Modelling Residential Water Demand in Adelaide Using Regression Analysis

by

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ABSTRACT

Accurate prediction of residential water demand improves the efficiency of operations, the accuracy of revenue prediction and the targeting of demand management programs. Regression analysis was used to model residential water demand for the city of Adelaide for a sample of households for the period 1978/79 to 1991/92. The rate structure includes a free allowance above which consumption is charged at a unit price. Models were developed using a dummy intercept to model consumption above and below the allowance. Price and rate structure were shown to be significant in determining the level of demand, with a 10% increase in real marginal price predicted to reduce demand in the long term by up to 6%. Other factors such as property value and household size were also shown to be significant determinants. Models were developed for forecasting annual and seasonal consumption.

ACKNOWLEDGMENTS

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The authors thank the Engineering and Water Supply Department of South Australia for providing the data used. The helpful comments provided by Mr P. Manoel of that Department are gratefully acknowledged.

The dummy intercept model was suggested by Dr T. Nguyen of the Economics Department, University of Adelaide.
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1. INTRODUCTION

The aim of the project is to estimate a demand function for residential water in Adelaide by quantifying the relationship between water demand, price and socio-economic and physical variables. This will allow more accurate prediction of water consumption and increase the understanding of how rate structure and price influence demand. It is hoped that this will assist to improve the efficiency of operations, the accuracy of revenue prediction and the targeting of demand management programs. The study forms part of a research project on optimal pricing and capacity expansion, funded by an Australian Research Council (ARC) grant. The study builds on the work undertaken by Dandy (1987) on residential water demand in Adelaide for the period 1978/79 to 1984/85.

The theory behind estimation of demand is presented in another report (Davies, 1995). This paper focuses on estimating demand for a case study using a sample of households in a pooled data set and investigating a range of models and alternative price specifications. Adelaide provides an example of the block rate structure which is common in Australia. The report starts with a description of the study area, followed by the building of the demand model and analysis of results.

2. THE STUDY AREA

The study area is defined as the Metropolitan area of Adelaide, as shown in Figure 2.1. The Engineering and Water Supply Department (EWS) is responsible for the provision of water supplies to households, industries and commercial properties in the area through a system of ten reservoirs and three major pipelines. This section of the report outlines the climate and water demands of the city as background to the development of the demand model.

2.1 Climate

2.1.1 Rainfall (Bureau of Meteorology, 1971; Linacre and Hobbs, 1977)

Adelaide is the driest of the Australian capital cities, with an average annual rainfall of 450 mm. Rainfall is distinctly seasonal with a winter dominant rainfall pattern. Average monthly rainfall for the Adelaide Regional Office (Kent Town) is shown in Figure 2.2. The first significant falls generally arrive in April or May. The months of June, July and August are usually the wettest months, with rains showing a marked decrease from October onwards. The rainfall is light and
unreliable in the summer months because of the influence of airmasses from the interior of the continent.

Figure 2.1: Map of study area
Effective rainfall is defined as the amount of rain necessary to start germination and to maintain plant growth above the wilting point. Based on this definition, summer rainfall in Adelaide for the period November to March inclusive is non-effective more than 50 percent of the time.

2.1.2 Evaporation

Potential water storage losses by evaporation greatly exceed the average rainfall in the summer months, but approximate the rainfall throughout the winter, as shown in Figure 2.2.

![Graph showing rainfall and evaporation from January to December](image)

*Figure 2.2: Average monthly rainfall and evaporation for Kent Town*

2.1.3 Temperature

Summer is generally considered to cover the period November to March inclusive. The hottest months are January and February, when mean monthly maxima on the Adelaide Plains is about 29°C (25°C in higher parts of the Mount Lofty Ranges). Prolonged spells with temperatures over 38°C occur in January in association with northerly airstreams with long trajectories over the interior of the continent. The average maximum daily temperature for each month is shown in Figure 2.3.
2.2 Water Demand in Adelaide

2.2.1 Rate Structure

The rate structure applying to residential water consumption in Adelaide consists of annual rates, which include an allowance and a unit price for all water consumed above the allowance.

The presence of an allowance in the rate structure creates a significant step in marginal price from zero to the unit price when the allowance is exceeded. This complicates the estimation of demand based on price changes because the price variation over time is overshadowed by the change between below allowance and excess consumption.

Prior to 1991/1992 the annual water rates were calculated as a percentage of the improved value of the property. The allowance was then determined by dividing the annual rates by the unit price of water for that particular year. For example in 1990/91 the base rate was 0.168% of property value and the nominal unit price of water was 80c/kL. For a property with a value of $100,000 the annual rate would be $168 and the allowance would be $168/0.8 = 210kL/year. Any water consumed above 210 kL would be charged at 80c/kL. The calculation of the allowance from property-based rates meant those households with high property values had large allowances and so often faced a zero marginal price.

In 1991/92 a constant allowance of 136 kL was allocated to each household and a 'tax' was placed on higher valued properties. The annual rates consisted of a minimum rate of $116 and a rate of 0.08% per dollar above the threshold property
value of $117,000. For higher valued properties this meant a considerable reduction in annual allowance from previous years. After 1992 the 'tax' was deleted. The effect of the dramatic drop in household allowance is investigated in this study.

Table 2.1 shows the unit price of water for the period 1979-1993. The real price was calculated using the Consumer Price Index (All Groups) for Adelaide (ABS Catalogue No. 6401.0). It is notable that the real unit price of water has not increased significantly since 1984 (Figure 2.4).

Table 2.1: Variation in unit price of residential water in Adelaide 1979-1993

<table>
<thead>
<tr>
<th>Price</th>
<th>Financial Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nom.</td>
<td>79  80  81  82  83  84  85  86  87  88  89  90  91  92  93</td>
</tr>
<tr>
<td>Real</td>
<td>22  24  27  32  37  45  53  56  62  68  71  75  80  85  88</td>
</tr>
<tr>
<td></td>
<td>58  57  59  63  66  74  84  82  83  85  83  82  82  85</td>
</tr>
</tbody>
</table>

Notes: Nom. = Nominal Price (c/kL), Real Price is in 1992 c/kL

Figure 2.4: Variation in unit price of water in Adelaide 1979-93
2.2.2 Demand Patterns (EWS, 1989)

This study only examines the residential component of Adelaide's water consumption which accounts for about 70% of the city's total consumption. The household is the consuming unit used in this study.

The trend in reticulated water use in Metropolitan Adelaide has been for consumption per household to decrease, however it is uncertain whether this trend will continue. One projection of water demand by the EWS foresees a reduction in average household consumption over the next thirty years from 348 to 291 kL/year because of demand management (installation of water saving appliances and lawn replacement) and increases in the real price of water. One aim of this study is to separate the effects of different factors on demand so as to be able to predict changes in consumption.

About half of domestic consumption in Adelaide is used outdoors, predominantly on lawns and gardens (around 90% of outdoor use). It is estimated a 25% reduction in the water used for gardens could be achieved with the use of water-saving practices, water-efficient plants and grass species, and a reduction in the area of lawn and garden. Not surprisingly, water demand in summer is greater than in winter. Seasonal models are used in this study to address these different components.

The long-term reduction in indoor use is likely to be less than outdoor. Reductions from using aerated shower nozzles and dual-flush toilets would largely be offset by an expected increase in the use of more water-using appliances, such as a 1.5% increase in the use of dishwashers. The installation of dual-flush toilets in new buildings is already mandatory and this is expected to lead to a 10.9% reduction in in-house use in the long term.

The percentage of users consuming water in excess of their allowance has been increasing over the last 14 years to a level of 66% in 1991. The percentage of excess users within the sample used in this study is consistently greater than for the population as shown in Figure 2.5.
3. BUILDING THE DEMAND MODELS

Building the demand model involved specifying the variables to be included and their functional form, and hypothesising the expected signs of the coefficients. Then the data was collected and the equation estimated and evaluated.

3.1 Data Collection

Most data for the study was collected directly from the EWS. Price variables (Section 3.1.4) were calculated from the rate structure. Monthly climatic data was collected from the Bureau of Meteorology and converted to seasonal variables (Section 3.1.5).

A total sample of 963 single dwelling households was used, stratified into 28 groups (or areas) of metropolitan Adelaide based on the proportion of total residential dwellings located within the group (Table 3.1). The sample was based on a set of households surveyed in an earlier study (Dandy, 1987). The number of households of this subset in each group (column 3 in Table 3.1) was subtracted from the group's required sample size. The remaining households (column 4) were chosen by selecting assessment numbers at regular intervals.

