Water Demand Management

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Water consumption trends and demand forecasting techniques

Fayyaz Ali Memon and David Butler

1.1 INTRODUCTION

This chapter gives an account of domestic water consumption patterns, factors driving change in consumption trends and demand-forecasting techniques currently in use. A major part of the paper is within the context of research that has taken place in the UK. However, wider references are made to present a broader picture and show similarities and contrasts in consumption tends.

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1.2 THE BIG PICTURE

Will the available freshwater resources be sufficient to meet future demand if current water consumption trends remain unchanged? This is an important question, but understandably, not one that can be answered simply, since it requires a thorough assessment of the impact of some complex factors such as the pace of population growth, emerging socio-economic trends and the extent of climate change. The total requirement of water for domestic use in the world is about 200km^3/year, which is some 0.5% of the average total runoff (Stephenson, 2003). Theoretically, it is possible to meet existing and future domestic water demands, but the problems associated with its distribution in time and space and affordability are some of the factors widening the gap between the demand and supply in many parts of the world.

Table 1.1 Water stress in terms of relative water demand (RWD)

Level of water stress	RWD
Low	<0.1
Moderate	0.1 to 0.2
Medium-high	0.2 to 0.4
High	> 0.4

The UN (1997) has classified the level of water stress in terms of relative water demand (i.e. the ratio of total use to total water from available resources) as shown in Table 1.1. Vörösmarty *et al.* (2000) made an attempt to predict the influence of population growth and climate change and assess the level of water stress for various regions of the world using a water balance model in combination with two global climate circulation models (CGCM1 and HadCM2). The water stress in 1985 and predictions for the year 2025 for each continent are shown in Table 1.2.

The results indicate that there is a considerable increase in the relative stress for all regions, with the increase mainly due to population growth rather than climate change. Comparison of the 2025 predictions with the water stress levels shown in Table 1.1 apparently paints a rosy picture. Yet, the global scale masks the water shortage and drought-like situations which emerge when investigations are made at smaller (country and regional) scale. For example, in 1993-94 in England and Wales, about half of the regions (covered by the Environment Agency) used more than 80% of the 1 in 50 year drought supply and one used more than 90% (DoE, 1996). This problem is exacerbated by an apparent change in climate that may be altering the reliability of water resource stock replenishment (Mitchell, 1999). There is an indication that the temporal distribution of precipitation is also changing with wetter winters and drier summers (Wigley and Jones, 1987). Therefore, there is no guarantee that sufficient quantities of water will be available, when needed, in the areas where long-term average annual precipitation is 'normal'. The 1995 drought caused severe problems in the UK, resulting in an additional cost of approximately £47 million to satisfy the water demand for that year. For the UK, as whole, 1997 represented the seventh year since 1989 that drought orders (legally enforced restrictions on non-essential use of water) were applied (Mitchell, 1999). Therefore, a better understanding of water consumption trends and the implementation of appropriately designed demand management studies is clearly essential.

In the UK, there are four main uses for water: domestic (public water supplies), power generation, industrial and agricultural. Figure 1.1 shows total water abstracted annually for these uses from 1971 to 1991 (in England and Wales). The figure shows that over the years there has been a substantial increase in public water supplies, a gradual reduction in water abstracted for industry and power generation and a marginal increase in agricultural sector. Despite the increase in public water supplies, the total quantity of water abstracted reduced by 16% in 1991 compared to base figures in 1971. Of the aforementioned four water uses, only the consumption aspects related to domestic supplies will be discussed in this chapter.

Table 1.2 Observed and predicted water stress in 1985 and 2025 (Vörösmarty *et al.*, 2000)

Area	Population (millions)		Available water (km^3/yr)		Water Stress in 1985	Change in water stress, relative to 1985, in 2025 (%)		
	1985	2025	1985	2025		Climate	Population	Combined
Africa	543	1440	4520	4100	0.032	10	73	92
Asia	2930	4800	13700	13300	0.129	2.3	60	66
Australia	22	33	714	692	0.025	2.0	30	44
Europe	667	682	2770	2790	0.154	-1.9	30	31
North America	395	601	5890	5870	0.105	-4.4	23	28
South America	267	454	11700	10400	0.009	12	93	121
Globe	4830	8010	39300	37100	0.078	4.0	50	61

1.3 PER CAPITA WATER CONSUMPTION

The primary aim of providing water to households is to meet the basic water requirements of the residents. Gleick (1996) proposed a minimum of 50 litres/person.day (lpd) as the basic water requirement for meeting the four basic human needs: drinking water for survival, water for human hygiene, water for sanitation services and modest household needs for preparing food.Unfortunately, over 50 sovereign states in the world are unable to meet this basic water requirement for domestic use. About 70% of these countries can only provide just less than 30 lpd, including countries such as Nigeria where there is substantial oil production. Per capita domestic consumption of water varies from country to country, largely depending on economic well-being, traditional habits regarding sanitation, availability of freshwater resources and political willingness to improve water efficiency. As an example, Figure 1.2 shows the domestic per capita consumption in a variety of countries. At the upper extreme is the USA with an average consumption above 300 lpd. At the lower end are countries such as Gambia and Nigeria where consumption is in the range of 4-30 lpd.

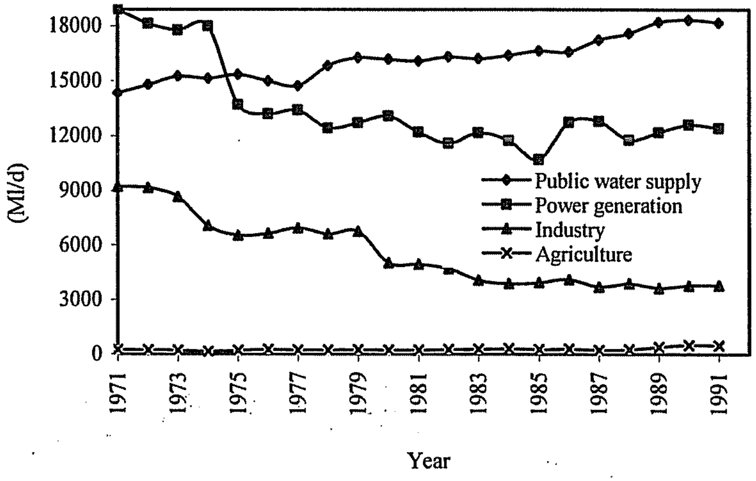

Figure 1.1 Licensed non-tidal water abstractions in England & Wales (Herrington, 1996).

