A GIS Based Water End-Use Demand Modelling

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ABSTRACT

The "end use" of water is a breakdown of the total household water usage such as water used for toilets, showers, washing machines, taps, lawn watering, etc. The Victorian Government, in Australia set a 15% per capita consumption reduction target by 2010 based on the Water Resources Strategy that has been developed for Melbourne. Therefore, there is a need to measure and model residential end uses of water to ensure the effectiveness of conservation efforts and to determine whether the set target reduction is achieved.

This paper describes GIS-based modelling of end uses of water from a number of single-family homes in Greater Melbourne, Australia. The study involves the analysis of water demand data at 1-minute and 5-second intervals from logged households collected by Yarra Valley Water in Melbourne, Australia in 2001 and 2004.

The result of this study improves understanding on the end uses of water and provides information to assist where to focus water conservation efforts that would yield the most effective result financially, environmentally and acceptable to everyone.

Keywords

Water End-Use, GIS, Java, Internet.

1. INTRODUCTION

The end use study for water will enable water planners, water authorities and household owners to know where water is used, how much and how often. This would even lead to determining where water is being wasted and therefore able to design and implement conservation programs specifically targeting areas where these programs yield the most effective result financially, environmentally and acceptable to everyone. Therefore, there is a need to measure and model residential end uses of water to ensure the effectiveness of conservation efforts that has been and will be implemented and to determine whether the set target reduction is achieved. This paper describes the end uses of water from a number of single-family homes in Melbourne. The study involves the analysis of water demand data from logged households collected by Yarra Valley Water (YVW) in Melbourne, Australia in 2001 and 2004. The study shows how much water is being used for outdoor and indoor purposes in a single-family home in Melbourne and compares the water usage before and after water restrictions, as well as a comparison of winter and summer water usage.

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Using the data from the logged households, a Residential Indoor Water Use Estimation program (Java Applet) which is designed to run within a Web-browser either on-line or off-line was developed. The program estimates the total indoor use, and the water use per major component of indoor use per household as well as at the zone level in Melbourne.

2. STUDY AREA

Melbourne is the capital city of Victoria and the major residential, commercial and manufacturing centre for the state. It is the second largest city in Australia and has about 70% of the state's population (Figure 1). Metropolitan Melbourne's population has increased by 389,253 from 1981-1996 [2].

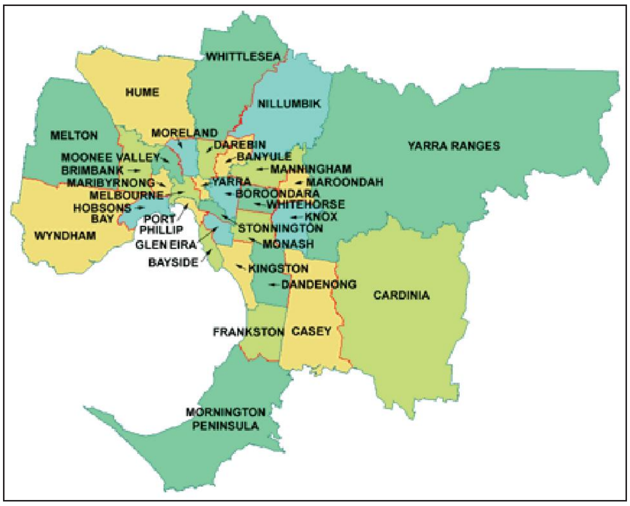

Figure 1: Greater Metropolitan Melbourne

The climate is temperate across metropolitan Melbourne, with warm dry summer and a moderate winter rainfall. Annual rainfall ranges from about 550mm in the West of the suburban areas, to about 900mm in the East. Mean daily maximum temperature is about 260C in summer, with extremes of 400C or more, in most years. There is little variation across the city in temperature, except in small areas of higher elevation, where temperature is usually marginally higher.

Melbourne's current water resources are composed of approximately 780,000ML average annual inflows to water supply storages, 30,000ML pumped from Yarra River, 5% is accumulated in storages and 300,000ML is released for environmental purposes and overflows [3].

