THE ESTIMATION OF URBAN DOMESTIC WATER USE: A STUDY WITH REFERENCE TO LEEDS

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

Abstract

The privatisation of the water industry in 1989 highlighted the need for greater precision in planning water resources. The absence of any large scale research on the pattern of domestic water use (DWU) accentuated the ignorance of the utilisation of more than 50% of supplies.

With the gradual introduction of domestic metering during the mid 1980s, there has been a considerable growth in information in this area. Since privatisation, the number of metered properties has risen and now amounts to 6% of the population. The data accumulated on the subject of domestic water use have increased the ability to understand better some of the processes involved, although there remained two major stumbling blocks on the way to analysing fully these data.

Firstly, the nature of the meters and the frequency with which they are read makes the understanding of the components which make up domestic water use almost impossible; and secondly, the profile of metered households is, by its nature, biased towards new properties which often have meters installed in them automatically, and small households, who opt to have a meter installed as they perceive financial gain resulting from it.

Under such circumstances the data containing the results of two surveys conducted by Yorkshire Water in 1992 are used in a new approach to geographical modelling. In the first stage the components with the highest DWU coefficients are determined by statistical means. A microsimulation technique, which lies beyond the scope of this work, is used in the second stage to model the spatial distribution of domestic water use in Leeds by using household components derived from the data by statistical means. The uniqueness of this thesis is in its association of these two techniques.

The overall conceptual analysis of all the issues involved in DWU, together with results of the two analyses, allow a better understanding of domestic water use of all properties, whether they possess a meter or not, from the smallest geographical unit - the household - to any spatial aggregation required.

The implications of this model for policy formulation and management strategy are numerous. The ability to forecast demand whilst incorporating environmental and economic scenarios, combined with the ability to concentrate on any geographical scale, renders this approach extremely useful in future developments which the water industry is about to enter.

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List of Abbreviations

ACORN	A Classification Of Residential Neighbourhoods
AMP	Asset Management Plan
BG	Bungalow
CBA	Cost Benefit Analysis
CR	Council Rented
DD	Detached property
DoE	Department of the Environment
DWU	Domestic Water Use
ED	Enumeration District
EEM	Error in Equation Model
FM	Flat / Maisonette
FOB	Free On Board
GNP	Gross National Product
HH	Household
IPF	Iterative Proportional Fitting
l/pp/d	Litres Per Person Per Day
LPA	Local Planning Authority
LSR	Least Square Regression
m^3/hh/pa	Cubic Meter per Household Per Annum
MSE	Means Square Error
NCC	National Consumer Council
NRA	National Rivers Authority
NVM	Noise in Variable Model
Occs	Occupants
OFWAT	Office of Water Services
OLS	Ordinary Least Square
OO	Owner Occupier
PA	Per Annum
PD	Postal District
PR	Private Rented
PS	Postal Sector
RPI	Retail Price Index
RV	Rateable Value
SD	Semi Detached
SGA	Small Geographical Area
Std.Dev.	Standard Deviation
Std.Err.	Standard Error
SWW	South West Water
TT	Through Terraced
UK	United Kingdom
UT	Other Tenant (usually Housing Association)
VIF	Variance Inflation Factor
WAA	Water Authorities Association
WC	Water Company (all)
WSA	Water Services Association
WSC	Water and Sewage Company (any one of the ten regional companies)
Yr	Year
YW	Yorkshire Water Plc.
YWA	Yorkshire Water Authority (pre 1989)

1 INTRODUCTION

1.1 The background

Because domestic water use (DWU) in Britain has never been researched on a large scale, there is ample evidence that future projections are made now, and were always made by a 'rule of thumb' (Brandon, 1984). This has never been the result of a shortage in projection techniques, rather the ignorance of the actual water use at the time the projections were made. The almost complete absence of domestic water meters until the mid 1980s has made any attempt to assess DWU an almost futile exercise. Even when properties began to be metered there remained the problem of imposing the information gathered from these properties onto the rest of the non-metered population.

None of this seemed to disturb policy makers in the industry until very recently. The standard of service and the funds allocated for the industry's operations were fixed by the Government, and the exact amount of water actually supplied to domestic customers did not seem to pose any problem. Since the privatisation in 1989 the industry finds itself accountable to its shareholders. Efficiency and levels of service became paramount on the industry's agenda. However, there was an almost total unfamiliarity with any figures associated with the demand of the industry's core product for over 50% of its customers.

The consequences of this situation are three: firstly, efficiency cannot be measured if the amount supplied is not known. Secondly, the amount of water lost in the system as a result of leakage and other occurrences cannot be reliably measured or even assessed; and finally, the new charging system which is meant to replace the property's rateable value by April 2000 cannot be constructed without first establishing the amount of water customers' use.

It was with this knowledge that the School of Geography, University of Leeds, accepted in 1992 an offer from Yorkshire Water Plc. (YW) to analyse the data collected from all metered domestic properties in Leeds.

1.2 The problems

The data collected by YW consist of two data sets. Firstly came the result of a survey carried out in April 1992, which covered the whole of Yorkshire. The 531 properties eventually surveyed were randomly sampled, and the questionnaire contained 18 questions. A second survey was carried out in November 1992. It covered the totality of metered properties in Leeds and contains 4039 cases. The questionnaire for the second survey contained only 16 questions.

The problems of analysing these data are of two types: component identification and generalisation. The first corresponds to the right choice of variables which could be modelled by microsimulation modelling and the second is the spatial implications which the findings of the model carry.

The information was gathered by YW for purposes other than the present research which means there are a number of variables whose influence and interrelationship with other variables have to be determined. Simultaneously, whatever little is known on the subject from the available literature has to be re-assessed, in particular if discrepancies between the findings of the present work and previous records arise.

Finally, there is a wide range of decisions which could be taken as a result of the model's findings. The possible implications of the findings on decision makers at all levels of corporate management have to be laid out and discussed.

1.3 The aims of the work

Accordingly, the two main aims of this thesis are as follows. Firstly, to determine a set of household characteristics and their relative influence on water use. The number and interrelationship between these variables is to be affirmed by more than one technique of analysis and the quality of the analysis will be sufficient for the requirements of microsimulation modelling.

The second result is the presentation of policy potentiality which emerge from the analyses. Following the microsimulation modelling, the potential of the techniques used in the present work allow the projection of different scenarios with greater accuracy than ever before. The advantage concealed in the detailed facts are to be outlined and their potential use made explicit.

1.4 The approach

All the statistical techniques used in the present work as well as the microsimulation modelling are well tested procedures. The originality of the present work is in the combination of these two methods.

A combination of descriptive statistics, first on a small set of data and later on the larger sample, is followed by a series of inferential statistical manipulations. The crystallising of the best set of variables is performed step by step, exhausting the information supplied by the questionnaires. (The set of criteria to be attained is reached, and only then are the results modelled.) Not all the variables pinpointed by the statistical analysis are actually used in microsimulation. The variable 'property type' was modelled although it did not score high in the statistical analysis because it matched better other data sources such as the General Household Survey. More on this issue in section 4.5.1.

Microsimulation modelling is not performed as an integral part of the present work, but its results are displayed and compared with the results obtained by standard statistical techniques. The implications of the model on a whole range of issues which arise during the analysis stage are considered by comparing similar attempts in the literature reviewed.

1.5 Thesis outline

An understanding of the issues that are investigated in the thesis requires an outline of the fundamental topics related to domestic water use. Accordingly, Chapter 2 explains the economics of domestic water both in theoretical terms (sections 2.2.2 and 2.2.3) and in its practical form (sections 2.3 to 2.3.7). The political and historical background to the present research are briefly outlined in sections 2.3.4 to 2.3.7. These sections, which cover the more politically orientated issues such as privatisation and charging methods are followed by a summary of the same issues in Yorkshire and in Leeds (section 2.3.8).

Having established the background, the literature looking at domestic water demand estimation and forecasting is reviewed in Chapter 3. As the literature reflects the diversity of approaches to the topic, each section of the literature reviewed deals with one of the diverse approaches. Following the presentation, the five approaches: social policy, the engineering, economic, disaggregate (component) approaches to DWU are discussed (sections 3.3 to 3.7), as well as the literature which looks at the more sophisticated techniques such as ACORN classification for water purposes. Throughout the chapter it is argued that the very terms used to define the household activities with regard to water (use, consumption, demand, etc.) underlay the whole approach to it, and are not a mere semantic choice.

Chapter 4 explains the principles which form the methodology of the thesis. It is pointed out that the nature of the problems associated with DWU requires innovative combinations of techniques in order to make better use of the computing hardware and software. Consequently, the association of descriptive and inferential statistics is summarised in section 4.5 to 4.5.6 while the next stage, namely microsimulation modelling, is explained in greater detail in sections 4.6 to 4.6.4.

In the next chapters, the detailed statistical manipulations which the data from both YW surveys undergo are described. In Chapter 5 the data from the first survey sample (April 1992) are analysed in order to assess the components most relevant to the purpose the research in the next stage. Chapter 6 describes the performance of similar descriptive statistics techniques on the larger sample (November 1992). The results of this stage are then subjected to another series of statistics tests in Chapter 7, where they undergo inferential statistics analysis.

This chapter, which constitutes the bulk of the technical aspects in this thesis, is composed of tests of normality of the data (section 7.1), correlation analysis, analysis of variance (section 7.2), and finally a full regression analysis which enables a meaningful selection of the variables to be used in the microsimulation model. Throughout these manipulations the results of similar works, both in Britain and abroad are compared, and the lessons drawn.

In Chapter 8 the results of the microsimulation modelling performed by Williamson (1993, 1994) are compared with the results obtained by statistical means. A series of maps reveals the water use pattern as it emerges in the model, and the assumptions which this model underlies. The interpretation of these spatial patterns is then discussed in Chapter 9.

In this chapter the essence of the work is discussed when the hypotheses, the literature and the results are brought together. The overall view of the issues and their implications are exposed to the specific requirements and pressures which they are likely to be put under in the next few years. The advantage of using the techniques which are employed in the present thesis are stressed, while the inevitable shortcomings are also pointed out. In the concluding section of this chapter, future developments in this area are given some consideration.

The concluding chapter (Chapter 10) provides a final summary of the thesis, recapitulating the main findings and offers a final consideration of the value of this work.

2. THEORETICAL & HISTORICAL BACKGROUND

2.1 Introduction

In order to understand the reasoning behind the present research and the questions which it raises, a basic understanding of the conditions in which it operates is necessary. This chapter briefly describes the historical background to such a research in Britain and explains the basic principles which characterise the water industry in general. In particular it concentrates on events which shaped this work, namely the privatisation of the water industry and its implications.

The chapter is divided into six parts. The first section explains the principles of the economics of water demand and supply in the domestic sphere. This explanation is, of course, limited in its scope and is intended to introduce some of the technical terminology used later in the work, and the problems associated with it. Consequently, apart from the basic notions of demand and supply of water, this section describes possible future charging methods for domestic water.

In the second section, the British economy in the early 1990s is briefly described, with particular attention paid to the water industry. This section is followed by the history of the water industry in England and Wales from the Industrial Revolution until April 1989, when the industry was privatised.

Section 4 expands on the programme of water privatisation and its implications. After a general description of the events, the structure, the responsibilities, some technicalities and the actual debate about future charging methods are discussed.

The chapter concludes with two more localised sections. The fifth section takes a concentrated look at the Yorkshire region in terms of economic activity and the role of the water industry in it. Finally the development of the water industry itself within the region in general and in Leeds in particular is discussed in the sixth section.

2.2 The economics of household water use

This section looks at the main economic terms and principles which are used in the analysis. It begins with definitions of the terms which will be used throughout the thesis and is followed by traditional outlooks of economic affairs: the demand and supply of water.

In this part, the economic approach is wholly derived from the paradigm of micro-economics. Thus exogenous influences and conditions mentioned in the first part of this chapter and in the final part, are ignored.

2.2.1 Definitions

Household: for the purpose of this work, a private household comprises of an aggregation of '*n*' adults and children living in one residential unit for most of the year (over 290 days) (OPCS, 1993: 9). Household composition by age or sex is not available in the main data set. Guest houses, secondary residences and residences used for employment are considered as households as it is impossible to separately identify them in a conclusive manner. The terms 'domestic' and 'residential' that occasionally replace 'household' water use are used synonymously. However, the term applies to the occupants rather than the property. 'Household size' always refers therefore, to the number of occupants, and never to the size of the property.

Price: the price of water is considered as being determined by a multitude of endogenous and exogenous considerations other than the costs of production and profit maximising alone (Bower *et al.*, 1984: 9). Thus, water price is determined by more than one body (i.e. water producers and distributors, the Government, a regulator); more than one type of customer (i.e. agricultural, energy, industry, domestic); and more than one product (water supply, waste evacuation and disposal).

Quantity: The measure of quantities of water used are given here in m^3 per annum which remains the basic unit of measurement for area analysis. When litres-per-person-per-day (l/pp/d) is used, a day is calculated as the 365th part of a year, without seasonal variations or leap year adjustments.

Water 'Demand': in the next section (2.2) only, this term implies demand in the economic sense, and indicates a perfectly rational propensity to withdraw any amount supplied. In other sections of this chapter and in the thesis in general, the term domestic water use (DWU) is employed most of the time in order to neutralise economic undertones (this issue is discussed further in section 3.2).

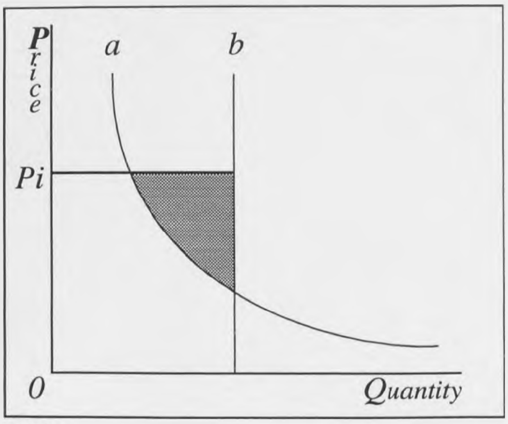
Yorkshire / Leeds: Yorkshire is all the area served by Yorkshire Water Plc. (Figure 5.1). Leeds is comprised of properties with a metered supply of water within the 29 postal districts of metropolitan Leeds (Figures 8.1 and 8.2).

2.2.2 Domestic demand for water

Howe (1979) quotes Adam Smith's diamond and water paradox: water is absolutely vital for human existence and yet is sold for a pittance, while diamonds are absolutely inessential but are sold for a high price. The reason is the difference between the marginal and average utility. In the above case, water's price for the vital needs would be expensive (if it did not exist), while any additional amount will quickly become less valuable. The demand curve of water for a single household has, therefore, particular characteristics. This section assumes in the first instance that price is a flat rate access fee - as indeed it is for most households in most of Britain today. The assumptions in this section are also that water supply is constant, that it is provided at a constant pressure, that households are only withdrawing from the system the amount they actually use, i.e. that taps are not left open for no reason; and that there are no leakages within the property itself.

The demand function in such conditions is assumed to be a vertical demand curve [*b*] (see Figure 2.1), where the price [p_1] is determined by the water company and the regulator(s), but the pattern of usage has no effect on pricing. In this case the demand line simply reflects the aggregation of all the elements which contribute to this demand, while still assuming a rational use. These elements must include at least two categories or 'variables': the household size and a constant. Kindler & Russell (1984) call this function 'requirement' whereas demand, they argue, is better described by the curve [*a*] (Figure 2.1) which has a negative relationship and reflects the decision maker's rationale to use less when prices are higher. The properties of the demand curve merit a closer inspection.

Figure 2.1
Demand function for domestic water



Source: Kindler & Russell (1984)

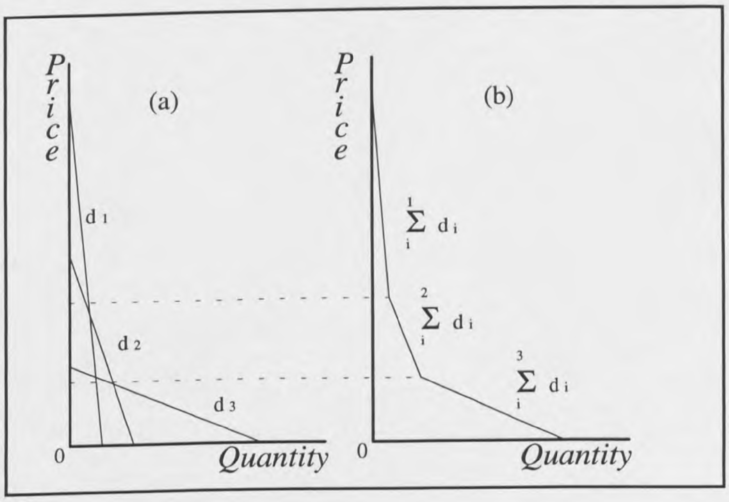
The shaded area which is created between a, b and p_l is the surplus which the user enjoys under the pricing p_l. It also represents, at least in theory, the price which the supplier believes can generate enough revenue in order for it to sustain and perhaps even improve its level of service while bearing in mind environmental and social obligations imposed by external bodies.

In general, a system of this type is charging lower than market prices for its services and is usually controlled by regulators who manage an allocative system. This is often the solution in cases where it may be argued that it is unethical to use price in order to curb access to publicly owned renewable resources (Rees, 1990).

On the other hand, household water demand could be submitted to a perfect market economy, where demand is a function of price only. In this case the demand curve reflects the aggregation of a variety of exogenous variables such as weather conditions, household's income and the monopolistic nature of the supplier, as well as its proportional part of costs associated with abstraction and the delivery of the goods.

However, it may be assumed that for an initial quantity of water (l), which is described in section 3.2 as 'need', a household (i) will be ready to pay a very high price. This is reflected in the preference line d_1 in Figure 2.2. In this case drinking, cooking and basic hygiene could be included. In the second instance, condition (*2*), preference line d_2 reflects the household's willingness to pay less for larger quantities associated with conveniences and utilities such as washing, water closet and cleaning. The third preference line, d_3, delineates condition (*3*) for water use in the household, where price acts as the only constraint. This category could include gardening, electrical utilities such as washing machines, dishwashers and car washing etc. The result is, in fact, similar to the demand curve *a* from Figure 2.1 above.

Figure 2.2
Preference lines in household water use.



Source: Grima (1972)

However, a household water demand curve rarely, if ever, reflects perfect market conditions. To begin with, the price is not determined solely in response to use. Government policies prevent water prices from reflecting the cost of supplying it (Rees, 1990), and the statutory obligation on water companies makes the demand curve lose its section d_1. Likewise, in a perfect market economy, price control rarely achieves a fully adjusted equilibrium when abundant resources are used as is seen in preference line d_3. In this case too, curve *a* in Figure 2.1 is probably more accurate in its description of the processes. The debate over water pricing under market conditions also centres around the principal question of whether there is a negative relationship between price and water use at all (Grima, 1972: 144). However, using the regression technique, a number of works (e.g. Opaluch, 1984; Williams, 1986; Nieswiadomy & Molina, 1988) have managed in the years since Grima's work to show without doubt that this relationship actually exists, and the demand curve as described above is correct in principle. The debate shifted, in countries where water is charged by usage (by meter), to another cardinal question, namely the elasticities of demand for each users group. Before engaging a full debate on this issue in the next section, there are some other, related topics which ought to be reviewed.

The position of the household as a single homogenous water user has so far been assumed as the basis for the explanations above. However, it is possible, and indeed advisable to construct a similar analysis for some of the utilities and amenities of the household. Thus the use of the bath, the dishwasher or the lawn sprinkler, all involve a decision based, at least partially, on economic considerations. The actual use of each good is seen by Archibald (1983) to be the function of the quantity used in each operation and the frequency of use.

Each utility has an optimal water usage which is indicated by the manufacturer, or determined by the user. For example, a dishwasher would consume on average between 46 and 62 litres per operation (for the most common programmes - there are variations within its programmes) and a shower might use between 19 and 35 litres per use (National Water Council, 1982). When multiplying these figures by frequency of use, it is possible to assume a reasonably accurate measure for the total of the utilities' water use. For example, the frequency of a dishwashers' use is between 0.79 and 0.84 a day per household, while a shower is used on average between 0.51 and 0.55 times a day (*ibid.*). In theory therefore, the need is only to find out the number of utilities, multiply it by the frequency of use, times the quantity used and an estimate of the quantity of water used will be achieved.

Two major questions were noted by Archibald (1983) in relation to this concept, and are discussed further in section 3.6. The first concerns the quantity: what is the best methodology to measure actual use as opposed to 'guesstimates'. The second question is of the same nature, but concerns the frequency.

To conclude the argument so far, two main approaches to household water demand can be identified: the first sees the household as a homogenous water using unit, where economic rationale and the number of persons permanently belonging to it determine most water use. Some leeway is allowed for the size of property and climatological factors. The second approach assumes the household to be the sum of a multitude of water consuming elements, which are divided into two categories: persons and utilities. Each person carries the following properties: sex, age, income and tastes, while utilities are divided into two categories - the mechanical and the non-mechanical utilities. The former are characterised by the relative precision of the amount of water used at each operation. A washing machine on the same programme, or toilet flushing, are two such examples. Non-mechanical utilities (e.g. hose pipes) are related to the manual opening and shutting of a tap, and are therefore more difficult to measure.

There is one other important dichotomy of the household's water demand function. It deals with the difference in demand between the 'indoors' and the 'outdoors' water uses (Danielson, 1979; Smith, 1988; Dandy, 1992; Lyman, 1992). Considering that lawn sprinkling, even in hot summers, is less of an issue in Britain than say, Texas - not to mention swimming pools - this dichotomy would, on the face of it play a relatively small role in this work.

The two approaches can be described in mathematical terms. The first, based on work by Metzner (1989) for example, assumes that the quantity [Q] in equation 2.1 used by a household is the function of the number of residents [n] and a constant [k]:

$$Q = f(n) + k \qquad 2.1$$

All the other factors, which may include dozens of variables are considered to be secondary to this paramount consideration: the number persons living in the house. This view of domestic water use allows for variations within each household; it also allows for these variations to offset each other. In the long-run, or in large aggregate numbers these variations are of relatively little importance. Many water distributors, it has to be said, use this basic formula for trend extrapolation (e.g. Rees & Rees, 1972).