The only years of data accessible from the EWS computer database are 1989/90 to 1991/1992. For these years the following data was collected for each property: address, land use code, housing characteristics (number of rooms, swimming pool), water consumption (6 monthly), date of meter reading, allowance, and
capital value. No household was included in the sample if there had been a change in ownership, a leakage problem (identified by an EWS code), or a restriction notice had been issued to the property during the three year period.

Table 3.1: Sample size for each group within the Adelaide metropolitan area

<table>
<thead>
<tr>
<th>Group</th>
<th>Name</th>
<th>Survey 1987</th>
<th>Additional</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>02</td>
<td>Adelaide</td>
<td>2</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>03</td>
<td>East Torrens</td>
<td>-</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>04</td>
<td>Port Adelaide</td>
<td>10</td>
<td>28</td>
<td>38</td>
</tr>
<tr>
<td>05</td>
<td>Prospect</td>
<td>-</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>06</td>
<td>Enfield</td>
<td>9</td>
<td>52</td>
<td>61</td>
</tr>
<tr>
<td>08</td>
<td>Mitcham</td>
<td>11</td>
<td>49</td>
<td>60</td>
</tr>
<tr>
<td>09</td>
<td>Unley</td>
<td>13</td>
<td>25</td>
<td>38</td>
</tr>
<tr>
<td>10</td>
<td>Marion</td>
<td>36</td>
<td>48</td>
<td>84</td>
</tr>
<tr>
<td>11</td>
<td>Glenelg</td>
<td>-</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>12</td>
<td>Brighton</td>
<td>9</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td>14</td>
<td>Happy Valley</td>
<td>21</td>
<td>7</td>
<td>28</td>
</tr>
<tr>
<td>15</td>
<td>Kensington and Norwood</td>
<td>3</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>16</td>
<td>St Peters</td>
<td>-</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>17</td>
<td>Campbelltown</td>
<td>21</td>
<td>19</td>
<td>40</td>
</tr>
<tr>
<td>18</td>
<td>Burnside</td>
<td>13</td>
<td>24</td>
<td>37</td>
</tr>
<tr>
<td>19</td>
<td>Payneham</td>
<td>6</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>20</td>
<td>Walkerville</td>
<td>5</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>21</td>
<td>West Torrens</td>
<td>11</td>
<td>37</td>
<td>48</td>
</tr>
<tr>
<td>22</td>
<td>Thebarton</td>
<td>-</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>23</td>
<td>Hindmarsh</td>
<td>-</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>24</td>
<td>Henley and Grange</td>
<td>3</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>25</td>
<td>Woodville</td>
<td>33</td>
<td>44</td>
<td>77</td>
</tr>
<tr>
<td>28</td>
<td>Tea Tree Gully</td>
<td>42</td>
<td>33</td>
<td>75</td>
</tr>
<tr>
<td>29</td>
<td>Munno Para</td>
<td>7</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>32</td>
<td>Elizabeth</td>
<td>12</td>
<td>14</td>
<td>26</td>
</tr>
<tr>
<td>33</td>
<td>Stirling</td>
<td>-</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>44</td>
<td>Salisbury</td>
<td>32</td>
<td>59</td>
<td>91</td>
</tr>
<tr>
<td>86</td>
<td>Noarlunga</td>
<td>21</td>
<td>49</td>
<td>70</td>
</tr>
</tbody>
</table>

Total: 320  643  963
3.1.1 Subsets of Data

A subset of the sample (Set S) consisted of those households surveyed in the previous study (Dandy, 1987) apart from those excluded for the reasons outlined in Section 3.1. Additional data for this subset was taken for the years 1985/86 to 1988/89 from master-meter microfilm records, to complete the period of record from 1978/79 to 1991/92. This subset of data was used for the majority of the models described below so as to ensure consistent numbers of households for each year, so that a model was not biased by the characteristics of a particular year.

Users who have consistently consumed above their allowance for the period of the study are addressed as a subgroup within the sample (Set H). These users have constantly faced a nonzero marginal price and thus are expected to respond differently to those consuming below their allowance.

3.1.2 Consumption Data

The annual consumption for a household is identified in this study by the variable FYCONS. Most models were developed using this consumption as the "explained" variable.

Different components of consumption were used for the seasonal models (Section 3.3.6). Based on Dandy (1987) summer consumption for a household (SUMCONS) is defined as the consumption for the six month period which includes December, January and February. Winter consumption (WINCONS) is for the six month period which includes June, July and August. Excess summer consumption or sprinkling demand (XSCONS) is defined as summer consumption minus the winter consumption for the corresponding twelve month period. Only households whose meters were read in March, April or May are included in the analysis of seasonal consumption.

3.1.3 Income Data

Income has been shown to be a significant factor in determining water demand (Davies, 1995). For this study annual income data was limited to the year 1986 in bands of $5000 to $10000 and only available for households investigated in the previous survey (Dandy, 1987). Since annual water rates are significantly less than the width of the income brackets, it was expected that this variable would not be significant in the analysis and is not included. Instead property value is used as a surrogate for income.

The use of this surrogate is justified by the correlation of property value to income in Set S. A correlation test was conducted of mean income against mean
property value for households within each income bracket. The results were significant with a (Pearson's) correlation coefficient of 0.9.

Real property values were used in this study. They were calculated from the nominal values using the Housing Group Index for Adelaide (ABS Catalogue No.6401.0).

### 3.1.4 Calculation of Price Variables

The value of the price variables used in this study had to be determined from the position of the consumer in relation to the rate structure. A brief description is given of the price terms used in this study with more detail provided in Davies (1995).

Marginal price (MP) is the price for the next unit of water. Those consuming below their allowance face a MP of zero. For excess users the MP is the unit price of water. Average price (AP) is the total bill divided by the quantity of water. Bill difference (BILLD) is the difference between the total bill and what the consumer would have paid if they purchased the entire quantity at the MP. This variable is a correction to the consumer's income to account for the income effects of the intramarginal part of the rate schedule. There has been much debate about the validity of different price variables in representing how the consumer perceives price (Davies, 1995).

For the property rates based system the annual rates are R, the allowance A, the price for additional water is P, and Q is annual consumption. The marginal price, average price and bill difference are given by:

\[
MP = \begin{cases} 
0 & \text{if } Q < A \\
\frac{R}{Q} & \text{if } Q \geq A
\end{cases}
\]  \hspace{1cm} (3.1)

\[
AP = \begin{cases} 
\frac{R}{Q} & \text{if } Q < A \\
\frac{R + P(Q - A)}{Q} & \text{if } Q \geq A
\end{cases}
\]  \hspace{1cm} (3.2)

\[
BILLD = \begin{cases} 
R & \text{if } Q < A \\
R - (A \times P) & \text{if } Q \geq A
\end{cases}
\]  \hspace{1cm} (3.3)
These equations apply to the year 1991/92 of the study. In Adelaide prior to that year the allowance was set equal to R/P therefore R = A*P. Substituting into the above equations gives:

\[
\begin{align*}
AP &= \begin{cases} 
  (A \times P)/Q & Q < A \\
  P & Q \geq A 
\end{cases} \\
BILLD &= \begin{cases} 
  AP & Q < A \\
  0 & Q \geq A 
\end{cases}
\]

(3.4)  
(3.5)

Equations 3.4 and 3.5 apply to the years 1979 to 1991 of the study.

### 3.1.5 Calculation of Seasonal Climate Variables

Seasonal climate variables are required for the Adelaide study because the minimum period available for consumption data is six months. Climatic data was obtained from the Bureau of Meteorology (Adelaide Regional Office in Kent Town) and the relevant monthly data converted to the following seasonal variables:

- seasonRAIN = average monthly rainfall during season (mm)
- seasonXTEMP = average maximum daily temperature during season (°C)
- seasonNTEMP = average mean daily temperature during season
- seasonEVAP = average daily pan evaporation during season (mm)
- SUMPE = total potential evapotranspiration during summer (mm)
- SUMMD = summer moisture deficit (mm)

where season = SUM for summer, AUT for autumn, WIN for winter, SPR for spring.

