Forecasting Peak Demand- What Do We Need to Know?

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ABSTRACT

Peak day demand is a key design parameter for assessing the future capital infrastructure needs of bulk water delivery systems. In addition, an understanding of peak demand is critical in designing demand management programs and establishing cost recovery pricing regimes. Despite the importance of peak demand on system design, little detailed research has been undertaken on developing approaches for forecasting peak demand.

Accordingly, this paper identifies the non-climatic factors found to affect peak demand and examines changes in technology, land use and behaviour and their influence on peak demand forecasts. Furthermore, the paper contrasts several methods for forecasting peak demand by emphasising the advantages and limitations of each.

The paper concludes by proposing an alternative methodology to forecast trends in peak demand through the creation of an innovative end use model for the residential sector. The limitations of the methodology and data requirements are discussed, as are the implications for designing peak demand management programs.

KEY WORDS

Peak demand, forecasting, demand management, peaking factor

INTRODUCTION

When assessing the future needs and design of bulk water delivery systems it is important to gain a sound understanding of the parameters that drive design. Bulk water delivery system performance is dependent on a number of factors, including the level of base, average and peak demand (PD). For system planning purposes, an estimate of future peak demands needs to be developed in order to plan the capital infrastructure required (Maddaus 1999). Adequate consideration of PD in system design can generate considerable cost savings to the utility in the medium to long term.

Other commonly cited reasons for obtaining data on peak demands are demand management and cost recovery. Demand management aims to reduce peak demands in systems experiencing supply or storage constraints by identifying the customers most responsible for the peaks and developing targeted programs. Cost recovery (also referred to as cost of service or peak pricing) involves the allocation of revenue responsibility to customer classes according to the costs they impose on the utility. Peak pricing is used in the United States; however, the benefits are yet to be applied in Australia.

Despite the relative importance of PD, limited detailed research has been devoted to this topic, particularly in relation to the factors driving PD and methods for forecasting PD. The current lack of understanding means that the planning of capital works and the design of demand management programs and pricing structures *may* not be as efficient as possible.

The objectives of this study are to identify the non-climatic factors found to affect peak demand and examine changes in technology, land use and behaviour and their influence on peak demand forecasts. Furthermore, the paper contrasts several methods for forecasting peak demand by emphasizing the advantages and limitations of each.

The overall aim is to develop an innovative end use model to generate more informed forecasts of PD based on possible future trends in demographic and socio-economic data. The advantages and limitations of the approach are identified, as are the data requirements to enhance the accuracy of the results. The potential role of demand management in reducing infrastructure costs and curbing demand in systems experiencing PD constraints, is also discussed.

NON-CLIMATIC DRIVERS OF PEAK DEMAND

A literature search was undertaken to identify articles containing information on peak, maximum or seasonal demands and outdoor water use. The literature review included results of surveys conducted by Sydney Water Corporation (SWC), in particular *Water use- Practices and intentions* (SWC 2000).

Table 1 summarises the key factors identified from the literature review. From the information available it is evident that the single residential sector has the greatest influence on PD, mostly as a result of climate-driven outdoor water use. As such, the main influences within this sector tend to be factors such as the type of irrigation system, demographic characteristics and lot size.

Table 1 Factors influencing peak demand.

Factor identified	Key findings	Reference
System/	- as system size increases demand variation decreases	Feather & Braybrooke 1996