The second approach discussed here is found in the works of Dun & Larson (1963); Foster & Beattie (1979) and Clouser & Miller (1980). In this approach however (Equation 2.2), there are more variations. Initially the total water use of household [Q] is the function of a variety of utilities and amenities in the household [h],

$$Q = f(h) \qquad 2.2$$

Or as is shown in equation 2.3, the functions of each of the utilities in relation to the quantity of water used per operation [i] by the number of users [n] which determines the frequency of the use of (x) utilities:

$$Q = \sum_{n}^{i}(h) \qquad 2.3$$

Equation 2.2, which assumes a linear water use function, would offer the possibility to regress quantity of water use with number of occupants, and obtain a per-capita use function which would then allow the construction of trends. The problems with this system are developed in the next section. Equation 2.3, still assuming a linear function, ignores the role played by the number of occupants in water use, and the results obtained from regressing utilities to total water use will only indicate their relative importance in a household.

Equation 2.3 however, incorporates the issue of colinearity and interdependence which are at the heart of assessing the quantity of water used by households. Each variable is influenced by other coefficients, and the cumulative effect of variables reflects more than just the function of persons or utilities. [x] number of utilities in a household may be used to reflect an income coefficient, as they must have been purchased, but only some of them could reflect the household size [n]. Sprinklers, for example, may be seen as related to garden size and hence to income, but certainly not to the number of occupants. Age and gender become independent variables which any aggregation will probably distort. This makes the possibility using of the Engel as the demand function to be impractical, as Thomas & Syme (1993: 24) explain:

> "If the Engel curves satisfy the adding up criterion they can provide only $n-1$ independent pieces of information - one too few to identify the specific weights. In fact, the ratios of the specific weights can then be estimated, but not their absolute size."

This would mean that water demand calculated solely by household size, as is the case in many institutions today (Kindler & Russell, 1984; WSA, 1993), does not only distort the prediction of the quantity of water used, but contributes to a discriminatory approach towards certain sectors of the population. A wider discussion on this issue is included in Gibbons (1986) and in section 2.2.4.

Thus far the household demand for water has been described. It is argued that, depending on the type of model used, demand calculations possess different attributes which can have an effect on other, interrelated, water using utilities and amenities in the house. The next sub-section will elaborate on the supply side of water for households.

2.2.3 Household water supply

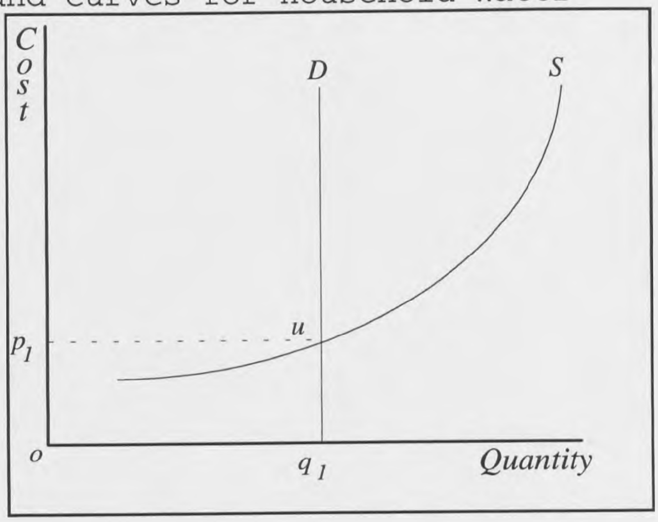
The supply curve for domestic water is based on the assumption that the price reflects the cost of extracting, hoarding, treating and distributing water to the users. Price is therefore an average price which includes the costs of servicing each customer individually, while reflecting their total distance from 'production' or the hoarding sites, and past cost of infrastructure necessary to carry out the treatment and delivery. The average price also incorporates the following costs: energy which pumping to places with different altitudes necessitates; seasonal variations which follow the scarcity of the resource in parts of the year; losses of water from reservoirs through seepage and evaporation, and leakages from water mains outside properties. In all these considerations however, the cost of evacuating waste water is not included.

In order to break even, water companies have to price water by a method which compensates between price difference for divergent users, while upholding social equity. Therefore price, which is restricted by the regulator according to a pre-fixed formula *RPI+K* (explained in sections 2.3.6 and 2.3.7), constitutes the minimum and maximum that can be charged for one unit. The problem is to determine what constitutes 'one unit' and to identify the supply curve for water.

For unmeasured supply 'one unit' is one portion of the curve which is the point [u] where a positive relationship between cost and quantity (Figure 2.3) is emerging (p_1, q_1), or at least the point where the supplier breaks even. The need to define 'one unit' is at the heart of this work, as it allows the equitable method of pricing presented in section 2.3.4 to be based on common ground.

Any quantity of water used by a household could be taken as a preliminary usage unit. Given that no details are known about the majority of water users, namely the unmetered users, it is a convention in the literature (see for example Stewart, 1993) to assign the average usage and its standard deviations the 'unit' value which in turn determines the price of water.

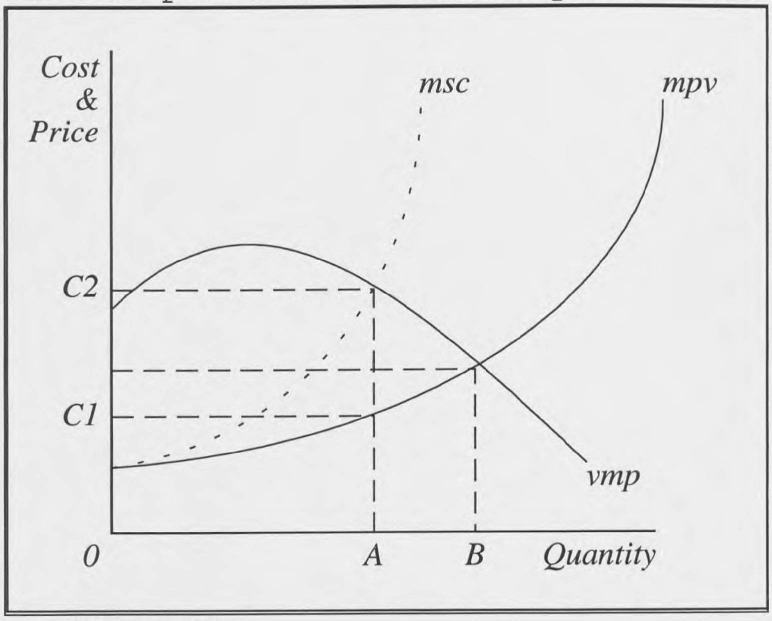
Figure 2.3
Supply and Demand Curves for Household Water



Within this unit, a WC can sell at price p_1 which would allow it to continue and operate even under the restrictions imposed concurrently by the market and the regulators, while safeguarding the equitable and statutory rights of every household for the provision of water. However, this explanation of water supply does not distinguish between the calculations associated with average and marginal costs.

Hirshleifer *et al.* (1969: 65) point to the effect which marginal social cost (*msc*) has on the output of a water company and its divergence from the marginal private cost (*mpc*) (Figure 2.4). The latter considers all the costs involved in delivering water to the individual, whilst the former is the consequence of an additional cost associated with another user.

Figure 2.4
Social and private optimum in a 'common pool' situation



Source: Hirshleifer *et al.*, 1969; page 66

Under these conditions, the value of the marginal product to the water company (*vmp*) meets the marginal social cost (*msc*) at point *A*, while *mpc* is only met at point *B*. The conflict between the two marginal costs are, according to Hirshleifer *et al.*, solved by the allocative nature of water supply. A tax which compensates what they call 'the pumper' for the difference in costs between c_1 and c_2 makes the operation worthwhile.

The full argument concerning the allocative nature of water and the use of taxation in order to regulate its demand is discussed in section 2.2.4. At this stage it is useful simply to note that the supply side of water economics is rarely, if ever, subjected to close examination since, as Hirshleifer *et al.* note:

> "Among the criteria bandied about in public discussions on the allocation of water supplies are such phrases as 'fair share', 'reasonable requirements', 'needs' 'beneficial uses' etc.; in some cases these can only be regarded as noises with emotive content used as substitutes for rational analysis" (page 36)

Although this is not the prevailing attitude in this country (see for example OFWAT's Director General's comments on metering, in 1992 in 'Paying For Water - The Way Ahead'), these are issues which ought to be taken into consideration when policy recommendations are proposed.

For a full discussion on the demand and supply of water in Britain see Herrington (1976). The next section introduces the issues and problems associated with the design and implementation of water pricing policies.

2.2.4 Charging methods

In theory, WCs have a wide range of charging policies available to them. These policies comprise two main elements:

the method by which households are charged; and the tariff structure which is to accompany any method. The Director General of OFWAT stipulated three main criteria upon which any charging policy should be based (1992):

1. Fairness and equity
2. Incentives to customers and companies
3. Simplicity and comprehensibility

The range of charging methods within these guidelines contains three possibilities: a flat rate charge, payment by unit and payment by banding using proxies. Each of these three possibilities is discussed below: firstly, in general terms and secondly, with relevance to the present research.

Langdon (1994) suggests that on the 1st of April 2000, the following charging method options will be open to the WCs. Firstly, it would be possible to continue with a rateable value system. The problem with this is mainly technical, namely the absence of DoE official rate values for properties built since 1990. This problem could be solved relatively easily by appointing a surveyor to carry out an estimate on behalf of the WCs, with an appeal mechanism similar to that which currently operates for the Council Tax. The main disadvantage of this method is that despite its having been in operation from time immemorial, it was never possible to prove the exact relationship between rateable value and amount of water use. Indeed, regression analysis carried out in Chapter 7 of this work suggests that there is little correspondence between the two. Out of the three elements desired from a charging system as described by OFWAT above, only simplicity is attained.

The second option for a charging method is to use bands obtained from Council Tax records. The problems with this method are of a different nature, and involve the transfer of information between institutions. This may be either undesired or forbidden by legislation concerning data protection, or both. The other disadvantage of this method is its reliance on similar assumptions to the previous method which, as explained provides room for unjust charging in many cases. Of the three aims, this method would provide some fairness but no other visible advantage.

The third option which is described as 'other banding', includes elements from the first and second options combined with a more sophisticated methodology to define the bands involved. This option corresponds to some of the subjects discussed further in section 9.2.2.

The fourth option for charging is by flat rate. The ineffectiveness of this method has been compared by Langdon (1994) to the Poll Tax both in its perception of being unfair, and in its inability to provide a platform for environmental or economic policies, or both. These factors make this choice even less likely to substitute the present system. Although simplicity and comprehensibility are present, the other elements appear to be absent.

Finally there is the payment by unit, which requires the metering of all properties. This method which is perceived by many as the optimal solution (e.g. Gehrels, 1985; OFWAT, 1994; Byatt, 1994), is not considered to be the optimal by most WCs mainly because of the cost of installation. Byatt sees in this charging method a solution to a variety of problems affecting the water industry including the cash shortage which capping charges imposes and says: "Metering can obviate building new reservoirs or enable restrictions in sensitive areas to be reduced." (Byatt, 1994) Hence reduced production costs and no need for higher charges. In short, OFWAT believes that metering water use is the charging method which answers the three criteria stipulated above. A more comprehensive presentation of the issues involved with domestic water metering is presented in section 2.3.7. Having looked at charging methods it is now necessary to examine tariff structures.

The two options available are both a combination of a fixed minimum charge with an additional element of price per unit. These options are flat rate tariff and incremental tariffs. The fixed minimum charge, which OFWAT believes has to remain low (OFWAT, 1992: 24) is meant to cover costs of operations which account, on average, for 55% of the total cost to the customers (OFWAT, 1994: 8). Doyle (1993: 114) supports this approach and points out that:

> "It does not matter how fixed costs are allocated but in practice a regulator may care about equity and therefore require a fair allocation of common costs."

On the question of tariff structure it is clear that OFWAT considers a rising block tariff structure to be unfair, in particular to large households (OFWAT, 1994: 9). It does not however, exclude the use of such a price structure in the future, when technology would allow the introduction of measuring devices which would enable the charging of different tariffs for peak time, i.e. hours of the day or months of the year etc. (OFWAT, 1992: 7). A single rate per unit in addition to a fixed service charge, as is indeed the situation today in all metered properties, is still the most likely tariff structure to apply in all metered properties in the foreseeable future.

In order to understand the charging system, a better understanding of the cost of water production to the WCs in Britain was needed. In 1992 OFWAT commissioned Stewart (1993) to assess the particular conditions in which the WCs in Britain operate, and to assess by econometric techniques the elements attributed to these costs of production. The terms of reference for this work did not involve a primary research into the actual expenditure of the WCs, rather the data used came from reports submitted to OFWAT as part of the first Asset Management Plan (AMP1).

The dependent variable, total water operating expenditure (OPEX), included elements such as the cost of pumping, and the cost of power and water treatment etc. The latter was found to vary according to its size (not necessarily return to scale) and the type of treatment required. The research also found that "There does not seem to be any evidence of significant cost effect of treatment type, source, size of works or any interaction between them", or the power needed for pumping water (Stewart, 1993: 12). Stewart's model does not include any labour element as it was estimated to vary regionally, for which data were not available (page 6). The model was tested to fit the data and explains 99% of the variations in costs in the sample (Table 2.1). However, Stewart notes that "If the model is rewritten as one for costs per unit of water delivered, then it explains only 63% of the variation in unit costs." (page 10)

The model began with 22 variables, discarding all variables under 10% significant levels in the first stage, while re-testing them at a later stage against those variables which proved to be significant (page 7). However, this log-linear model did not contain an overall interaction matrix between all variables due to the computation power required (page 8).

Table 2.1
OLS estimates of log linear cost function

Explanatory variable	OLS estimates of log-linear cost function*
ln(WDELA)	0.57 (0.08)
ln(LEN)	0.38 (0.08)
NHHLD/WDELA	-0.62 (0.27)
ln(PHT)	0.13 (0.06)
Constant	3.34 (0.39)
R^2	0.99
Adj.R^2	0.99
RSS	0.381
SEE	0.119
F	848.8

* Numbers in brackets are standard error
Source: Stewart (1993:19)

The main finding of the model are the four variables most associated with the cost of total water operating expenditure (OPEX). These were identified as the volume of water delivered (WDELA), total length of mains (LEN), measured water delivered to non households (NHHLD), average pumping head (PHT) and the proportion of input from some distribution treatment categories technically defined as groups 2 and 3 (GW23).

2.2.5 Allocation and equity

The aims of water suppliers, and for that matter of the political agenda within which they operate, must include, at least implicitly, the promotion of social good (which could be determined for example by fulfilling Pareto conditions) via the provision of this vital service (Finster, 1971). Interconnected to this objective are three, sometimes conflicting interests, all of which ought to be addressed by any policy formulator (Kindler & Russell, 1984: 211). These three interests are:

1. The supplier's, to promote the sale of its goods at the highest price possible.
2. The consumer's, to use as much as possible at the lowest price.
3. The environmental interests that dictate a reduction in amount used at all costs except social good (as defined above).

There is, of course, a fourth interest: that of the regulator. This institution's role is discussed in section 2.3.4.

As it does not yet play a major role (though it is a growing one) in the case of domestic water, environmental interests are dealt with at the end of this section. Customers however, are discussed in the previous section as they constitute the demand side of water. Their effects on policy formulation are considered to be through secondary channels: firstly, their preferences and choices of uses, secondly, their participation in democratic processes that have influence on supplier's policies, and thirdly, by lobbying power via institutionalised organisations or through informal protest (Tomlinson, 1993). The prime interest of this section is therefore of the relationship between the suppliers and of the domestic water user.

The initial formulation of policy is usually based on the choice of one guiding principle. For example, when a decision is taken to form a new policy, two options are immediately rejected: to retain the status quo, and, to allow decisions to be made on an ad hoc basis (Hirshleifer *et al.*, 1969). Although neither may be considered as a policy *per se*, as no formulation or direction are needed or indeed, provided (at best a rethink of any consequences may occur), this is often the preferred option for old, large and cumbersome bodies. The water industry in Britain certainly fits this last description and it would probably not have embarked on a radical policy change had it not been for privatisation.

Two main tools are available to policy makers in the public utility sector: pricing and allocation. The former is the market's tool for the regulation of supply and demand, while providing the firm with the funds necessary for its day to day running as well as for its investment programmes. Allocation policy is usually propagated and enforced by the Government in the interest of social equity (Waterstone, 1993). In the UK, when the water industry was nationalised, the Government assumed the allocative role by the nature of its relationship with the WCs. However, since privatisation the direct intervention of the Government in policy matters has become impossible, and a new regulatory body, OFWAT, is now in charge of allocative policy formulation (also discussed in section 2.3.4).

Therefore, this discussion primarily addresses pricing policy. Two types of pricing policies can be identified: paying by usage (for units already used), and flat rate. The former is the most common method of pricing any good. A unit of the good or utility on offer is defined and agreed upon between a buyer and a seller, and a price is attached to this unit by the seller which is then negotiated by the buyer, according to a set of considerations (which may include what are sometimes defined as irrational considerations), until the right price is agreed upon. This process does not, of course, occur in the domestic water market, not even in countries where the regulatory mechanism is relatively weak such as the USA (Crew & Kleindorfer, 1986). In the UK, as has been previously mentioned, the flat rate price for domestic water use still constitutes the majority of payment methods. It is based on two premises: a) that there is enough water in Britain to sustain any requirement for the foreseeable future, and b) that domestic users will not use more that is 'necessary'. (Rees, 1990: 23)

Prima facie, both these assumptions are confirmed: there is no shortage of water for domestic use in Britain, although seasonal variations sometimes reveal the unequal geographical distribution of the resource; and there is no conclusive evidence for 'unreasonable' domestic water use. These premises remain open to interpretation mainly because the actual amount used cannot be measured, and as long as customers do not complain of lack of water, the assumption is that there is sufficient. There is a third, hidden assumption attached to flat rate charging, which postulates the average water use per household. This assumption, which is often based on the results of the present type of work, attributes to the average household water use a money value. By dividing the total cost between a number of users an assumption can be made that, while some pay more than they actually use, others pay less, and a structure is created which eventually balances itself out.

Clearly this idea lacks the notion of social justice and its implementation depends on compensatory measures towards some groups of users who may encounter economic difficulties (Hirshleifer *et al.*, 1969). Such a method operates in large parts of Britain until this day. The compensatory measure is the attachment of water use value to the rateable value of the property (RV) with the underlying assumption that a property which possesses a higher value is either bigger, and hence accommodates a larger number of inhabitants (who use a higher amount of water); or that owners of such properties could afford to pay the charges even if they did not use much water. Proxies for wealth, such as ACORN, have failed to proved any significant association with water use (Russac *et al.*, 1991). Thus the option to continue charging for domestic water on the basis of a flat rate in future operations of the WSCs seems untenable.

Marginal cost is defined as the increase in one unit of cost caused by an addition of the last unit of output. Marginal cost pricing is the principle by which the price of a good is determined by the marginal cost of production. These terms are of course in negation to average cost pricing where the price charged equals its average cost, and the firm appears therefore to make no loss and no gain.

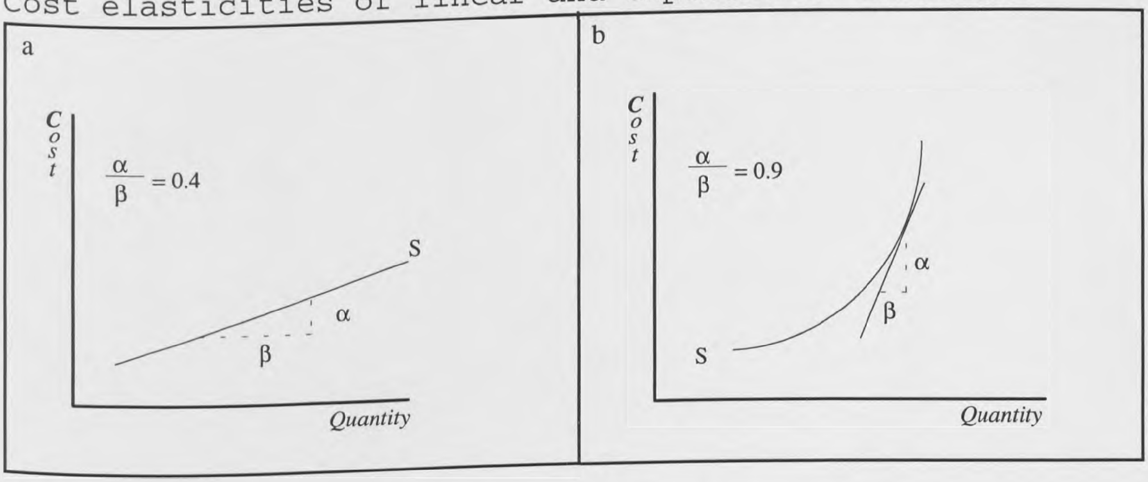
Marginal costing can be described in terms of elasticity of supply. Elasticity denotes the proportional change of one magnitude that is caused by proportional change of another magnitude, or, in other words, the ratio of production and output. In mathematical terms elasticity (E) may be expressed as:

$$E = \frac{\frac{dy}{y}}{\frac{dx}{x}} \qquad [2.1]$$

This ratio determines the slope of the line (or a point on the curve) it produces, and can therefore be measured by the x and y coordinates (Figure 2.5) or the x and y which correspond to the radiant of the slope at the point measured (Figure 2.5). The higher the elasticity (nearer to 1) the higher the price effectiveness is, and vice versa. Thus in Figure [2.5a] the elasticity ratio of α to β is 0.4, whilst in Figure [2.5b] the ratio is 0.9. Whilst in a linear curve (S_1) the ratio remains regular, each point on the curve (S_2) in Figure [2.5b] would produce a different ratio according to the tangent it produces, and the point at which it is measured.