The hot dry summers of Adelaide (Section 2.1) suggest that the variables most likely to affect residential water demand include rainfall (total and number of raindays), maximum daily temperatures and evaporation during the summer period. The moisture deficit term combines the effect of rainfall and evaporation and is discussed below.
3.1.5.1 Moisture Deficit

The moisture deficit (MD) variable is used in the demand models because it represents the combined effect of rainfall and evaporation in a period and resembles actual watering requirements. The calculation of the variable is based on the method used by Howe and Linaweaver (1967). Potential evapotranspiration (PE) is calculated using Thornthwaite's method (Thornthwaite and Mather, 1957) then moisture deficit (MD) is determined from the equation MD = PE - 0.6R where R is rainfall. The expression 0.6R represents effective rainfall. Only summer moisture deficit is calculated. The values for Kent Town are shown in Table 3.2. The comparison of moisture deficit to the mean annual water use of the sample in Figure 3.1 indicates a close relationship between the two variables.

Table 3.2: Values of summer moisture deficit (MD) for Kent Town station (mm)

<table>
<thead>
<tr>
<th>Financial Year</th>
<th>79</th>
<th>80</th>
<th>81</th>
<th>82</th>
<th>83</th>
<th>84</th>
<th>85</th>
<th>86</th>
<th>87</th>
<th>88</th>
<th>89</th>
<th>90</th>
<th>91</th>
<th>92</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD</td>
<td>360</td>
<td>325</td>
<td>399</td>
<td>368</td>
<td>361</td>
<td>343</td>
<td>349</td>
<td>301</td>
<td>294</td>
<td>337</td>
<td>362</td>
<td>357</td>
<td>359</td>
<td>317</td>
</tr>
</tbody>
</table>

Figure 3.1: Comparison of summer moisture deficit to mean annual water use for sample
3.2 Selection of Variables

3.2.1 List of Variables

The literature review of factors affecting water consumption (Davies, 1995) indicates variables that are likely to be significant determinants and outlines the possible magnitude and direction of the relationship. The list of variables used for this study (Table 3.3) was based on those suggestions considering the availability of data for Adelaide as described in the previous section. Seasonal climate variables are listed in Section 3.1.5. Demand is expected to have a negative relationship with price and rainfall and a positive one with all other variables.

Table 3.3: Definition of variables used in regression

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACODE</td>
<td>area code (example 04 for Port Adelaide)</td>
</tr>
<tr>
<td>AP</td>
<td>average price (bill divided by quantity) ($)</td>
</tr>
<tr>
<td>BILLD</td>
<td>bill difference ($) = total bill minus (quantity x MP)</td>
</tr>
<tr>
<td>DIMEN</td>
<td>plot size of property (square metres)</td>
</tr>
<tr>
<td>DUMVAR</td>
<td>dummy =1 if FYCONS &gt;=ALLOW, =0 if FYCONS&lt;ALLOW</td>
</tr>
<tr>
<td>DYR</td>
<td>dummy for constant allowance, =1 if year = 1992, =0 otherwise</td>
</tr>
<tr>
<td>MP</td>
<td>marginal price ($1992) - price paid for next unit (kL) of water</td>
</tr>
<tr>
<td>NUMRES</td>
<td>number of residents per household (1979-86 only)</td>
</tr>
<tr>
<td>POOL</td>
<td>dummy variable, = 1 if household owns pool, = 0 otherwise</td>
</tr>
<tr>
<td>ROOMS</td>
<td>number of rooms in household</td>
</tr>
<tr>
<td>RPROP</td>
<td>real property value ($1992) or RVPROP = value in $000</td>
</tr>
<tr>
<td>Dvariable</td>
<td>variable multiplied by DUMVAR</td>
</tr>
</tbody>
</table>

Variables from Table 3.3 were included in the demand model on the basis of theoretical relevance, completeness of data sets, correlation with consumption (including direction) and independence from other variables. The latter two requirements were tested using the correlation coefficients described below. If variables that are closely correlated are included in an equation there may be bias in the estimated coefficients.
3.2.2 Correlation Coefficients

The Pearson correlation coefficient $r$ indicates the strength of the linear relationship between two variables $X$ and $Y$:

$$ r = \frac{\sum_{i=1}^{N} (X_i - \bar{X})(Y_i - \bar{Y})}{(N - 1)S_X S_Y} \quad (3.6) $$

where $N$ is the number of cases, $\bar{X}$ and $\bar{Y}$ are the mean values of $X$ and $Y$, and $S_X$ and $S_Y$ are the standard deviations of the two variables.

The results for the correlation tests (two-tailed) for climate variables are given in Table 3.4 (Page 39). The magnitude of the coefficients suggest that the most significant climate variable is evaporation. The summer moisture deficit term combines the effects of rainfall and evaporation and is significant for annual, summer and excess summer consumption. As expected, consumption is less affected by climate in seasons other than summer.

Correlation coefficients for all other variables are shown in Tables 3.5 and 3.6 (Pages 40 and 41). The results show that consumption is correlated with the price variables but the relationship is a positive one for marginal price. This is probably a result of the simultaneity problem often described in literature (Davies, 1995), with the marginal price depending on the quantity consumed rather than price determining the quantity consumed. The strong contrast of a MP of zero below the allowance and a relatively high value above the allowance would contribute to this problem. The use of a dummy intercept in the demand models (Type D) attempts to overcome this problem (Section 3.3.2).

All variables other than price are shown to be correlated to the different components of consumption (Table 3.6). This suggests any of the variables could be used in a model with the order of selection based on the magnitude of correlation. There is also significant cross correlation between the variables (Table 3.5) indicating that care should be taken in using multiple regression analysis.

3.3 Types of Models

The following types of models were investigated using the REGRESSION command in the SPSS computer package. They represent the alternative methods of estimation suggested by the review of literature (Davies, 1995) with the addition of a model type that specifically addresses the issue of an allowance (model type D in Section 3.3.2). The results of the models are given in Section 4.
3.3.1 Type A models - ordinary least squares

Ordinary least squares (OLS) analysis of annual consumption was undertaken to provide the basis for comparing methods. Previous studies have shown that OLS can provide adequate results with the advantage of simplicity.

3.3.2 Type D models - with dummy intercept and dummy slope

The block rate structure with an allowance is common in Australia. Developing a method for describing consumption under such a rate structure is fundamental to this study. The following model was suggested by Nguyen (pers comm, 1993).

The model is based on the theory that consumers face a MP of zero when consuming below their annual allowance so that water consumption depends only on needs that vary with household size, climate and other factors. When consuming above the allowance water usage will be responsive to price and the response to various needs is expected to be lower in absolute value.

For use of block rate structures with allowance (A):

\[ Q = \beta_0 + \beta_1 I + \beta'_3 Z + D(\gamma_0 + \gamma_1 (I - A \times P) + \gamma_2 P + \gamma'_3 Z) + \mu \quad (3.7) \]

or

\[ Q = \beta_0 + \beta_1 I + \beta'_3 Z + \gamma_0 D + \gamma_1 D(I - A \times P) + \gamma_2 DP + \gamma'_3 DZ + \mu \quad (3.8) \]

where \( D = \begin{cases} 1 & Q < A \\ 0 & Q \geq A \end{cases} \)

where:
- \( Q \) = quantity of water consumed (kL)
- \( A \) = annual allowance (kL)
- \( I \) = annual household income ($)
- \( P \) = price variable (may be AP, MP, or combined MP and BILLD)
- \( Z \) = vector of other variables (household size, climate, etc)
- \( D \) = dummy variable for intercept (DUMVAR in this study)
- \( \beta, \gamma \) = coefficients
- \( \beta'_3, \gamma'_3 \) = vector of coefficients
- \( \mu \) = error term

There is an expectation that \( \beta_1 > 0, \gamma_0 > 0, \gamma_1 > 0, \gamma_2 < 0 \). It is expected there is a positive relationship between income and consumption and a negative one
between price and consumption. The intercept for consumption above the allowance is expected to be greater than that for consumption below the allowance.

Care needs to be taken in interpreting the regression results. In particular,

\[ \beta_0 = \text{intercept for } Q < A; \]
\[ \beta_0 + \gamma_0 = \text{intercept for } Q \geq A; \]
\[ \gamma_0 = \text{difference between intercepts.} \]

The conventional test of significance on \( \beta_0 \) is testing whether the intercept for \( Q < A \) is significantly different from zero. The same test on \( \gamma_0 \) is testing whether there is any significant difference between the intercepts of above and below allowance users (Johnston, 1978).

The use of slope dummies for non-price variables allows slopes to be different above and below the allowance. The underlying theory is that the response to needs is lower in absolute value when consumption is above the allowance.