The trend in water consumption changes from country to country, depending on several factors including climate, availability of resources, technological advancement, water price structure, incentives and legislative provisions. For example, an analysis of 27 years of data on per capita consumption in OECD countries showed that per capita average consumption in Japan has been reasonably constant since 1990. In England and Wales and Korea, water consumption has increased over the years. In Germany, a falling per capita consumption can be observed (Herrington, 1999).

In the UK, per capita consumption is about 150 lpd and rising, but this average figure masks a considerable variation between individuals. Figure 1.3 shows a log-normal plot, with elongated tail, reflecting high consumption by a small section of the sample population.

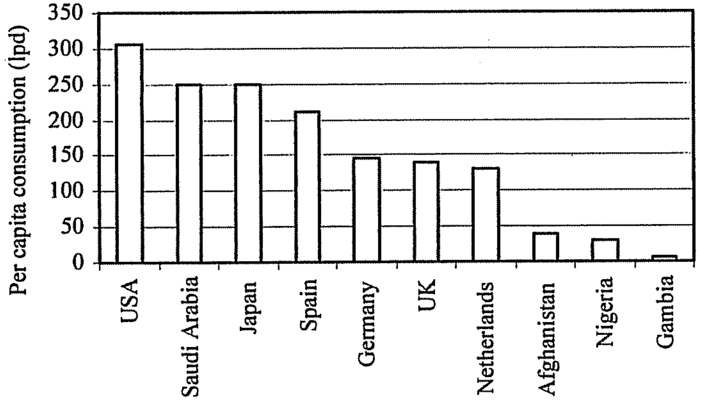

Figure 1.2 Per capita domestic water consumption in some countries.

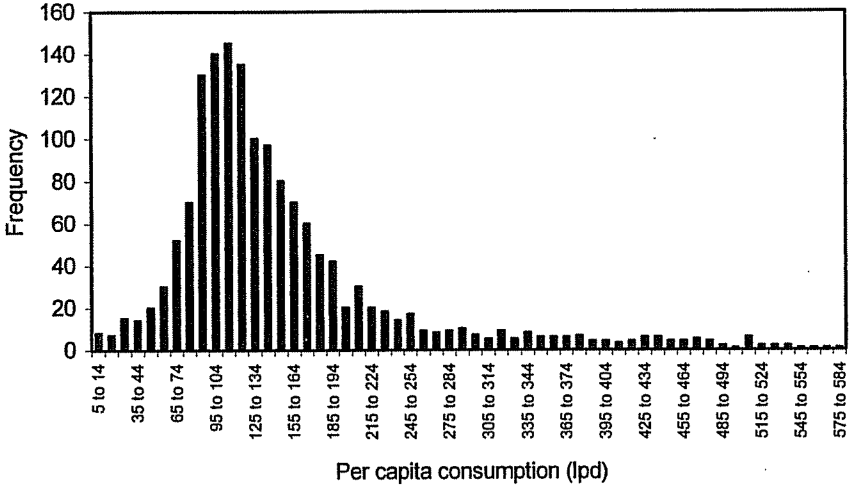

Figure 1.3 A typical frequency distribution profile for per capita consumption in the UK (Edwards and Martin, 1995).

1.4 FACTORS INFLUENCING CONSUMPTION

The level of domestic demand varies considerably from household to household depending on the socio-economic factors and household characteristics. Several studies, conducted to investigate the influence of such factors, have revealed that per capita consumption changes with, for example, household size, type of property, ages of household residents and time of the year. The results of these studies are briefly reviewed.

Occupancy (i.e. number of people living in a household) has a direct influence on per capita consumption. Although an increase in the number of inhabitants per household increases the total domestic water consumption, there is a general agreement that per capita consumption decreases with increased occupancy (Butler, 1991; Edwards and Martin, 1995). For example, in a single person household, per capita water consumption is 40% greater than in a 2-person household, 73% greater than in a 4-person household and over twice that in households of 5 or more people (POST, 2000). This trend is shown in Figure 1.4. From a future water demand perspective, this relationship between the occupancy and per capita consumption is very important since much of the projected growth in the number of households over the coming decades in developed economies is expected to be from single-person households and other small properties. According to the UK government projections, the number of new homes in England and Wales is expected to increase by 3.3 million between 1996 and 2016 and the trend is towards homes with smaller household size (EA, 2001).

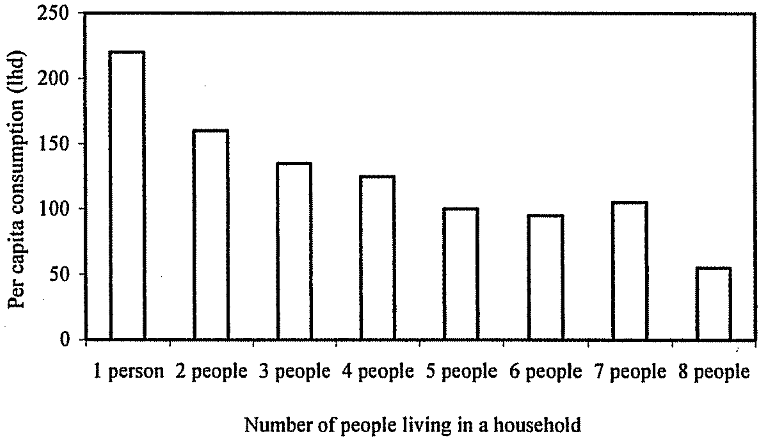

Figure 1.4 Impact of household size on per capita consumption (Edward and Martin, 1995).

The influence of household type (e.g. detached, semi detached house, flat) on average consumption per household was investigated by Russac *et al.* (1991). He found that the demand was highest in detached houses and lowest in flats. This was attributed to the relatively low per capita garden watering requirement for flats. Additionally, the high water demand in detached houses may be linked to the greater space available for appliances or socio-economic reasons. BSRIA (1998) and AWWA (1999) found a correlation with floor space.