Figure 2.5

Cost elasticities of linear and exponential functions



Price discrimination describes the sale of one good for different prices to different markets, or the sale of the same good to the same markets but the prices are in different units. Price discrimination is practised, for example, when for the same amount of water used, which is the case of the present system, two different users who live in different types of properties will pay different prices, regardless of any other elements. The RV of their properties puts them in different 'markets'. Conversely, flat-rate pricing practised in most of Britain today, where the price charged for water is the same for two identically valued properties. But the probability of two properties using exactly the same amount of water is very small, and each of these households pays the same amount for different quantity of water used.

To develop matters further, apart from the simple division into flat-rate and charge by usage, noted above, there are several other pricing policies. Flat-rate pricing is, according to the conditions set above, a discriminatory pricing system. 'Discriminatory' does not necessarily mean being non-equitable, but under the flat rate there is certainly an element of this as it is based on the average cost of production, which, as explained earlier, would automatically differ from one household to another. On the other hand, payment by usage seems to attach to every used unit an equal price, but this equitable element ignores another important concept: the principle of diminishing returns which is related to the rule of economies of scale. This principle asserts that a household which uses more water, for example, should pay less. As the fixed charge, which determines the cost of delivering a minimum amount, is static, the more water is used, the less it costs to produce and hence less should be charged for it. Conversely, it could be argued that there is no reason to 'penalise' a user who does not 'waste' water, and households should therefore pay less for the first 'essential' quantity of water used, and be penalised for 'over-usage'.

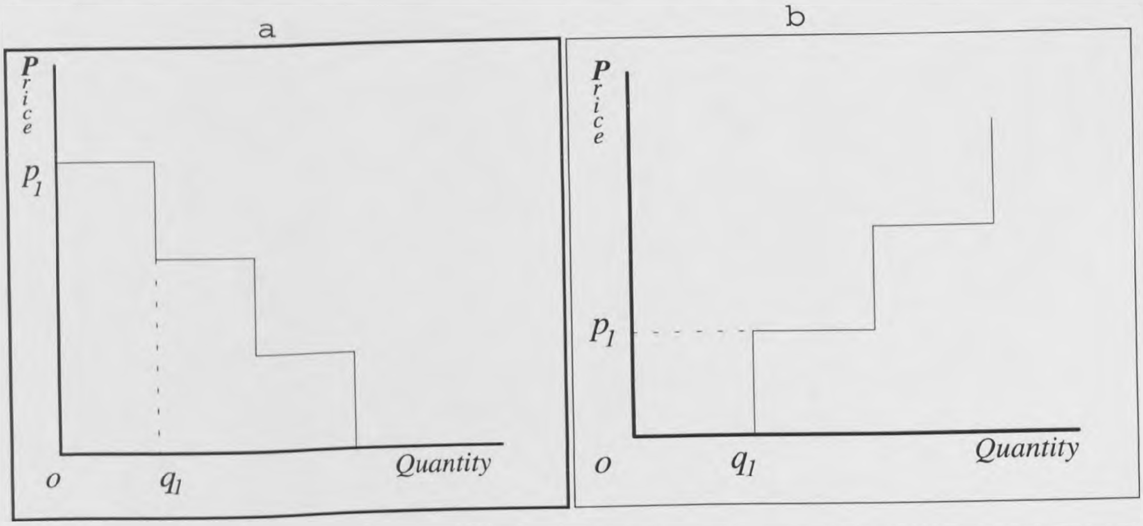
Writers like Howe & Linaweaver (1967) and Kher & Soroshian (1986) argue that average cost pricing should be used to calculate domestic water price as it eliminates, by definition, the need for compensatory measures. Many other writers such as Charney & Woodard, (1984), Agthe & Billings (1980), Metzner (1989), and Nieswiadomy & Molina (1991), on the other hand, point to the advantages of marginal cost pricing.

The argument is made clearer when ascending and descending block rates are used. In some countries, notably in the USA and in Australia, domestic water is priced in ascending or descending block rates. A descending block rates (Figure 2.6a) emulates the demand curve (*a*) in Figure 2.1 where the price per unit remains fixed and the only variables are price and quantity. In that system, a water company increases its marginal revenue, while seeking to take on board social consideration by decreasing its average revenue. The argument for the choice of this system over the flat rate is that it reflects the reduced marginal cost of production after the fixed cost is paid. An increasing block rate (Figure 2.6b) structure could be assumed to assure social welfare by supplying water 'need' (d_1 in Figure 2.2) at a low marginal price, while increasing average price as a punitive measure to control excessive use. Such a system is used in some provinces in Australia when drought orders are in force. Price p_1 and the quantity q_1 are therefore determined by the supplier according to the markets rules, while incorporating any considerations imposed by the political sphere.

Brown & Sibley (1986) state that:

> "The objectives of the firm (or regulator) shall be to choose prices that maximise the sum of consumer and producer surplus perhaps subject to a break-even constraint. Such prices achieve the object of attaining a maximum feasible economic efficiency" (page 25)

Figure 2.6
Ascending and descending block rate pricing



The formulation of pricing policy has therefore to be decided according to the following criteria:

1. Whether the firm's pricing of domestic water is aimed at creating a profit or to cover costs
2. The measure of the unit of water which would be attributed a price
3. The model which would best reflect the economic rationale and social justice of providing this utility.

Each of these three criteria is developed below, together with its associated policies. The decision which the policy maker has to make is, therefore, one of budgeting. The urban domestic user, which is the largest single category of users can determine large slices of the revenue generated by selling water (core business). The profit structure could however be such as to allow the cost of servicing domestic users to break even, while generating revenue from other sources.

By opting to charge according to marginal costs, the firm would define a relatively high level of 'K' which would allow it to develop its existing assets and utilities and perhaps even to develop new ones. To put it differently, in an average pricing situation the revenue generated from selling water to domestic customers could produce enough income to maintain this service, while a different scale would be charged for industry where prices are negotiated individually, with very little regulation. This would allow the WSC to compensate losses from households whose marginal cost of supply is high. The problem of a single price to all measured units is therefore in its becoming a *de facto* ascending block rates price. The environmental effect of such a policy may be considered desirable: it would deter the use of surplus water by becoming prohibitively expensive beyond a certain threshold. The equitable element of such a pricing system may however not be desirable as larger households will probably use more than a smaller sized household, regardless of their prudence.

By block rate charging the firm can emulate the steps performed by market mechanism, while following a carefully designed path which allows efficiency and equity to be promoted equally. It does however concern the size of the unit charged, which is the second criterion for policy making.

In an incremental pricing situation, as is the case presently for metered households in the Severn Trent Water area (WSA, 1993: 28), the charging unit is small enough to allow a change in charging for every use of water (Charney & Woodward, 1984). If water were to be charged by the pint, or litre, for example, each water use would have to be calculated and paid for at a higher rate. Thus, as every household in Britain uses on average 140 litres a day (WSA, 1993), the price of a unit would have to be initially miniscule (0.0001 penny per litre for example) in order to allow a realistic price structure on the upper part of the scale (0.008 penny per litre). The advantage of a system of this type is in its equitable appearance since each household would pay for exactly what they use. Such a system would also reflect the different marginal cost of providing water to each property. Three problems can be noted with such a method:

1. The cost of metering - which is a technical subject by its nature (section 2.3.7).
2. The underlying assumption referred to earlier, that price of water discriminates among weaker economic groups and large households, and
3. The consequence of 2, is the price which would be paid for the fixed charges, also described as 'need'.

Work on this subject suggest that such a method could effectively cause a reduction in health standards (Dun & Larson, 1963; Shin, 1985; Nieswiadomy & Molina, 1991).

So far the mechanism by which the price of a unit of water changes relatively to the amount used has been discussed. The other pricing option consists of a set of block rates within which the price per unit remains fixed. This system would price units of water in the order of cubic meters of water, for example. This method would firstly permit the usage of a minimum amount for basic need while keeping a minimum charge for the operator; secondly, it would allow households to use water within their one block up to its ceiling without being penalised; and thirdly, it would allow the price structure to reflect the marginal cost and the marginal utility of water in the household (Harris, 1992). The setting of the scale of the units will be determined by the elasticity of water price, and thus will reflect social preferences with economic constraints (Gibbs, 1978; Williams & Suh, 1986).

The shortcomings of a unified price are in the social equity part of the scheme. Large families and other households where the number of occupants is over three persons would pay large parts of their water charges in the higher bands.

Works by Archibald (1983), Russac *et al.* (1991) and NERA (1993), suggest that there are diminishing returns to scale in the household. In other words, one person in a single person household uses more than one person in a five person household. This in turn suggests that there might be ways to incorporate the number of inhabitants, which is suggested to be the main factor affecting quantities of water used, while being the cause for the most hardship as it is defined by OFWAT (1992c). Pricing policy could also consist of a descending block rate, as discussed in the literature. Terza & Welch (1982), suggest that this action would have an adverse effect for both the equitable and the economic interests.

2.3 HISTORICAL AND POLITICAL ISSUES

2.3.1 Britain's economy 1980-1993 - water issues

Britain's north-south divide during the 1980s (Lewis & Townsend, 1989) did not escape the water industry. The reasons for the north-south water divide are twofold. In the first place is the hydro-geography of the British Isles, water resources in Scotland, the north of England and in Wales being more abundant than in the South and East. The average rainfall in the Welsh Water area is for example, more than double that in the Anglian Water area (WSA, 1993: 13). The second reason is that the economic and demographic profiles of the Midlands and the North of England also made these regions heavier water using parts of the country, with relatively older infrastructure than other parts of Britain except London (Funnel & Hey, 1974). The consequences are that water companies such as North-West Water and Severn-Trent have to invest considerably larger sums than other WSCs such as Southern or Wessex in the maintenance and development of water infrastructure (WSA 1993: 35).

The changes in the economic and social structures of British society in these years was reflected in the water industry in two ways. First, the level of service requirement increased both in volume and in quality. Secondly, at the same time, a political philosophy which promoted the abandonment of policies based on egalitarian values of a national scope became prominent, and the transformation of public utilities into market orientated, profit based institutions was achieved (Wilding, 1992). One local example of this trend was the reduction of the number of employees in the energy and water industries in Leeds from 12,287 in 1981 to 7,417 in 1991 - a reduction of 39.6% (Sawyer, 1993: 273).

The increase in quality of the level of service can be explained by the growing availability of water consuming utilities, such as washing machines, the ownership of which has increased from 74% of the population in 1979 to 87% by 1991 and to 88% by 1994 (Central Statistics Office, 1994). An even more dramatic increase occurred in the dishwasher market, where ownership of 3% in 1979 increased to 14% in 1991 (OPCS, 1993) and to 16% in 1994 (Central Statistics Office: 1994). Changes of this type, as well as the radical change of home ownership - owner occupiers composed 57% of all households in 1971 and now compose 67% (OPCS, 1993) - required the water services to change both their approach to their clients and their technical appraisal of their ability to fulfil their obligations.

In the study of the preliminary survey of April 1992 (Chapter 5), the variable of home ownership was provided, whereas in the November 1992 survey (Chapter 6) this question was not asked. Some linear bivariate regression analyses were performed on these data, which showed that property tenure does not provide a satisfactory explanation for water use (R^2

was less than 1% in a variety of combinations). A more detailed presentation of these calculations and their meaning are offered in Chapter 5. However, the effects referred to here are not only of a quantitative nature. The fact that home ownership has increased so rapidly has, no doubt, altered responsibilities in and outside the properties and increased the awareness of the quality of service, both in terms of the actual quality of water - i.e. its chemical and aesthetic properties - and in the sense that rates paid for these services should reflect a reasonable, uninterrupted level of service (OFWAT, 1992b; 5-1).

These changes in attitude are difficult to measure, but they undoubtedly aided the Government of the time, which was considering the privatisation of the water industry following the successful privatisations of the gas and the electricity industries. Before looking at privatisation in detail, a brief presentation of the historic development of the water industry in England and Wales.

2.3.2 Historic review of the water industry in Britain

Water was not traditionally seen as an industry. Rather, for many centuries it was looked upon as God's gift which was free for all (Barty-King, 1992). The resulting common law in Britain is underpinned by the riparian doctrine which grants abstraction rights to any user on the river bank (*ripa* in

Latin) provided they do not impede other users downstream. With the urban growth of the 19th century, the need for a regular and reliable water supply drove local authorities to develop their own departments for the supply of water, usually relying on the private sector to carry out the technical and financial aspects of these tasks.

The overall provision of fresh water for, and the evacuation of waste water from, residential and industrial properties in England and Wales remained in the hands of private companies which undertook water supply functions for the local councils until the water industry reorganisation of 1974. It is important to note that the rate of growth in demand for fresh water, which corresponded to the speed of urbanisation and industrialisation in the previous hundred years, was mostly satisfactorily met, and the reorganisation was the result of an efficiency drive and growing awareness of pollution issues (Okun, 1977: 42).

At the same time the competition between urban domestic and industrial uses (agricultural users often withdrew water directly from streams) grew more acute, as much in the financial as in the technical sense. As the last major water projects ceased in the early years of this century (main aqueducts and reservoirs for London, the Midlands and the North West), industry and residential requirements continued to grow and the perceived competition between the two main urban users - industrial and domestic - intensified during the

1960s and early 1970s. The 1963 Water Resources Act put the emphasis on health and safety requirements for water quality. Pressure groups, such as fire fighters and environmental groups, increased the demand (in the economic and political sense) for cleaner water at greater pressure - at all times and probably even at all costs.

The water industry, which was effectively nationalised by the 1973 Water Act, found itself managing areas and resources on an unprecedented scale. In the next years the responsibilities for all water services were redrawn around the ten big river catchments in England and Wales. The geographical, economic and social scope of planning and managing water business came to be on a par with only a few other organisations in the country - such as gas, electricity and rail services, where the often conflicting requirements of suppliers, users and third parties were meant to be regulated by Government policy. However, the social needs associated with the water industry could not always compete with the strong economic pressure groups such as the heavy industry could muster for their cause, and in particular the Regional Water Authorities failed to secure the Government funds which were necessary in order to continue to provide a satisfactory level of service to all users (Rees, 1989).

Growing investment requirements and the 'free market' credo of the Conservative Governments since 1979 steered water authorities towards privatisation in the second half of the

1980s. The model chosen for this privatisation was (as is often the case) a compromise between the principles of private ownership and responsibility, public health and well-being, and immeasurable bureaucratic considerations.

2.3.3 The privatisation of water in England and Wales

Water privatisation has to be assessed in the light of the economic policies and processes which occurred in Britain during this period. The options for privatisation were not based on a simple economic decision, nor was this political decision free from outside pressures which modified it considerably. Rees (1989) points out that privatisation occurred after a long period in which the Regional Water Authorities were starved of financial resources, which made them neglect their maintenance programmes, in particular the sewerage systems. The reason for this policy is not clear, but these actions (or inactions) will probably dominate the WSCs' agenda for the foreseeable future.

The Parliamentary Act concerning privatisation was passed in August 1989 and came into effect in September 1989, and was almost entirely replaced by the Consolidation Acts which came into effect in December 1991 (the Water Industry Act, 1991; the Water Resources Act, 1991; the Statutory Water Companies Act, 1991; the Land Drainage Act, 1991, and the Water Consolidation (Consequential Provision Act, 1991). The debate concerning the privatisation of water services prior to the Act being enacted centred around three arguments:

a. The technical aspects and structure of the new water companies;

b. The pricing mechanism and its regulation; and

c. The social and welfare implications of a. and b.

The question of the boundaries of the new water companies was debated relatively early, when privatisation began to appear to be a real option. On the one hand there was the will to reduce the monopolistic power of the water companies, something which could only be done (partly) if there were a multitude of small companies who could compete with each other for neighbouring areas. Alternatively, a system could have been devised whereby, as in Germany or France, local authorities would franchise water services independently to competing bidders. This could have provided a reasonable solution for water supply, and perhaps even waste evacuation, but it would not have provided the element of competition for the water users, who might not necessarily have had the same objectives as their local authorities. It might also have had to rely on a stricter regulatory system to maintain the quality of service (including, in this case, pricing) and consideration of environmental concerns. The solution which was reached is typically bureaucratic and changes the status of the Regional Water Authorities to Water Services Companies, but maintains the control over water supply which is in the hands of a different body altogether, namely the National

Rivers Authority (NRA). The point of preserving the old boundaries of the Regional Water Authorities, the area within which is too large to allow most of the users to take advantage of any competition, while taking away the underlying responsibility for the whole water cycle are in Rees's (1989) opinion contradictory and were made solely for bureaucratic and political reasons.

The second debate addressed the deterioration of the infrastructure caused by cuts in funds allocation during the years prior to privatisation. In particular, the problem seemed acute in the case of old sewerage systems which needed refurbishment and upgrading, without which the whole system of waste disposal may have collapsed. However, this system requires large sums of money to be spent far from the public's eye (mostly underground or out of town) and hence was presented to be of small political gain. As the price of water could not conceivably be determined by a market mechanism alone, as discussed in section 2.3.4 below, a need was identified to develop a pricing mechanism which would allow for considerable investment in the infrastructure while maintaining users' interests, and at the same time shunning politically sensitive issues.

Previous privatisations, such as those of the gas and the electricity companies (in 1986 and 1988 respectively) produced a pricing mechanism which was assumed to take into account the above considerations albeit without the huge investment for backlog expenditure on infrastructure. The formula which operates in these industries allows the price of their services to be calculated in periodic intervals on the basis of the retail price index (RPI) minus an agreed amount which would allow for the fact that the retail price index itself includes the same services. This formula, known as RPI-X, did not seem to match the needs of the water industry for four main reasons.

Firstly, as opposed to the two industries mentioned above, water supply does not seem to have any reason to assume a considerable increase in quantity required as a result of a technological shift or usage pattern. Higher demand for electricity, for example, occurred as a result of ownership of utilities such as dishwashers or home computers which became increasingly common in domestic households (Taylor, 1975). In this narrow sense, the total national quantity of future water requirements is easy to calculate (within the variations of seasonal effects and drought years): it will gradually increase as it has done for the past thirty years (Rees, 1989; WSA, 1993). The problem is more the location than the total amount. The second difference is the backlog of investments which had to be taken into account. Thirdly, is the equitable, or social nature of water as a natural resource - and its link with public health and hygiene. The fourth and final reason is the inevitable change of payment method by the largest sector: household water rates moving from a single bulk payment for supply and another for waste evacuation to a usage-related payment method (Littlechild, 1988). The metering debate and its implications are discussed further in section 2.3.7. The end result of this debate, however, was that a new formula had to be found which would incorporate the needs stipulated above.

The formula eventually arrived at was that each water company would be allowed to charge the base rates according to the RPI of that year and, in addition, a specific amount according to the needs of each company would be attached. The ceiling of this additional element, known as 'K', was to be determined by the regulatory body. This formula is known as RPI+K, and its precise technique and implications on potential policies is discussed later in this chapter (section 2.3.6).

The last debate which was related to the privatisation was the type and the nature of the industry's regulator. Rees (1989: 133) counts the regulator's eight tasks :

1. To curb price rises, limit the use of price discrimination and promote the use of least cost methods of production;
2. To establish minimum standards of service, monitor company performance and ensure compliance with established service requirements;
3. To limit externalities and increase the public good;
4. To take account of public health and humanitarian needs;
5. To ensure that there are adequate financial resources to cope with infrastructural requirements;
6. To ensure that investments yielding significant public benefits are made;
7. To establish a 'safety net' to secure the continuation of services in the event of failure of a utility company; and

8. To make the services accountable and responsive to the public.

As can be seen, this list shows that a regulator is required to ensure a co-lateral equity between each of the three main interested parties defined in section 2.3.6. Indeed, Rees acknowledges that, in some ways, the new, independent regulator created after privatisation plays the role formerly played by the Government. In Rees's words:

> 'Government regulation changes name but not effect: statutory duties, financial targets, borrowing limits, performance standards and direct ministerial guidance became licence conditions, tariff controls and disciplinary measures.' (1989: 131)

In other words, the independence of the agency which was to be established could, and should, be in the interest of the companies and its customers simultaneously, but not independently of the Government. This agency, the Office of Water Regulation (OFWAT) should monitor the ability of the water companies to carry out, in an efficient manner, their maintenance and development plans on the one hand, while ensuring that the welfare and equitable rights of the customers are not damaged on the other (staff = 132, budget £6.3m funded by industry; Wilks 1994: 74). It is easy to understand the problems, antagonism and criticism which a mechanism of this type can provoke among so many users and interested parties.

2.3.4 The role of the regulator

After privatisation in 1989, the water industry came to be regulated by nine bodies who, in one way or another, have a say in the running of the industry. These nine regulators are: the Secretary of State for the Environment who has an overall supervisory role; the Director of Water Services (OFWAT) who is responsible for the efficiency of the WCs and to monitor their ability to carry out their duties *vis-a-vis* their customers; the Customer Services Committees who act within the WCs, but under OFWAT's supervision; the Drinking Water Inspectorate (DWI) which is responsible for the quality of water supplied; the National Rivers Authority (NRA) which is responsible for the state of the rivers (including flooding), fisheries and the management of water resources in general; Her Majesty's Inspectorate of Pollution (HMIP) which advises, prepares and enforces anti-pollution legislation; the Ministry of Agriculture, Fisheries and Food (MAFF) which, together with the NRA, is responsible for some aspects of river management and fisheries; the Monopolies and Mergers Commission (MMC) which serves as a 'court of appeal' in disputes between the WCs and OFWAT; and the Office of Fair Trading (OFT) which oversees OFWAT.

It is little wonder, then, that Helm points out:

> "Regulators may now have greater planning roles in water companies than they ever had in the past. Public ownership has been replaced by public regulatory control." (1993: 24)

He also notes that this multitude of supervisors creates a situation where "policy objectives are probably not achieved in a least-cost fashion" but in a way which eases the position of the WCs within the regulatory system (1993: 25).

For the purpose of the present work the regulator with direct influence over domestic water use, OFWAT, is referred to as 'the regulator'. Although it is clear from the above list that all of these agencies are interlinked, the direct influence over domestic water pricing policy formulation rests chiefly in the hands of the Director General of Water Services.

