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Climate corrected urban water use and estimation of water savings

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Abstract: Urban water supply systems provide water to serve uses ranging from human consumption to fire control and from garden irrigation to industrial processes. Water demands are highly variable, depending on such factors as size of city, characteristics of the population, the nature and size of commercial and industrial establishments, climatic conditions, and cost of supply.

Understanding of the influences of climate variability on water consumption is integral to urban water authorities to evaluate the effectiveness of water conservation programs and to assess water savings against the consumption targets. In order to quantify the water savings and tracking of true trends of water use, the observed urban water use values need to be adjusted to a level that it would have been under the normal climatic conditions and free of water restrictions. This is known as the climate-correction process. Normal climate is defined as the long run average of climactic variables. The climate-corrected water use would thus be defined as the water use evaluated using the normal values of the climatic variables.

This paper presents a climate-correction framework, which will incorporate the development of an improved residential urban water demand model, a refined definition of normal climate, and a methodology to estimate water savings. The residential urban water demand model is specifically developed for use in estimating water savings due to water conservation programs. A non-conventional multiple regression technique known as ACE (Alternating Conditional Expectations) is used to develop the urban water demand model. ACE does not require prior transformation of independent and dependent variables through known functions. For each year, the urban water demand model is calibrated and then run with the normal climate to produce the climate corrected water use. Water savings are then estimated using climate corrected water use for the current year and the reference year.

In this study, initial work done using two years of data (2003–04 and 2004–05) obtained from Barwon Water for the Greater Geelong area shows promising results. Normal climate is obtained by averaging the climatic variables over a ten year period, starting from the 1st of July, 1997. The ACE regression based water demand model is calibrated for two years, which are 2003–04 (which is the base year) and 2004–05. The predicted water demand is then calculated under the above mentioned normal climatic conditions for these two years to give the climate corrected water use. It is observed that the climate corrected water demand had reduced by 6.9% in 2004–05, when compared to that in 2003-04.

Although permanent water saving measures was imposed only from 1st of December, 2005, the water conservation by-law 187 was adopted on the 1st of February, 2003. It appears that this by-law, which was much discussed in the media, made people aware of the necessity to conserve water. This seems to have led to the observed reduction in climate-corrected demand in 2004–05.

Keywords: *Urban water demand, climate correction, water conservation programs, water savings*

1. INTRODUCTION

Global water shortage has been the topic of concern and interest recently worldwide. In Australia, water shortage is becoming an increasingly significant issue and poses an immense challenge in the future. The construction of new reservoirs has been the apparent solution in the past to address increasing water demands. However, in establishing the long-term water resources strategy for Greater Melbourne, it was proposed that no dams or reservoirs to be built for the next 50 years due to environmental concerns, the difficulty in sourcing new catchments and the financial costs involved (DSE, 2005). Therefore, the demand management plays an important role in addressing increasing water demands.

There are two demand management strategies in relation to urban water use reduction. These are through water restrictions and water conservation programs. Melbourne, Victoria is experiencing its tenth year of drought which has severely reduced the amount of water flowing in our rivers and streams and the levels of water storage. The current drought has forced water restrictions to be imposed after 20 years of unrestricted supply. In Victoria, various water conservation programs were introduced by the water authorities to reduce urban water use; including education programs, incentives schemes and pricing. The recommended demand reduction programs include water-efficient household appliances, education for efficient garden practices and incentives for rainwater tanks and use of recycled water (DSE, 2005).

The Victorian Government has established a 15% of water savings target to be attained by 2010 from the 2004 levels to aim at the reduction of urban water use and protect precious water resource now and in the future (DSE, 2005). Victorian water consumers have already responded favorably to water conservation campaigns and continuously maintained the water conservation efforts through voluntary implementation of the recommended demand reduction programs. It is essential for the water savings to be quantified in order to evaluate the effectiveness of water conservation programs and to track water use against the consumption targets.

The computation of water savings involves correcting the observed water use values to a level that it would have been under the normal climatic conditions with and without water conservation measures. This adjustment process is known as climate-correction (Maheepala and Roberts, 2006) and is the subject of this study. The climate-correction also allows the prediction of true trends in water use.