Russac *et al.* (1991) also made an interesting observation with regard to consumers' age groups and water demand. Retired people in one-person dwellings consumed 200 litres per day on average as compared to 140 litres per day by an adult living in a single-person residence. This may be due to the fact that retired people stay at home for longer periods. Age-related diseases such as diabetes and, in men, prostate problems often result in the increased frequency of urination and hence use of the toilet (Green, 2003).

Seasonal variations are also reported to cause changes in the level of water demand. This demand variation is generally linked to garden watering. According to Herrington (1996), garden watering in houses in the South and East of England, using sprinklers, took place once every six days during May to August in an average year in the early 1990s. The estimated average volume for each irrigation session ranges between 1000-1200 litres. About 40% of households use hosepipes, on average, three times per week in hot dry weather consuming approximately 315 litres per use (Three Valleys, 1991). The UK based water consumption monitoring projects suggest that much of the peak demand is due to garden watering, with an estimated 4% of annual consumption taking place over an eight week period due to this activity (CC:DW, 2001). In long dry periods, garden watering could constitute up to 40% of the total consumption in some months.

Clearly, affluence is a key factor in influencing water consumption. This is most starkly illustrated in developing countries (see Table 1.3) where per capita water consumption can vary significantly, depending on economic well being of the community. This topic is returned to again in Chapter 8.

Table 1.3 Variation in domestic water use as a function of affluence (adapted from Stephenson, 2003)

Type of dwelling/supply source	Average consumption (lpd)
High-quality housing areas	225
Urban residential areas	180
Suburban low cost housing	95
Urban areas served by standpipes	60
Rural areas served by standpipes	40
Rural dwellings with distance to source >1km	20

1.5 CONSUMPTION BY MICRO-COMPONENT

To understand consumption patterns and trend more deeply, it is necessary to study the individual uses of water within the house (micro-components), whether for personal hygiene (e.g. water use in wash basins, WCs, shower and bath) or communal use (e.g. water use in washing machines, dishwashers, garden and car washing).

Significant information is now available and patterns of micro-component use have been studied with respect to their share of total household demand, volume per use, frequency of use, level of ownership and their peak use hours. The main findings of several key studies are reviewed here.

In the UK, a comprehensive study of domestic water consumption patterns (SoDCon) by Anglian Water has been ongoing since 1991. The study includes water consumption monitoring in about 3000 houses in the Anglian (eastern England) region with 100 houses exclusively monitored for every micro-component. Figure 1.5 shows the averaged values from 1993 to 1998 of the SoDCon data. Over a year, the greatest uses (60%) are for personal hygiene, followed by washing machines and dishwashers (21%), kitchen taps (15%) and outside taps (4%).

In the USA, domestic water consumption patterns for single-family houses were studied over two years in 12 different cities located in different climatic regions by AWWA (1999). The results showed that average water consumption was highest in toilets (27.6%), followed by clothes washing (21.7%), showers (16.8%), faucet (13.7%), baths (1.7 %), dishwasher (1.4%) and other domestic uses (2.2%).

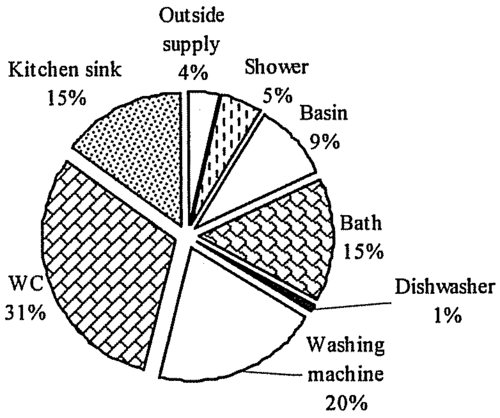

Figure 1.5 Water consumption share of different micro-components (POST, 2000).

In the Netherlands, the highest consumption is for toilets (37%), followed by bathrooms (26%), kitchen use (16%) and clothes washing (16%). In Sweden, the appliance share is slightly different. The major consumption is in bathrooms (32%) followed by kitchen use (23%), toilets (18%) and clothes washing (13%) (EAA, 2001).

Butler (1991) carried out a diary survey in 28 households in Southern England to investigate the pattern in which different appliances are used within a household throughout the day. The flow and the usage pattern of each micro-component varies with time. The peak frequency and time to peak discharge from several appliances are shown in Table 4.1, based on UK data.

Table 1.4 Approximate peak frequency and time to peak use for different appliances

Micro-component	Peak frequency (Uses/hour) Butler (1993)	Time of peak (Edwards and Martin, 1995)
Washing machine (WM)	0.03	10:45
Dishwasher (DW)	-	03:15
Bath	0.14	18:45
Shower	0.32	07:30
Toilet (WC)	1.2	08:00

In a separate study, Herrington (1996) observed that the frequency of bath/ shower increased during 1976 to 1990, suggesting that a cultural change in personal washing has occurred and is continuing. A comparison of change in domestic water consumption pattern for Southeast of England over 25 years is shown in Figure 1.6. The per capita water consumption for the bath/shower has increased from 27% in 1976 to 33% in 2001 of the total consumption. Figure 1.6 also shows a marginal decrease in per capita consumption for toilet flushing, perhaps resulting due to introduction of low flush toilets.

Table 1.5 Average water consumption in domestic appliances (EEA, 2001)

Appliance	England & Wales	Finland	France	Germany
Toilet	9.5 l/flush	6 l/flush	9 l/flush	9 l/flush
Washing machine	80 l/cycle	74-117 l/cycle	75 l/cycle	72-90 l/cycle
Dishwasher	35 l/cycle	25 l/cycle	24 l/cycle	27-47 l/cycle
Shower	35 l/shower	60 l/shower	16 l/minute	30-50 l/shower
Bath	80 l/bath	150-200 l/bath	100 l/bath	120-150 l/bath

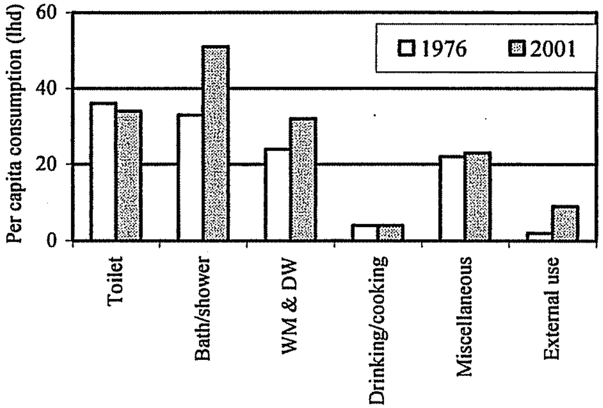

Figure 1.6 Change in domestic water consumption in South East England.