From the outset, the question of the regulator's level of intervention in the daily affairs of the WCs was crucial. There were those who doubted the powers of OFWAT to enforce its targets without becoming part of the process itself, as Rees (1994: 63) says:

> "There is a clear possibility that the price rises associated with high risk premium rates of return will in themselves increase regulatory risk by reducing political and consumer confidence in the regulatory regime.";

whilst others feared that too little power from OFWAT would limit the regulatory effect on the industry thus rendering it prone to unstable policy changes (Helm, 1993: 27).

Technical problems related to the mechanism of regulation are of the most fundamental importance to the manner in which the industry runs its business. How should the regulation of prices affect the treatment of sewerage, for example? Should the prices of sewers be regulated by a separate K factor, or should the K be a singular element encompassing the whole range of services provided by the WCs? (Byatt, 1994a).

The most important element which emerged as a major role for the regulator, in addition to determining the rate of water charge increases, was to monitor the frequency and speed in which these increases should happen. In other words, the regulator does not only determine the amount which any WC can charge over the RPI, but the spread of this amount over the assigned period. The *K* element of the charging formula is, therefore, not just determined for one year but, as in the last review which was published in July 1994, for the next five years.

Considering that prices have risen in the past five years by 93.8% in the case of Anglian Water (Table 2.2), the average *K* rise of 1.5% planned for the period ending in the year 2000 should modify this trend considerably. It has to be remembered however, that the *K* is only one component of the price structure and the limit dictated by OFWAT is the only upper limit. Table 2.2 also points to the significant differences between the regional WCs' past and present needs. South West Water will have to continue to increase its household bills on account of the beaches cleaning operation which is required to perform. Even so, it will not be the WC with the highest water bills, which Welsh Water (Dwr Cymru). An even higher increase which they were planning to introduce was capped by OFWAT and is pending the decision of the MMC. YW appears to be at the bottom of both past increases and future planned increases, although its average household bills for 1995-95 are in the middle of the table.

It is also useful to remember that the average amount paid by domestic customers for water services in England and Wales is far below the expenditure on electricity and gas (and wine, beer, spirits, telephone, and TV), and is higher only than the average annual expenditure on newspapers and magazines. In 1992 a household spent on average £155 a year on water bills (943 litres per day) including the evacuation of waste water. But, as Carney notes, "a significant number of householders pay more than the average" (Carney, 1992: 35).

Table 2.2
Average household bills for unmeasured water.*

Company	% Increase '89-'90 by '94-'95	% Increase '93-'94 by '94-'95	Levels for 1994-95 (£)
Anglian	93.8	7.6	124
Dwr Cymru	69.8	2.6	129
North West	65.5	7.9	85
Northumbrian	68.9	9.7	88
Severn Trent	69.7	9.1	80
South West	89.5	12.4	119
Southern	65.3	7.3	84
Thames	55.9	5.6	79
Wessex	67.9	6.9	102
Yorkshire	53.7	3.6	97

** Percentage increase includes the effect of inflation*
Source: OFWAT leaflet Water and Sewerage Bills 1994-5, in Rees (1994) page 77

This section has highlighted the multitude of responsibilities endowed on the regulator. The forms this responsibility takes and the allegiance of the regulator are arguably left vaguely defined on purpose. There appears, however, to be a clear understanding that whilst not against the customers, the regulator's main concern is the WCs effective operations.

In the next section (2.3.5) the burden of social responsibility is described together with the problems associated with it.

2.3.5 Social responsibility

Does the Government represent the customers or is this the role of the regulator? Is the regulator just a government agent in its relationship with the WCs, or is it an independent institution (Rees, 1992)? These questions cannot yet be answered despite these issues having been addressed in numerous works (e.g. Rees, 1989; CRI, 1992c; Helm, 1993; Vass, 1994). It is important therefore to establish the social role the water industry plays, if it does, in our society. Rees (1994) believes that there is an apparent reluctance on behalf of the water companies to adopt any form of social responsibility. She says:

> "The water companies deny that they have a social service role and some claim that the introduction of social tariffs would contravene the no discrimination clauses in the water statutes and licences." (page 67)

This assertion is, of course, contested by the Director of the National Consumer Council, who points out the social responsibilities of the water industry towards its customers by emphasising the role which variables such as ability to pay should play in the formulation of policies (Gardner, 1994). This raises two questions: who are the customers considered to be? In other words, which category of customers are referred to? Are they the customers who buy and use the water (i.e. all of us) or are they the society which has to live with the consequences of environmental mismanagement (the same people or future generations)?

The industry's answer to the first question is fairly straightforward. The water industry considers itself to be misunderstood, and deliberately derided despite its serious attempts to improve their environmental and social commitments (Jones, 1994). The industry's response to its newly acquired social responsibility consists mainly of diverting the 'social burden' to other bodies. McAllister (1994), for example, suggests that instead of disconnecting customers (in cases of non-payment of bills), a special independent trust, composed of councillors and social workers, should find solutions - restructuring of debt, etc. The responsibility is therefore shifted into the hands of the professional social workers, and the WCs can concentrate on business alone.

The second issue, namely the conflict between pricing policies and environmental investment, is much more dramatic (Rees, 1994:66). This is so because it requires more money than that which is used to compensate for bad debts, but it is also more dramatic because it is the subject of political and economic pressures from outside the UK, where the water industry does not have a traditional power base. The debate over water policies in any context, including domestic water usage in Leeds, is affected if not dominated by the requirements for higher efficiency and better monitoring in the environmental behaviour of the WSCs. The NRA's position on this issue is clear (and rightly so). Lord Crickhowell, the NRA's chairman, stated that:

> "The water industry is in essence a natural monopoly and is a low risk business. For that reason alone, part of the savings which accrue from efficiency gains, if and when they are realised, should go to water company customers in the form of environmental quality improvements and/or slower price rises" (1994: 15).

On the same theme, Helm states:

> "Cleaning beaches and many related activities, ... are only tenuously related to water consumers, but might be thought of as wider public goods with pay-offs to people other than direct customers." (1993: 27)

However, these views are disputed by Jones (1994) who complains about the 'Brussels legislation', and suggests that any 'good' resulting from the WCs' improvement should be in terms of lower charges. In his words,

> "The efficiency benefits of privatisation, rather than result[ing] in lower charges, have been overshadowed by the enormous costs of new mandatory quality obligations which customers find it difficult, if not impossible, to relate to."

The Government does not consider the social issues resulting from water policy to be its responsibility. At least this is what can be understood from the absence of reference to this topic. Following the large scale drought of the summer of 1976, some efforts were made to tackle the problem of water waste. Rump (1978) exemplifies the single approach which was usually chosen, but it is by no means the only example. The DoE (1992: 6) suggests, in a leaflet 'Using Water Wisely', that the role of industry in saving water is producing water saving devices. The water industry itself makes no such efforts and any water saving as a result from their actions or inaction is ignored by the DoE.

The majority of customers are likely to be interested in lower charges and higher quality service in terms of water taste and colour than in environmental issues, which are not always what the WCs have in mind. Carney (1992: 43) notes that "the bias in the water industry now is in favour of providing a quality higher than is necessary, and than customers want or are willing to pay [for]." The best description of customers attitude is perhaps described by Langdon (1994) who noticed that customers are comforted that "it [still] costs more to heat a bath than to fill it".

2.3.6 Measuring efficiency

Having determined the interests of the parties involved (the WCs, the regulator, the Government and the customers) and the directions in which they are pulling, it is necessary to assess the practical options open to each of them in terms of recuperating costs incurred from the distribution of water. It is important to note that this section puts to one side the numerous other costs of WCs, such as capital investment required for flood defence and sewerage treatment, which lie beyond the scope of this work.

Any policy which is designed to satisfy the interests of the shareholders alone is likely to meet opposition from water users. Therefore, pricing has to take into account profit maximising only when the conditions set by the regulators are met. Under these conditions, the issue of efficiency becomes paramount. Efficiency can be measured in several ways, all of which contribute to the greater benefit of one or more of the parties related to the process of water supply and demand. In economic terms, efficiency is only treated here in one of the three senses usually related to it namely: technological, product choice and allocative efficiency (Cowling & Sugden, 1993). The first is beyond the scope of this work, while the second does not apply (except for bottled drinking water, which does not constitute a sizeable proportion of domestic water use anyway).

Allocative efficiency (the word 'allocation' has a slightly different meaning from that used in 'allocation policy' mentioned at the beginning of this section) is concerned with the optimisation of the economic processes involved in the distribution of goods (Waterstone, 1993: 29). Thus, cost-cutting methods and pricing techniques are brought to an optimal point where any further changes would result in the worsening of the supplier's economic position, or the users utility from the service. The problem of defining efficiency in the case of water supply and demand is, in fact, that the water industry acts as a monopoly, and this determines much of its incentives and disincentives to improve its effectiveness. In other words, if, under a perfectly competitive condition setting, the price of every commodity is equal to its marginal cost, then the firm and the customer do not lose and do not gain. This clearly is not the condition, nor the interest of the industry. Moreover, Rees (1990; 143) argues that even in perfect market conditions, efficiency practised by the 'neutral' forces of buyers and sellers alone is not as efficient as it might be with the intervention of a regulator.

The WCs' charging ceilings are limited by the capping which the '*K*' factor imposes on their charging tariffs (sections

2.2.3; 2.2.4). The *K* factor is itself composed of *-x* and *q*. The former is the efficiency component i.e. it is the reduction of costs (including capital) and therefore of prices in real terms and therefore bears a negative sign. The second component, *q*, reflects the statutory improvement in drinking water and environmental quality standards (OFWAT 1994b: 15-17). This regulatory mechanism was chosen rather than the Rate of Return price control because it was considered to have a higher social welfare, although only on condition that there is full information (Clemenz, 1991 in Doyle, 1993).

The question of measuring efficiency in the distribution of domestic water is highly important, and begins with the question: against what is performance measured - output or expenditure? (Rees 1992: 62). In other words, Rees asks whether supplying more water to more customers can, or should be, considered as 'greater efficiency' in the way that it would be for any other good, or whether it is cuts in expenditure alone that would count, as is the case in many other Government departments.

Helm explains the complexity of a exercise of this nature and points out that:

> "The present structure [of WCs] places very little reliance on the market. The degree of regulatory intervention is very high, and higher than in any other privatised utility." (1993: 24).

Hence efficiencies which would be expected to arise as a result of market competition are limited. As Byatt (1994a) noticed, the competition between WCs is mainly in terms of raising funds and not so much in acquiring customers although there are exceptions, such as in certain areas of Croydon, for example, where households can choose between Thames Water who charge 47 pence/m^3 or East Surrey Water who charge 71 pence/m^3 as a result of averaging tariffs within the company area (Byatt, 1994). These cases, however, are few and only help to highlight the absence of customer-orientated competition elsewhere.

In order to assess the efficiency, OFWAT set two periodic reviews (Asset Management Plans - AMP1 and AMP2) which would help to determine the '*K*' limit for the following period. Seven criteria for company performance in terms of domestic customers were set: water shortage; low pressure; supply interruption; hose pipe ban; sewer flooding; billing inquiry; and written complaints (OFWAT, 1994a: 4). The performance of each WC was compared to the others, while using indices for area and size of population served in each of them. However, as Rees (1994: 70) notes:

> "Measuring relative efficiency is a notoriously difficult exercise, particularly in an industry where operating costs vary markedly due to a whole host of factors which have nothing to do with operating efficiency."

By which is meant that geographic, demographic and historical characteristics of any region should be assessed and indexed separately. Apart from questioning the advantages of the whole exercise (Gilland & Vass, 1994), there are other related questions. These are the scope of choice for customers; whether their preferences really taken on board, or are their opinions (as reflected in the survey for charging methods, for example) are merely serving to release pressure? (Rees, 1994: 62)

An answer to these questions is suggested by Byatt (1994), who states:

> "Perhaps success or failure by companies in achieving high standards of service to customers should be more fully reflected in price limits in future reviews"

As part of these exercises, the costs of water production and distribution were calculated (Stewart, 1993) and the results are presented in section 2.2.4. Overall, Rees's (1994) verdict is that:

> "It is widely acknowledged that the consultation exercise had its flaws"..."It is notoriously difficult to derive accurate data on willingness to pay for service improvement from surveys posing hypothetical questions." (page 64)

However, most companies have recognised the importance of this exercise and it is likely therefore become a continuous process (page 65).

2.3.7 The metering debate

In 1992, OFWAT commissioned a survey from the Office of Population and Censuses (OPCS) to assess the desires of the population concerning charging methods, and in particular the introduction of a universal domestic metering method. This survey's commission and in particular its publication, were in marked contrast to the water industry's former policy of secrecy and lack of consultation with its customers (Rees 1994). The survey was carried out by interviewing a random sample of 3700 households. Over a half (54%) of the respondents suggested that they would prefer to be charged by meter, 25% opted for banding (with reference to the Council Tax), and 9% thought that flat rate was the best method (OFWAT 1992: 15). In a different, more structured survey, OFWAT conducted their own research by asking WCs to add a questionnaire to all their customers' periodic water bills. The results of this survey (Table 2.3) confirmed and even reinforced the impression from the OPCS survey, namely that the majority of those surveyed favoured metering as a method of charging. Although YW's management does not support the metering option (Byatt, 1994a), public opinion in this region seems to be wholly supportive. Politically, too, water metering appears to be an issue for debate, and Freeman (1985) raises the point of social justice encapsulated in it.

Table 2.3
Result of OFWAT survey of preferred charging methods

Option	National	Yorkshire
Metering	64%	63%
Banding	20%	21%
Licence fees	14%	15%
No preference	2%	1%

Source: OFWAT (1992) pages 17-18

Part of the problem with metering in Britain is the time table and the cost that would be required to install them in all, or at least most, properties in Britain. OFWAT estimates that at present around 6% of domestic properties are already metered (the rate is 73% for non-household customers), and that 20% could be metered by the year 2005 if a progressive metering programme is undertaken by all WCs immediately (OFWAT, 1994b: 43). In fact, it advocates the slow process by which "metering should be targeted and should spread progressively" to targeted households in all the regions (OFWAT 1992: 4) and should not be introduced in one or several moves.

In an attempt to locate areas of potential injustice, OFWAT commissioned a survey to check the potential social and economical hardship which could occur as a result of the introduction of universal domestic water metering. The results (OFWAT, 1992a; 1992b; 1992c; 1992d) suggest that only a relatively small proportion of the population (3.8%) would suffer from the impact of metering (1992d: i). The group most vulnerable to 'hardship', the criterion for which is a set of calibrated variables (OFWAT, 1992c: 1-5), was identified and the water use elements which may contribute to this hardship pointed out. One inevitable finding was that:

> "A high proportion of the households who had experienced most financial difficulty [as a result of being charged by meter] had five or more members." (OFWAT, 1992d: vi)

Also as expected, hygiene was the greatest concern of the respondents, as these are the elements most closely related to a constant and cheap water use. However, much of the customers' perception of the amount of water used was found to be not necessarily reliable: only less than one in five customers in the 'hardship' group estimated correctly the costs of using any water source in the house.(OFWAT, 1992d: 11, section 3.16).

Although there is clearly an affordability problem for a minority of customers (Rees, 1994: 67), there were several points in this survey which put the results in perspective.

First and foremost, the hardship survey (as opposed to the other two mentioned above) was carried out in the areas where the metering trials were carried out. However, as OFWAT points out,

> "Metering trial areas are generally more affluent than, and therefore unrepresentative of, Great Britain as a whole. Metering in other areas could result in higher rates of hardship than found in this study. This would also be influenced by the tariffs used." (1992d: v)

The interviewees also seem fairly relaxed about the issue of water bills in general: 76% did not worry about their water bills, and 41% of this group made no attempt to reduce water use at all. (OFWAT, 1992d: ii) When attempts were made, they included less garden watering (which is a seasonal element) and not leaving the tap open, which is a subjectively-perceived element.

The social problems metering could raise are most acute in the case of households who cannot, or do not want to pay their bills. The Director of the National Consumer Council (NCC) suggested that one way to deal with such customers would be by a means test which could determine the type of help needed (i.e. reduction of amount, spreading the costs etc.) for households that find it difficult to pay the water bills in its present form. In any case, the NCC promised to support any Bill submitted to the House of Commons which would forbid the disconnection of properties in most circumstances (Evans, 1994). McAllister (1994) suggested to refer such cases to special committees, composed of social workers, for arbitration.

The WCs' main argument against the introduction of universal domestic metering is primarily the cost involved in installation, in reading the meters, in computing the bills, dealing with inquiries and perhaps introducing a higher level of customer awareness (OFWAT. 1992: 20) which would reduce water use and hence average revenue. Related to this is the fact that metering would increase the element of uncertainty in revenue compared with the present system which guarantees a regular fixed amount minus non-payment cases (OFWAT 1992: 5).

The metering issue is part of the more general debate in which the UK water industry is currently engaged. The implications and consequences of this debate influence the policies of the industry at present and in the future.

The last section of this chapter abandons the national view of the water industry and concentrates on the more localised picture.

2.3.8 The history of the water industry in Yorkshire and Leeds

So far this chapter looked at the relevant issues in a national context. All these issues could be assumed to be generally correct in Yorkshire as well. However, some of the particular conditions of the region in which the surveys took place and in Leeds, where the major survey was carried out, need to be briefly described.

Yorkshire's first water works is recorded in 1693. Henry Gilbert and George Sorocold proposed, and the borough of Leeds accepted, the provision of fresh water from the Pitfall Mills area of the River Aire to all 7,000 residents of Leeds in that period (YWA, 1974). The rapid growth of the city to 17,000 inhabitants by 1754 and to 171,000 by 1852 meant that the level of water requirement grew in a like manner (Barber, 1982). A service reservoir built near St. John's Church, at the end of Briggate, in 1694 became obsolete within 20 years (Barty-King, 1992). Similar patterns occurred in Settle, where, in 1769 one Thomas Preston offered a similar deal to the town of Settle and in 1816 to Keighley (Winstanley, 1977). A variety of water companies of all sizes emerged all over the region in order to provide fresh water and to deal with the evacuation of waste water. In many areas, especially in the growing cities, it was soon realised that the capital necessary for such operations would require larger firms, and as pollution grew downstream as a result of the growing number of textile and steel industries, so too did the number of residents who competed for the same water. Thus water companies were formed in Hull (1838), in Bradford (1854), in Huddersfield (1868) and in Sheffield (1887).

Other towns and cities continued to be serviced by a multitude of small operators until after the Second World War. Barnsley united its water operations in 1956. Harrogate, Ripon and Wetherby agglomerated their water operations in 1958 while Wakefield, Doncaster, Ilkley, Otley and others performed this operation in the 1960s (Winstanley, 1977). The Yorkshire Water Authority was formed in 1974 from what used to be in excess of 80 small water supply firms. Water evacuation was not much different, except for the fact that most water users disposed of their waste water directly into the nearest water conduit. Later regulations (for example the 1909 Housing Act) forced users to treat their waste water before disposal, which resulted in a multitude of treatment works. At the time of the creation of the YWA, 624 separate sewerage treatment works were in need of rationalisation (Okun, 1977; 216).

Pollution issues were at the heart of the YWA on its foundation, notably owing to the appointed chairman, J. C. Brown, who prior to his appointment was employed by Imperial Chemical Industries (ICI). In an interview he was alleged to have said that 'too much attention is given to pollution control' (Okun, 1977; 168). Other issues however, such as the provision of high quality water for an ever growing demand in different places, continued to occupy YWA until its transformation in 1989. YWA was separated into four divisions (Northern, with its HQ in Harrogate; Eastern, in Hull; Southern, in Sheffield; and Western, in Bradford) and these remain the same after privatisation, as do the 580 operational reservoirs (DoE, 1989; 565). The conflicts between the economic needs of the region, and in particular of the local planning authorities (LPAs), and the financial constraints of YWA were not always solved to the advantage of the latter (Synott, 1985; Falkenmark & Biswas, 1987; Kashti, 1989, DoE, 1992:11), but it was the need for heavy investment in a rapidly ageing infrastructure which accelerated the privatisation process (Rees, 1989). In the last years prior to privatisation, YWA made an effort to 'beef up' and its turnover and profits figures (Table 2.4) are compatible with this trend.

Table 2.4

Yorkshire Water Authority Turnover and Profits 1985-1989 (in £ millions)

	1985	1986	1987	1988	1989
Turnover	218	239	265	282	308
Operating Profits	74	86	96	115	112
Profits on Ordinary Activities (after interest)	18	22	37	57	56

Source: DoE (1989)

Whereas the turnover grew steadily by an average of 10% in this period, the profits appeared to grow considerably faster. While profits in 1985-1987 are in the region of 12%, they grow by 20% in the next year but in 1989 the profits were small again. A similar pattern seems to have occurred in the profits from ordinary activities. However, 4% of the distribution mains needed immediate replacement, a burden which the Authority transferred onto the privatised company presumably with great relief. On the positive side, YWA possessed 60,000 acres of land, of which 10,500 acres represents specialised properties, meaning that its purpose of use could only be changed with difficulties. However, another

2,100 acres of non-specialised properties, some of which are in attractive locations in cities, were subsequently sold.

2.4 Summary and conclusion

This chapter has covered the background necessary for understanding the issues tackled in the body of the thesis. The three main axes which are highlighted here are the economic processes influencing water use, the historical roots of the present situation and the political pressures under which the WCs, and Yorkshire Water Plc. in particular, operate today.

Although it is clear that all three topics are related, some of these issues could only be understood through a more detailed explanation. The principles of domestic water demand and supply are, no doubt, influenced by historical decisions as well as by present political perceptions.

Most of the issues discussed here are touched upon in the next chapter: the literature review. Other parts of the thesis are referring to this chapter in different ways. However, the real importance of this introduction comes to light in the analysis in chapter 9, which could not be understood without this introduction.

3. LITERATURE REVIEW

3.1 Introduction

The terms and definitions used in the world of water resource planning, it is argued here, have a direct effect on the actions taken by the water companies. Thus, when the term 'withdrawal' is used to describe the movement of water out of the customer's tap, it is most likely to be associated with engineering, the main concern of which is to be assured that supply is constant and a minimum pressure maintained. When the term 'demand' is used to describe the same action, the approach is more likely to reflect the value of water as a commodity, with its market value properties. The question of water thus becomes an economic issue. Terms such as 'water use', 'water servicing', 'water needs', 'water requirements' and 'water consumption' all depict not only the subject or the topic discussed, but also the attitude with which it is approached.