Theory suggests that allowance should not be included as a variable in the model. If consuming below the allowance then the consumer is responding to needs and allowance is not one of them. If consuming above the allowance then the consumer is responding to costs as well as needs. The information relating to the allowance is incorporated into the equation in the price variable and the variable DUMVAR which indicates if the consumer is above or below the allowance.

The model includes a variable of income minus minimum water rates \((I - A \times P)\) in Equation 3.7 to indicate how much income is left after paying the minimum rates. This variable was not used in this study since property value is used as a surrogate for income (Section 3.1.3) because of the lack of income data.

3.3.3 Type G models - dynamic models

The rationale for the use of dynamic models is the assumption that water use will respond slowly to changes in price and other variables due to the slowly changing stock of water-using consumer durables such as washing machines, dishwashers, and swimming pools (Dandy, 1987).

The dynamic model used in this study is of the Koyck distributed lag type as shown below:
\[ Q_t = \beta_0 + \beta_1 P_t + \beta_2 Z_t + \beta_3 Q_{t-1} + u_t \]  \hspace{1cm} (3.9)

where \( t \) is time period.

The effective sample size is reduced because the first year of consumption for each household is needed as an explanatory variable.

### 3.3.4 Type L models - with log transformation of variables

The high values of the correlation coefficients in Table 3.6 suggest that most of the independent variables in this study are linearly related to consumption. However, since theory does not clearly define the potential relationship, a demand model of the Cobb Douglas type was estimated by regressing the logarithm (base 10) of annual consumption against the logarithms of all explanatory variables (except dummy variables).

### 3.3.5 Type V models - using instrumental variables

One method of reducing the simultaneity problem involved in estimating demand is to use the 2-stage instrumental variable model as described in Davies (1995). In this study such a model was developed by regressing \( MP \) and \( BILLD \) against other variables in the first stage. The predicted values of these variables are then used in the second stage when consumption is regressed against all other variables including \( MP \) and \( BILLD \). The results of both stages are presented in Section 4.1.5.

### 3.3.6 Type S models - seasonal consumption models

Previous studies have shown that more accurate models of water consumption are developed if consumption is disaggregated into inhouse (winter) and exhouse (excess summer) use. Consumption models for \( WINCONS \) (winter), \( SUMCONS \) (summer) and \( XSCONS \) (excess summer) were developed for OLS, dummy intercept and dynamic models.

### 3.4 Testing the Models

Each model has to be tested to confirm it is correctly specified and that the assumptions on which it is based are not violated.

### 3.4.1 Selection Criteria

Specification criteria can be used to compare alternative estimated equations. Four of the most common specification criteria are described below and applied
to this study. The results of the tests for each model are described in Section 4. The discussion on the first three methods is based on Studenmund and Cassidy (1992).

3.4.1.1 Adjusted R Squared

The term $R^2$ is the coefficient of determination, indicating the goodness of fit of an equation in describing the sample. It is the square of the correlation coefficient between $Y$, the observed value of the dependent variable and $\hat{Y}$, the predicted value of $Y$ from the fitted line. Adjusted $R^2$ is the coefficient of determination adjusted for the degrees of freedom and so takes account of the number of variables in the equation. The term is expressed as:

$$\text{Adj}R^2 = R^2 - \frac{p(1-R^2)}{N-p-1} \quad (3.10)$$

where $N$ is the sample size and $p$ is the number of explanatory variables. The adjusted $R^2$ is used in this study.

3.4.1.2 Ramsey's Regression Specification Error Test (RESET)

The Ramsey RESET is a general test that determines the likelihood of an omitted variable or some other specification error by measuring whether the fit of a given equation can be significantly improved by the addition of the $\hat{Y}^2$ and $\hat{Y}^3$ terms, where $\hat{Y}$ is the predicted value of $Y$. The term $\hat{Y}^4$ is often added to the test. The additional terms act as proxies for any possible (unknown) omitted variables or incorrect functional forms. The terms form a polynomial function which is a powerful curve-fitting device that has a good chance of acting as a proxy for a specification error if one exists. If the proxies can be shown by the F-test to have improved the overall fit of the original equation, then there is evidence that there is some sort of specification error in the equation.

The steps for the test are:

1. Estimate the equation to be tested using OLS:

$$\hat{Y} = \beta_0 + \beta_1Z \quad (3.11)$$

2. Take the predicted $Y$ values from Equation 3.11 and create $\hat{Y}^2$, and $\hat{Y}^3$, add these terms to the equation as additional variables and estimate the new equation with OLS.
3. Compare the fits of the two equations using the F-test:

\[
F = \frac{(RSS_M - RSS)/M}{RSS/(N-p-1)}
\]  

(3.12)

RSS\textsubscript{M} is the residual sum of squares from the restricted equation (Equation 3.11), RSS is the residual sum of squares from the unrestricted equation, M is the number of restrictions and the expression (N - p - 1) is the degrees of freedom in the unrestricted equation. Residuals are the difference between observed values and the values predicted by the model. The test only indicates that a specification error is likely to exist in an equation, it does not specify the details of that error. The critical F-value for this study is 4.61 with 2 degrees of freedom for the numerator and > 120 for the denominator at the 1% level of significance (Johnston, 1978).

### 3.4.1.3 Amemiya's Prediction Criterion (PC)

Another category of formal specification criterion involves adjusting the RSS by a factor to create an index of the fit of an equation. One of the easiest to use is Amemiya's Prediction Criterion (PC). It compares alternative specifications by adjusting RSS for the sample size and the number of explanatory variables. The lower the PC the better the specification. The equation for the criterion is:

\[
PC = \frac{RSS(N+p)}{(N-p)}
\]  

(3.13)

If all other factors (such as theoretical relevance) are equal, then the specification with the lowest value of PC should be chosen. The criterion is similar to adjusted \(R^2\) but it penalises the addition of another variable more than adjusted \(R^2\) does. The theoretical basis for PC is that it is a proxy for Mean Square Error (MSE). MSE is a specification selection criterion that allows a tradeoff between bias and variance. This tradeoff is important because including an additional explanatory variable may reduce bias but at the cost of increasing the variance of the estimated coefficients.

The values of PC for this study are divided by \(10^4\) for ease of comparison.

### 3.4.1.4 Root Mean Square Error (RMS)

Root Mean Square Error (RMS) provides a measure of accuracy of the model by calculating the difference between the actual and predicted values. It is defined as:
\[ \text{RMS} = \left( \frac{\sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2}{N} \right)^{0.5} \]  

(3.14)

where \( Y_i \) = the \( i \)th observed value of annual water consumption and \( \hat{Y}_i \) = the \( i \)th predicted value of annual water consumption.

Using the squares of the errors removes the sign of the error and so prevents positive and negative errors of similar magnitude cancelling each other.

3.4.2 Testing of Model Assumptions

To draw inferences about population values based on sample results, a number of assumptions are needed. These assumptions are described below together with a discussion of how violations were searched for, using residuals. The REGRESSION command in SPSS package provides simple methods of testing these assumptions (SPSS, 1990). The results of these tests for one correctly specified model (Model D1) are given as an example in Section 4.1.2.

3.4.2.1 Normality and Equality of Variance

Assumption: for any fixed value of the independent variable \( X \), the distribution of the dependent variable \( Y \) is normal, with mean \( \mu_{Y/X} \) (the mean of \( Y \) for a given \( X \)) and a constant variance of \( \sigma^2 \).

*Normality of Variance*

The normality of variance was tested by comparing the observed distribution of residuals to that expected under the assumption of normality. The test involved plotting the two cumulative distributions against each other for a series of points. If the residuals are normally distributed then a straight line results.

*Equality of Variance*

If the spread of residuals increases or decreases with the values of independent variables or with predicted values, the assumption of constant variance of \( Y \) for all values of \( X \) is questionable. For a multiple regression model a partial regression plot is used to test this assumption.

3.4.2.2 Independence of Error

Assumption: the \( Y \)s are statistically independent of each other, so that observations are not influenced by other observations. For this study the cases
were sorted by year then the residuals plotted against this sequence variable. If the sequence and the residual are independent there should not be a discernible pattern in the plot.