3. METHODOLOGY

Three sets of data were analysed in this study (Figure 2):

- Feb 2001 – Summer before water restrictions. YVW surveyed and installed data loggers to monitor the water usage at 1-minute interval of 25 of its staff, which are single residential household owners with gardens across Greater Melbourne as part of its High Water Using Appliances Study. Each of these households kept a diary to record water usage for toilet, shower, washing machines, gardens and other major uses, the corresponding times of usage, including duration and water level for washing machines during the first week. For the second and third week of the monitoring period, respondents recorded their garden usage only, its duration and method.
- Feb 2004 – Summer during water restrictions. YVW surveyed and installed data loggers to monitor water usage at 5-seconds interval in 93 households across Greater Melbourne.
- Aug 2004 – Winter during water restrictions. Of the 93 households surveyed and monitored at 5-seconds interval in Feb 2004, 80 households were again logged in Aug 2004.

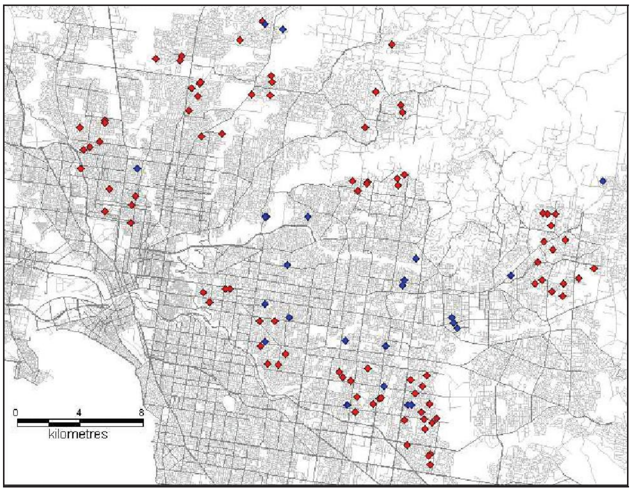

Figure 2: Households Logged in 2001 (Blue) and in 2004 (Red)

3.1 Data Analysis

The analysis of the data involved the disaggregation of data into end uses of water such as water used for toilets, showers, washing machines, garden watering, etc and undertaking regression analyses to determine the factors affecting water usage.

For the logged data in Feb 2001 monitoring, disaggregation of flow data into major components of water use such as gardening, shower, toilet, washing machine and others was undertaken manually. This is the most time consuming process of the study. For the 2004 data however, the data was disaggregated into end use level by using computer software, Trace Wizard (Figure 3).

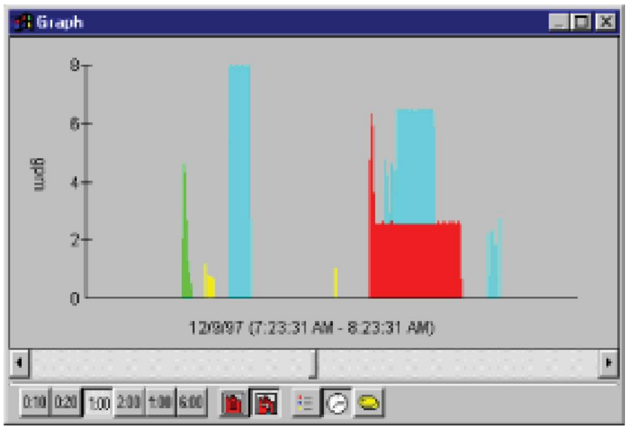

Figure 3: Trace Wizard showing water use events; clothes washer (blue), shower (red), toilet (green), and tap (yellow)

3.2 Model Development

The semantics of the model was developed using Protégé. The Protégé platform is an open-source development environment for ontology and knowledge-based systems. The Protégé-OWL (Figure 4) editor is an extension of Protégé with support for the Web Ontology Language (OWL)[1].