This study presents initial work done for the estimation of water saving using two years of data (2003–04 and 2004–05) obtained from Barwon Water for the Greater Geelong area. The urban water demand model is developed using a non-conventional multiple regression technique known as ACE (Alternating Conditional Expectations). The climate corrected water use is then calculated for the two years to get an estimation of the water savings.

The following sections present the description of Barwon Water's initiatives for development of water supply demand models for the Greater Geelong Water Supply System, followed by the water demand model used in this study. Then presented is the calculation of the climate corrected urban water use for Greater Geelong area, followed by discussion on the results and conclusions.

2. BARWON WATER'S DEMAND MODELS FOR GREATER GEELONG

The Geelong Water Supply System provides water to a population of approximately 235,000 within the Geelong region. Since 1999, Barwon Water has been involved in investigations with MWH for the development of water demand models and climate correction models for the Greater Geelong Water Supply System. It is mainly served by catchments within the Barwon River system to the west of Geelong, and the Moorabool River system to the north (Barwon Water, 2003).

In April 2004, Barwon Water and MWH undertook a study to enhance the ability of Barwon Water to track water demands on a climate corrected basis and allow for improved understanding of both total water production and water consumption in different consumer groups (Barwon Water, 2004). In that study, with a view to establishing the current climate-corrected demand for the Geelong region, a multivariate regression analysis based model was developed.

A survey of the literature reveals an increase in past decades or so in the development of statistical models, typically multiple regression and time series, for predicting urban water demand (Gato et al., 2007; Zhou et al., 2001). These regression based methods attempt to fit a relationship between the response (water demand) and different predictors (selected key climatic and non-climatic variables). The Barwon Water model (Barwon Water, 2004) also takes the form of a regression equation, a brief description of which is presented in the next section.

2.1. The Barwon Water Demand Model

In the Barwon Water model, the regression equation takes a form as presented in Equation (1). This model was calibrated over a 3 year period from 1st July 1994 to 30th June 1997.

$$D_t = B_0 + B_1 f_1(S_t) + B_2 f_2(T_t) + B_3 f_3(E_t) + \varepsilon_t \tag{1}$$

where

D_t = Per capita demand on day *t* (liters),

S_t = Soil moisture index on day *t*,

T_t = maximum temperature on day *t*,

E_t = Evaporation on day *t* (mm),

B_0 to B_3 are regression parameters and ε_t is a random residual.

The transformation equations f_n (n = 1, 2, 3) were of the form:

$$f(v) = \tan^{-1}\left(\left(v - \frac{(v_U + v_L)}{2}\right)\left(\frac{\pi}{v_U - v_L}\right)\right) \tag{2}$$

for appropriate values of the parameters v, v_L, v_U.

The soil moisture index S_t, unlike the other input parameters and the demand D_t, which were derived from observations, was calculated through the following recurrence relation:

$$S_t = g\left[g(S_{t-1}) + M_R R_t - M_E E_t^P g(S_{t-1})\right] \tag{3}$$

where

$g(v) = 0$ if $v < 0$

$=100$ if $v > 100$

$= v$ otherwise,

R_t = Rainfall on day *t*,

M_R = Rainfall multiplier,

E_t = Evaporation,

M_E = Evaporation multiplier,

P = Evaporation power.

The multiple regression coefficient obtained by regression of the demand on the input variables over the three year calibration period was 0.824. This model, with the coefficients obtained during 1994-1997 was applied to the period 1 July 2004 to 30 June 2005. The multiple regression coefficient obtained was 0.654.

3. THE ACE REGRESSION BASED WATER DEMAND MODEL

3.1. Overview

The demand model presented in this study was specifically designed to address the problem of determining the climate-corrected effect of water conservation measures on demand in Greater Geelong. The starting point for this model was the one developed by Barwon Water (Barwon Water, 2004), which was discussed in Section 2.1. This model, which is based on the ACE regression algorithm, is briefly presented below.