3.4.2.3 Linearity

Assumption: the mean values of $\mu_{Y/X}$ all lie on a straight line, which is the population regression line. Systematic patterns between predicted values and the residuals suggest possible violations of this assumption. If the assumption was met the residuals would be randomly distributed in a band about the horizontal line through zero.
4. ANALYSIS OF RESULTS

The regression results for all models are given in Tables 4.1 to 4.7 (Pages 42 to 52) with the t-statistic for each regression coefficient given in brackets. The results are discussed under the different types of models (Section 4.1) and the various explanatory variables (Section 4.2). The values for the adjusted R², RESET, PC and RMS tests are given in the last four columns of each table. A model was defined as being correctly specified if it met the RESET criteria. However this did not appear to be always valid given that a model with a correct RESET value could still have variables with incorrect signs suggesting the model was not theoretically plausible. The results of the other three criteria tests allow comparisons of the accuracy of the different models.

The set of data used was predominantly Set S (described in Section 3.1.1). The subset of households consistently consuming above their allowance (Set H) are used for some models. For this subset DUMVAR is always 1 and so the models used are simply OLS models.

4.1 Analysis by Model Type

4.1.1 Type A models - OLS

The model using AP (Model A1 in Table 4.1) had an adjusted R² value of 0.39. Significant variables are property value, plot size, household size, ownership of swimming pool, number of rooms, the price variable and dummy variable DYR. The values of the RESET test suggest the model is not correctly specified.

A model using MP gave an incorrect sign for the price coefficient and is not included in the results. A model was developed using unit price as the price variable (Model A3). This assumes that all consumers perceive their price as the current excess water price, regardless of where they consume in relation to their allowance. The RESET value again suggests the model is not correctly specified.

A simple OLS model (Model A5) incorporates the data available to the EWS. It uses the variables of lagged consumption, real property value, plot size, number of rooms, ownership of pool, and unit price. The adjusted R² is 0.64 and it has a low RMS of 84.15. The RESET value however suggests it is not correctly specified.

OLS models with lagged consumption are discussed in Section 4.1.3.
4.1.2 Type D models - with dummy intercepts and slopes

The introduction of dummy intercepts and slopes gave a correctly specified consumption model D1 (Table 4.2) with a RESET value of 2.69 and an adjusted R² of 0.49.

The intercept for consumption below allowance is 35.73, which is shown not to be significantly different from zero by the t-statistic of 1.80. The intercept for consumption above the allowance is 402.08 (35.73 + 366.35). The t-statistic of 11.43 for the above allowance coefficient indicates that there is a significant difference between the two intercepts. The individual explanatory variables of the equation are discussed in Section 4.2.

Another model (D5) was developed to include the number of rooms but exclude the variables of household size and plot size. This was done because data on household size is not often available to water authorities and both this and the plot size variable are correlated to the number of rooms (Section 3.2.2). The RESET value suggests the model is not correctly specified. One possible explanation is that data on household size is required together with the number of rooms to provide the variability required to identify differences between individual households.

The model for consumption prior to 1987 (Model D4) was estimated to compare the results with those of the previous study (Dandy, 1987). The earlier models all included the allowance variable which was not included in this study. The current model gave an adjusted R² of 0.56 compared to 0.32 for the similar model in the previous study. Comparisons of regression coefficients are impossible given the inclusion of different variables. The RESET value of 7.71 for Model D4 suggests the model is close to being correctly specified.

Models with the addition of climate variables (Models D2 and D3) are discussed in Section 4.2.6.

A problem inherent in the use of this type of model is that the model requires knowledge of whether an individual household is consuming above or below the allowance by the dummy intercept (DUMVAR). This variable has to be predicted for households outside the sample and for future years. This problem is addressed further in related work on estimating water demand using neural networks to predict binary choices (Davies and Dandy, 1995).
4.1.2.1 Verification of Model Performance

The results of Model D1 were verified by using 90% of the sample data for developing the model and comparing predicted with actual values for the remaining 10% of the sample. The cases were divided by selecting every 10th case for the 10% sample. The verification results are shown in Figure 4.1, with a RMS of 93.73. This value is lower than the RMS of 100.02 for the entire sample (Table 4.2). The plot of actual against predicted values demonstrates a reasonable fit with the model underpredicting consumption above 500 kL. Lack of data in this region of the sample would contribute to the error.

![Figure 4.1: Verification results using 10% sample for Model D1](image)

Testing of Model Assumptions

The model assumptions described in Section 3.4.2 were tested for this model. The line of observed residuals followed approximately the line of expected values and so the assumption of normality of variance was not violated. The partial regression plots for the independent variables showed a reasonable scatter of residuals suggesting there was equality of variance. The plot of residuals against year showed no discernible pattern indicating an independence of error, although there was a tendency for the model to be more likely to underpredict in the latter years of the study period. The partial regression plots showed no pattern between predicted values and the residuals and so the assumption of linearity was not violated.
4.1.3 Type G models - dynamic models

The dynamic models gave better results in terms of adjusted $R^2$ than the static models with values of 0.72 for MP (Model G1 in Table 4.3), 0.68 for AP (Model A2 in Table 4.1) and 0.65 for unit price (Model A4 in Table 4.1). However, the RESET values suggest none of these are correctly specified.

The coefficients in Model G1 indicate that household response to lagged consumption increases if consumption is above the allowance. Possibly these households have a greater stock of water-using appliances or greater inertia in their habits.

For consistent high users (Set H) the dynamic model for annual consumption (Model A7 in Table 4.1) is a better model (in terms of all four tests) than the static one (Model A6) suggesting that this group of users continues its water-using habits more than the entire sample. This is confirmed by the lower response to price by this group (Section 4.2.1).

The regression coefficients (Table 4.3) are short-run values. The long-run or steady-state coefficients are given by:

$$\beta_L = \frac{\beta}{1 - \alpha_i}$$  \hspace{1cm} (4.1)  

where $\beta_L$ is the long-run regression coefficient, $\beta$ is the coefficient of the variable for time $t$, and $\alpha_i$ is the coefficient of $Q_{t-1}$ (Dandy, 1987).

The long-run coefficients for this model type are similar to those derived from the comparable type D models. The logarithmic models and IV models are discussed separately in Sections 4.1.4 and 4.1.5 respectively.

4.1.3.1 Verification of Model Performance

The verification results using a 10% test set (as in Section 4.1.2.1) are shown in Figure 4.2, with a RMS of 67.21. The plot of actual against predicted values demonstrates a reasonable fit with the model predicting consumption above 500 kL more accurately than Model D1.
4.1.4 Type L models - logarithmic models

The logarithmic Model L1 (Table 4.2) has similar explanatory power to the linear model D1. The RESET value of 2.00 suggests it is correctly specified. Given that the model does not significantly improve the goodness of fit the simpler linear model is preferred.

4.1.5 Type V models - instrumental variable models

The results of the first stage of the IV model are given in Table 4.8 and 4.9 below for the price variables of MP and bill difference.

<p>| Table 4.8: Regression results for first stage for independent variable of marginal price |
|------------------------------------------|----------|-------|</p>
<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>unit price</td>
<td>1.206</td>
<td>17.98</td>
</tr>
<tr>
<td>property value</td>
<td>-.001</td>
<td>-5.81</td>
</tr>
<tr>
<td>dyr</td>
<td>.1747</td>
<td>7.15</td>
</tr>
<tr>
<td>plot size</td>
<td>.00009</td>
<td>3.90</td>
</tr>
<tr>
<td>constant</td>
<td>-.385</td>
<td>-7.30</td>
</tr>
</tbody>
</table>

Note: Adjusted $R^2 = 0.14$
Table 4.9: Regression results for first stage for independent variable of bill difference

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>unit price</td>
<td>-53.00</td>
<td>-7.99</td>
</tr>
<tr>
<td>property value</td>
<td>.270</td>
<td>14.02</td>
</tr>
<tr>
<td>dyr</td>
<td>-5.500</td>
<td>-2.28</td>
</tr>
<tr>
<td>plot size</td>
<td>-.0095</td>
<td>-4.05</td>
</tr>
<tr>
<td>constant</td>
<td>44.93</td>
<td>8.62</td>
</tr>
</tbody>
</table>

Note: Adjusted $R^2 = 0.08$

The values of MP and BILLD were predicted from these equations and then used in an OLS model (Model V1 in Table 4.1), a model with dummy intercept (Model V2 in Table 4.2) and a dynamic model (Model V3 in Table 4.3). The OLS model gave the correct sign for the MP variable. None of these models are correctly specified although the RESET values are lower than for many other models. The values for the other three specification tests are virtually identical to those for other model types.

