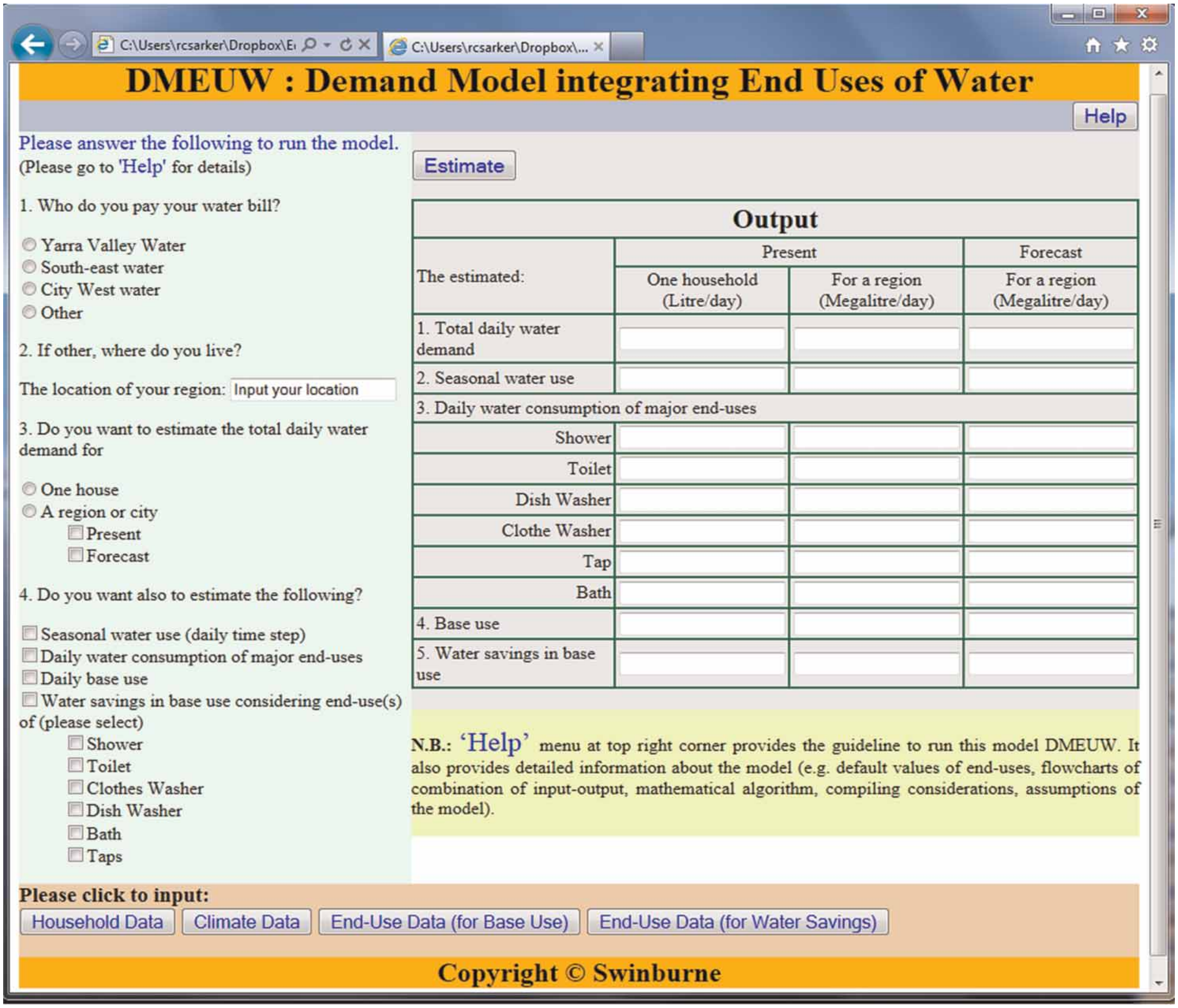

Figure 4 | The outlook of the computer interface of the model DMEUW.

Downloaded from https://iwaponline.com/wst/article-pdf/71/4/529/469617/wst071040529.pdf
by guest

inputted climatic data as a future one unless other users input the forecasted rainfall and temperature data.

Computer interface of DMEUW

The computer interface (web-based application) of the model DMEUW (Figure 4) was designed using hypertext markup language (HTML). An HTML-embedded web scripting language hypertext preprocessor (PHP) works for the calculation of the mathematical algorithm of the model, since PHP is applicable for database applications. Only the required data input options appear while running the model. The 'Help' menu, in the right-top corner of the window, contains detailed information about the model (e.g. default values of end uses, instructions for running the model, algorithm of the model, etc.) to provide the users with guidelines to run the model.

LIMITATIONS

The model includes the following limitations:

- The model is complex and a large amount of data is needed to run the model.
- The model does not incorporate effect of rainwater tank on calculating water demand. This integrated model does also not consider water supply network issues, such as water supply pressure, water supply system – intermittent or continuous, etc.
- The model does not consider a single event. The model is not capable of separating the demand for tourism, industrial, and commercial activities. Any demand during religious, national events and vacations are taken during those days and these may increase the average demand since the model considers historical demand, rainfall and temperature and uses time-series analysis.

CONCLUSIONS

An integrated water demand model can be developed to contribute to sustainable water management, specifically, in water demand modelling, where there is a lack of integration of end uses of water, climatic factors, and water conservation programmes including water restrictions. This integrated model addresses the limitations of currently used models and will assist water authorities and water resource planners in their future planning of sustainable water management.