3.2. The ACE Regression Algorithm

One aspect of the Barwon Water model that was of concern was the fact that the transformation equations f_1, f_2 and f_3 are symmetric with respect to their mid-values. It was felt that more flexibility was required. For example, a strong demand saturation effect should be expected at high temperatures but not at low ones. Such problems can be automatically dealt with by using the ACE regression method. ACE method is briefly described here and for a complete theory description of the regression method, the reader is referred to the original paper by Breiman and Friedman (1985).

ACE regression models a smoothed function (or transformation) of the dependent variable as the summation of smoothed functions (or transformations) for the independent variables:

$$\theta(y) = \phi_1(x_1) + \phi_2(x_2) + \ldots + \phi_n(x_n) + \varepsilon \quad (4)$$

where y is the dependent variable, the x_i are the independent variables and θ, $\phi_1,\ldots,$ ϕ_n are smooth transformations of the data and ε is a random residual.

No particular form (linear, quadratic, logarithmic, etc.) need be assumed for these ACE transformation functions. These functions are computed in such a way so as to maximize the correlation between $\theta(y)$ and $\phi_1(x_1) + \phi_2(x_2) + \ldots + \phi_n(x_n)$ or to minimize the summation of squares of the model residuals. In this study, the ACE algorithm is implemented in the statistical computing package SPLUS (Venables and Ripley 1999).

4. CLIMATE CORRECTED WATER USE FOR GEELONG

This section presents the methodology used for the calculation of climate corrected yearly water demand for the two years of 2003–04 and 2004–05 in Greater Geelong. The climate correction of water use entails three main steps (Maheepala and Roberts, 2006):

- Defining the normal climate,
- Expressing the water demand as a function of selected key climatic and non-climatic variables and then calibrating and validating the model to observed use,
- Computing the water use under normal climate, which is the climate-corrected water use with and without water conservation measures. Then, the water saving is estimated.

The methodology used for the above steps are discussed in the following sub-sections:

4.1. Defining Normal Climate

Normal climate needs to be defined because climate correction involves estimating the amount of water use if the weather conditions had been normal. Normal climate is usually defined as the 30-year average of climatic parameters (Maheepala and Roberts, 2006). However, the concept of normal climate is distorted by the climate change phenomenon because the average of climate over a period differs from decade to decade.

In this study, normal climate is obtained by averaging the climatic variables over a ten year period, from 1 July 1997 to 30 June 2007.

4.2. ACE Regression based Water Demand Model

This section presents the development of an ACE regression based demand model, using the observed data from 2004–2005 (1st July 2004 to 30th June 2005) for calibration. In addition to the three input variables used in the Barwon Water model (presented in Section 2.1), a categorical variable x_4 representing the days of the week was added because the day of the week is expected to influence the water use behavior. It is to be noted that this variable takes only seven integer values, namely 1,…, 7, corresponding to the seven days of the week. Thus, the ACE regression was then carried out using the following four inputs:

x_1 = Soil moisture index

x_2 = Maximum temperature

x_3 = Evaporation

x_4 = Day of week

The graphs of the transformation functions ϕ_1, ϕ_2, ϕ_3, ϕ_4 and θ are shown in Figure 1. In order to be able to use Equation (4) (without the residual term) to carry out validation and prediction, the transformations ϕ_1, ϕ_2,

ϕ_3 were approximated by appropriate polynomials. For ϕ_4, each of the seven values of x_4 had a transformed value. As for the output transformation θ, it was its inverse, θ^{1}, that had to be approximated. The appropriate order of the polynomials and the corresponding coefficients were evaluated by means of polynomial regressions.

As far as evaluating the predicted value y_{pred} of the demand y is concerned, it was done as follows:

- The transformed value of y, y_t, was regressed (linearly) on the polynomial approximations of the transformed x_t, denoted by g_{xi}:

$$y_t = d_0 + \sum_{r=1}^{4} d_r g_{xr} \quad (5)$$

- Then y was regressed on the calculated y_t, yielding for the predicted value of y, y_{pred}, a polynomial of order four:

$$y_{pred} = \sum_{r=0}^{4} p_r y_t^r \quad (6)$$

The coefficients were: 356.87, 38.50, 33.17, 28.64 and -7.39.