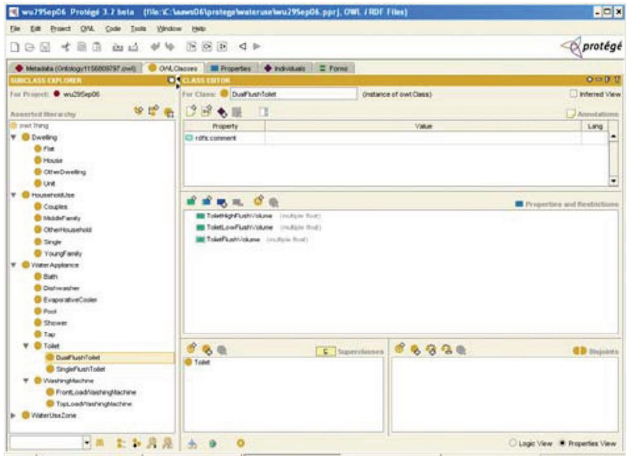

Figure 4: Protégé-OWL Editor

In computer science, ontology is a data model that represents a domain and is used to reason about the objects in that domain and the relations between them. Ontology is used in artificial intelligence, the semantic web, software engineering and information architecture as a form of knowledge representation about the world or some part of it. Ontology generally describes:

- Individuals: the basic or "ground level" objects
- Classes: sets, collections, or types of objects
- Attributes: properties, features, characteristics, or parameters that objects can have and share
- Relations: ways that objects can be related to one another

[1] http://protege.stanford.edu/plugins/owl/

The residential water use household-based model is simply a collection of objects, with properties, relationships to each other and definable behaviours. The model consists of several objects or entities such as a household, person, shower, clothes washer, toilet, bath, dish washer, taps (faucet), hot water system, evaporative cooler, and spa. The model does not include outdoor water use. These objects are related to other objects. For example:

- Every person is a member of a household
- All households have a shower, a clothes washer, a toilet, a water tap, a dish washer, a hot water system, an evaporative cooler and can have a spa.

An object can have attributes. For example:

- A shower has a flow rate (L/min)
- A clothes washer has a use capacity (L/load)
- A toiler has a use capacity (L/flush)
- A dish washer has a use capacity (L/load)
- A water tap has a flow rate (L/min)

The model contains several behavioural rules, such as:

- The total indoor water use, the number of clothes washer loads, the number of dish washer loads, the number of tap usage and the number of toilet usage are all proportional to the number of persons in the household.
- A person takes a shower in any given day with a probability $p \leq 1.0$

3.3 Software Implementation

The model was implemented using Java based on ESRI MapObject[2] software products (Figures 5) and Alov Map Java Applet[3] (Figure 6). Java is an object-oriented programming language developed by James Gosling and colleagues at Sun Microsystems in the early 1990s.

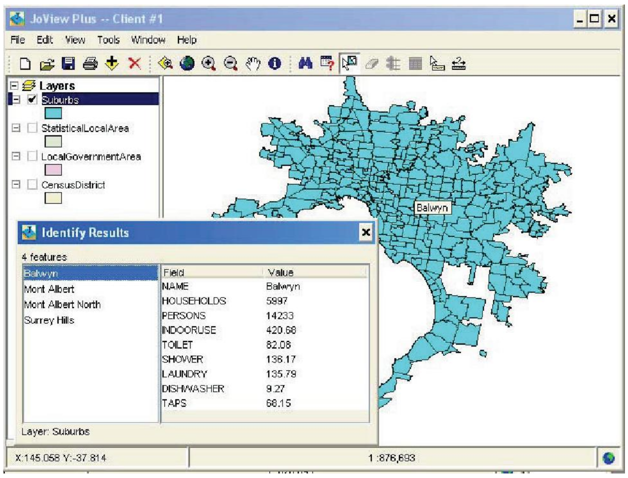

Figure 5: A MapObject client application showing Residential Indoor Water Use Model Estimate for Multiple Zones

MapObjects consists of embeddable mapping components available as separate products for Windows and Java developers. MapObjects can be used to build powerful client and desktop applications or add GIS capabilities to existing applications. These capabilities include a wide range of map display, geographic query, and data retrieval activities.