Some of these terms hold philosophical values which relate them to one of the 'worlds' of water services: socio-economic or engineering. Consumption, for example, is described by Raymond Williams (1983) as a "predominantly descriptive noun of goods and services which defines the creation of needs in the capitalist society". This term has therefore an economic connotation without ever being explicit. 'Consumed' is also a wrong term for water use in the sense that it is being returned to nature (albeit polluted) in the water cycle. Dzurik (1990) solves this conflict by coining the term 'consumptive use' which refers to actual loss from the system by leakage for example. With this in mind, the literature examined in this chapter is not viewed as a collection of manuals or treatise on technical issues. From the outset, the intention is to attribute to the terms the meaning which they contain.

This chapter is divided into eight sections. Following this introduction, the second section looks at the definitions of water demand as they appear in the literature, and examines their possible implications. The rest of this chapter inspects these definitions as they are used in policy formulation and research techniques concerning DWU. The third section looks at the social policy choices facing water resource planners and managers as they appear in the literature. Only a few publications are written by practitioners in the water industry, and the majority of the work is carried out by academics.

In the fourth section the engineering approach to DWU is reviewed. This approach is the most obvious and demonstrates whichever policy is decided upon, and has therefore a prominent place in this work. Section five looks at the economic approaches to domestic DWU, which, together with the engineering play a major role in defining the outcome of any analysis.

Modelling DWU depends largely on the variables, their parameters and their constraints (Major & Lenton, 1979). The choice of variables in the various models mentioned above is therefore reviewed in section six. In section seven the publications related to microsimulation and ACORN analysis are reviewed.

This chapter concludes with an evaluation of the direction which is offered to the present research in the light of the literature reviewed here.

3.2 Definitions of domestic water use

This section is divided into two parts. The first looks at the significance and reasoned activity for opening a tap, and the second assumes the reason for opening a tap to be irrelevant for the purpose of water supply management, while putting the emphasis on the volume of the water used and the speed of its flow.

Kindler (1992) remarks that water systems can be measured in two ways: according to their results (production) or according to 'needs' (withdrawals). Water 'need' is probably the minimum without which no life could be maintained (Kirby, 1984: 63). Its satisfaction could therefore be of the highest importance on the one hand, but the simplest matter, on the other. Foster & Beattie (1979: 44) point out that the terms 'need' and 'requirements' could result in assuming economic models, which could and do, create an over capacity of the industry. More on this subject will be discussed in section 3.5, where the term 'withdrawal' is also discussed.

The term 'requirement' is used by Domokos *et al.*, (1976), Kindler (1992) and Mayo (1990). It seems to imply a connection between price, allocation policy and 'need'. Apart from the assertion that requirement is growing, as it is for many other natural resources, it does not appear to be a very potent element when creating a demand function. Renzetti (1992) uses it in a typical way when explaining the construction of an economic model:

> "There is no recognition of the role played by prices to signal resource scarcity, because consumer demands are seen as exogenuosly determined 'requirements'." (page 149).

Tate (1989), in a similar fashion, states:

> "The fact that water demand can be conditioned by policy related actions and are not just 'requirements' to be met is what distinguishes the demand management approach from the previous supply management orientation of water development" (page 72)

The consumer side of water may see the water industry as providing a service, fulfilling a 'requirement', supplying demand and therefore answering needs. Charney & Woodard (1984) for example, develop a work by Opaluch (1984) to determine whether consumers respond to average or marginal price. The flaws in the demand function as presented by Opaluch are revealed to be assumed perfect information about the price of goods and services. This, in turn, leads to a mis-representation of consumer behaviour which is established not as a 'need' but as a 'perceived need', and the difference between 'perceived need' and 'requirements' may not be so big.

Other authors using the term 'need' with a similar meaning are Roberts (1986) and Ransey & Harris (1990).

The term 'demand', used by writers such as Howe & Linaweaver (1967), Archibald (1983) and Harris (1992) could, according to Cameron & Wright (1990; 180), be considered only as a 'perceived need'. In other words, it is the amount of water humans (as opposed to any other form of life) believe they could either not survive without - or that would reduce their 'quality of life'. This, in turn, influences humans' incentive to use, but at the same time to save water. Bower *et al.* (1984) distinguish between demand and requirements, attributing to the latter the notion that it does not necessarily obey then laws of 'common-sense' (page 8).

This assertion is qualified by Domokos *et al.* (1976) who point out that:

> "To the economist, a demand function for any commodity involves price, by definition. In discussing future use or requirements of water, energy or other resources, this distinction frequently is ignored and the word demand refers to the maximum or reasonable amount of a commodity that would be used if available." (page 264)

This raises the question whether demand for water is, in fact, unlimited. This issue has already been raised in section 2.3.6, where it is presented as the maximum amount of water households would actually use if water were free of charge.

Water 'use' as employed, among others, by Brandon *et al.* (1984), Clouser & Miller (1980) and Martin & Kulakowski (1991), is usually applied when looking at the supply side of water, or when the topic discussed is technical by nature. For managers in the water business, for example, the term 'user' covers economic as well as the engineering elements of water services (e.g. Billings & Day, 1989). Water 'use' is also closely linked to water withdrawal, discussed below, but attributes less importance to the flow of water. Thus, for example, Gehrels (1985: 45) sees the management as users when he points out that:

> "Management of the demand for water can pay large dividends by postponing or even canceling the need to invest capital in water supply augmentation projects."

It is interesting to note that whilst the inhabitants and water institutions in the Yorkshire area are referred to by the industry's regulator as 'customers', when un-measured non household customers are referred to they become 'users' (OFWAT, 1994: 26). The significance of this reference is perhaps that using water for manufacturing is 'more' than 'demanding' it for domestic purposes. It might also mean that as opposed to measured non households (who constitute the majority of 'customers') the un-measured customers return water to the environment in a relatively un-transformed way, such as cooling etc.

Withdrawal, as it appears in Kindler (1992) and indeed the sense that Kindler and Russell (1984) attribute to it, has, apparently, no causal explanation. It is the mere water flow out of a tap for whatever reason (or for no reason). In the absence of 'reason' or 'demand' for withdrawal, managers can use this term to justify calculations and policies aimed at empire building. As Tate (1989) notes:

> "Demands are over-estimated for the purpose of system expansion, as water systems developers and their consultants continue to conceptualise 'demands' as constant or ever growing requirements." (page 76)

Similar expression is used by Archibald (1983) who notes that:

> "The traditional long term demand forecasting method in the UK has been trend extrapolation, but during the 1970s there has been increasing concern about the risks of over-provision associated with this approach."(page 181)

This may suggest that the demand was not necessarily expressed by the users themselves, but by the industry's inability to adjust their means of forecasting to changing realities.

The terminology used in these works has determined in more than one way the approach and methods which are used to analyse the data. It is clear however at this stage that the most important element in determining the approach of the 'real world' to this question is the water policy makers. Section 3.3 looks at the way the literature examines possible water resource planning policies.

The term applied in this thesis (from the beginning) is, domestic water use (DWU) which was chosen for its seemingly neutral connotation.

3.3 Social policy choices

As the definitions in the previous section point out, there are several possible types of water uses which relate to economic factors, social influence or political pressures. All these uses may not relate to the paramount role engineers play in this equation. It is perhaps important to note that the whole notion of water policy's relationship to social policy is new. As Waterstone (1993) points out:

> "In many instances, the connection between water policy and social policy remains unexamined and implicit, or at least unvoiced." (page 481)

However, there is a growing awareness of this social role both as a result of the industry's privatisation in England and Wales, and due to the perceived shortage of this mineral in the past years. It is still the case that most operations and decisions are made in the water industry without being fully accountable to the public. As Brown and Ingram (1987) note:

> "Pressure towards public decision making about water is further amplified by growing insistence upon openness in the water policy making process. For most of the development period, decision making in water matters was left for the technicians and specialists.[However,] a broad array of interests now insist upon a voice in the policy-making process (pages 26-27)."

The fact that they refer to Arizona state in the USA, does not reduce its relevance to the present work.

The following section is divided into two parts: the first deals with works which see the formation of water policies as a function of market forces, and the second, which reviews works examining water issues in a variety of aspects, from a welfare tool to a reliable reflection of the economic state of a nation.

Many of the policies in the past decades concentrated on fulfilling water demand, as cities grew larger and service standards heightened. The dilemma facing policy makers, usually municipal governments, was whether to use the most obvious tool available in capitalist society - price, or develop a more educational policy to that end. Cameron & Wright (1990) say that:

> "Under current water policies [in the US], immeasurable psychological factors, such as the desire to conserve resources for the common good, appear to be more influential than economic consideration in determining the household's water conservation devices" (page 187).

This point is strengthened by Shin (1985), Martin & Kulakowski (1991) and Cameron & Wright (1990) who note that the real effect of pricing policies is more in the perceived price than in its proportion of the total household income. Authors belonging to this approach often see 'the household' as a rational economic unit which determines its (water use, amongst other) policies according to their own general good.

A whole gallery of writers add weight to this perception of water as a social commodity. Tate (1989), for example, says that management's aim must be to increase net social welfare through water management, and not necessarily to save water for the sake of it. Although in the case of Tate's work it may be surprising that with the abundance of water in eastern Canada, the notion of water as a social tool is still dominant.

The 'social tool' approach to water resource management is criticised by Kindler (1992: 312), who argues that water requirements, when applied as a guide for allocation (see section 2.2.5), should be assessed according to multicriteria and not only socio-economic criteria. When assuming that the user bears in one way or another the full cost of water used, Kindler argues, they can use as much water as they wish and as much as the system can supply within their means. Multicriteria may be the guide for water allocation methods only when the resource is scarce. But if the user bears the full cost of water he uses, as is the case in only a few countries, they would be most satisfied with the lowest costs possible (see section 2.3.5). In most cases however, Kindler concludes, without either coerced service interruption or forced implementation rationing, the allocation problem is the most important in water supply and not the demand.

So far this chapter has looked at works assessing water policies based solely on the assumption that water is an economic commodity. Water management policies are formed, this school says, either to increase demand (or withdrawals) in countries where water is distributed by private companies; or to save it in arid and semi-arid zones. In both cases the tool should be economic, with separate (and sometimes no) consideration for social equity and welfare.

Renzetti (1992) belongs to the other school of thought which questions the practice of 'efficient gains pricing' for water, and argues that improvement in welfare should be the main aim of water policy makers. The normal price of water, he points out, does not usually include the costs of withdrawing and transporting water by distance from 'production', but the costs of storage, treatment and distribution to customers (page 149). One example of actions motivated by multicriteria policy decision is pointed out to be the installation of flow detection meters which would minimise water use which, in turn, would lead to a decrease in sewage treatment costs (page 160).

Renzetti sees each user's annual fee as the total value of the water deficit divided by the number of users connected to the system, with no discrimination of any user's group (average pricing). The decline in domestic welfare as a result of the proposed water pricing system, he concludes, would be offset in aggregate by the increase in the 'welfare' and the value of commercial properties.

The complexity of this issue is further stressed by Lund (1988), who develops a different approach and suggests that water should not be sold per volume or any other means, but that it ought to be sold as a 'right' to the user, with an obligation for a continuation on behalf of the supplier. Writers such as Tate (1989), see the practical problems associated with this approach and say:

> "The most equitable method of financing water supply systems is for the user to pay in proportion to his use of service, as is done universally for the provision of electricity" (page 76)

These two schools represent the main issues concerning this industry (while the term industry by itself may imply production of goods for sale) worldwide, and post-privatisation England and Wales in particular. The links with electricity and sometimes gas services is often used to describe the advantages of payment by units (metering) and its workability.

The proposed 'solution' to the current policy debate in Britain at the moment (see sections 2.3.3 to 2.3.7), namely the installation of meters, is part of the 'approach' issues as well. Writers like Hanke & de Maré (1982) note that many objections raised to global metering could be addressed if water companies used Cost Benefit Analysis (CBA) for decision making on where and when to install meters. Other writers, such as Lund (1988), analyse national (or Federal in the USA) structures and goals according to a benefit-cost analysis. The costs and the benefits do not always apply to the same party, but once a uniform price tag can be attached to a project its viability can at least be evaluated, he argues. However, Dzurik (1990) points to the years between 1960 and 1980, when many of the large water projections in the USA were based almost solely on this type of analysis, and argues that while this approach encouraged values such as efficiency of expenditure, public participation and state intervention, it was considered to be insufficient when non-monetary values (such as national heritage or the role of the Welfare State) were considered. As Wilson (1981: 249) points out, CBA is by its nature an economic tool of appraisal and therefore should not be expected to deal with unmeasurable values.

Other examples of the combination of the political and economic sphere are no less complex. Mayo (1990) looks at the water policies formation in El Paso County, Colorado, in the past 300 years as a basis for future actions. A further development of the county was planned, and the question of future resources became urgent. Buying water from other areas, or investing in developing new sources (renewable or non-renewable) was the question. The limits which have been imposed on developers, both in density and in the speed of building led to a solution to create a further 300 years water 'guarantee' which is based, amongst others "on presumptive use values" (page 206). Whether political or economic, the terminology of the problem used by Mayo is in demand while the solutions are in terms of 'needs'.

Finally, Lindh (1988) looks at the connection between the general condition of a state economy, water consumption and the infrastructure levels. His inevitable conclusion from population growth observation of developing countries is that "there will be an increased extraction (of water) with increasing values of GNP". (page 138) He therefore suggests an inter-related model which incorporates water policy making and national economic targets, or the linking of needs with demands, and withdrawals with consumption. It is however an idea which would probably appeal only where these links can be proved to be decisive.

This section highlighted the two possibilities open to water management interpretation. Depending on the type of activity the water industry has to service, a policy which sees water as either a marketable commodity or a tool for increasing social welfare can be chosen. The next section covers the literature with the engineering approach to urban water resource management.

3.4 The engineering approach

In the light of points made so far, engineering approach literature is reviewed as the practical, 'hands on' type of policy choice. As it transpires, typical engineers do not often question any of the philosophical or ethical questions which their trade may raise. Indeed, much of the literature offers straightforward solutions to urban water supply problems and demand is considered only in terms of water pressure in the pipes. Economies of scale still seem to solve any problems, which usually means that 'the bigger the solution, the better' (Bland, 1986).

Only a few writers who are categorised here as belonging to the engineering 'world', argue that modelling water resources is more complicated than meets the eye. Loucks (1992) who is one of the few, stresses that this is so not only because of the multitude of variables, but

> "because we do not understand sufficiently the multiple interdependent physical; biochemical; ecological and social, legal and political processes that govern the behavior of water resource systems." (page 214).

This however is the exceptional approach to this issue, and may be the result of his attempt to evaluate the success of engineering projects in terms of user satisfaction. Brandon *et al.* (1984) however, demonstrate a typical engineering approach. As the 'official' manual of the water industry in the UK, their work does not seem to be troubled by the fact that the consumption criterion of *unit per person per day*, equates 'persons' of different age, sex and/or other variations (e.g. size, health and wealth) in the households. Much of the literature viewed in this section deals with this subject in a similar way, often without even appreciating that these issues exist. Brandon *et al.'s* work does not assign DWU issues the same weight as provided to the supply side. In other words, demand is considered to be the total of water supplied. In Brandon *et al.*'s words a customer is anybody "who uses water from the mains supply" (page 95).

The reason for this simplistic approach to the demand side may be explained by the fact that the main data for the demand side of Brandon *et al.*'s work comes from the Malvern and Mansfield studies made by Thackray *et al.* (1978) who assume that household size is the only determinant component of DWU (a wider discussion on this work is in sections 5.3, 6.1, 7.4 and 8.4). Even when discussing components of water consuming durables such as washing facilities or other appliances (e.g.

dishwasher) there seems to be no attempt to associate the data in this document with socio-economic grouping. The underlying notion of this document is that DWU is not the engineers' problem as they can supply as much as is needed, and the issues to be reviewed are efficiency and costs only.

Being British, Brandon *et al.* may seem to make some of the points made here look somewhat specific and local. Kindler & Russell (1984) however, demonstrate that the issues, as well as the approach are universal. In the USA, they note,

> "The result of existing national water use studies are subject to fundamental bias towards exaggerating future levels of withdrawal and towards stimulating alarm, and unfortunately, action designed to provide for projected uses."(page 219)

Kindler & Russell's work estimates that a national model built from an aggregation of a multitude of smaller, localised and specified models, would not only be more reliable and accurate, but might reflect different issues, never before taken into account. Their approach is therefore not the typical engineering approach, but since their work is concerned with the modelling of water in technical terms only, their giving a thought to the non-engineering problems is worth mentioning.

This section pointed to the somewhat over-simplified approach to DWU modelling and forecasting as it is represented in the technical literature. It is however, impossible to ignore the fact that engineering solutions depend in the final analysis on economic considerations. The following section will look at these issues as they are reflected in the literature.

3.5 The economic approach

The main issue with which the literature concerned with estimating domestic water is the assessment of water as a good. This question is crucial for two reasons:

a. When unmeasured supply of water is the main means of domestic provision, as is the case in Britain today, the only way to assess quantity used in households is by proxies. These can be derived from income curves of individual households or their aggregations, and with the assumption that there is a positive relationship between income level and water use.

b. Where water is charged by measured units, the elasticities of water demand are important in order to obtain an equitable system of water pricing. In countries where water pricing is used to regulate quantities used (e.g. Australia), the elasticities of water within the bundle of other goods is an essential tool to assure a choice of an effective and equitable policy.

The problem of measuring water demand elasticities is tackled by all the writers reviewed in this chapter. Two approaches to household water use estimation are identified in the literature: time series; and cross sectional water demand elasticities. Both use a variety of combinations of other techniques including cost-benefit analysis, price analysis technique and regulation controls. The terminology used throughout these works is, of course, of demand and supply although technical terminology from other disciplines is occasionally introduced.

In the first instance, writers using time series are reviewed. The advantage of this technique is well illustrated by Maidment & Parzen (1984) Maidment *et al.* (1985) and Miaou (1990 and 1990a). They use this method for its most obvious advantages: measuring climatic effect on patterns of DWU. In these works the main variables are the seasons and length of time in which data is collected.

Looking at time series, Miaou (1990) builds a monthly water use model where the climatic effects (temperature, rainfall) take a more important role than that of socio-economic aspects of DWU. The results achieved using variables of the latter type, he argues, are due to analysis interpretations rather than the statistical significance of these variables. This work, and his subsequent one (Miaou, 1990a), is concerned with finding an adequate time scale to fit models which would best capture the main components affecting domestic water use. Other aspects of his work are reviewed in section 3.6 of this chapter.

The most relevant findings in Miaou's (1990a) model for the present work are that the different types of socio-economic variables are highly correlated among themselves, and climatic variables are moderately correlated. But even more importantly, the correlation between the coefficient of water use and socio-economic variables are high, while correlation between water use and climatic variables turned out to be low (page 1893). Miaou encounters problems separating temperatures from other seasonal effects, and using a threshold technique he finds that:

> "Time can be employed as a substitute for socio-economic variables in explaining trend variations" (page 173)

This conclusion has considerable implications on the present work, and is discussed further in section 4.3 below.

Using the same general method but with different results, Maidment & Parzen (1984) built a time series model of monthly municipal water demand (in Canyon, Texas). Time series, they point out, is more suitable to fast growing cities than cross-sectional analysis. Their work deals primarily with water production and distribution. The response of water use to population or economic change can be measured on a yearly basis, while price and temperature are short-term functions of months, for example. They developed a 'cascade' modelling technique to adjust their time series, and remove 'noises' from their four factors: trend, seasonality, autocorrelation and climatic correlation (page 17). Following these four 'filters' (as the factors which are used to remove noises are also called), only a random error series remains. The results from their empirical test suggest that poor data quality prevents this method from achieving significant results, although it did help highlight some interesting phenomena. Among them is the observation that:

> "Population is the only significant variable describing trend in water use (...). Although household income grew significantly during this period [1961-1978] (...) population grew in parallel, so the independent effect of changes in household income on water use was not found to be statistically significant at those locations" (page 21)

This same conclusion, reached from another direction, is discussed further in the thesis.

It is interesting to point out here than Kher & Soroshian (1986) too, attempt to remove noise from time series. Most time series models, they note, have a K at the end of a model which denotes the error-in-equation models (EEM) to compensate for the inexact relationship between the other components of the model. They propose a noise-in-variable model (NVM) which they choose to demonstrate in a first order lag dynamic mathematical model (an input-output model), and which, they argue, transforms the original linear identification problem into a non-linear programming model. When applied to the city of Tucson, Arizona, their model proved that there was, at the time of this publication, still a long way to go before it can be successfully used.

Maidment *et al.* (1985) take the more potent elements from the time series model described above, and assess the effect of rainfall and air temperature on urban water use (Austin, Texas, 1961-1981). Their model uses a daily logged data base and is composed of two elements: basic and seasonal water use. In the absence of rainfall during the research period, air temperature (especially when very high) is the dominant variable in water use in this work. Important dates on the city's calendar can explain some periodic variations, certain hours could probably do the same. The conclusion reached there is that the levels of time aggregation may determine the relevance of the variables used in the model.

Another work in the same direction, but with more intricate variables, is by Danielson (1979), who looks at DWU as a function of rainfall, temperature, property value (as a proxy for income), household size and price of water. Using a monthly cross sectional model, in addition to a time series model based on periodical metered readings, this work puts great emphasis on the difference between winter and summer demand. In accordance with the previous work reviewed here, Danielson notes that "an increase of household size from 3 to 4 (33%) is associated with an increase of 24% (page 765)" for annual summer use. This observation, which corresponds with Grima's (1972), is not the main result of this work, but is mentioned here for comparison purposes with other works. Danielson's main conclusion is that water price is important principally for lawn sprinkling, and therefore for seasonal water use estimation, but income and household size are more meaningful variables for projections of future water demand.

A similar conclusion is reached by Agthe & Billings (1980), who look at monthly water use in Tucson, Arizona with the use of a variety of econometric models. Their models are testing price elasticity based on a time series model, and examine block rates as well as fixed charges effects. When tested however, their model produced poor results on long term prediction. Their explanation for this result is that: "Strong announcement effect of price changes, cause consumer overreaction." (page 479) which have changed their DWU patterns. This failure highlights the issue of price perception and reaction time.