4.1.6 Type S models - seasonal models

The division of consumption into component models results in two correctly specified models, Model S1 for winter and Model S10 for excess summer consumption (Table 4.4 and 4.6). The best model based on RESET value for summer consumption is a type D model (Model S6). One of the aims of constructing these models was to investigate the influence of climate. This variable is discussed in Section 4.2.6.

4.2 Factors Affecting Water Demand in Adelaide

This section discusses the influence of the individual explanatory variables on water demand in Adelaide. Investigating these effects enables changes in consumption to be predicted given changes in the determinants. The influence of price and rate structure is particularly relevant to water authorities because it is the only variable over which they have control.
4.2.1 Changes in Rate Structure and Unit Price

4.2.1.1 Price

An important parameter in assessing the effects of pricing policy on urban water demand is price elasticity. This is defined as the percentage change in quantity demanded divided by the percentage change in price.

\[ \varepsilon = \left( \frac{\Delta Q/Q}{\Delta P/P} \right) \]  \hspace{1cm} (4.2)

where \( \varepsilon \) = the price elasticity of demand, \( Q \) = the quantity demanded when the price is \( P \) and \( \Delta Q \) = the change in quantity resulting from a price change of \( \Delta P \).

Values for price elasticities are shown in Table 4.10. They are calculated for a linear model by using the formula \( \beta(P/Q) \), where \( \beta \) is the regression coefficient and \( P \) and \( Q \) are the mean values of price and consumption respectively. A point elasticity is thus determined. For models with dummy intercepts the overall response is calculated by using the percentage of water consumption that is above the allowance. For logarithmic models the elasticity is given by the coefficient of price.

The literature (as discussed in Davies, 1995) suggests a range for long-run (LR) elasticity of -0.20 to -0.40 for both AP and MP. For this study the corresponding range is -0.20 to -0.60. The upper limit is set by the MP model. The lowest response is for Model D4 which represents the period prior to 1987, suggesting an increase in response has occurred as awareness has increased. The short-run (SR) value range is -0.12 to -0.22.

Consistent high users are shown to have a LR response of -0.31 to -0.52 and a low SR response of -0.09. Estimated price elasticities for this group in the previous study (Dandy, 1987) was -0.35 to -0.47 for LR response and -0.10 for SR response, which demonstrates consistency in results. For models with dummy intercepts the elasticity for consumption above the allowance is calculated to be higher than for the overall response.

For winter consumption the elasticity values were -0.09 (SR) and -0.23 to -0.35 (LR) compared to a suggested range of 0 to -0.10 in the literature. However, the latter was based on only a few studies.

For summer consumption values were -0.28 (SR) and -0.54 to -0.67 (LR). These values agree with the suggested range from literature (Davies, 1995) of -0.50 to -0.60 for LR.
Table 4.10: Elasticity values for selected variables

<table>
<thead>
<tr>
<th>Model</th>
<th>Price</th>
<th>Property Value</th>
<th>No. Residents</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SR</td>
<td>LR</td>
<td>SR</td>
<td>LR</td>
</tr>
<tr>
<td>Static models</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>-0.57</td>
<td>0.25</td>
<td>0.34</td>
<td>unit price</td>
</tr>
<tr>
<td>D1</td>
<td>-0.49</td>
<td>0.32</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>V1</td>
<td>-0.22</td>
<td>0.35</td>
<td>0.20</td>
<td>IV, no dummy</td>
</tr>
<tr>
<td>V2</td>
<td>-0.22</td>
<td>0.32</td>
<td>0.19</td>
<td>IV, with dummy</td>
</tr>
<tr>
<td>L1</td>
<td>-0.34</td>
<td>0.27</td>
<td>NS</td>
<td>log</td>
</tr>
<tr>
<td>D4</td>
<td>-0.20</td>
<td>0.47</td>
<td>0.18</td>
<td>&lt; 1987</td>
</tr>
<tr>
<td>A6</td>
<td>-0.52</td>
<td>0.35</td>
<td>0.14</td>
<td>high users</td>
</tr>
<tr>
<td>Dynamic Models</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>-0.22</td>
<td>-0.60</td>
<td>0.14</td>
<td>0.38</td>
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<td>V3</td>
<td>-0.12</td>
<td>-0.33</td>
<td>0.09</td>
<td>0.24</td>
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<tr>
<td>A7</td>
<td>-0.09</td>
<td>-0.31</td>
<td>0.10</td>
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<td>Seasonal Models</td>
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<td>Winter</td>
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<td>S2</td>
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<td>0.28</td>
<td>0.32</td>
<td>static</td>
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<tr>
<td>S3</td>
<td>-0.09</td>
<td>-0.23</td>
<td>0.16</td>
<td>0.33</td>
</tr>
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<td>S4</td>
<td>NS</td>
<td>NS</td>
<td>0.28</td>
<td>0.58</td>
</tr>
<tr>
<td>Summer</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>S6</td>
<td>-0.54</td>
<td>0.41</td>
<td>0.10</td>
<td>static</td>
</tr>
<tr>
<td>S7</td>
<td>-0.28</td>
<td>-0.67</td>
<td>0.15</td>
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</tr>
<tr>
<td>S8</td>
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<td>0.51</td>
<td>NS</td>
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<tr>
<td>Excess Summer</td>
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<td></td>
</tr>
<tr>
<td>S10</td>
<td>-0.64</td>
<td>0.51</td>
<td>NS</td>
<td>static</td>
</tr>
<tr>
<td>S11</td>
<td>-0.40</td>
<td>-0.78</td>
<td>0.27</td>
<td>0.53</td>
</tr>
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<td>S12</td>
<td>NS</td>
<td>0.34</td>
<td>0.89</td>
<td>NS</td>
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</table>

Notes:
all models are for MP unless specified
NS = not significantly different from zero
NA = not applicable, SR = short run, LR = long run
For sprinkling demand the observed range for western US was -0.73 to -0.82. This region has a similar dry summer to Adelaide. The values estimated in this study were -0.64 to -0.78 (LR) and a value of -0.40 for SR. These values indicate that sprinkling consumption in Adelaide is only slightly less elastic than other areas studied previously.

Overall the values estimated are within the range of other studies and contribute to the understanding of the effect of price on Australian water consumers.

Effect on consumption and revenue

Based on the above price elasticities of demand a 10% increase in MP would result in a reduction in average demand of up to 6% and an increase in revenue of 3%.

4.2.1.2 Change to Constant Allowance

The dummy variable DYR was used to estimate the effect of the introduction of a constant allowance of 136 kL in 1991/92. The results for Model D1 suggest that the change resulted in a reduction of around 70kL per household (or 21% of average use). The corresponding coefficients for seasonal consumption suggests the reduction can be divided into 20 kL for winter (Model S2) and 50 kL for summer (Model S6). The variable is significant for all models.

Another method for estimating the impact of the rate change on water use was based on Young et al (1983). Demand functions were estimated for the period before rate change, with and without dummy intercept in models R1 and R2 (Table 4.7 on Page 51), respectively. The functions were estimated with the price variable excluded. The change in water use associated with the rate structure change was then estimated by deducting actual water use in 1992 from predicted use, based on these pre-1992 consumption patterns. The estimated impact of the rate change was 21% in average use for Model R1 and 17.4% for Model R2. This confirms the value obtained for DYR in Model D1.

4.2.1.3 Bill Difference

According to Agthe et al (1986) the bill difference variable is expected to be negative for an increasing block structure (such as in Adelaide) unless the availability of service charge is large.

Prior to 1992 the bill difference is equal to AP (according to Equation 3.5) if consumption is below the allowance and zero if consumption is above the allowance. The bill difference is positive for those consuming below their
allowance and thus the effect of the allowance is to create a decreasing rate structure (in terms of bill difference) for these consumers.

Before 1992 the variable DBILLD (=DUMVAR×BILLD) is always 0 since:

if FYCONS ≥ ALLOW then DUMVAR =1 but BILLD 0, so DBILLD 0
if FYCONS < ALLOW then DUMVAR =0, so DBILLD =0

In 1992 the effect of the 'tax' on higher valued properties was to give a positive bill difference for those properties with a value higher than $117,000. The value of BILLD increased in proportion to the property value.

4.2.2 Property Value and Income

Property value is a surrogate for income in this study and is shown to be significant in determining water demand. The variable RVPROP is used which is the real property value in $1992 expressed as thousands of dollars.

For Model D1 the coefficient is 0.71 for below the allowance and 1.46 for above the allowance. The significant difference between the two coefficients indicates that property value has a greater impact when consuming above the allowance. This agrees with the theory that income is a more influential factor for consumers facing a non-zero marginal price.