The average water consumption for each appliance per use for different countries is shown in Table 1.5.

1.6 WATER CONSUMPTION TRENDS AND SAVING POTENTIAL

The cumulative domestic water consumption profile, appearing as the result of the above-mentioned micro-component frequency and flow patterns varies significantly throughout the day (Figure 1.7). There are four distinct periods: a sharp morning peak around 08.00 am, moderate mid-day flow lasting up to 4.00 pm, an evening and relatively small late night peak and subdued low night flow until 4.00 am. The peak discharge from the WC, shower, bath and sink in the morning is on average simultaneous. Flows from the washbasin are rather more uniformly spread whilst washing machine use shows an increase after midday. Similar diurnal patterns are observed in the USA (AWWA, 1999).

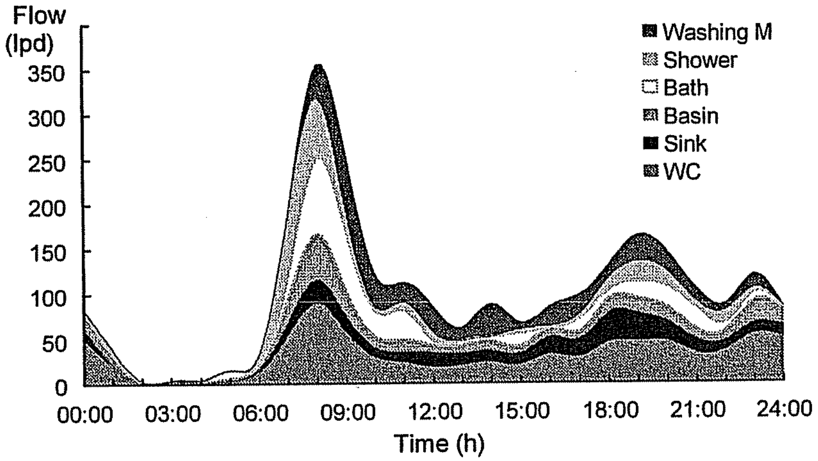

Figure 1.7 Appliances' daily wastewater discharge pattern (Butler and Davies, 2004).

The data in Table 1.5, refers to water for the appliances that have already been installed. However, new regulations and policy initiatives should ensure reduced consumption by future appliance installations. For example, the UK Water Supply (Water Fittings) Regulations of 1999 set 6 litres as the maximum volume for single flush toilets from the year 2001. Requirements for new WCs to operate at flush volumes lower than 6 litres were introduced in countries such as Singapore and Australia due to the lack of available freshwater supplies. For general use, Singapore has a maximum flush volume of 4.5 litres for newly installed WCs and Australia has a maximum flush volume of 4 litres. Australia has the lowest flush volume requirement for WCs that can be directly connected to sewers system. This requirement has reduced WCs' water consumption from 55 (in mid 1950s) to 18 litres per person per day in early 1990s (Cummings, 2001). The use of low-flush WCs is becoming increasingly popular and several low flush toilet retrofitting projects have been undertaken in different parts of the world. The estimated economic and financial gain from these projects has been reported as considerable (Green, 2003).

Technological advancements and policies designed to encourage efficient use of water have produced significant reductions in water consumption by different appliances. Figure 1.8, for example, shows the influence of water conservation measures and technological improvements giving a gradual reduction over time in the water used by washing machines. A focused discussion on the impact of various water saving devices and associated implications influencing water consumption trends is provided in Chapter 4.

BSRIA (1998) has investigated the impact of low water consuming devices and made a scenario-based assessment of potential savings in water and cost in various types of buildings (including households) in eight regions of the Environment Agency in England and Wales. The main statistics obtained from the study are shown in Table 1.6. The total water savings in England and Wales are reported to be in the range of 2.0 to 2.8% of current consumption. There lies a potential of a further 24% saving. The payback period is the lowest for factories (1.7 years) and the highest for households (29.6 years). This high payback period for households is surely one of the main barriers to be overcome. The trends for wider uptake of greywater recycling at domestic level are also not encouraging. The Environment Agency (EA, 2001) has anticipated that the uptake of greywater recycling systems at a domestic level is unlikely to exceed 10% even after 2016. The penetration of greywater recycling units is estimated to reach 18% by the end of 30 years (EA and UKWIR, 1996). The main barriers and potential drivers for the successful implementation of greywater recycling systems are identified in Chapters 3 and 9. Rainwater harvesting, as discussed in Chapter 2, appears to be a relatively more pragmatic and cost-effective option compared to greywater recycling.

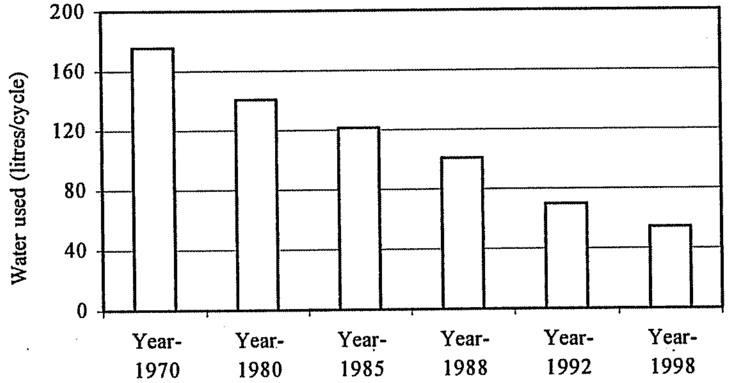

Figure 1.8 Reduction in water consumed by washing machines in last 30 years (EEA, 2001).