The notion of seasonality combined with socio-economic variables is not unique to the Mid-West of the USA, as it may appear from the selection of works above. Related to these areas of domestic water use research is Dovey *et al.* (1993) who looked at the metering trials in the Isle of Wight where seasonal population alters DWU. This work highlighted the combined effects of time and human activities which create the notion of peak time consumption. Dovey *et al.* work's conclusions are discussed later in this work (section 3.6), but the use of time series in circumstances other than precipitation pattern is an important element in this work.

Lyman (1992), for example, argues that the pricing of water is radically different in long-term and short-term periods. This is related in particular to peak and off-peak periods, which should be approached differently when consumers behaviour is based on real cost. By 'peak' and 'off-peak' Lyman means seasonal and non-seasonal, for which billing period data is sufficient as a source for micro-data. However, as highlighted by Dovey *et al.* (1993) peak is not necessarily related to rainfall pattern but can also be attributed to social-behavioural patterns, such as the tourist season on the Isle of Wight.

Dealing with peak and off peak water demand forecasting prompts the question of forecasting horizons. Time series are useful to highlight the problems related to long term forecasting, but also to pinpoint the socio-economic issues involved in this mode of extrapolation.

Domokos *et al.* (1976) note that for short-term extrapolation where changes are relatively regular (e.g. for a year or two), a time series model is sufficient. However, more sophisticated mathematical models are required for long term models, but they are prone to error for other reasons. When using pure time series technique, they say, assumptions remain rigid. Sometimes, in order to rationalise them exponential smoothing is used, which is based upon socio-economic weight (page 267). The main problem with time series, they therefore note, is the constrained environment and limits to growth which they impose on any model. Domokos *et al.* also point to three additional problems with time series:

a. Time series usually violate some crucial assumptions of linear regression models, otherwise known as the 'normality, homogeneity of variance and serial independence of errors'. In their words:

"In time series data, auto-correlated errors are likely to occur if the explanatory variables are auto-correlated. For example, population and income are almost certainly auto-correlated over time, as are most other variables likely to be appropriate for forecasting water requirements. Thus, the errors in predicting water requirements are also likely to be auto-correlated." (ibid. page 269)

b. The independent variables are almost always correlated among themselves over time series observation, 'multi-collinear independent variables'.

"When explanatory variables are multi-collinear, estimates of their associated regression coefficients are not precise and it is difficult, if not impossible, to determine the relative importance or influence of the explanatory variable." (*ibid.*)

In other cases, they point out, one explanatory variable may be omitted altogether without being noticed; and finally,

c. The future values of each of the explanatory variables must be known, or at least estimated in advance. This problem can be solved with the use of lagged regression for some or all of the explanatory variables, but this is only effective when the regular updating of values is possible. The issue of multicollinearity is discussed further in sections 4.5.5 and 7.3.

In the USA, price variables are assumed to affect water use. In most cases pricing policies are introduced to control allocation (as is explained in section 2.2) or demand for water. Time series prove a valuable tool with which to assess pricing policies whose real effect is often recognised only long after their introduction.

Martin & Kulakowski (1991), for example, used 20 years of Tucson, Arizona data to create a model of pricing policy's effects. They concentrate much on past pricing policies of this arid research area. However, their conclusion concerning prices only reinforces results from other works using shorter time spans:

> "Where income and weather variables have been included, all models show a positive correlation between level of income and levels of water use; and positive correlations between temperature and evapo-transpiration adjusted for rain and level of water use." (page 158)

The advantage of long term time data however, is in the opportunity to examine long-term effects of policies. Their overall conclusion, not directly related to the debate over the scope of the time series, is that:

> "Preachments about conserving water apparently have little or no effects in the absence of accompanying significant real price increases, particularly when in the presence of increasing real incomes" (page 163)

A conclusion which would probably not be so decisive without the benefit of long term observation to back it up.

Carver & Boland (1980) look at similar issues. They investigated long and short-run effects of price on municipal water use. Six years of Washington DC water production were measured in one year intervals. They use five regressions for each of the time pooled series data sets: ordinary least square; with lagged consumption; with dummy variables for cross sectional units only; with dummy variables for time series only, and with dummy variables for cross sectional units and time series.

Only the ordinary least square obtained some significant results, but it is still far from Howe & Linaweaver's (1967) baseline results at which they were aiming. One of the reasons for this discrepancy, they suggest, might be their use of aggregate data for commercial, institutional and residential water use, which may have masked the actual response of residential alone (page 614). However, considering that Boland *et al.* (1975) put the proportion of residential use at 51% of total annual use (or 45% of seasonal) the difference with Howe & Linaweaver (1967) could, at best, only be reduced but not eliminated altogether. Carver & Boland's (1980) concluding remark is that the differences arising from differences in life style or other socio-economic effects between two areas, are far greater than a time series model could cope with.

To conclude, the criticism raised against the use of time series for household water use modelling is best summarised by Miaou (1990a), who points out that the problems with time series are of 4 types:

(1) Relatively short time series data assessing too long periods;

(2) Large constant coefficients, in particular the socio-economic variables, environmental variables, and technological variables;

(3) Multicolinearity which confounds the true value of each variable; and

(4) Auto-correlated model errors (e.g. omission of relevant explanatory variable or inadequacy in the model structure).

Thus far, literature using time series regressions has been reviewed. Its advantages and wide range of investigation direction were briefly discussed, and the major shortcomings of this technique were reviewed. The next technique which is used for the purpose of identifying DWU is measuring water demand elasticities. This part of the literature looks at a model which identifies DWU through linear, non-linear and some use of time series regression of household components, consequently establishing a demand elasticity curve for water in relation to other, known, components of DWU.

Nearest to the previous category reviewed here (time series) is Metzner (1989) who developed a model which is based on the assertion that:

> "Multiple regression analysis is a trial and error process to determine which of the variables are significant in explaining the level of water use" (page 57),

However, development in regression modelling by Terza & Welch (1982) reviewed below, could prove the opposite. A good component analysis for the present topic, Metzner points out, should stipulate its expected results in the following way: the mean squared error (MSE) should have a low value (near zero);

no serial autocorrelation should exist among residuals; there should be no significant correlation among any independent variables (absence of multicollinearity); all regression coefficients should be significantly different from zero; and the equation should be significant as a whole.

Williams & Suh (1986) follow similarly rigorous methodology but point out that even if followed, there are variables such as regional differences which cannot be wholly captured by the regression model even by dummy variables (page 1280). Similarly, Sankaran & Viraraghavan (1988), concentrate mainly on the effects climate has on urban water demand in eight cities. They too, found that while they can model minute details of daily precipitation, relative humidity, evaporation, and sunshine hours per month; water use itself was taken from the cities' total use, without excluding non-residential users. Their preliminary findings showed that:

> "As the daily temperature deviated or fluctuated from the mean to either extreme, the corresponding water use fluctuated more than proportionally." (page 61)

Their findings prove indeed that there is a positive relationship between water use and maximum temperatures, but the large variation in R^2 while using different climatic variables point, according to the authors, to the lack of the 'smoothing influence' of economic variables in their model. 'Causal models', they argue, are superior to time series models because they are easier to interpret and because of the restricted assumptions time series models impose (page 63).

Once income variables and price factors are included in any model, the issue of price elasticity is hard to avoid. The following works are all concerned to a greater or a lesser degree with the price elasticity of water.

The simplistic argument of Williams & Suh's does not seem to convince Agthe & Billings (1987). A simulation model of DWU assumed that the higher income group not only uses more water, but possesses higher elasticities of demand (page 276). An argument based on Gotlieb (1963), Morgan (1973), Foster & Beattie (1979), and Billings & Agthe (1980). They note that

> "It is frequently assumed that low income households have the lowest price elasticities of demand because they have fewer uses for water and fewer substitutes for these uses. High income households, however, may have lower price elasticity of demand because water represents a relatively smaller proportion of their total expenditures. Thus, the question of which income group of water consumers has the lower price elasticity must be determined empirically rather than on a priority grounds." (page 279)

The linear, two stages least square model which they deployed, corresponded much to their expectations: income variable positive correlation (although their income groups are assigned by medians); vegetation positive for higher and middle income groups and negative for the lower groups (which they could not explain) and a strong effect of a swimming pool. They conclude by noticing that

> "Household size variable was significant for all but the highest income groups." (page 284)

However, Thomas (1993) points out that such conclusions are to be expected as

> "Most attention has been given to household size and composition variables. Other 'nuisance variables' are normally dealt with either by using dummy variables to allow for, for example, difference in social class, or by dealing only with sub-samples within the total cross section." (page 208)

A more 'economic' approach, he points out, looks at the price of water itself. This is, of course, dependent on water being charged according to measured use, which is not the case for most households in the UK nor, for that matter, in New York City and other metropolitan areas in North America.

Nieswiadomy & Molina (1988) look at the block rates price system, common in the USA, and its advantages and faults in demand models. The data used in their work consist of (monthly) time series of 101 owner occupier households in Denton, Texas, facing increasing block rates for the first half of the length of the experiment (1976-1981), and decreasing rates in the other half(1981-1985). Based on a demand function by Nordin (1976), their model includes lawn size, house size and weather as explanatory variables in addition to the price of water, income and a constant. All variables in both scenarios yielded the expected results, were statistically significant and bore the expected sign.

In a later work, Nieswiadomy & Molina (1991) analysed whether consumers behave differently under slightly different conditions than described in their 1989 paper. The billing time was changed and the perception of price caused marginal price to be higher than the perceived cost.

Opaluch (1984) argues that the hypothesis determining whether consumers respond to average or marginal price is logically inconsistent. The point, he argues, is that there are flaws in demand function which assumes perfect information about the price of goods and services they buy, which leads to mis-representation of consumer behaviour, which he suggests, ought to be divided into well-informed and ill-informed consumers. Charney & Woodard (1984), in a direct response, argue that although the argument in general is correct, the technical formula used by Opaluch to make this point is erroneous, and a paper published previously by Gibbs (1978) developed a similar but more successful argument for the use of marginal price of water in regressions, as opposed to the more conventional average use.

On the face of it, income appears to be the nearest proxy to the ability to pay for water. However, Jones & Morris (1984), who measured the price of water compared to other prices related to income, concluded that models estimating water use attribute too much weight to water price within the normal socio-economic system in Western states (page 200). In other words, they believe that the estimation of water price would be difficult to establish even if household income was provided and certified as correct (e.g. Foster & Beattie, 1979, discussed above).

Another proxy, which is often used to assess the propensity of the household to use water is the property's value. Indeed, in Britain this was the sole method for charging until the mid 1980s. However, Morgan (1973) questions models based on Howe & Linaweaver (1967), where the variable which denotes the number of residents in a household was dropped, and was replaced by household value and price. Howe & Linaweaver's result, he argues, are due mainly to the averaging of areas. He uses a survey from 92 randomly chosen (see the discussion concerning the selection and randomness of water users in section 4.3.1), single family residences in Santa Barbara, California, where annual water use data was taken from the local water company and the property price was obtained from County records.

The result turned out to have a low R^2, which made Morgan assume that there are large variations remaining in the micro-data. People-per-dwelling elasticities ranged from 0.45 to 0.57, which supported yet again the hypothesis that the number of residents was "an important determinant of water demand over dwelling unit"(page 1066). Some economies of scale were detected, demonstrating for example, that a 10% increase in household size will produce 5.7% increase in water use, which leads to the conclusion that "as household size increases, water use per person declines" (Morgan 1973: 1066).

Considering that property size might not be the ideal proxy, Foster & Beattie (1979) try an alternative to assess the effects of the region and the size of the city on DWU. The fact that regional differences may affect water use is already established through the work of Williams & Suh (1986) mentioned earlier. The interest here is to establish whether there could be indicators in the size or type of the region as to its total or average water use. Primeaux & Hollman (1973) used price of residence as a surrogate for income (see also Danielson 1979). The model, which relies on the neo-classical theory of consumption, is based on Fourt's (1958) model, in which different variables, climatic and socio-economic, are regressed against quantities of water delivered.

As a neo-classical theory, Foster & Beattie point out, it has four cornerstones: price of goods, price of related goods, income and tastes. The price of water, they argue, is the most important component of any model in the USA, but only as being complementary to other goods such as appliances or gardening. In view of the fact that it has no substitutes, cross price effects are found to be negligible.

Foster & Beattie (1979) assigned overall median family income as 'income' variable, to avoid multicollinearities arising from using proxy data such as property value or number of bathrooms. The standard unit for measuring water use is the number of persons per meter, which adds another dimension to the term 'household'. Indoor and outdoor uses are aggregated. Dummy variables are introduced in order to incorporate any social, political, economic, environmental or cultural factors which would be significant on a regional level. The category of city size was favoured over sectors, and four city size categories established: (a) under 20k; (b) between 20k and 50k; (c) between 50k and 150k; and (d) over 150k persons. Their resulting R^2 for the first stage model was 0.545. Each coefficient had the expected sign: price was negative, income and residents/m^3 were positive, and rainfall was found to have a negative relation with water use.

A preliminary conclusion at this stage was that the "city size has an insignificant effect on per household residential water demand" (page 52). However, at the second stage, when climatic elements were introduced, they reached a more significant R^2 (0.741). Price elasticity for arid regions, where demand for water is greater than in wet regions, was found to explain differences of elasticity estimates between regions of the south-west of the USA compared with those of the West and Mid-West. They attributed it to lower average median income, as well as to the mean density level in the regions. This helps Foster & Beattie to come to the conclusion that indoor demand may be more elastic, as in the poor region there is a greater number of poor large families with few or no lawn sprinklers. Their work managed to match elasticity of water demand in various places in the USA with earlier works (e.g. Gotlieb, 1963), which allows them to believe that their work is applicable. However, they reject the hypothesis that water demand is invariant in sub-regions of the USA.

Another way to investigate DWU using a similar technique was discussed by Berry & Bonem five years earlier (1974). They investigated total water use (not only residential) in a group of cities in New Mexico, and their result, which was an aggregation of more than one town, they believe allows for a greater confidence in a non biased sampling group, together with a wider variety of climatic and socio-economical variations. The result of their regression of income by per-capita daily water use achieved an R^2 of 0.415, which leads them to believe that time series models would yield better results for income variables (page 1241).

Dandy (1992) argues that outdoor watering restrictions, for example, are in fact an economic 'second best' decision after pricing policy, or in other words, a viable substitute on which to base a cross elasticity of demand analysis (page 1759). He argues however, that one ought to take account of the economic price of outdoor watering restrictions which are different in say, city centres than in suburbs. Dandy suggests that the demand curve for a household, the supply curve in the cases of London and New York, for example, should be denoted as a horizontal line. His analysis is based on the assumption that restrictions merely reduce producers and consumers surplus. Dandy concludes that in economic terms the cost of restrictions is greater than, say, price increases.

A similar view is expressed by Woo (1992), who reached it from another direction, since political as well as technical conditions in Hong Kong made the imposition of restrictions an unlikely option. In Canada as well as in Australia however, on the same topic, Gehrels (1985) and Harris (1992) discuss the advantages of pricing as an allocation and drought management mechanism, proving that the price of water is a valuable measure for ability to pay.

Having reviewed the literature which uses economic time series and cross sectional elasticities techniques, it is now appropriate to look at two more categories of works. The first category of works uses a combination of the technique mentioned above in Britain (Thackray *et al.*, 1978, Archibald 1983 and Hall *et al.*, 1988), and other works which concentrate solely on the correct sampling techniques for this very particular type of survey.

Thackray *et al.* (1978) is the most comprehensive research of DWU in Britain. It used the data from meter readings in Malvern and Mansfield. Most of the details concerning their work is reviewed in section 3.6, as it is the components analysis which is at the heart of their investigation. However, the regression technique which they used to assess DWU for water can be regarded as cross sectional elasticities, and is important in its being closest to the area which the present research can be compared with.

To allow the use of time series (the data for which could be found in the Malvern sample, it being the oldest metered town in Britain), Thackray *et al.* eliminated factors such as climatic or seasonal effects. However since their work was also carried out in Mansfield, where the meters were installed especially for the purpose of their research, much of the effect of these time series is lessened.

In a regression of a variety of variables against water consumption, they conclude that only 61% of the variation could be explained, which discarded a regression technique for forecasting purposes. As Thackray *et al.* put it:

> "The average consumption within groups of similar rateable value follows a reasonable linear trend, but overall the dispersion is very great and individual relationship between rateable value and (water) consumption is tenuous in the extreme" (page 55)

This could imply, that in most trend extrapolation of the type used by Thackray *et al.,* this technique is prone to over estimation resulting from the gross overestimation noted by Archibald (1983) earlier on (section 3.4).

Archibald refers to The Water Resources Board (WRB), an institution which disappeared with privatisation in 1989. He comments that the WRB often calculated demand on the basis of engineering committees who regularly double counted neighbourhoods supplied from two 'loops', and industrial demand was calculated on a per capita basis. Works like that of Thackray *et al.* helped to dispel some of these legacies, although the methodological difficulties which they faced rendered much of their results unsafe.

Archibald (1983) compares his results with Clouser & Miller (1980) who achieved an elasticity of household water demand of 0.82 to 0.89 in the US, and not to Thackray *et al.* (1978) who achieved only 0.61. The latter result, he remarks, may be the outcome of the absence of price variable in the UK combined with little external water use (e.g. lawn sprinkling) which is often a target for price policies. This led him to assert that regression models as used by Domokos *et al.* (1976)

> "Do not provide a framework to investigate possible changes in the ways in which water is used". (page 183)

The disaggregate approach to household water using components is, he concludes, the best way forward, and the results of his work are discussed further in section 3.6.

This raises however, a more substantial methodological question, which is how to ensure that the sample used for these regressions is statistically safe. Hanke & Mehrez (1979) propose to monitor individual connections: instead of relating group average of independent variables to group average water use, they propose to relate the relevant independent variables (lot size, family size, mean value of house, price of water etc.) for each customer in the sample to his (or her) water use.

Much of the technique which this proposal implies is reviewed later. Hanke & Mehrez propose a two stage sampling procedure: firstly within the location, on the basis of water use determinants, and secondly within the locations on the basis of climatic zones and pricing policies. Only the former procedure is relevant to this work, and the next sub section will concentrate on the literature which estimates DWU using the disaggregate approach.

This section reviewed the literature discussing DWU from what is called here 'the economic approach'. This literature deals with the various issues related to the attempt to assess quantities of water demanded, allocated and paid for in a variety of statistical and econometric techniques. The common basis for all these works is the treatment of water as a commercial good which behaves, to a greater or a lesser extent, as any other commodity.

3.6 The disaggregate approach or component analysis

Following the economic perspective which attributes DWU its relationship with income, there is another aspect with which the present work is mostly concerned. It is the micro-data approach, disaggregate approach or component analysis of domestic water use. To put it differently, the total of a household's water withdrawals does not necessarily provide sufficient information for the construction of a credible model. The problem is that very little is known of the amount of water used by individual components inside and outside the house. Most of the works reviewed in this section are mentioned earlier, but in a different context.

The disaggregate approach corresponds in some ways to the cross sectional regression techniques reviewed in the previous section, rather than time series. It is given a separate review as it tackles water use not necessarily as an economic activity, but as an ensemble of activities, some economically motivated, others hygienic and still others with no apparent motive at all (the use of a shower instead of a bath can illustrate all three cases). The aggregation of these components, the literature reviewed below seems to suggest, provides a better understanding of water use pattern and therefore increases its modelling suitability.

Some of the works are based on direct testing of the individual components (e.g. Thackray, 1978), while others infer the components either by deducing it from other data (e.g. Hall, 1988), or by desegregating household totals according to set formulae (e.g. Lyman, 1992). In any case, the methodological problems with gathering this type of information are considerable, and are discussed in detail in section 4.3. This section however, leads us through the details as they are considered by the literature, and which may be considered to be worthy of inclusion in any future DWU model. The number of works interested in the micro-data of DWU which are British represent more than their proportional share in this literature. Works originating from the USA and elsewhere use the price analysis technique for that purpose and will be reviewed in the second sub-section.

The first part of this section looks at the literature which uses actual data for the purpose of estimating DWU. In the three works reviewed here first, data were collected by market research firms, who used, amongst others the technique of asking users to fill (usually by a tick ✓) a pre-designed form each time they use water. This technique is criticised by, among others, White (1978) who points to the decrease in toilet flushing rate in Thackray's (1978) work and suggests that:

> "As the study progressed people became more lax about recording their visits to the WC which is the most significant single use of water in the home" (page 484).

Between May and July 1976 (a year of an outstanding drought) Thackray *et al.* (1978) investigated households in Malvern and in Mansfield - chosen for several reasons. Malvern's metering history made it a 'natural' choice, and Mansfield was chosen for its comparable size, together with its different socio-economic base (as can be seen in Table 3.1), which would allow a contrast.

Some of the socio-economic details were obtained from a commercial market research firm (Table 3.2) which explains their being a rather simplistic form of ACORN classification. As a technical aid, two cul-de-sac streets were chosen to provide a control group, where supply could not come from other sources. Other methodological problems which the authors set themselves to solve are:

1. Was consumer behaviour (in Mansfield) altered by metering? To which the answer is that "the overall data would suggest that there is some tentative evidence for an initial and short-lived metering effect over about 3 months" (page 42)

2. Did the 1976 drought and the water conservation propaganda have an effect? They conclude that "the effect of the

drought is seen as cancelling a probable increase in consumption in a hot, dry summer, rather than reducing a prevailing consumption level." (page 43)

3. Did the seasonal effects during the survey's period affect the results? To which the answer is that "There is evidence to suggest that the overall average consumption during the 10 week period [of the research] is similar to that of the winter/spring period" (page 43).

Table 3.1 demonstrates the sample type in the research area. The trends in both communities, as well as in the whole of the Severn Trent area, are similar. Owner occupiers living in semi-detached properties form the majority of cases in all three columns. However, Mansfield's larger number of council owned accommodation combined with its almost double the percentage of terraced properties attributes to it a 'working class' or a lower socio-economic status. Thackray *et al.* found that household size is correlated to social grouping, and noted that newer houses consumed more water, whilst only automatic washing machines augmented water use.