The final multiple correlation achieved between the observed values y and the fitted values y_{pred} was 0.873, which is significantly better than that achieved by the Barwon Water model (0.824).

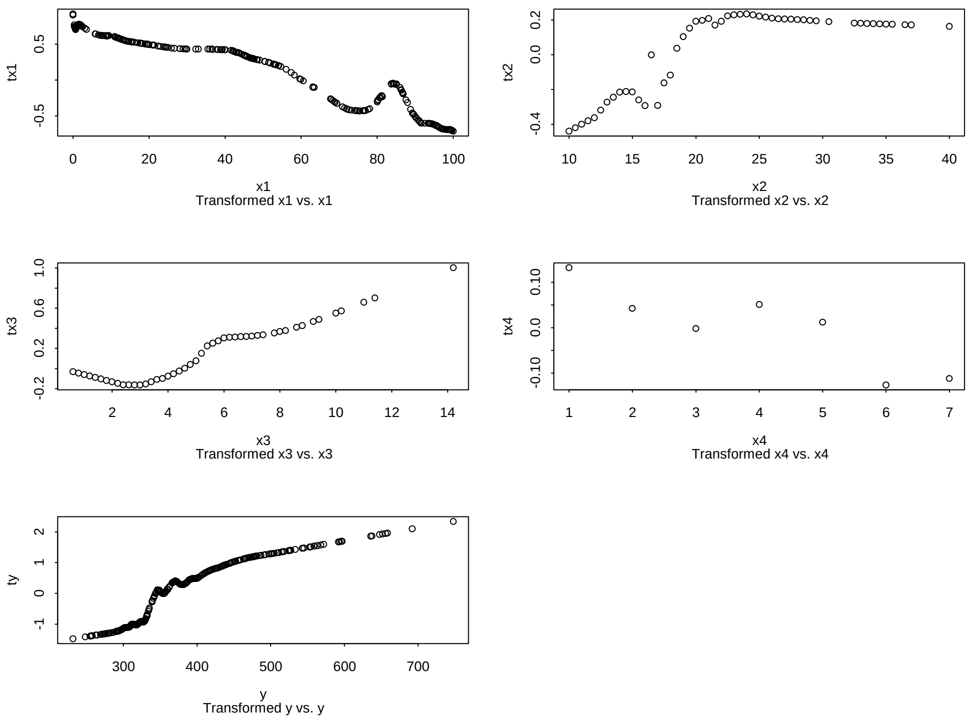
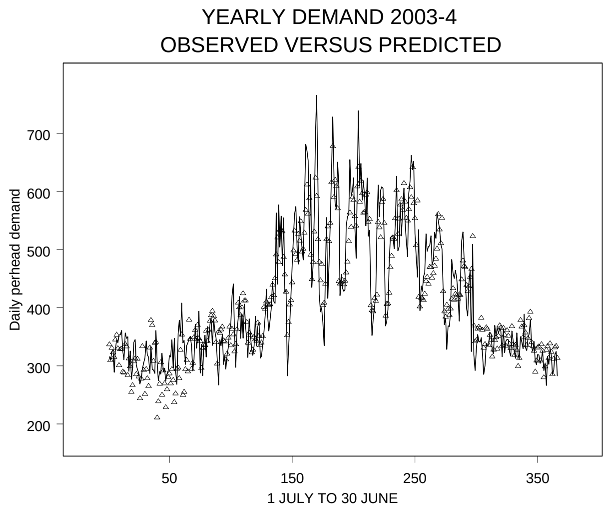


Figure 1. Graphs of inputs and output transformations

The validation was carried out for the year 2003–2004 (i.e., from 1st July 2003 to 30th June 2004) using the formula that was calibrated for the year 2004–2005. It is worth mentioning here that for calculating the climate-corrected water use and estimation of water savings, the calibrated model does not have to be validated. A validation of the calibrated model was done for an adjacent year (which is 2003-04) just to verify if the calibrated model performs well in an adjacent year. For this validation year, however, the multiple correlation achieved was 0.903, which was actually better than that for the calibration year. For a visual comparison of the observed versus predicted demand, time series plots of the demands for both the calibration and validation years are presented in Figure 2.