Table 1.6 Water savings made and potential for further savings in different types of buildings in England and Wales (BSRIA, 1998)[1]

Type of Building	Savings made already		Current saving potential	
	Water (Ml/d)	Financial £ k/year	Water (Ml/d)	Financial £ k/year
Households	55	2627	335	15958
Factories[2]	49.6	28545	37.2	21408
Hospitals	0.6	305	2.6	1271
Hotels/Motels	30.2	15989	11.6	53296
Leisure centers	1.0	524	2.7	1399
Nursing Homes	0.4	221	8.3	4865
Offices	24.9	13778	24.9	13778
Schools	43.7	23264	124.3	66219
Universities	30.5	15459	14.1	7135
Retail Stores	3.6	2447	4.7	3389

[1] As suggested by BSRIA, a thorough understanding of the assumptions and limitations is necessary before referring to the values reported in the table. Financial savings were calculated using water tariff schedules from the water companies operating in the UK.

[2] Does not include process water

1.7 DEMAND FORECASTING TECHNIQUES

In order to meet future water supply needs and assess environmental and financial sustainability of various demand management options, an accurate prediction of water demand is essential. According to Herrington (1987), forecasting water demand helps to serve the following purposes:

- Strategic planning;
- Investment appraisal;
- Operations planning;
- Appraisal of demand-management policies and innovations;
- Demand management in "crisis" periods;
- Calculation of future price trends as efficiency signals; and
- Some supply forecasting (via wastewater reclamation).

Water demand forecasting based on rules of thumb or naive extrapolation is now recognized as being inappropriate, since estimates obtained in this way have been shown to deviate significantly from the observed demand and also are of no help in appraising water conservation initiatives (Herrington, 1987). Owing to increases in population, constraints on freshwater supply and the rising costs (both economic and environmental) involved in the development of new water resources, there is a need to develop methods capable of demonstrating a high correlation with actual demand. Such methods should ideally incorporate the influence of:

- Spatial and temporal variability;
- Properly-appraised water conservation policies such as: metering, water saving devices, water recycling measures and the rate at which these measures would be adopted by consumers in the future
- Characteristics associated with various appliances used (e.g. ownership, frequency and volume of water consumed per use)
- Lessons learnt from the forecasting techniques used in the past; and
- Past water consumption trends.

Additionally, the forecasting methods should reflect a scientific basis, acceptability to the regulator and feasibility with regard to cost and data collection and validation requirements.

Selection of the forecasting technique also depends on the nature of demand that needs to be predicted. Demand varies in time. Peak daily consumption has been observed to be 1.8 times the average hourly flow and peak seasonal demand are about 1.4 to 1.8 times the daily demand (Green, 2003). Predictions of hourly and peak daily demands are helpful in managing/providing the water distribution network. For strategic and planning decisions, information on micro to macro scale (including seasonal) variations in demand is often desirable.

Forecasting techniques can be broadly divided into two groups:

- Techniques that build conceptually and require a relatively limited amount of data to produce future projections in water demand. These techniques are generally used for long-term forecasts.
- Techniques that require extensive data collection. The data is then used to formulate often complex statistical relationships and infer the rules that will indicate the level of demand. These methods are normally for short-term forecast.

Owing to a number of resource constraints and unavailability of sufficiently large sets of data on consumption patterns, it is hard to develop such forecasting techniques, which represent all the above-mentioned aspects. However, UKWIR (1997) made an attempt to develop forecasting methods in order to meet the needs of UK water companies. These methods have considered three different components of water consumption viz: unmeasured and measured household and measured non-household demand. Forecasting methods related to households will be reviewed here. These methods were designed to make long-term predictions.

1.7.1 Unmeasured household demand

UKWIR (1997) recommends two related forecasting methods using micro-component analysis and micro-component *group* analysis.

In micro-component analysis, the information on ownership level, frequency of use and volume of water consumed for each appliance (or household water using-activity) is used to calculate demand. The per capita consumption is estimated by adding up water contributions from each appliance (or activity) in unmeasured households using the following relationship.

$$pcc = \sum_{i} \left(O_i \cdot F_i \cdot V_i \right) + pcr \qquad (1.1)$$

Where

pcc - per capita consumption
O_i - proportion of household using appliance (or undertaking activity) *i*
F_i - average frequency of use of appliance (or activity) *i* per capita among the proportion of household
V_i - volume of water consumed by appliance (or undertaking activity) *i* per use
pcr - per capita residual (miscellaneous) demand

The *pcr*, in effect, is the difference between the estimated cumulative demand from all appliances (activities) in the period under consideration and actual total demand observed during this period. For the purposes of forecasting, *pcr* is usually kept to a constant value or it can be projected by assuming it is a fraction of total *pcc*. This method does not require historical records of time series data covering several years. It is flexible enough to accommodate the change in appliance usage patterns (e.g. individual actions, water efficient devices). However, depending on the level of accuracy required in predictions, the method does require a considerable amount of resources to gather the data on appliance characteristics (e.g. ownership, frequency of use and volume of water per use).

In micro-component group analysis, the residential units showing distinct similarities in terms of appliance penetration rate, usage frequency etc. are classified into a single group. The group classification criteria are decided considering the factors having a direct or indirect influence on water consumption patterns. Some of the criteria suggested are: socio-economic (indicating the purchasing power of a particular household), type of house (e.g. flat, detached, semi-detached, terraced) and composition of household (e.g. retired, single adult, families with more than two children). The ACORN (A Classification Of Residential Neighborhoods) classification has also been widely used in the UK water industry to choose groups based on demographic attributes (Mitchell, 1999). In group analysis, the estimation procedure builds on the micro-component method as given below:

$$pcc_g = \sum_i \left(O_{i,g} \cdot F_{i,g} \cdot V_{i,g}\right) + pcr_g \qquad (1.2)$$

where

g - number of groups identified

The non-measured household (NMHH) demand can thus be estimated as:

$$NMHH = \sum_g \left(pcc_g . pop_g\right) \qquad (1.3)$$

pop_g - population in group g

Group identification is the key feature of this method. This helps in examining the implications of targeted policies aimed at water conservation measures. The significance of a group-based approach increases in the case where a sharp increase in metering penetration (and hence a shift in consumer base) is expected.