The range of elasticity values established from the literature (Davies, 1995) for this variable is 0.33 to 0.55 in the LR for annual consumption. In this study, the elasticity range is 0.24 to 0.47 (Table 4.10). The highest value was for Model D4 which represents the period prior to 1987. Price elasticity for this model was the lowest of the group investigated. It is possible the strong relationship between property value and the level of allowance (and therefore MP) may have influenced the results for this model.

The elasticity values for seasonal consumption were 0.33 for winter, 0.49 for summer and 0.53 for excess summer. This agrees with the theory that exhouse use is more responsive to income levels.

The values established for the SR were 0.09 to 0.14 for annual consumption, 0.16 for winter, 0.15 for summer and 0.27 for excess summer.

For high users (Set H) the LR value was 0.35 which is within the range of previous studies. The values for seasonal consumption were even higher, being 0.51 for summer and 0.89 for excess summer consumption. The mean property value for high users was around 15% less than that for other users. This probably
reflects the previous system of property-based rates which meant that properties with lower values had lower allowances and thus there was more chance of consuming above the allowance, if all other factors were constant.

4.2.3 Number of Residents

The number of persons in a household has previously been found to positively influence the amount of water consumed for domestic uses such as bathing or toilet flushing. Outdoor uses such as watering are less influenced by the size of the household. The variable was found to be significant for all models except those with lagged consumption (Table 4.3).

The coefficient for consumption above the allowance was found to be not significantly different from that for consumption below the allowance. This agrees with the theory that household size influences the base water use for households and can be classified as a need which is a similar for all households.

The high users group had an average household size of 3.89 (mode of 4) compared to the average for the whole group of 3.21 (mode of 2). This suggests that the high consumers are, on average, larger households and the question of equity has to be addressed in formulating rate structures.

The elasticity values identified in the literature (Davies, 1995) suggest a range of 0.25 to 0.57. Thus the increase in consumption is less than proportional to an increase in household size. For this study the LR range was 0.11 to 0.34 (Table 4.10) and the SR value was 0.03.

For this study the values for winter consumption were 0.32 to 0.42 in the LR and 0.19 in the SR which is in the range previously identified. The variable was not significant for summer and excess summer demand, which agrees with the theory that variations in consumption during the summer period are more related to sprinkling demand than inhouse use.

4.2.4 Plot Size

The water requirements of a garden can be related to the area to be watered. Although some data on watered area was available from Dandy (1987) its accuracy is questionable. A variable for plot size (square metres) was used as a surrogate for watered area. The variable was found to be significant only for those models without a dummy intercept (such as Models A1, A3 and S5) and the annual consumption model for consistent high users (Model A6). None of these models were classified as being correctly specified by their RESET values.
The variable may not be significant because it does not accurately reflect the actual water requirements of the garden area, given that the percentage of area under lawn and the watering habits of the individual household are expected to vary widely.

### 4.2.5 Location

It was hypothesised that the location of a household in Adelaide would have some impact on water demand, particularly the amount used for sprinkling. Some suburbs have more established gardens or a significant emphasis is placed on garden appearance. This factor would incorporate less tangible factors than those included in plot size.

Since the area codes used in the study have no numerical significance, the impact of location was tested using dummy variables for each area. The dummy variable AD4 has a value of 1 for area code 04 (Port Adelaide) and zero for all other areas, and similarly for each area code. The results for the regression model (D6) which includes these dummy variables are shown in Table 4.2 with the details for the location variable given below in Table 4.11. Only significant results are shown, so that for all other locations the value is not significantly different from zero.

Those areas with significant positive values (higher consumption) include areas with recent development which may require more watering to establish gardens or areas with well-established gardens (such as Burnside). The coefficients derived from this study are specific to the sample used. Their significance, however, illustrates that location needs to be considered in estimating demand.

**Table 4.11: Significance of location on water demand using regression coefficients for Model D6**

<table>
<thead>
<tr>
<th>Area</th>
<th>Regression Coefficient</th>
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<tbody>
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</tr>
<tr>
<td>10</td>
<td>Marion</td>
</tr>
<tr>
<td>17</td>
<td>Campbelltown</td>
</tr>
<tr>
<td>18</td>
<td>Burnside</td>
</tr>
<tr>
<td>19</td>
<td>Payneham</td>
</tr>
<tr>
<td>21</td>
<td>West Torrens</td>
</tr>
<tr>
<td>25</td>
<td>Woodville</td>
</tr>
<tr>
<td>29</td>
<td>Munno Para</td>
</tr>
<tr>
<td>44</td>
<td>Salisbury</td>
</tr>
</tbody>
</table>
4.2.6 Climate

The magnitude of the correlation coefficients for climate variables against annual consumption (Section 3.2.2) suggests the use of evaporation as an input to the equation. One model was developed using summer moisture deficit (Model D2 in Table 4.2) which combines the effect of evaporation and rainfall (Section 3.15.1). Another model was developed using spring evaporation as a variable (Model D3). Both models have significant results for consumption above and below the allowance, and there is a minor increase from Model D1 in the value of adjusted R². The RESET values for both models indicate that they are almost correctly specified. Other climate variables were tested which had been shown to be significantly correlated. However no model was correctly specified according to the RESET test and/or resulted in an increase in the value of adjusted R².

The coefficient for consumption above the allowance is less than that for below the allowance. This suggests that consumers respond to climate as a need, which decreases in absolute value for consumption above the allowance.

Winter evaporation is shown to significantly affect winter consumption (Models S1 to S4), with a coefficient of around 1.10 to 1.30. For both summer and excess summer models the coefficient for summer moisture deficit is significant for the correctly specified models (Models S6 and S10). Consumption above the allowance is not influenced any differently to that below the allowance for all seasonal models, apart from summer consumption (Model S6).

4.2.7 Number of Rooms

The number of rooms is a significant variable for the correctly specified type D models, with a coefficient of around 10 to 15. The number of rooms per household varies from 3 to 10 in the sample. Around 50% of households have 5 rooms. There is not a statistical difference between consumption below and above the allowance for this variable.

4.2.8 Pool Ownership

The ownership of a swimming pool would be expected to increase a household's water consumption. Ownership was represented by the value of 1 for the dummy variable POOL. The variable was significant for the static models, with a coefficient of around 50 to 70 for consumption below the allowance and around 10 to 15 for consumption above the allowance. This suggests water use above the allowance is more price responsive and the response to the 'need' of filling a pool is lower.
In dynamic models the POOL variable is not significant, suggesting the lagged consumption variable assumes its role.

5. CONCLUSIONS

Regression analysis was used to model residential water demand for the city of Adelaide for a sample of households for the period 1978/79 to 1991/92. The rate structure includes an allowance above which consumption is charged at a unit price. Prior to 1991/92 the allowance for a property was based on a percentage of the improved property value.

Correctly specified demand models were developed using a dummy intercept to model consumption below and above the allowance. The bill difference variable was used to incorporate the income effect of the rate structure. The marginal price variable was included to measure the effect of an increase in the price of the next unit of water.

Effect of rate structure and price

The overall price elasticity for marginal price was estimated to be in the range of -0.20 to -0.60, suggesting an increase of 10% in the real marginal price would result in a reduction in demand in the long run of up to 6% and an increase in revenue of 3%. Any increase in price would result in a greater reduction in summer demand than that for winter.

The change to a constant allowance of 136 kL in 1991/92 was estimated to have reduced annual demand by 70 kL per household (or 21% of average use). Most of this reduction (50 kL) occurred during the summer period.

Effect of other factors

Other factors such as property value and household size were also shown to be significant in determining the level of demand. A continuing trend in the reduction of household size is likely to reduce the level of household demand, with a 10% reduction in size resulting in a decrease of up to 3% in demand in the long-run. Increases in average property value, if they reflect increases in income, will result in an increase in demand of up to 4.7% for a 10% increase in the real property value.