Factor identified	Key findings	Reference
population size	- peaking ratio decreases as the population increases	Clewitt & Applegren 1991
	- larger cities have a lower peak day to average day ratio due to a greater diversity of demand and larger base load demands from industrial users	Anderson & Vickers 1989
	- inverse relationship between population size and PF	Yakemchuk 1996
	- a low ratio of single to multi residential dwellings may have the effect of 'reducing' the size of the system	this study
Customer classes	- zones that are predominantly commercial and industrial have lower peaking factors	Clewitt & Applegren 1991
	- commercial and large volume/industrial users do not drive system peak demands - water use for multi residential users is only marginally above average on system peak days - single residential has the highest peaking factor - single residential customers tend to have similar coincident and non-coincident peaking factors, while multi residential, commercial and industrial tend to have greater non-coincident peaks	Rothstein 1993
	- single residential customers have the greatest peaking factors for both daily and hourly demands and peak days coincide with system peak days, whereas other classes had daily peak demands on other days	Aquacraft 1996
Outdoor water use	- maximum day events are characterised by significantly greater outdoor demands	Feather & Braybrooke 1996
Gardens	- households who maintain a garden use 30% more water outdoors than those without a garden	AWWA 1999*
	- 34% of households are more likely to water lawns and gardens on extremely hot days	SWC 2000
Lawns	- houses with the entire garden planted in grass use significantly greater amounts of water for irrigation	Kiefer & DeWitt 1996*
Lot size	- Lot-size showed that greatest level of statistical significance among the variables in the irrigation component in relation to consumption	Kiefer & Dewitt 1996*
	- weakly correlated with water consumption (r= 0.05)	Gregg & Curry 1996*
Swimming pools	- homes with pools are estimated to use more than twice as much water outdoors than homes without	AWWA 1999*
	- the likelihood of over irrigating increases with the presence of a swimming pool	Kiefer & Dewitt 1996*
	- 6.8% of households are more likely to fill/top up pools on extremely hot days	SWC 2000
	- 4.7% of households are more likely to fill/top up children's wading pools on extremely hot days	SWC 2000
In-ground/fixed irrigation systems	- older homes tend to use less water for irrigation purposes than new homes on comparably sized lots, as they typically do not have automatic irrigation system	Mayer et al 2000*
	- homes with in-ground sprinkler systems use 35% more water outdoors than those without an in-ground system	AWWA 1999*
	- drip irrigation systems use 16% more water outdoors than those without a drip irrigation system	AWWA 1999*
	- customers with automatic irrigation systems use the most irrigation water (per metre2) than those with hose and sprinkler systems	Vickers & Scott 1996*
	- irrigation systems strongly correlated to water consumption (r= 0.44) - irrigation system increased consumption by 808 L/day (C.I. 725- 892 L/day), therefore strongly influence water consumption	Gregg & Curry 1996*
	- the likelihood of over irrigating increases with the use of an in-ground irrigation system	Kiefer & Dewitt 1996*

Factor identified	Key findings	Reference
Automatic timers	- households with an automatic timer on their irrigation system used 47% more water outdoors than those that do not	AWWA 1999*
	- increased consumption as a result of having an irrigation system is related to watering on a set schedule (timer)	Gregg & Curry 1996*
	- households with automatic timers use significantly greater amounts of water for irrigation	Kiefer & DeWitt 1996*
	- automatic sprinkler systems tend to move residential peak hour use to mornings, while the peak for households without irrigation systems is in the evening	Rothstein 1993
	- new homes use more water, despite having more efficient water using technologies, as a result of automatic irrigation systems	Mayer et al 2000*
	- the likelihood of over irrigating increases with the use of an automatic timer	Kiefer & Dewitt 1996*
Garden water features	- 2.5% of households are more likely to fill/top up on extremely hot days	SWC 2000
Recreational use	- 6.8 % households are more likely to play with water outdoors on extremely hot days	SWC 2000
Demand management programs	- although indoor conservation measures will reduce average day and peak day demands, savings in landscape, cooling water and other summer uses will have greater effects on reducing the peak	Maddaus 1999
House / lot value	- strongly correlated to water consumption (r= 0.40)	Gregg & Curry 1996*
Money spent landscaping	- strongly correlated to water consumption (r= 0.46), and irrigation systems (r= 0.40)	Gregg & Curry 1996*

* these studies focussed mainly on outdoor water use as opposed to peak demand.

For each of the non-climatic variables and end uses identified, time series data was collated. Trends in these factors were then compared to historical PD trends in a real system (Prospect delivery system- Sydney) to test the potential relevance. Future trends in these factors and the likely impact on PD, were also predicted (Table 2).

Table 2 Historical and likely future trends in the factors that influence peak demand.

Factor	Survey results, trends and key characteristics	Implications on peak demand
Market sector mix	Increase in number of single residential dwellings	Decrease
	Increase in multi residential dwellings and the number of households per development (all systems)	
	Decrease in the ratio of single to multi households	
Gardens and watering	Ownership (Sydney): 1987= 73% ; 2000= 92%	Increase
	Possible trends towards smaller gardens as a result of decreasing lot size and increasing house area (pers com Col Goldsworthy, SWC)	Decrease
Lot size	The size of *new* lots is decreasing	Decrease
Irrigation equipment	Ownership (Sydney): 1987= 4%; 2000= 18%	Increase: due to incorrect use (Gregg and Curry 1996; Kiefer and DeWitt 1996)
	Single dwellings almost 4-times more likely to own a fixed irrigation system than multi dwellings	
	Larger gardens more likely to have a fixed watering system	
Showers	Overall water efficiency of showers has increased since 1980 due to increased stock of water efficient showerheads	Decrease
Swimming pools	Ownership (Sydney): 1987= 13%; 1999= 16%	Increase
	Not homogenous throughout Sydney. Pools are becoming popular in neighbourhoods where "they have never been thought possible in the past" (Sydney Morning Herald 30/11/00)- plunge and lap pools	
Occupancy	Decreased in all systems; more so in single than multi dwellings	Increase

House ownership	Home owners are more likely to own a garden and water it than renters (SWC 2000)	
	Home owners more likely to fill/top up swimming pools and water features (SWC 2000)	
Households with children	Almost all outdoor activities are more likely to be practised by people with children at home (SWC 2000)	Decrease: due to ageing population

APPROACHES FOR FORECASTING PEAK DEMAND

Forecasting based on statistical programs
The Omaha water utility uses a program based on historical production data for predicting system-wide estimates of peak demands (Christensen and Macdissi 1989). The program uses a database search function to find historical information on peak demand days based on climatic and other functions.