Specifically, the following can be concluded:

- One component of DMEUW determines the prospective WRL through the direct relationship between rainfall and the WRL, which eventually estimates the seasonal and total water demand based on determined WRLs.
- The model determines the amount of water savings of a household resident, a suburb or a region.
- The model is able to estimate the water consumption at each major end-use level such as shower, toilet, clothes washing, dish washing, tap, etc. which can assist with determining areas, or regions, that are consuming more water and at which end-use level.
- Eventually, this model could assist water resource managers and planners in developing, implementing and evaluating water management strategies and programmes including, but not limited to, retrofitting houses with efficient water appliances and fixtures to reduce the water demand.

Likewise, from a planning point of view, this model could help planners and demographers in their understanding of new urban planning and community development.

REFERENCES

Athuraliya, A., Roberts, P. & Brown, A. 2012 Residential water use study. Report: Yarra Valley Future Water Residential Water Use Study Volume 2 – Summer 2012, Yarra Valley Water (Editor), Vol. 2, Victoria, Australia.

AWA/Deloitte State of the Water Sector Survey 2012 *The Australian Water Directory 2013*. Australian Water Association (AWA), 24th edition, pp. 48–49, NSW, Australia.

Bisgaard, S. & Kulahci, M. 2011 *Time Series Analysis and Forecasting by Example*. John Wiley & Sons, Inc., Hoboken, New Jersey, USA, pp. 222–223.

Blokker, E. J. M., Vreeburg, J. H. G. & van Dijk, J. C. 2010 Simulating residential water demand with a stochastic end-use model. *Journal of Water Resources Planning and Management (ASCE)* **136** (1), 19–26.

Box, G. E. P. & Jenkins, G. M. 1976 *Time series analysis: forecasting and control*. Paper presented at the Holden-Day, San Francisco, CA, USA.

Gato, S., Jayasuriya, N. & Hadgraft, R. 2005 A simple time series approach to modelling urban water demand. *Australian Journal of Water Resources* **8** (2), 153–163.

Gato, S., Jayasuriya, N. & Roberts, P. 2007a Forecasting residential water demand: case study. *Journal of Water Resources Planning and Management* **133** (4), 309–319.

Gato, S., Jayasuriya, N. & Roberts, P. 2007b Temperature and rainfall thresholds for base use urban water demand modelling. *Journal of Hydrology* **337** (3–4), 364–376.

Downloaded from https://iwaponline.com/wst/article-pdf/71/4/529/469617/wst071040529.pdf
by guest

Gato-Trinidad, S., Jayasuriya, N. & Roberts, P. 2011 Understanding urban residential end uses of water. *Water Science and Technology* **64** (1), 36.

Giurco, D., Mohr, S., Fyfe, J., Rickwood, P., Teng, M. & Franklin, J. 2013 Modelling bounce-back in water consumption post-drought. *Journal of the Australian Water Association* **40** (5), 79–84.

Gupta, S. K. 2010 *Modern Hydrology and Sustainable Water Development*. http://SWIN.eblib.com.au/patron/FullRecord.aspx?p=792631 (accessed 30 July 2014).

Jacobs, H. & Haarhoff, J. 2002 End-use modelling as a means to predict the effects of water demand management. In: *Biennial Conference of the Water Institute of Southern Africa (WISA)*.

Maddaus, W. O. & Maddaus, M. L. 2004 Evaluating water conservation cost-effectiveness with an end use model. In: *Water Sources Conference, Austin*, Texas, USA.

Maidment, D. R. & Miaou, S. P. 1985 Transfer function models of daily urban water use. *Water Resources Research* **21** (4), 425–432.

Mayer, P. W. & DeOreo, W. B. 1999 *Residential End Uses of Water*. AWWA Research Foundation and American Water Works Association, USA.

Rathnayaka, K., Malano, H., Maheepala, S., Nawarathna, B., George, B. & Arora, M. 2011 Review of residential urban water end-use modelling. In: *19th International Congress on Modelling and Simulation*, Perth, Australia.

Roberts, P. 2005 Yarra Valley Water 2004 Residential End Use Measurement Study, Yarra Valley Water, Victoria, Australia.

Roberts, P., Athuraliya, A. & Brown, A. 2011 Yarra Valley Future Water: Residential Water Use Study Volume 1 – Winter 2010, Yarra Valley Water, Victoria, Australia.

Sarker, R. C., Gato-Trinidad, S. & Imteaz, M. 2013 Temperature and rainfall thresholds corresponding to water consumption in greater Melbourne, Australia. In: *20th International Congress on Modelling and Simulation (MODSIM2013)*, Adelaide, Australia.

Turner, A., Willetts, J., Fane, S., Giurco, D., Kazaglis, A. & White, S. 2008 *Guide to Demand Management – The Urban Water Planning Framework*. WSAA Occasional Paper (18), 31, 35, 58.

Willis, R., Stewart, R., Panuwatwanich, K., Capati, B. & Giurco, D. 2009 Gold coast domestic water end use study. *Water: Journal of Australian Water Association* **36** (6), 79–85.

Worthington, A. C., Higgs, H. & Hoffmann, M. 2009 Residential water demand modeling in Queensland, Australia: a comparative panel data approach. *Water Policy* **11** (4), 427–441.

First received 31 August 2014; accepted in revised form 15 December 2014. Available online 2 January 2015

Downloaded from https://iwaponline.com/wst/article-pdf/71/4/529/469617/wst071040529.pdf
by guest