1.7.2 Measured household demand

Metering household water supply can have some impact on water consumption trends. In the UK, national metering trials conducted between 1989 to 1992 found an average reduction in household consumption of 10.8% for 11 small-scale sites. The average demand effect of metering in the Anglian region is estimated at around 15 to 20% and for peak demand it is 25 to 30% (EA and UKWIR, 1996). However, installation of meters to measure household consumption is rather sluggish. According to Ofwat (2001), approximately 22% of households in England and Wales are metered. Thus sufficient amounts of historical data on water consumption in metered households are not yet available for establishing consumption patterns. However, due to a growing emphasis on water conservation in certain regions, a significant increase in the proportion of metered houses is anticipated, as discussed in Chapter 11.

UKWIR (1997) has reported on various approaches to forecasting this component of the water demand. Among these, the micro-component group analysis method was recommended, the method being broadly similar to that for unmeasured household demand. For measured households, it was suggested that the forecast is made by carrying out the micro-component analysis separately for each identified group first, and then projecting the size of the respective group. The emphasis in this method is on the significance of identification of different groups, since the composition of metered households is changing substantially. Other group identification criteria, in addition to the criteria mentioned for unmeasured demand, may include new homes and water tariff structure.

Confidence in the performance of these methods, particularly the methods using group analysis, is yet to be established. In group analysis, the data gathered from a small section is assumed to be representative of the entire water consumer base falling within that particular group. This assumption may not work well in its entirety. For example, Russac *et al.* (1991) found that similar demand occurred in different ACORN groups, and that markedly different demands occurred in the same ACORN group.

1.7.3 Scenario-based forecasting

The Environment Agency (EA, 2001) has developed a rather different scenario-based approach to forecast public water supply demands in the years 2010 and 2025 in 125 resource zones of water companies operating in England and Wales. The forecasting procedure is essentially the application of the micro-component method proposed by UKWIR (1997) but involves an extensive consideration of the influence of socio-economic changes, which could emerge in the future due to changes in social values and systems of governance in the UK. Four distinct scenarios were developed; following work undertaken by the UK government 'Foresight Programme':

Scenario Alpha (Provincial Enterprise): Under this scenario, society's interest in environmental issues and social equity is low due to low economic growth and lack of investment.

Scenario Beta (World Market): This scenario assumes a high level of economic growth but little consideration is given to social equity. Concern for the environment is low particularly in less well off sections of the community.

Scenario Gama (Global sustainability): Consideration of sustained economic growth and social equity driven by global institutions is the main feature of this scenario. The scenario assumes considerable investment in environmental research, which would produce clean technologies that help in resource conservation

Scenario Delta (Local stewardship): In this scenario, leadership at local level takes collective action to resolve environmental problems.

The application of these scenarios was demonstrated for the household sector using a set of drivers perceived to influence domestic demand. These are:

- Water policy drivers (metering and water regulations, pricing): These will affect the volume of water used in the household and restrict the ownership of high consumption appliances.
- Technology drivers (water efficient appliances, grey and rainwater reuse): Owing to investment in research and regulatory requirements, innovative technologies will render savings in water consumption.
- Behavioural drivers (type and pattern of personal washing, garden watering): This will change the pattern of the frequency of appliance use and the extent of ownership.
- Economic drivers (affordability): These influence the extent of ownership and affordability of low/high consumption devices.

The forecasting methodology is given in detail in EA (2001), but a summary of the key assumptions made to reflect the influence of four scenarios on water consumption by key micro-components is shown in Table 1.7.

Using the above-mentioned assumptions, the average measured and unmeasured per capita consumption and total household demand for water was calculated for 2025 and the results are shown in Figure 1.9. The figure shows the relative increase or decrease in forecast water demands for 2025 with respect to the corresponding data for the year 1997-1998.

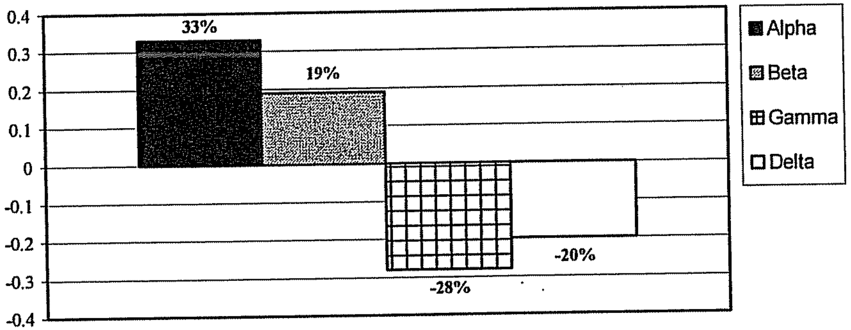

Figure 1.9 Percent change in total household demand predicted by each scenario for year 2025 as compared with 1997-1998.

Table 1.7 Key assumptions in the scenario based forecasting method (EA, 2001)

Factor		Assumptions
WC	Ownership	Alpha and delta: Rate of replacement of old WC with less water consuming device is 1 in 40 years, owing to slower technological development and lack of national regulation Beta: Replacement rate is in 1 in 30 as a result of effective implementation of existing regulation and uptake of available technology Gamma: Replacement rate is 1 in 20 due to increased affluence, awareness to environmental issues stringent regulations and efforts to develop efficient technologies
	Volume	Six devices differing in level of water consumption were considered, but in each scenario volume of particular device under consideration and frequency of use was maintained. However, the ownership for each cistern type varied according to specific scenario assumptions throughout the forecast period
Power shower	Ownership	Alpha: Power shower ownership is assumed not to exceed 50% by the year 2025 Beta: Due to high affluence 59% household will own power showers by the year 2025 Gamma: The trend for power showers is assumed to be reversed due to enforcement of strict regulations on maximum flow rate and people's willingness to replace the power showers with the normal devices. The assumed rate of replacement is 1 in 20 years. Delta: The community at a local level considers power showers inefficient and strives to minimize their personal impact on environment. Power shower use is almost eliminated by the year 2025.
	Volume	Alpha & beta: In 2025 the volume of water per power shower event is assumed to reach a maximum of 150 liters (15 l/minute for 10 minutes) Gamma & delta: Stringent regulations will limit the use of power showers exceeding the flow rate of 6 litres/minute.
Washing Machine	*Ownership*	Alpha, Beta and Gamma: Ownership reaches to 94% and then remains constant for the remaining forecast period. Delta: Ownership declines by 4% within the period of 2015 to 2025, reflecting the emergence of community laundries.
	Volume	Alpha: water consumed in washing machines is reduced to 80 litres by the year 2010 and afterwards it remains constant. Beta: 50 litres by 2025, Gamma and Delta: 40 litres by 2025.
Dish washer	*Ownership*	Alpha: Increase in the ownership at a rate of 1.7% per year and then increase at a reduced rate of 1.5% a year until 2025. Beta: Owing to high level of affluence the ownership increases at 2% a year. Gamma and Delta: Increase in the ownership at a rate of 1.7% per year and then increase at a reduced rate of 1% a year until 2025.
	Volume	Alpha: 30 litres by 2010 and remains constant thereafter. Beta: 20 litres by 2025, Gamma and Delta: 15 litres by 2025
Water recycling measures		Alpha & beta: Very limited recycling Gamma & delta: Reduction in mains water due to availability of water conservation technologies is assumed after 2010 for scenarios gamma and delta. It is assumed that 10% of the household will have greywater systems installed by the year 2025.