Table 3.1
Malvern and Mansfield study area's housing conditions

	Malvern %	Mansfield %	Severn Trent %
TENURE			
Owner-occupier	68	53	56
Local authority	24	32	32
Private rented	3	6	9
Other rented	5	9	3
TYPE			
Detached	31	15	15
Semi-detached	40	53	43
Flat/Maisonette	5	2	11
Bungalow	15	13	7
Terraced	9	17	24

Source: Thackray et al. (1978)

Water use associated with the sample structure as displayed in Table 3.2 is the essence of this type of work. Thus, the hegemony of owner occupiers in water use is well established, although the variations within the two locations are noticeably smaller in Mansfield (standard deviation 7.4) than in Malvern (standard deviation of 15.2). Overall, the tenure structure in both cities is displaying the same trend as the regional average. The number of persons is characterised by a marked return to scale factor, where the larger the number of persons in the house, the less water each of them uses. These findings are confirmed in section 3.4 as well as in Chapters 5 and 6 of the present work, and in Russac *et al.* (1991), later on in this section. The sample in the research shows that Malvern has a more 'typical' household structure to the region than Mansfield. Household type water use shows a similar pattern in both communities, as does the house age (except the pre 1919 buildings which are different but with no apparent explanation) and washing machine usage. The possession and ownership pattern for these variables reinforces the findings from Table 3.2, regarding the overall social profile of the two cities.

The interesting difference can be found in the water use pattern of the six social groups. Whereas the Standard Deviation of Malvern is 53.53, that of Mansfield is only 17.81. When looking at the different patterns of usage between the similar groups, the inevitable conclusion is that this criteria is imperfect for the purpose of water use estimation. Further insight into the problems associated with the mechanism of social grouping in relation to water use are discussed in section 6.12.

Table 3.2
Average consumption for a range of household characteristics.

HOUSEHOLD	MALVERN		MANSFIELD		Regional Household Survey
	l/pp/day	%	l/pp/day	%	%
Tenure					
Owner Occupier	106.7	68	105.1	53	56
Private Rented	99.5	3	89.8	6	9
Other Rented	95.7	5	93.6	9	3
Local Authority	71.6	24	89.0	32	32
No. of persons					
1	127.3	9	116.1	6	13
2	105.1	33	117.9	27	33
3	110.1	20	109.0	23	20
4	91.2	22	91.9	24	21
5	89.0	11	96.3	13	8
6	73.6	3	75.2	4	3
7 or more	100.1	2	68.9	3	2
Type of House					
Detached	117.0	31	114.5	15	15
Bungalow	104.8	15	115.0	13	7
Flat / Maisonette	99.0	5	109.1	2	11
Semi-detached	86.5	40	93.2	53	43
Terraced	72.0	9	89.4	17	24
Social Group					
A - Professional	149.7	4	126.0	1	4
B - Managerial	13.8	21	116.6	12	11
C1 - Clerical	10.6	30	100.4	19	18
C2 - Skilled/Manual	80.5	24	97.7	41	38
D - Unskilled	74.4	18	92.8	6	3
E - Unclassified	104.5	2	75.7	6	3
Age of House					
< 1919	107.6	26	79.0	9	21
1919-1944	92.8	15	91.9	31	28
1945-1960	84.5	27	93.5	24	21
1961-1970	102.1	25	107.0	27	20
> 1970	109.4	7	109.3	9	10
Washing Machine					
Automatic	118.7	26	114.7	26	29
Twin tub	86.8	38	93.0	45	34
Single tub	90.2	11	89.6	24	17
None	92.7	25	104.3	5	20

Source: *Thackray et al. (1978)*

One serious problem this work faced, which is believed to be common in such works (Walker, 1978), was that the meters used as standard in Britain were shown to be prone to inaccuracies (or to fail altogether). This may account for much of the inaccuracies in measurements in this particular research, but there are, no doubt, faulty or inaccurate measurements in every work of this type.

Thackray *et al.* considered domestic water use to be the function of two elements, frequency of use times the volume of each use. Table 3.3 offers an insight into the type of results which this approach yields. It shows, as may be expected, low daily frequency for outdoors use such as car washing and lawn sprinkling, but with a very high daily volume of water. Conversely, bathing and toilet flushing have a high frequency associated with low volumes of water. It is worth noting that while in Malvern the overall average in ten weeks of outdoors water use increased over the first 4 weeks, the same phenomenon did not occur in Mansfield. The type of correlations performed on these findings produced interesting results of the type "The rate of bathing decreases generally with the increasing household size" (page 55) , but since these estimates stop short of being calibrated ratios, there is little use for them in any proposed model. The low level of dishwasher ownership at the time of the survey may explain the very low frequency of use, and the overall lowering in frequency of toilet flushing in both towns suggests that White's (1978) remarks earlier in this section are well founded.

Table 3.3
Water use per household in Malvern and Mansfield

	MALVERN				MANSFIELD			
	Daily Frequency of Use*		Volume Used in Litres		Daily Frequency of Use*		Volume Used in Litres	
	10 Weeks	First 4 weeks	10 Weeks	First 4 weeks	10 Weeks	First 4 weeks	10 Weeks	First 4 weeks
Car Washing by								
hose	0.001	0.002	119.5	90.7	0.002	0.006	121.4	154.2
bucket	0.015	0.017	50.2	61.3	0.027	0.025	59.5	47.6
Garden Watering	0.165	0.111	71.3	92.8	0.124	0.067	56.5	63.0
Lawn Sprinkling	0.004	0.002	311.7	250.5	0.002	0.004	156.9	164.6
Bathing	0.634	0.601	71.6	82.7	0.726	0.686	71.4	80.2
Showering	0.162	0.112	30.2	35.3	0.109	0.078	35.2	36.9
Toilet Flushing	9.648	9.978	9.7	9.7	11.798	12.201	9.5	9.5
Waste Disposal	0.018	0.019	38.6	44.3	0.003	0.004	36.6	31.0
Washing Machine	0.185	0.181	23.3	23.1	0.216	0.233	32.8	31.9
Clothes Rinsing	0.440	0.444	20.5	2.4	0.807	0.750	17.1	18.9
Dish Washing	0.015	0.013	1.1	1.1	0.008	0.009	1.1	1.0

* The frequencies in the table are averaged over all households, not just those which own or use specific appliances.
Source: *Thackray et al. (1978)*

Basic water use (Table 3.4), often referred to as 'other uses', such as tap running for any use, is often deduced from the known quantity of appliances less the total water use on rainy days, when it could be safe to assume that no external use was needed. The comparison with other works proves to be difficult for this reason as well as for different categorisation and methods of measurement. The comparison is however interesting inasmuch as it offers an insight into some of these problems. Thus, the waste disposal unit uses according to the Severn Trent survey of 1973 together with the basic use and dishwasher, are less than toilet flushing, whilst Thackray *et al.* found basic use to be bigger that toilet flushing on its own. Similarly, the methods used to measure these quantities and the sample sizes are not known or necessarily compatible. It is interesting to note in this context that the toilet flushing component is somewhat lower in all three works reviewed in Table 3.4.

Table 3.4
Comparison of water use (l/pp/d) in three works

Component	Sharp 1967	Severn Trent 1973	Malvern	Mansfield
Toilet Flushing	50	31	32	33
Waste Disposal	together with ⇑	29	*	*
Basic (drinking, cooking, washing up , etc.)	18	together with ⇑	34	32
Dishwasher	together with ⇑	together with ⇑	*	*
Bath	45	32	16	16
Shower			1	1
Washing Machine	14	12	8	9
Garden Watering	5	5	3	1
Lawn Sprinkling			*	*
Car Washing		1	*	1

* use less than 0.5 l/pp/d
Source: *Thackray et al. (1978)*

The other important work of this nature was done by Archibald (1983) who took part in the Thackray *et al.* (1978) work. He used a similar approach to household water consuming components, namely component analysis, but based his methodology on the work of Power (1981) who looked at the electricity industry, and on Clouser & Miller's (1980) who examined water use.

Archibald added another dimension to the assessment of domestic water use. In addition to frequency and volume he calculated the proportion of the population owning appliances. The possibility of using this technique effectively, he cautions, remains limited mainly because of the restricted ability to predict usage frequency and market saturation data (page 183). He used a survey of 853 properties in cul-de-sac streets in Malvern and Mansfield, chosen for similar reasons as Thackray *et al.* (1978), and constructed a table which desegregates water consumption in a household (Table 3.5).

The results as shown in this table are presented in a manner which disaggregates the components of one property. The four large components: toilet flushing, washing machine, bathing and miscellaneous ('basic'), remain the major users as in the previous work reviewed here, and the breakdown into some of the more trivial details, such as the methods of washing the car or the type of washing machine, do not alter them significantly.

The problem which Archibald faced, and indeed as do all works of this nature, was how to measure the amount of water named 'basic' or 'miscellaneous'. This amount is included, in his work, with the 'unaccounted for' withdrawals which includes leakage. Estimation of miscellaneous can, he points out, only be done by cross data and deduction, much the same way as Thackray *et al.* did it, but the level of leakage is mainly a policy variable (page 182).

Table 3.5
Components of household water use in Malvern and Mansfield

Component		% l/p/d
Car Washing	hose	0.3
	bucket	0.3
Garden Watering		1.3
Lawn Sprinkling		0.2
Auto Washing Machine		6.8
Twin Tub	washing	1.6
	rinsing	3.0
Single Tub	washing	1.1
	rinsing	1.2
Dishwasher		0.3
Bathing		16.6
Showering		0.8
Toilet Flushing		35.1
Miscellaneous		32.3
Total		99.7

Source: Archibald (1983)

In order to add the third dimension to the equation, namely the ownership rate, Archibald bases his calculations on a set of assumptions which can be seen in Table 3.6. The method of collecting the initial information for these assumptions and the technique used to predict future rates leave room for improvement. However, the combination of ownership rate with water use ration amounts to scenario building, which is at the heart of the present work. Assumptions such as increasing hose pipe car washing or increasing lawn sprinkling are difficult to challenge as they are almost impossible to measure in the first place. Certainly the latter corresponds to a great extent to the weather conditions. Toilet retrofits, which were an important issue in the mid 1970s following the big drought of 1976, do not seem to constitute a major component in later works. However, Archibald attributed water use for toilet flushing higher values than were measured by Thackray *et al.*, and nearer to those noticed by Young (1978) of about 39 l/pp/day and Sharp (1967) at 50 l/pp/day.

Issues like saturation in washing machine markets and its sensitivity, turn out to be underestimated, at least as far as the present work shows below in Chapter 6, and the number of occupants effect on toilet flushing is criticised by Young as being far from conclusive.

Table 3.6
Assumptions and forecast of water consumption attached to household components

Component	Assumptions	Forecast usage (l/pp/d) 1980	1991	2001	Sensitivity
Car Washing	Car ownership near saturation (75%)		1	1	
	Increasing use of hose pipe for car washing.			1	
Garden	Increasing ownership of hose pipes		3	4-5	
	and lawn sprinklers.			5-6	
Bathing & Showering	Increasing ownership and use of showers with decreasing frequency of bathing by shower owners.	20	21-23	23-26	5% reduction in household size = 1% increase in toilet bathing component
Toilet Flushing	Decision of owner about user controlled flush valve. (i) no valve (ii) with valve	37	(I)35-38	(i)36-39 (ii)28-31 (ii)23-26	5% reduction in household size = 1% increase in toilet flushing component.
Waste Disposal	Continued growth of luxury appliances		1	2-3 4-5	
Dishwasher	Continued growth of luxury appliances		1	4-5 7-8	
Washing machine	Increase of automatic machines - level close to saturation	15	21-23	23-25	If ownership in 2001 is 82%, l/h/d could reach 27-29.
Miscellaneous	Decreasing in proportion (leakage control?)	37	46-50	51-55	
Total		155	(i)137-145 (ii)130-137	(i)153-162 (ii)140-149	

Source: Archibald (1983)

The third important work using component analysis was carried out by Hall *et al.* (1988) who during 13 months in 1977-78, investigated the water usage pattern of a thousand households, with a follow-up in 1983 of 863 households in the south west of England. Using meter readings, questionnaire survey and diaries, they chose the participating households by a stratified sampling frame (Moser & Kalton, 1971). Their sample had to match the profile of the parish or ward in which they were situated. A daily reading of meters was carried out for two weeks during the whole period, in which the household was meant to fill in diaries with its water consuming activities.

In essence the technique used was that developed by Archibald (1983) but the scenarios were replaced by applying regression technique and trend extrapolation. The results in Table 3.7 differ from the previous two works as they are presented in terms of litres per household a day and not per person a day. Nevertheless, the four large components pointed to in the previous works remain here as well.

Table 3.7
Per capita consumption (l/hh/d) in a survey of SWW 1977-78

Appliance	Properties with Shower	Properties with Washing Machine	All Ordinary Properties	High Consumption Properties
Toilet	36	36	37	41
Bath	14	16	16	20
Washing Machine	13	13	13	17
Shower	3	3	3	3
Miscellaneous	51	49	45	55
Dishwashers	0	0	0	9
Waste Disposal Unit	0	0	0	9
External use	4	3	3	7
Total l/h/d	121	120	117	161

Source: Hall et al.. (1988)

The results of the 1983 follow-up and its 1986 extension are provided in Table 3.8. The updated data allowed Hall *et al.* to compare appliances ownership and to use data provided by manufacturers as well as 'Which?' magazine, to determine the amount of water actually used by each utility. Thus, automatic washing machines were calculated to use 116 litres per use and dishwashers 40 litres. However, the more 'fluid' water usage in the house remained essentially based on rough general figures. Baths, for example, were calculated as using 105 litres per use, showers 20 litres per use, hand basins 4.5 litres per use, toilets (single and dual flush) 9.0 and 7.5 litres respectively, and waste disposal units 11.48 l/hh/d. The results in Table 3.8 suggest that external use, washing machines and 'other usage' were the main growth areas. The explanation being the ownership of automatic washing machines, the rate of which doubled during this period, as did the number of dishwashers and sprinklers. The number of showers in households tripled (page 630).

Table 3.8
Per capita household water consumption (l/hh/d): Comparison between 1977 and 1985

Component	Consumption (l/hh/d) 1977	1985
Drinking and Cooking	5.0	5.0
Washing and Cleaning	12.4	14.0
Personal Washing	35.9	41.1
Waste Disposal Unit	0.1	0.3
External use	5.1	9.1
Toilets	32.5	32.6
Laundry	13.4	18.2
Other use	5.6	11.3
Total Per Capita	110.0	131.6

Source: Hall et al.. (1988)

McClure (1978) produced another comprehensive survey of 10,000 households in Devon and Cornwall, representing the complete spread of the socio-economic groups, between February and April 1976. Although it is not said which method was used, all households which agreed to participate had to inform SWW of their ownership of all water consuming appliances and 35% of them complied. Of these, a thousand households were eventually selected and fitted with meters, and particular attention was given to households which were likely to have a higher than average water usage (with swimming pools or with more than eight persons as permanent residents). McClure does not develop his own method of analysis, and his results correspond largely to the findings of Thackray *et al.* (1978).

Russac *et al.* (1991) are the last British authors to be reviewed here. They look at some of the assumptions and techniques used by the previous two authors, as well as some of these authors' results. Using data from the Isle of Wight metering trial, their work proves most interesting for several reasons. Interesting not least for its inclusion of the basic model developed by Archibald, the analysis of socio-economic variables, which is absent from both works reviewed above. The ACORN classification used for this purpose is reviewed in section 3.7 of this chapter, since its relevance to the methodology deployed by the present work is crucial.

Thus far the British literature with its detailed empirical analysis of household contents was reviewed. Next, component analysis literature from elsewhere, but mostly from the USA is reviewed. As the analysis methods vary considerably, this sub section is divided into two parts: the first looks at literature concerned with primary data analysis, whilst the second looks at literature concerned with the assessment of data obtained for other purposes.

Cameron & Wright (1990) examine the long-term effects of retrofit water saving devices (shower head flow restrictors, toilet tank water displacement devices). Their research does not directly concern the subject of the present work, but it provides some insight into the use of the technique elsewhere. Their model is based on works by Gibbons (1986) who quotes Milne (1979) and Palmini & Shelton (1982). It assumes that 70 standard gallons [265 Litres] of water per day is used indoors by each household in California. Of this, 5% is "essential for drinking and cooking, 40% toilet flushing and 30% is bathing and 'personal use'" (page 179). Their variable list includes square footage of the house, and ownership of swimming pool and dishwasher. Other interests of their work deal with energy savings' correlation with water saving, and is therefore not directly related. The measurement of property size fits however, with Danielson (1979) and Agthe & Billings (1987) who note that:

> "The household size variable was significant for all but the highest income groups." (page 284)

Lyman (1992) examines the seasonal variable associated with 'peak' and 'off-peak' water demand. His work, which looks at 656 households in Idaho, examines amongst others, components which are ignored by other works, and is therefore of great importance. Apart from the usual variables such as the price of water, durables and size of property (Table 3.9), Lyman examined the effect of the household's age composition and type of garden. The overall R^2 for his log linear regression model is 0.71, and the coefficients for age and gardens indicate the relative importance of the former and the negligible role of the latter. The coefficient for adults, Lyman found, is below half that of children. Because the number of adults increased the average age of household out of proportion, the coefficient of $ln\ AVAGE_t$ was excluded from the final model. Overall, Lyman agrees with Hanke & de Maré (1982) that

> "while adults use less water than children, they use more water than teenagers." (page 2166)

His work leads him to make the following observations which question the basis for most models assuming a positive relationship between water use and income levels:

> "It is significant that both household income and property value are found to be important variables. (...) A priori, household income and house/property valuation are probably always correlated but, theoretically, should be variables that measure and represent different things. Specifically, house or property valuation may
>
> (1) Be a proxy for wealth,
>
> (2) Reflect preferences and behavior focused on 'home living' and the related use and maintenance of residential property and structures, and/or
>
> (3) Otherwise be positively related to water use because of systematic and typical relationships between property values and outside landscape and yard features requiring additional water use." (page 2166)

The exact means to assess the property value and its relationship with income is not in the thrust of his work, but without it, little can be substantiated in terms of water use. Other variables, such as the lawn and the age of house are positively related to water use, but interestingly, the number of bathrooms was found to be significantly negatively related to water use.

So far the literature originating from the USA which is reviewed here produced empirical research. The next sub-section looks at works which develop data collected for other purposes, and were analysed in relation to DWU.

Table 3.9
List of DWU variables, their signs and definitions as used by Lyman (1992).

Variable		Definition
QUANTITY, PRICE, AND ECONOMIC VARIABLES		
1.	q^*_t	long-run, per period demand for water
2.	q_t	quantity of water purchased in period *i*
3.	FC_{t-1}	fixed charges for water
4.	MP_{t-1}	marginal price for water
5.	MPD_{t-1}	ratio of the peak and off-peak marginal price
6.	PI_t	price index
7.	$INCOME_t$	household income
8.	HVALUE	assessed value of house and property
AGE DISTRIBUTION VARIABLES		
9.	$AVAGE_t$	average age of household members
10.	$HS1_t$	number of individuals in household less than 10 years old
11.	$HS2_t$	number of individuals in household between 10 and 20 years old
12.	$HS3_t$	number of individuals in household over 20 years old
HOUSE AND DURABLE GOODS CHARACTERISTICS		
13.	HEAT	dummy variable (1, water heat; 0, otherwise)
14.	AGEHOUS	age of house
15.	TOTB	total number of bathrooms
YARD AND OUTSIDE CHARACTERISTICS		
16.	SPRK	dummy variable (1, sprinkler system; 0, otherwise)
17.	LAWNSZ	index for lawn size
18.	SHADE	index for degree of yard shaded
19.	FLOWER	index for size of flower garden
20.	VEG	index for size of vegetable garden
CLIMATE VARIABLES		
21.	$C1DD_t$	number of cooling degree-days
22.	$TEMP_t$	average temperature
23.	HDD_t	number of heating degree-days
24.	$PRECIP_t$	precipitation
DUMMY VARIABLES		
25.	D_{op}	dummy variable (1, off-peak; 0, peak period)
26.	D_p	dummy variable (0, off-peak; 1, peak period)
27.	D_{sp}	dummy variable (1, peak and spring; 0, otherwise)
28.	D_s	dummy variable (1, spring; 0, otherwise)

Source: Lyman (1992)

Metzner (1989) provides a model for San Francisco. The explanatory variables he uses are: population; number of people per household; employment (commercial, industrial and total); marginal price of water and sewer services; temperature; precipitation; and precipitation deficit in prior year (which was used as a surrogate for the imposition of rationing regulations). His work is interested in the aggregation of households and has little relevance to the microdata approach of the present work. However, the component analysis technique proves to be useful in Metzner's case too. His linear regression model results for the residential class yielded an R^2 coefficient of between 0.84 and 0.99, which is considerably higher than most other works on this subject. However, since his model aggregates domestic with non-domestic water use it is considered to be not very accurate, and not very relevant to the present thesis.

Miaou (1990a) suggests a grouping of some variables in order to assess their calibrated weight, but does not recommend the use of 'black box' analysis for testing strength of relationship. The variables for his model (which is not of direct interest to the present work) include all the standard variables, without exception.

One interesting idea in Miaou's (1990a) model is however, the check of the correlation of log transformed sets of socio-economic and climatic variables. The results proved that the three socio-economic variables ranked highly with each other. Climatic variables, on the other hand are moderately correlated. But most importantly, the correlation between the coefficient of water use and socio-economic variables turned out to be very high. The correlation between water use and climatic variables produced low results.(page 1893)

This section looked at the possible variables to be included in a DWU model, and the various approaches to the possible weights attributed to each of them. By the nature of this work, more consideration was given to works carried out in England and Wales, although techniques used by the Americans are taken into account.

3.7 Acorn technique for DWU analysis

The modelling techniques discussed in the previous sections do not, in most cases, use detailed geo-demographic variables. The exceptions were Russac *et al.* (1991), Lyman (1992) and Dovey and Rogers (1993). It is important to note the implementation of ACORN technique to water demand management as is reported by the first and last of the above authors. It is this mechanism which is used by YW and other water companies to assess present use levels and forecast future demand.