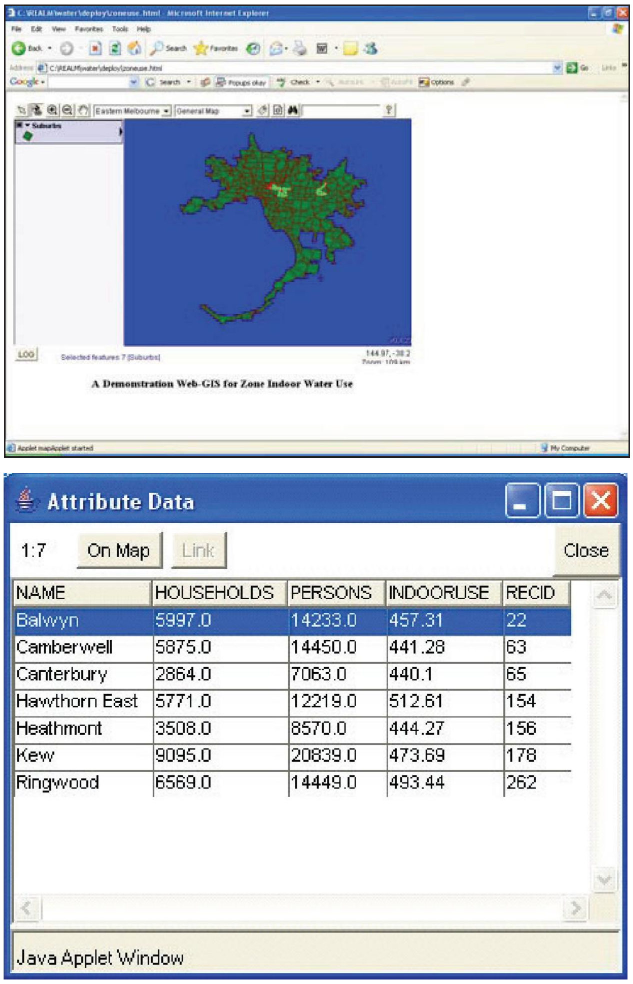

Figure 6: Alov Java applet showing Residential Indoor Water Use Model Estimate for Multiple Zones

ALOV Map/TMJava is free, portable Java® application for publication vector and raster maps to Internet and interactive viewing on web browsers. It supports the complex rendering architecture, the unlimited navigation and allows working with multiple layers, thematic maps, hyperlinked features and attribute data.

3.4 Future Development

It is further proposed to develop software that would simulate household water end-uses for all households within Metropolitan Melbourne. The simulation will take into account household characteristics such as size, type of dwelling, water appliance (washing machine, dishwater, air conditioning system, hot water system, showers, bath tubs, spas, and toilet) and the presence of swimming pools and gardens. The simulation model will also consider population-household dynamics, rainfall, temperature and day of the week.

[2] http://www.esri.com/software/mojava/index.html

[3] http://www.alov.org/index.html

3.4.1 Population-Household Dynamic

Since data were collected in the first Australian Census in 1911, there has been a slow but steady increase in the size of Australian dwellings. This is demonstrated by the rise in the average number of rooms over the period to 1981. This increase occurred despite a steady decline in the average number of persons per dwelling (from 4.5 to 3.0 persons) over the same period. These changes have meant that, between 1911 and 1981, the average number of persons per room declined from 0.9 to 0.5 persons. The average size of new homes has continued to increase over the last two decades. Between 1986 and 1999, the average size of new dwellings increased almost 30% [1].

The trend toward smaller households can be attributed to factors such as changing patterns of household formation. For example, rising divorce and separation rates often lead to the formation of smaller households. Another example is the trend for couples first to delay starting a family, then to have fewer children.

Between 1921 and 1996 the proportion of two person households increased from 13.9% to 32.4%. There has also been a marked increase in the proportion of one person households, particularly over the latter half of the 20th century.

This can, in part, be attributed to the ageing of the Australian population. Older persons, left alone after the death of their partner, contribute significantly to the numbers of single person households. Between 1911 and 1961 the proportion of single person households fluctuated only slightly (between 8% and 11%). By 1996, a total of 1.4 million persons, nearly a quarter (23%) of all households, lived alone. Some 38.5% of these households comprised persons aged 65 and over.