The EA (2001) water demand forecasting methodology provides demand projections in England and Wales for each resource zone of the Environment Agency. However, when analysing at a smaller scale, a considerable variation in domestic consumption has been reported in different parts of the same resource zone (Williamson, 1998). This variation is attributable to the change over time in demographic features, household size, social aspects (for example, change in the married and divorced fraction in the community), age groups and fertility and mortality rates. Williamson attempted to assess the impact of these factors on future water demand (at a ward level) using an official database for the metropolitan district of Kirkless, West Yorkshire. Population growth projections and variation in household composition were obtained using a static ageing technique within the micro-simulation framework, an established technique used in social and healthcare services. Although the crudeness of the forecasting assumptions to predict the water demand is acknowledged, it was demonstrated that the inclusion of spatial features in the forecasting process increases complexity, and differences in domestic water demand were visible in the spatial dimension. A detailed account of the micro-simulation approach adopted is available in Williamson (1998).

1.7.4 Statistical methods

In the USA, AWWA (1999) has developed a rather different forecasting approach. This builds on a number of complex statistical relationships developed using a part of the data collected over 2 years from metered single-family residential units in 12 cities in different climatic regions of the USA. The daily water consumption from each micro-component in a household was expressed in terms of several demand-influencing parameters such as household size and income, house floor area, degree of water conservation appliances and marginal price of water. The detailed statistical procedure adopted to derive the micro-component equations is given in full in AWWA (1999). Here, only the most relevant equations are presented. Equations 1.4-1.10 were proposed to model the water demand from each micro-component.

1. Toilet Water use Model (US gallons per household per day)

$$\hat{q}_{TOILET} = 14.483 \cdot (MPW)^{-0.225} \cdot (HS)^{0.509} \cdot (HSQFT)^{0.117} \cdot e^{-0.091(PRE60s)-0.164(POST80s)-0.076(ULTRATIO)-0.539(ULTONLY)} \tag{1.4}$$

Where

MPW - marginal price of water
HS - Household size (average number of persons)
$HSQFT$ - Home square footage (average)
$PRE60s$ - fraction of houses built before 1960
$POST80s$ - fraction of houses built after 1980
$ULTRATIO$ - fraction of all toilets that are ultra-low-flow (ULF)
$ULTONLY$ - fraction of customers that are completely retrofitted with ULF toilets

2. Shower/Bath Water Use Model (US gallons per household per day)

$$\hat{q}_{SHOWER} = 3.251 \cdot (MPW)^{0.514} \cdot (HS)^{0.885} \cdot (INC)^{0.171} \cdot e^{0.349(RENT)-0.16(ULTSRATIO)} \tag{1.5}$$

where

INC - household income ($, average)
$RENT$ - fraction of customers that rent
$ULSRATIO$ - fraction of all showerheads that are low-flow

3. Faucet Water Use Model (US gallons per household per day)

$$\hat{q}_{FAUCET} = 7.972 \cdot (HS)^{0.498} \cdot (HSQFT)^{0.077} \cdot e^{-0.254(RENT)+0.238(TRTMENT)} \tag{1.6}$$

where

$TRTMENT$ - fraction of customers with home water treatment systems

4. Dishwasher Water Use Model (US gallons per household per day)

$$\hat{q}_{DISHWASHER} = 0.409 \cdot (MPW)^{-0.5171} \cdot (HS)^{0.345} \cdot (INC)^{0.196} \tag{1.7}$$

5. Clotheswasher Water Use Model (gallons per household per day)

$$\hat{q}_{CLOTHESWASHER} = 2.293 \cdot (HS)^{0.852} \cdot (INC)^{0.162} \tag{1.8}$$

6. Leak Water Use Model (US gallons per household per day)

$$\hat{q}_{LEAKS} = 1.459 \cdot (MPW)^{-0.485} \cdot (MPS)^{-0.160} \cdot (HS)^{0.392} \cdot (HSQFT)^{0.214} \cdot e^{-0.2641(RENT)+0.712(POOL)} \tag{1.9}$$

MPS - marginal price of sewer ($/kgal)
$POOL$ - fraction of customers with swimming pools

7. Outdoor Water Use Model (US gallons per household per day)

$$\hat{q}_{OUTDOOR} = 0.046 \cdot (MPW)^{-0.485} \cdot (HSQFT)^{0.634} \cdot (LOTSIZE)^{0.237} \cdot e^{1.116(SPRINKLER)+1.039(POOL)} \tag{1.10}$$

Table 1.8 Observed and predicted water consumption in US gallons per household per day (AWWA, 1999)

	Boulder		Seattle		Waterloo	
Micro-component	Observed	Predicted	Observed	Predicted	Observed	Predicted
Toilet	43.7	40.8	44.9	39.7	51.4	43.9
Clotheswasher	35	28.6	30.5	31.3	37.5	36
Shower/bath	32.4	28.4	34.3	26.4	28.5	33.3
Faucet	25.4	21.3	22.8	22.9	50.3	28.7
Leaks	5.5	5.9	9.3	5.4	17.0	6.6
Dishwasher	3.6	2.8	2.6	2.4	2.1	2.9
Other/unknown	2.6	3.0	2.8	2.5	3.8	2.9
Indoor	148.1	130.9	147.2	130.6	190.4	154.3
Outdoor	198.3	58	204.2	21.1	74.2	27.6

These equations can be used to formulate predictions of water use for each micro-component given assumptions about the demographic make-up of a particular water service area. Conceptually, one may derive a prediction of end usage over time from these equations as household and property characteristics change over time (e.g. study the effects of growth in household sizes, incomes, and home and lot sizes). In addition the toilet and shower models build in a mechanism to study the impact of particular water conservation programmes that seek to replace inefficient fixtures (AWWA, 1999).