Forecasting based on peaking factors
The most common approach to estimate PD is to use of a peaking factor (PF); the ratio of peak day water use to average day water use. In the simplest application the PF is multiplied by average day forecasts to create estimates of PD (1). This assumes that the distribution of water use between indoor and outdoor activities, or the reasons for the peak day event, is constant. However, PD is often characterised by greater outdoor demands, and as such a constant pattern cannot be assumed.

$$Q_{PD} = Q_{AD} \times PF_{AD} \qquad\qquad (1)$$

where: Q_{PD} = peak day demand; Q_{AD} = average day demand; PF_{AD} = peaking factor relative to average day demands
The following examples are variations on the use of peaking factors to generate PD forecasts.
a) Design standards: these are often developed by a variety of sources including the water industry, engineering bodies and federal and state regulators. Sometimes the PF is presented by customer classes but more often a system-wide value is given. The recommended PF value varies and is basically a "rule of thumb" and it is often up to the engineer to determine the "best guess" value for a given situation (Yakemchuk 1996).

b) Historical demand data: Feather and Braybrook (1996) devised a model with separate indoor and outdoor peaking factors. Indoor use is assumed to remain constant (1.0) during a peak day event, while the proportion of outdoor water use increases, taking the responsibility for all of the demand increase. The outdoor PF will therefore be greater than the PF for total water use. PF_O is calculated by combining equations (1) and (2) and setting them equal to each other. The value for PF_O is calculated from baseline conditions and does not change over time. The values Q_I and Q_O change over time. Using historical water use records from Las Vagas Valley Water District the PF_{AD} using equation (1) was found to be 1.56, compared to a FP_O of 2.1 using the enhanced approach.

$$Q_{PD} = Q_I (PF_I) + Q_O (PF_O) \qquad\qquad (2)$$

where: Q_{PD} = peak day demand; Q_I = indoor demand estimate; PF_I = indoor peaking factor (assumed to equal 1.0); Q_O = outdoor demand estimate; PF_O = outdoor peaking factor estimate

The advantage of this approach is flexibility, as PD forecasts are sensitive to changing values of indoor and outdoor water use (e.g. as a result of demand management

programs). However, the assumption of constant indoor demand is disputable, as the SWC survey (2000) reveals that people are likely to shower more frequently and/or longer on a peak demand day.

Day (2001) developed projections of PD based on both the historical per capita and per residential lot peak demands. The average PD for each was then multiplied by population and residential lot projections to generate forecasts of PD. Using the same data projections were also prepared by SWC by multiplying the historical PF by the current average water usage and lot projections for each customer class. The projection was calculated based on a peak day value for 1999 of 50 ML/d. The results in Figure 1 highlight the range of PD forecasts produced from the different approaches.
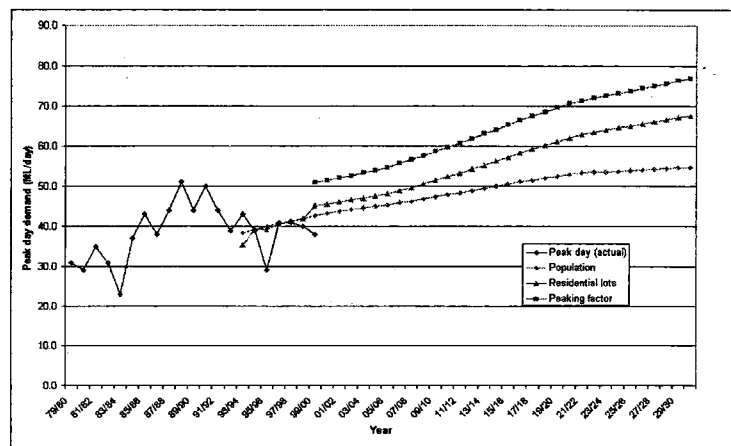

Figure 1 Comparison of peak demand forecasts generated using different approaches.