These changes in household and dwelling characteristics over time have a potential impact on the residential water demand. For example: The population in East Doncaster incurred an average decrease of 0.2% per year between 1991 and 1996 but the household number increased at an average rate of 1.43% per year. In comparison, the water consumption from 1994 to 1996 incurred an increase of almost 20%.

3.4.2 Rainfall, Temperature and Day of the Week

The "dynamic" effect of the occurrence of rainfall on urban water demand also showed that each time rainfall occurred, water use is reduced immediately, and then it gradually resumed its regular pattern. Examination of the "state-dependent" effect of rainfall on daily water use over the period 1991 – 2000 showed that the occurrence of rainfall causes a reduction in seasonal water use and the higher the seasonal water use prior to the rainfall event, the more reduction can be observed. The water use reductions due to rainfall occurrence are approximately proportional to their previous day's seasonal water use level, and the proportionality increases as the rainfall increases.

The analysis of the effect of temperature on urban water demand showed that in the absence of rainfall, maximum daily temperature is the dominant variable governing urban daily water use. The assessment of the effect of a significant increase in temperature and hot consecutive days on urban water consumption during rainless days reveals that an increase in temperature of 3° to 16° results to increase in water demand up to a maximum of 4ML/D.

It was also noted, based on the analysis of the half-hourly data and daily data, that residents use more water on weekends than on weekdays on all seasons of the year and during the period 1991-2001.

3.4.3 Demand Profiles

Using the simulation model, water demand profiles can be computed. For example, see Figure 7 and Figure 8.

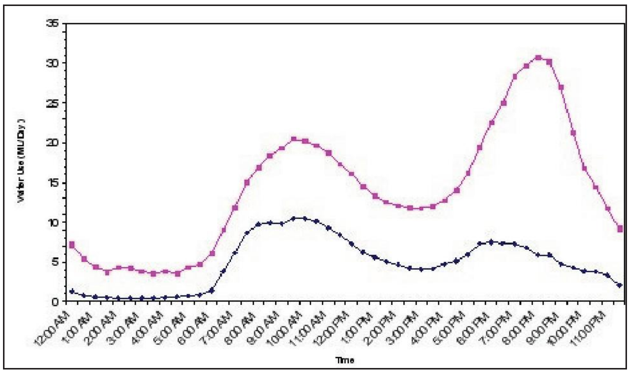

Figure 7: Half-hourly summer (pink) and winter (blue) water demand profile

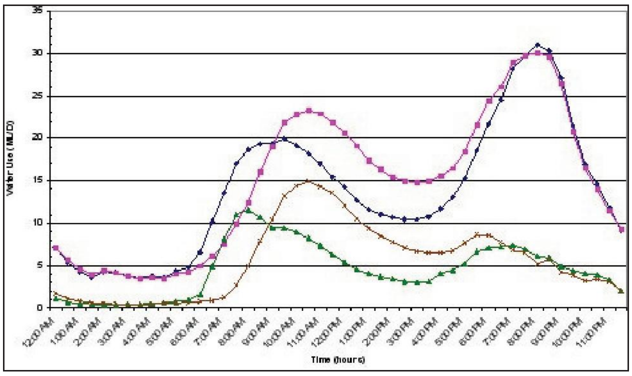

Figure 8: Half-hourly summer week-ends (pink) and summer week-days (blue), winter week-ends (brown) and summer week-days (green) water demand profile

The model would also allow the simulation of particular end-use components such as half-hourly summer and winter shower usage patterns. Figure 9 illustrates summer usage patterns for several end-use components.

Study results show that showers, clothes washers and toilets are the most prominent end uses in summer. Shower use is virtually non-existent from 2 to 4am then ramps up sharply peaking at 8am. A lower but secondary morning peak occurs at 11am then decreases sharply for the rest of the morning and early afternoon reaching an afternoon peak but lower than the first morning peak at 7pm then another secondary but lower afternoon peak at 10pm.

Clothes washer is also non-existent from 1 to 6am but increases dramatically an hour after the toilet and shower peak at 9am. Clothes washer use is fairly steady for the remainder of the day, decreasing down to almost nothing at 10pm.

Toilet use increases steeply from 6am until it reach its morning peak at 8am. It decreases slightly during the later morning and afternoon and increases again in the evening between 5pm to 10pm.