The statistical relationships were applied using the input data collected from 13 different cities in order to assess the performance of the developed model. The results from three locations are shown in Table 1.8. For all micro-components (except outdoor water use), the difference between the observed and predicted values is small. The performance of the outdoor model is, however, poor. This may be due to the absence of various demand-influencing parameters such as weather (temperature and precipitation) and season (month of the year) from the outdoor use forecasting equation (Equation 1.10). In order to account for this, an extended version of the model was proposed. The modified version uses the output from the micro-component equations, monthly billing records and temperature and precipitation data to forecast the monthly total water demand. A marked improvement in predictions was observed when the refined model was tested (AWWA, 1999).

1.7.5 Forecasting techniques for network operations

Several other approaches have been developed to estimate total daily demand. These methods are intended for predicting the demand to address distribution network operational issues: optimisation of water head in the service reservoirs, achievement of required level of pressure in the water distribution network and reduction in pumping and thus the associated costs. Realisation of the implications of inaccurate estimations of instantaneous water demand on optimal operational management efficiency (of water distribution networks), has led to further research and the use of statistical and complex computational tools. A brief review of some of the demand prediction strategies is given here.

An *et al.* (1996) proposed an expert-system method based on the rough-set approach to automatically frame probabilistic rules for predicting the daily total demand. The method applies a rigorous statistical treatment and takes into account the uncertainty in the available time series data on various factors influencing the level of demand. These factors include day-to-day variation in minimum and maximum temperatures, rainfall, snowfall, average humidity and speed of wind and bright sunshine hours. An example of the most generic form of the rule is:

$$(53 < a_4 \le 58) \wedge (22.98 < a_{14} \le 28.45) \wedge (13.30 < a_{18} \le 15.20) \xrightarrow{1} (124 < D \le 134)$$

The rule means that: if today's average humidity (a_4) is between 53 and 58% and the day before yesterday's maximum temperature (a_{14}) is between 22.98 and 28.45 °C and the day before yesterday's bright sunshine hours (a_{18}) are between 13.30 and 15.20, then the water demand (D) is between 124 and 134 Ml with a certainty factor of 1. The rules framed using the proposed method have been reported to produce an average error of approximately 10%.

Although statistical methods, particularly the auto-regressive integrated moving average model (ARIMA), have been used in the past to forecast consumer demand by taking into account time series observed data on weather conditions and measured flows, the predictions often indicate a considerable estimation error. Recent developments show a shift towards more sophisticated approaches such as fuzzy logic and neural networks. These approaches tend to produce somewhat better results.

Lertpalangsunti *et al.* (1999), for example, have described the development of a software package: Intelligent Forecasters Construction Set (IFCS). The package provides a range of intelligent tools (e.g. artificial neural networks (NN), fuzzy logic (FL), knowledge-based and case-based reasoning (CBR)) which can be used singly and in combination to develop a particular application. The package was applied to water demand forecasting. A comparative study using the above-mentioned intelligent tools showed that multiple NNs (i.e. each NN predicting the separate feature, for example demand on weekdays and demand on weekends) approach produced the minimum error. Mukhopadhyay *et al.* (2001) also developed a neural network based model using a year long dataset collected on water consumption and associated social, economic and seasonal characteristics for 48 residential units in Kuwait.

The above-mentioned demand forecasting techniques require an extensive amount of data covering a wide band of variability to train the neurons. Thus the precise extent of confident forecasting would depend upon the degree of similarity of the input data sets compared to the data used for developing the model.

1.8 CONCLUSIONS

In the UK, per capita water consumption has shown a trend of steady growth over time. This appears to be the combined effect of improved affluence, level of service and change in traditional values. The diurnal pattern of consumption indicates the WC and washbasin as the most water-using and frequently used appliance, respectively. Per capita consumption increases with reduction in household size. This could have considerable implications for increased demand, since the number of households with single and two occupants is anticipated to increase significantly in future. There is a considerable scope for water savings if low flush toilets are installed in place of old high-water using WCs. A range of water efficient technologies for households is commercially available. The uptake of water conservation measures (installation of water efficient devices and greywater and rainwater recycling systems) is relatively slow compared to many developed countries. An apparent reason for this is the high cost and absence of subsidies from the government.

The importance of producing reliable water demand forecasts is now realised and there have been several attempts to devise water demand-forecasting strategies. The typical problem associated with most of these strategies is the scarcity of suitable historical data on water consumption trends, micro-components' characteristics, socio-economic influences and temporal and spatial factors responsible for altering the composition of existing consumer base. The use of techniques incorporating micro-component features seem to be the most promising approach to forecasting long term water demand, since it offers a flexible framework to accommodate the influence of emerging socio-economic changes.

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2

The technology, design and utility of rainwater catchment systems

Alan Fewkes

2.1 INTRODUCTION

This chapter reviews the technology, design and utility of rainwater catchment systems applied to small scale systems using rainwater collected primarily from roofs for use by the building occupants. Initially, the application of systems in developing and developed countries to supply both potable and non-potable water is considered. The reasons underlying the renewed interest in rainwater catchment systems over the past twenty years are identified. Generally, these relate to economic, operational and environmental difficulties associated with centralised water systems. The second part of the review concentrates upon the different types of rainwater system, which can be used to supply non-potable water in developed countries. Systems can be categorised according to how they store and deliver rainwater within dwellings or in relation to their hydraulic properties. The

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