Prediction of consumption

Model D1 was verified as predicting consumption although there was underprediction in the range above 500 kL. It is recommended that this model be
used for long-term forecasts of annual consumption and Model G3 for short-term forecasts. Models S3 and S7 should be used for short term forecasts of seasonal consumption and Models S1 and S6 for long term forecasts. A simple OLS model (Model A5) incorporates the data available to the EWS. It uses the variables of lagged consumption, real property value, plot size, number of rooms, ownership of pool, and unit price.
REFERENCES


Table 3.4: Correlation coefficients for climate variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>FYCONS</th>
<th>SUMCNS</th>
<th>WINCONS</th>
<th>XSCONS</th>
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<td></td>
<td></td>
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<td>Max Temperature</td>
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<td>.120 **</td>
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<td>Pot. Evapotranspiratn.098</td>
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<td>.030</td>
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<td>.074 **</td>
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<td>-.028</td>
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<td>-.016</td>
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Notes: ** significant at 0.01 level, * significant at 0.05 level
Table 3.5: Correlation coefficients of independent variables

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<th>NUMRES</th>
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<th>AP</th>
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Notes: ** significant at 0.01 level, * significant at 0.05 level
### Table 3.6: Correlation coefficients of independent variables to consumption

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Note: All significant at 0.01 level
Table 4.1: Annual consumption models without dummy intercept

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<tr>
<th>Model Lag No. Cons</th>
<th>Prop Value</th>
<th>Plot Size</th>
<th>No. Resid.</th>
<th>No. Rooms</th>
<th>Pool DYR</th>
<th>PA</th>
<th>PM</th>
<th>PB</th>
<th>Const. Samp Size</th>
<th>Subset Adj Data</th>
<th>RES</th>
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<tr>
<td>A1</td>
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<td>2710</td>
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<tr>
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<td>.007(7.24)</td>
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Table 4.1 (continued): Annual consumption models without dummy intercept

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For notes see end of Table 4.7
Table 4.2: Annual consumption models with dummy intercept and slope

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### Table 4.2 (continued): Annual consumption models with dummy intercept and slope

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### Table 4.2 (continued): Annual consumption models with dummy intercept and slope

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<td>(-0.47)</td>
<td>(3.98)</td>
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### Using 2-stage least squares

| V2        | .727 | .013 | 19.45    | 11.99     | 68.12 | -120.72 |       |     |     | 38.81           | 2710           | Set S | 0.49 | 16.95 |
|           | (6.97) | (0.81) | (6.39) | (3.37) | (4.83) | (-5.37) |     |     |     | (1.95) |      |       |     |
|           |       |       | .024    | .043      | 2.99  | 3.50   | -53.52 |     |     | -274.4          | 1.19           | 206.76 |    |     |
|           |       |       | (0.06) | (2.06)   | (0.85) | (0.78) | (-3.21) |     |     | (-3.40)        | (0.65)         | (3.74) |     |

For notes see end of Table 4.7
### Table 4.3: Annual consumption models with lagged consumption and dummy intercept

<table>
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<tr>
<th>Model</th>
<th>Lag No.</th>
<th>Prop Cons</th>
<th>Plot Value</th>
<th>No. Resid.</th>
<th>No. Rooms</th>
<th>Pool DYR</th>
<th>Other</th>
<th>PM</th>
<th>PB</th>
<th>Const. Samp Size</th>
<th>Subset Adj Data</th>
<th>RES</th>
<th>PC</th>
<th>RMS</th>
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*Model using 2-stage least squares*

| V3    |         | .475      | .380       | .007       | 4.87      | 10.11    | 30.24  | -82.55 |    | -3.56          | 2483           | Set S | 0.71 | 19.65 | 141.53 | 74.98 |
|       |         | (17.28)   | (4.43)     | (0.53)     | (1.89)    | (3.52)   | (2.61) | (-4.89) |    | (-0.22)        |                |                  |      |      |      |
| with D | .160    | .072      | .011       | 1.20       | 5.18      | 30.01    |        |       |    | -148.0         | -0.60          | 133.89 |      |      |      |      |
|       |         | (5.07)    | (0.26)     | (0.65)     | (0.41)    | (-1.45)  | (-2.23) |        |    | (-2.43)        | (-0.04)        | (3.20)          |      |      |      |

For notes see end of Table 4.7
Table 4.4: Seasonal consumption models for winter

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<th>No. Rooms</th>
<th>Pool</th>
<th>DYR</th>
<th>Win-Evap</th>
<th>P_M</th>
<th>P_B</th>
<th>Const. Samp Size</th>
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For notes see end of Table 4.7
Table 4.5: Seasonal consumption models for summer

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<th>P_B</th>
<th>Const. Samp Size</th>
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For notes see end of Table 4.7
Table 4.6: Seasonal consumption models for excess summer

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<th>No. Rooms</th>
<th>Pool</th>
<th>DYR</th>
<th>Summd</th>
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<td></td>
<td>(2.86)</td>
<td>(4.37)</td>
<td>(1.85)</td>
<td>(-0.86)</td>
<td>(-1.25)</td>
<td>(-1.19)</td>
<td>(0.63)</td>
<td>(-4.77)</td>
<td>(-1.36)</td>
<td>(1.15)</td>
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<tr>
<td>Consistent high users</td>
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<tr>
<td>S12</td>
<td>.615</td>
<td>.669</td>
<td>.004</td>
<td>-8.39</td>
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<td>20.56</td>
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<td>.137</td>
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<td>17.76</td>
<td>393</td>
<td>Set H</td>
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<td>(16.41)</td>
<td>(4.63)</td>
<td>(0.35)</td>
<td>(-3.08)</td>
<td>(0.22)</td>
<td>(1.37)</td>
<td>(-2.09)</td>
<td>(1.03)</td>
<td>(-1.13)</td>
<td>(-0.02)</td>
<td>(0.25)</td>
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For notes see end of Table 4.7
Table 4.7: Annual consumption models to determine effect of rate structure change

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<thead>
<tr>
<th>Model Lag</th>
<th>Prop No.</th>
<th>Cons No.</th>
<th>Value No.</th>
<th>Pool</th>
<th>Plot Resid.</th>
<th>Rooms Const.</th>
<th>Samp Size</th>
<th>Subset Adj Data</th>
<th>RES</th>
<th>PC</th>
<th>RMS</th>
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<tbody>
<tr>
<td>Before 1992, without price, with dummy intercept</td>
<td></td>
<td></td>
<td></td>
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<td>R1</td>
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<td>.012</td>
<td>19.88</td>
<td>12.04</td>
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<td>40.21</td>
<td>2485</td>
<td>&lt;1992 0.46</td>
<td>3.19</td>
<td>272.06</td>
<td>104.09</td>
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<td></td>
<td>(6.71)</td>
<td>(0.74)</td>
<td>(6.22)</td>
<td>(3.26)</td>
<td>(4.66)</td>
<td>(1.53)</td>
<td></td>
<td>Set S</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>.263</td>
<td>.008</td>
<td>3.27</td>
<td>12.14</td>
<td>-54.57</td>
<td>37.80</td>
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<td>(1.90)</td>
<td>(0.45)</td>
<td>(0.87)</td>
<td>(2.57)</td>
<td>(-3.12)</td>
<td>(1.82)</td>
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<tr>
<td>Before 1992, without price variable or dummy intercept</td>
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<tr>
<td>R2</td>
<td>.757</td>
<td>.030</td>
<td>38.04</td>
<td>11.60</td>
<td>37.78</td>
<td>65.58</td>
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<td>&lt;1992 0.26</td>
<td>34.80</td>
<td>372.82</td>
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<td>(9.60)</td>
<td>(3.25)</td>
<td>(20.43)</td>
<td>(4.36)</td>
<td>(4.02)</td>
<td>(4.45)</td>
<td></td>
<td>Set S</td>
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</tbody>
</table>

For notes see next page
Notes for Tables 4.1 to 4.7:

t-statistics in brackets

Explanation of abbreviations:

# = unit price $/kL
Adj R2 = adjusted R squared (see Section 3.4.1.1)
DYR = dummy for constant allowance, =1 if year =1992, =0 otherwise
Lag Cons. = lagged annual consumption (1 year)
No. Resid. = number of residents in household
PA = average price ($/kL
PB = bill difference ($1992)
PC = Prediction Criterion (see Section 3.4.1.3)
Plot size = plot size of property (square metres)
PM = marginal price ($/kL)
Pool = presence of swimming pool (positive =1)
Prop value = real property value ('000 in $1992)
RES = Ramsey Regression Specification Error Test (see Section 3.4.1.2)
Rooms = number of rooms in household
RMS = Root Mean Square Error (Section 3.1.4.4)
Sprevap = spring evaporation (mm)
Summd = summer moisture deficit (mm)
Winevap = winter evaporation (mm)
With D = variable multiplied by DUMVAR (see Section 3.3.2)
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