Dishwashers seemed to be not in use from 2am to 7am and are fairly steady from then onwards until 1am. Other indoor uses follow the same pattern as the toilet usage.

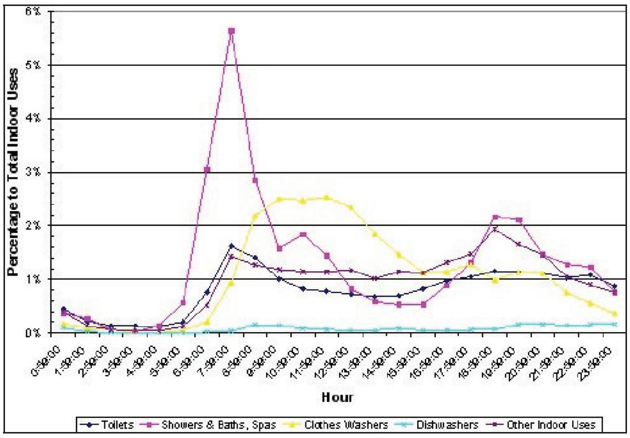

Figure 9: Half-hourly summer water use profile for different end-use components

4. RESULTS

End uses of water from a number of single-family homes in Greater Melbourne, Australia which included water demand data at 1-minute and 5-second intervals from logged households collected by YVW in Melbourne, Australia in 2001 and 2004 respectively are analysed. The results show how much water is being used for outdoor and indoor purposes in a residential home in Melbourne and compare the water usage before and after water restrictions as well as between winter and summer water usage.

End use models for toilet, shower, laundry, tap and cooler in the form of regression equations are developed from logging data and household survey during the February 2004 monitoring. These end use models are validated using Aug 2004 and Feb 2001 monitoring data. Based on these end use models a Residential Indoor Water Use Estimation computer program, which is designed to run within a Java enabled Web-browser either on-line or off-line is developed. The program estimates the total indoor water use per household, its major component. Using the end use models and the ABS Census 2001 Data, a GIS-based Residential Indoor Water Use model is also developed which calculates the average daily indoor use for each suburbs in Greater Melbourne, Australia.

A new daily time series model for East Doncaster, Melbourne, Australia is also evaluated. The daily urban residential water model depends on the postulate that total water use is made up of base use and seasonal use, where base use is characterised by the water use during winter months and seasonal use on seasonal, climatic and persistence components. Using the daily data collected by Yarra Valley Water (one of Melbourne's water utility company) for East Doncaster water supply distribution zone and the corresponding rainfall and temperature data from Bureau of Metrology from 1990-2000, the base values were calculated based on lowest months of water usage in a year and were correlated with the day of the week, temperature and rainfall.

5. CONCLUDING REMARKS

Melbourne is like other urban cities in the world, its growing population means increasing water demand. Melbourne is also already on its eight year of dry climatic conditions that forced water authorities to impose water restrictions after 20 years of unrestricted supply. The current drought, dwindling supplies and possible impact of climate change highlight the importance of making better use of this precious resource.

Recognising the lack of understanding on end use of water and the need for improved demand forecasting models as well as the development and evaluation of conservation strategies, this research adopted a detailed investigation of water use known as end use analysis. It will improve understanding on water use particularly at end use level and develop models to forecast urban residential water demand.

This research on end use measurement and analysis will provide information to assist Water Authorities and the community to: make informed decisions when they consider options to focus water conservation efforts. It also serve as a tool for community education, and to support with planning and policy development for adopting particular strategies relating to water demand management. The forecast demands will assist with accurate planning of infrastructure to service future growth.

It is also possible to quantify the amount of water used in the households that can be recycled and determine what component of end uses of water can be sourced from "other than drinking water". These measurements can be used for third piping system designs and in determining appropriate rainwater tanks sizes. This will enable the development of strategic conservation programs and their effective implementation. It is also hope to improve the understanding of where and how water is being used within the households which will increase awareness and educate all consumers, planners and water authorities on what component of end uses of water could be reduced and by how much.

6. ACKNOWLEDGMENTS

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