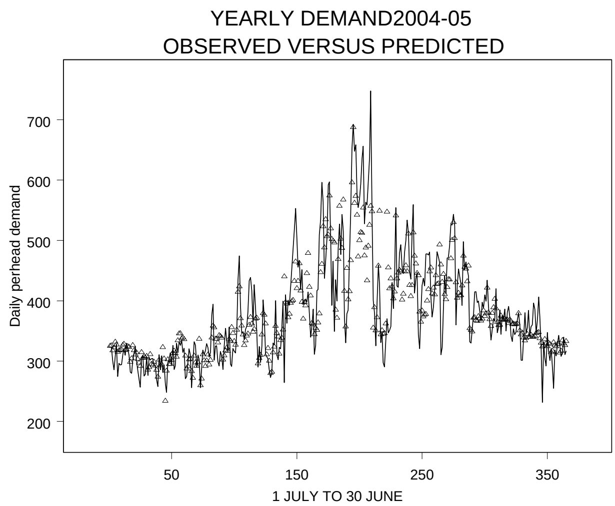


Figure 2. Time series plots of observed versus predicted daily per head demand in litres (lines are observed demand and triangles are predicted demand)

4.3. Computing Climate Corrected Water Use and Water Savings

For calculation of the climate corrected water savings between the two years, the model for 2004-2005 is recalibrated for the data of 2003-04. Using the normal climate mentioned above in Section 4.1, the predicted water demand under normal climate for the two years 2003-04 and 2004-05 is calculated, which is mentioned in Table 1.

Table **1**. Climate corrected water use

	2003-04	2004-05
Predicted and observed correlation	0.92	0.87
Predicted yearly demand per head under normal climate (L)	139,771	130,108

From this table, it can be observed that the percentage reduction in yearly water demand from 2003-2004 to 2004-2005, corrected for climate is calculated as:

100 × (139,771 – 130,108) / 139.771 = 6.9%

Thus, it is observed that the water demand corrected for climate had reduced by 6.9%.

5. DISCUSSION ON RESULTS

A possible interpretation for the reduction in climate corrected water demand can be given as follows. The level of water restrictions since the beginning of 1998 is given in Table 2. As presented in this table, in July 2001, all water restrictions were lifted. But on the 1st of February 2003, the water conservation by-law 187 was adopted. It appears that there were numerous discussions about adopting the by-law within the community at that time (media release from the Office of the Premier). This might have affected the people's opinion and have led to adoption of conservation measures with the consequent reduction in demand (climate corrected) that is observed in the above calculations.

Table **2**. Barwon Water: water restrictions

Date	Level of water restriction
30-Jan-98	Stage 1 Water Restrictions
12-Dec-99	Stage 2 Water Restrictions
14-Nov-00	Stage 1 Water Restrictions
01-Jul-01	Restrictions in all regions were lifted
01-Feb-03	**Water Conservation by-law 187**
01-Dec-05	Permanent Water Saving Measures
01-Jul-06	Stage 1 Water Restrictions
16-Sep-06	Stage 2 Water Restrictions
1-Nov-06	Stage 3 Water Restrictions
09-Dec-06	Stage 4 Water Restrictions

6. CONCLUSIONS

Victorian water consumers have already responded favorably to water conservation campaigns and continuously maintained the water conservation efforts through voluntary implementation of the recommended demand reduction programs. It is essential for the water savings to be quantified in order to evaluate the effectiveness of water conservation programs and to track water use against the consumption targets.

This study presented a climate-correction framework, which included the development of an improved residential urban water demand model based on the ACE (Alternating Conditional Expectations) regression, a refined definition of normal climate and a methodology to estimate water savings. For each of the two years of data (2003-04 and 2004-05) from Greater Geelong, the urban water demand model is calibrated and then run with the normal climate to produce the climate corrected water use. It is observed that the climate corrected water use had reduced by 6.9% in 2004-05, as compared to that in 2003-04. This indicates awareness amongst the people to conserve water, which seems to be due to the much discussed Water Conservation by-law 187, which was adopted in the beginning of February, 2003.

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