The use of historical data is generally most relevant for the generation of a system-wide PF (ie using daily bulk flow records). The use of monthly or quarterly billing records to generate peaking factors for each customer class is less accurate, as the demand patterns over these longer time periods may not correspond with those on a peak demand day.

c) Actual customer data: Rothstein (1993) and DeOreo and DiNatale (1997) both conducted studies using portable inline data loggers to collect hourly demand data and to generate peaking factors and diurnal demand curves for various customer classes. The results highlighted the diversity between and among customer groups and gave an insight into the number and type of end uses contributing to PD. The disadvantage of data logging studies is that they often cannot capture seasonal variability unless long-term studies are implemented.

The major limitation in using peaking factors to forecast PD is that it is a top-down approach that can not account for PF variations that result from the system size, market mix, climate, geography etc, or for changes over time in the variables that drive PD (e.g. garden ownership). The application of a PF to forecast peak demands also makes it difficult to measure the impact of demand management programs targeted at PD. The use of historical and actual demand data is more accurate than the application of a standardised peaking factor, as the data used for forecasting is specific to the particular system being studied.

FORECASTING PEAK DEMAND USING END USE ANALYSIS

The above findings were used in developing an end use model to forecast PD. End use analysis (EUA) focuses on the factors and technologies which affect water use, including emerging trends. Demand for each end use is calculated based on demographics, ownership of appliances, usage patterns and technologies. This was developed for the residential sector only, as end uses for the non-residential sector are not well understood.

Two models were constructed based on the SWC End Use Model to forecast PD. A garden watering end use model was also developed for both single and multi residential dwellings to account for outdoor water use. In lieu of actual demand data, the PD model was developed based on interpreting the results of the survey *Water use: Practices and intentions* (for details refer to SWC 2000 in Table 1) in order to formulate key assumptions (e.g. *how* much longer people spend in the shower on a peak day). A sensitivity analysis was then undertaken to determine the factors having the greatest influence.

The key finding from the PD end use model in the delivery system studied was that peak demand is likely to decrease (Figure 2). The main contributing factors are the decreasing proportion of single to multi dwellings and increasing water use efficiency for showers and toilets. Average demand in the system is also decreasing the PF remains constant.

Increasing the 'structural' trends, that is, the ratio of single to multi dwellings, garden ownership and ownership of water efficient showerheads, all result in decreased PD. Conversely, increasing the ownership of fixed irrigation systems increase PD. Modifying the outdoor structural trends had the greatest impact on PD. Sensitivity analysis of the survey interpretations indicate that increasing all the assumptions lead to an increase in PD, with showering behaviour having the greatest impact (although this decreases over time due to increased ownership of water efficient showerheads).

The major limitation of an end use approach is the detailed data requirements, which tend to be compounded by the lack of data on outdoor water usage. This can be overcome by long-term data logging studies or outdoor real time montoring, which would provide real data on the extent of behavioural changes on peak demand days. The difficulty in developing end use models for the non-residential sector means that the impact of this sector on PD cannot be determined, and a PF approach based on historical records may be more appropriate.
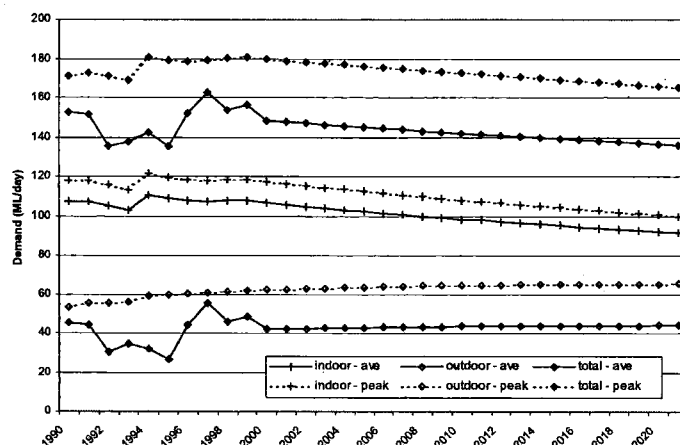

Figure 2 Average and peak demand forecasts for Ryde water delivery system.

CONCLUSIONS

Peak demand forecasts based on historic trends and peaking factors tend to overlook the fact that what was important in the past may not be so in the future. End use analysis, conveys a greater understanding of what actually happens on a peak demand day and improves the PD forecast by accounting for changes in socio-economic and behaviour (e.g. the housing mix, appliance ownership). This information is also essential for the design of relevant and effective demand management and efficiency programs.

Analysis of the end use of water and customers means of delivering those end uses (e.g. automatic vs. manual sprinkler systems) is at the core of further advancements in peak forecasting, demand management and cost of service analysis. Further studies to refine the end use model using real data to investigate the possibility of overlaying multiple regression models, using climatic variables, on the end use projections is now needed.

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