Russac *et al.* (1991) analyse initial information from Brookmans Park (Herts.), where extended metering trials have been practised since 1989. Their classification of variables is important to the present work and incorporated remarks made by Rydz (1978), who argued for the inclusion of the age factor in water consumption. The following categories were decided to be most suitable for DWU purposes:

Property:	Detached; Semi-detached; flats; detached and semi-detached bungalow; and mixed property.
Size of household:	1,2,3,4,5 and more than 5.
Age distribution:	pre-school, school, adult, retired.

The absence of terraced properties, and of categories of tenure, indicate the particularity of the survey area, which is considered to constitute high income residents. The results obtained in this work indicate that most of the households consist of 2 persons, and the predominate type of housing is detached. Their cross tabulation produced in table 3.10.

Table 3.10
Results of Russac (1992) *et al.* in factorial terms

Variable	Factor
Total Househols Water Use	
HH Size	4.5
Ownership of aliances	4
RV	3
Type	2.5
Age Profile	1.5
Per Capita	
Ownership of Appliances	2
Age (retired)	1.7
HH Size	1.2

The attribution of a coefficient to variables is a necessary condition for any mathematical modelling, and is therefore referred to later in the present work (section 7.2). It is important to note however, that appliance ownership and the age/employment factor (points 6 and 7) are attributed low coefficients. On the other hand, rateable value scores fairly high, which is not supported in any other work reviewed here. In their conclusion Russac *et al.* point out the major shortcoming of their work:

> "Preliminary comparisons between the Lee Valley Company's consumption figures and the associated ACORN classification, suggest that there are significantly different consumption figures for the same ACORN classification and also that similar consumption occurs with different ACORN groups" (page 350)

which means that this classification "is not sufficiently sensitive to identify variations in demand". (page 351) This is precisely the gap in water use estimation which the present work is filling. Another comment is that data used is only from one reading (one per quarter!), which in any terms could hardly be considered a significant sample (*ibid.*).

Dovey *et al.* (1993) describe the metering trial in the Isle of Wight (IoW) using ACORN classification. A tourist island with a population variation from 125,000 to 190,000 in the summer, the IoW is self contained in water needs. The match between national and local ACORN groups is illustrated in Table 3.10. The high percentage of older housing and better off retirement areas (group C and K respectively) in the IoW compared with the national average, and the inverse trend in the poorest Council estates and multi-racial areas (group G and H respectively) are the most noticeable differences in this comparison. This may suggest a higher than the national standard of living, and can therefore be considered, together with its self-sufficiency in water, as a perfect laboratory to test some assumptions correlating income with water use.

Table 3.11
A comparison between ACORN groups in the UK and on the Isle of Wight.

Group	Description	% IoW	% National
A	Agricultural areas	3.6	3.4
B	Modern family housing	5.9	16.2
C	Older housing	37.5	17.6
D	Poor quality older terraces	4.9	4.3
E	Better off council estates	8.3	13.0
F	Less well off council estates	3.1	4.9
G	Poorest council estates	0.0	7.6
H	Multi-racial areas	0.0	3.9
I	High status non-family	1.7	4.2
J	Affluent suburban housing	15.0	15.9
K	Better off retirement areas	19.2	3.8
U	Unclassified	0.9	0.7

Source: Dovey et al. (1993)

Dovey *et al.*'s work is concerned with leakage, which directs much of the work into the investigation of meter location. One of the interesting results of this research was that the average consumption of external metered premises was between 13-21% higher than internally installed meters. Another finding of the same nature was that summer losses from leakage were 19% whereas winter losses were only 12%. These apparently tangential findings to the present work can explain some of the fuzzy results obtained from other sources.

This section looked briefly at the works where the ACORN classification system was used for water use estimation. None of these works attempts a full scale modelling of DWU as is the aim of the present work, but there is no doubt an important lesson is to be learned from them. In addition, these works highlight the need for a more comprehensive modelling work along the same lines.

3.8 Summary and conclusion

This literature review is by no means complete. It does contain however a wide ranging selection of works which are concerned with DWU, need, consumption and withdrawal. Several works which are mentioned here were not reviewed in detail. Some are used in future chapters in a step by step comparison with the present thesis, whilst others did not appear to add any substantial information for the purpose of the present work. The NERA report (1993) commissioned by Yorkshire Water is one good example of a work of the first category, while Kher & Soroshian (1986) represent the latter.

The point raised in this chapter is that the terminology used in many cases reveals the type of analysis from which it results, and affects any findings. Hence, the section dealing with the terminology is meant to provide an overall view of the different approaches.

The approach, or the term used to denote the activity which households perform when using water is referred to as 'water use', and is similar to the approach used by Archibald (1983). It reflects the growing importance of the multidisciplinary considerations in the formulations of water policies, both on the supply side and on the demand side. However, it does not mean that the terms 'water withdrawal' or 'water demand' are avoided. On the contrary, whenever either of these terms appears it would point to a particular characteristic which is expected to be understood in the light of the analysis in section 3.2.

Considering that much of the literature is related to conditions which either no longer reflect the economic situation in this country, or come from another country altogether, this review serves merely as a panoramic view of the issues and problems involved in this topic, rather than stating the 'state of the art' situation.

4. METHODOLOGY

4.1 Introduction

Domestic water use (DWU) is difficult to assess without an accurate metering system and a leakage-proof water mains system. The problem of modelling DWU in Britain is due to the almost total absence of domestic metering until the mid-1980s. As pointed out in section 2.3.2, only 6% of domestic properties are metered (OFWAT, 1994b: 43) compared with the non-domestic sector, where 73% are metered (Byatt, 1994). Moreover, leakage control exercises carried out in recent years (Dovey & Rogers, 1992, GMAP, 1992) do not appear to suggest a significant improvement on the 10% error margin or even 30% which has come to be accepted as the optimal leakage measurement (Haughton & Hunter, 1994; Brandon, 1984).

In order to assess DWU in properties without a meter, some insight has to be gained into a general DWU pattern obtained from metered properties. Such an approach has two major shortcomings. The first concerns the possible innate bias of metered properties. This problem is dealt with in sections 4.6.1 and 4.6.2 of this chapter. The second problem, which is the more substantial, is which technique should be used to apply the usage pattern of metered properties onto non-metered properties. This is the main thrust of the present research and therefore forms the dominant part of this chapter.

In the first part (sections 4.3 to 4.3.4) the validity of the data is assessed and their shortcomings highlighted. The following four sections (4.4 to 4.4.6) develop the particular advantages and deficiencies of the techniques mustered in this work: descriptive statistics, correlation analysis, analysis of variance, multiple regression and microsimulation modelling. It is argued in this chapter that although each of these techniques is by itself well tested, the combination of multiple regression to identify prominent variables with microsimulation modelling is a unique combination which may be applied to other areas of research, and indeed, to other disciplines.

In the second part (sections 4.5 to 4.5.4) microsimulation modelling is explained. The technical principles and the advantages and disadvantages of this system are elaborated more than the other techniques given that it is not reviewed elsewhere.

4.2 Early methods

Modelling domestic water use is not a new area of research. From the 1950s statisticians and engineers in the USA (e.g. Fourt, 1958) attempted to assess and sometimes model DWU in cities where growing demand posed considerable problems to urban development. The means of assessing DWU and, at a later stage, forecasting future water use concentrated primarily on bivariate regression techniques which considered DWU to be a function of a single variable, namely number of persons in the household.

In the 1960s it became clear, partly as a result of imprecise estimation (Dun & Larson, 1963), that there are more components responsible for DWU than just the household size. The research on this subject was then divided into two main areas: the effect of price on water use, and the seasonal effect on water use. The former, which includes work such as that of Pyatt and Rogers (1962), Pyatt (1964), Howe & Linaweaver (1967), Lee (1969) and Hirshleifer *et al.* (1969) is concerned with the elasticity of water demand, and belongs therefore to the paradigm of economics; while the latter (e.g. Fair *et al.*, 1971 and Lewis *et al.*, 1973) measures the effects of outdoors water use in peak times, and sees the problem from the engineering angle. A more detailed account of these works was produced in chapter 3.

It is not until the 1970s and 1980s that other aspects, notably the components which together compose DWU, are investigated. Works by Morgan (1973) and Grima (1972) in the USA and Canada, as well as by Rees & Rees (1972), Batchelor (1975), Thackray *et al.* (1978) and Archibald (1983) are concerned with this aspect of DWU. However, two elementary limitations in this period prohibited these works from further developing this technique: the first was the ability to measure these components accurately and the second was the ability to compute the complex interdependencies between the variables themselves and their spatial implications.

The first problem is not dealt with by this work. It is assumed that the actual water use of each component is impossible to measure without considerable technical improvement in telemetric flow measurement, although there is an unconfirmed report of such a survey currently undertaken by Anglian Water Plc., where 2000 selected properties in its supply area are connected to a telemetric logging system, which reads individual components in the property twice a day. However, this is not the case in the present work, and the contribution of each component to the overall water use is assessed by the combination of all four statistical techniques which form the basis of this thesis: descriptive statistics; correlation analysis; analysis of variance; and regression analysis.

The second problem, which is a direct outcome of the first, is at the heart of the present work, and is therefore dealt with extensively throughout this chapter.

4.3 Validity of the data

4.3.1 Sampling

The data for this research come from two surveys carried out by YW on all its metered customers. The aim of this section is to describe these surveys and highlight the advantages and weaknesses which they may bear.

As Moser & Kalton (1971; 62) point out, a sample survey can either estimate a population (in the statistical sense) or be used to test a hypothesis. It is not clear from the nature of the sample, or indeed from communications with the officer in charge of the survey, which was YW's approach. The survey appears to have been designed with some general purpose in mind without too much attention to theoretical issues. The sampling strategy consisted therefore, in most likelihood, of an attempt to avoid biased sampling. The first sample (April 1992) was "selected at random" as a letter from the officer in charge of the survey confirms[1], and the second survey (November, 1992) was sent to all metered households in YW's supply area. The problem of selecting a representative sample for this type of research is fully discussed by Hanke & Mehrez (1979).

It is not clear whether the limitation of the first method, or indeed the advantages which may have been perceived in the second, were the reasons for the change of the sampling method of the second survey. It appears that the designs of the survey in general, and of the sampling technique in particular, were not conceived with a clear strategy of analysis in mind. The same is true of the design of the questionnaires, as described in section 4.3.3 below.

4.3.2 The surveys

The questionnaires were sent in 1992 to all households in the Yorkshire Water supply area (Figure 5.1) with a metered water supply. These households can generally be divided into two groups: those who are 'meter optants', i.e. who chose to have a meter installed in their property, usually because they perceived a financial gain in their being charged by unit rather than by their property's rateable value; and those who are compulsorily metered. This second group consists of all domestic customers occupying houses built after 1990, which do

1 The information in this section was supplied by Mr S. Hallas, Income Control Manager, YW.

not possess a rateable value. It is important to note that most properties built since 1986 have the preparatory work for meters built in, but only those built after 1990 are obliged to be charged by metering. It means however, that the largest group of households questioned in the survey (36%) are compulsorily metered.

In all, three batches of questionnaires were delivered. The first was sent in April 1992 to 824 metered domestic customers, selected at random from the whole of YW's area (see appendix I). The random households were chosen by listing every one hundredth metered domestic record held on the billing file at the time of the survey. They received 546 replies (a response rate of 66%) which were judged valid of which 21 replies (4%) were considered not valid. The criteria by which answers were validated or not were the following:

a. There had been a change in the occupancy within the last year.
b. The premises were not wholly domestic.
c. Details of occupancy levels and number of bedrooms were not provided.
d. A customer provided 'dubious' information.

This last comment was not sufficiently clarified by YW, but it may relate to a discrepancy with other records held by YW. The answers to this questionnaire formed the basis to what is referred in this work as the 'preliminary analysis' (Chapter 5). This phase of the research helped the formation of the methodology, and indicated potential weaknesses in the quality of the data and in the method of analysis.

The second survey was carried out during November 1992. All measured households in Yorkshire at that time (about 49,000) were sent a questionnaire (Appendix III) with an explanatory letter and a pre-paid reply envelope. The rate of return for this questionnaire was 64% (31,500 replies). The number of valid and invalid replies to this questionnaire was not precisely recorded, but YW estimates that between 500 to 1,000 were immediately rejected for the reasons described above. Out of these replies, 4039 which answered the above criteria and which had a minimum of one year's occupancy in the Leeds postcode area were sent for analysis in this research.

The information collected by this questionnaire constitutes the main data base for the research. However, the objectives of the questionnaire design were not directly related to the present research. Instead, five main objectives are cited by YW:

1. To look for a possible replacement for the current rateable value based charge for unmeasured customers.
2. For the development of tariff strategy.
3. To assess supply pipe loss.
4. For demand forecasting.
5. To increase knowledge of customers' usage pattern.

A third survey, which does not concern the present work, is being carried out since November 1992. Questionnaires are sent to all newly metered households after the above dates, aimed at three categories of customers:

1. New occupants of existing metered properties.
2. Occupiers of new properties not previously sent questionnaires.
3. Meter optants who had not provided answers to all the questions when they first contacted YW about having a meter installed.

Every new meter optant receives a questionnaire when they first contact YW. The current assumption (as of October 1994) is that all metered households in Yorkshire Water's supply area have given the required details to YW. It remains to be seen how often these details are updated, and whether different information is being sought on a non-regular basis. As has been already said, the information collected in this phase is not included in the present research.

4.3.3 The questionnaires

Neither questionnaire included any direct or indirect incentive to customers who replied. Such incentive could have been in the form of a direct cash reward or a general incentive to improve billing methods from which the customer may benefit in the future (Sudman & Bradburn (1982: 269).

Questionnaire I

The formulating of the first questionnaire (appendix I) corresponds well to the requirements from mail orientated surveys, according to Sudman & Bradburn (1982: 262). There are no complex or open-ended questions, the questionnaire is short (one A4 side) and its design is simple: the customer is supposed to tick to indicate a choice in most cases, and in three categories the customer is meant to indicate a number (the number of persons by age; number of bedrooms; and number of appliances).

There are three elements absent from the first questionnaire. Firstly, there is no identification of the customer, which is meant to encourage respondents to be more open about details which they would otherwise not be willing to disclose. The second element is that this questionnaire contains no questions which may be considered as sensitive such as income levels or occupational profile of the house. Thirdly, the absence of any qualitative questions such as 'Are you satisfied with the service?' or, 'Do you get good value for money?'. Avoiding 'opinion questions' is an advantage which, as Moser & Kalton (1971: 317) point out, helps to obtain a higher rate of returned questionnaires. There was, however, an accompanying letter which is considered by Kane (1984: 87) to be of major importance. This letter (Appendix II) describes the reasons for this survey as "to assist with our [YW] long term planning and to help give customers advice on water consumption". The letter is carefully aimed at the customer's public consciousness ('long term planning') and self interest ('give customers advice'), although it does not state how this questionnaire could do either.

<u>Questionnaire II</u>

The letter accompanying the second questionnaire (Appendix IV), indicates the name and full address of 'a responsible person' in YW. It outlines the importance of the questionnaire and the uses to which it will be put. The purpose of the questionnaire is described as trying to attain better information which "would help to cope with the lower than average rainfall" of the region, thus increasing the customers' benefit.

The second questionnaire (Appendix III) has 15 questions only, as opposed to 17 questions in the first, the omitted two being the two categories of age of occupants (those under 14 years old, and those over it). It is more stylised but, as mentioned above, the rate of return was only slightly lower than that of the first questionnaire, and both are considered high, above the accepted 'reasonable' response rate which McNeal (1990: 40) estimates to be between 30 and 40%.

4.3.4 Summary

The data used in the present work has two main sources. For the bulk of the thesis the surveys performed by YW in 1992 provide the sole source of primary data. Its quality is sufficient for the type of statistical manipulation it is supposed to withstand. For the microsimulation modelling however, other data sources are consulted: the General Household Survey and the National Census of Population, which provides the necessary scale for the generalisation which is accomplished by microsimulation modelling. For a further discussion on this subject see Pownall (1978) and Krupp (1986).

The next two sections describe the analytical operations that underlay the analyses in chapters 5 to 7.

4.4. Statistical techniques

4.4.1 Descriptive statistics

The next section examines the series of four statistical techniques: descriptive statistics, correlation analysis, analysis of variance and regression analysis which is performed in Chapters 5 to 7. The results obtained by these techniques enables the modelling procedure in Chapter 8 to be performed with greater accuracy.

Chapters 5 and 6 are concerned with the details of DWU as observed in the raw data. This is the type of manipulation which early British writers, such as Batchelor (1975) used in order to draw their main conclusions on the subject. Although most works go on to develop a more sophisticated inferential technique, it is an accepted method for the initial stage of the analysis. Frequencies, averages and measures of dispersion provide the backbone of the analysis (Moser & Kalton, 1971: 441). There are several ways to produce averages, and the problem in the present research concerns the values which should be averaged, the categories to be cross tabulated and the groups to be looked at in more detail.

The value to be averaged was decided by the nature of the work. As the search is for household characteristics in relation to the amount of water used, it is 'water use' in which all variables are averaged. Thus the number of residents, the number of bedrooms and the type of houses, etc. are all measured by their average water use. The next decision to be made is the unit of water to be used in the analysis. The unit in which the information came from YW's data base was m^3 per household per annum. Naturally this would have been the easiest measurement to use, but the alternatives had to be considered.

A large number of choices is open in this respect. Firstly, the choice of the measurement unit: is it to be litres as is done by Archibald (1983); cubic feet as in Agthe & Billings (1980); or in gallons (Jones & Morris, 1984; Martin & Kulakowski, 1991)? Secondly, to change the user unit, i.e. per person as in Kindler (1992), Berry & Bonem (1974) or by household (Clouser & Miller, 1980)? Thirdly, the spatial scale: per ward (Williamson, 1993) per city (Gibbs, 1978) or per region (Foster & Beattie, 1979)? And lastly, the temporal unit: per hour (Shvartser *et al.*, 1993), per day (Maidment *et al.*, 1985), per month (Renzetti, 1992; Miaou 1990, 1990a), per season (Kulik, 1993) or per year (Carver & Boland, 1980)?

Each of these units, except for the very last one, could easily be derived from the original data and each would no doubt allow an understanding of a different perspective and characteristics. The choice of the final unit was made, however, according to the following principles:

1. To remain as faithful as possible to the nature of the collected data.
2. To use the most applicable form of data for policy modelling purposes.
3. To use the most workable data in computational terms.

Accordingly, the unit of m^3 per year was chosen as the most suitable unit for the present work. The first principle is self explanatory, the second suggests that since YW are themselves working in m^3 p.a. it would be the most useful unit, and the third principle does not impose any particular problems for the present work as the computer power available was sufficient for any scale of analysis.

The role of the descriptive stage in any analysis is summarised by O'Brien (1992: 46) as providing the following characteristics of the data:

1. The size of the data set.
2. The 'shape' of the data ('typical' values).
3. The central tendency of the data.
4. The scatter of the observation about the central, typical value.
5. Irregular aspects of the data which cannot be accommodated by characteristics 2 to 4.

This is carried out in a series of tables measuring water use average by each of the 22 variables in which the data were collected in both surveys. In places where the average alone does not provide a wide enough picture, a cross tabulation with other variables is carried out (Joliffe, 1986). Thus for example, the magnitude of the 'house type' variable in the present work (section 5.4) is compared to the same variable in previous surveys (section 6.2), and the 'type' is cross tabulated with 'number of bedrooms' in order to establish whether there are any patterns which link these two variables. A similar operation is carried out for each of the variables.

4.4.2 Correlation

Sayer (1984: 197) points out that one advantage of the social sciences over natural sciences is its possibility to adapt a theory or a part of it as a result of it being plausible. However, Moser & Kalton (1971: 446) warn that this is precisely the type of easy methodology which may cause researchers to perform what they call 'fishing' which they define as "the process of using the data to choose which of the number of candidate variables to include in an explanatory model". Correlation analysis is therefore performed in this work in order to eliminate a situation where variables would be too easily 'fished' in the processes which follows this analysis (section 7.2). Correlation analysis between a set of variables and water use was applied amongst others by Agthe & Billings (1980), Sankaran & Viraraghavan (1988) and Martin & Kulakowski (1991). Kulik (1993) uses correlation analysis to assess the relationship between electricity and water use in different climates in Australia. The resulting correlation model resembles in its methodology a regression model, in that it allows the acceptance or rejection of assumptions according to some pre-determined rules. In the present case, the six variables with the highest correlation coefficient were to be chosen as temporary explanatory variables for modelling.

The absence of a preliminary process of variable elimination, which is the function of the correlation analysis in the present work, can create situations such as in Camp (1978: 454). In this instance the third most significant coefficient (out of 14 variables including 'race' and 'size of swimming pool') is attached to the variable 'number of clothes washed per residence'.

A Pearson product moment correlation is therefore performed on all variables to measure their linear association with water use. The results are listed in descending order and the first six variables earmarked for further analysis. However, as Pearson correlation is by its nature bivariate, these results are only used as a general guide for cross reference before multiple regression is performed (section 7.3).

4.4.3 Normality of the distribution of data

Prior to performing a correlation analysis, a test was needed to validate the normality of the distribution of the data. The z transformation is defined by Molloy (1989; 66) as "transforming maps of series f_k indexed by an integer value k into a function on the variable z. This mapping is accomplished by summing the series after multiplying each element by a different power of the variable z." A 'z' (normal distribution) test is performed in section 7.1, and the results confirms within 95% the hypothesis of the normality of the data's distribution.

Following the 'characterisation' of the data, as O'Brien (1992) calls the descriptive statistics in the previous sections, the next stage of the analysis concentrates on inferential statistics.

4.4.4 Analysis of variance

The use of a one way analysis of variance in this work (section 7.2) is needed for two reasons. Firstly it is necessary to eliminate the null hypotheses of the possibility of any relationship inferred in the regression stage as being caused by coincidence (*t* test). Secondly, it is "used to attribute a certain amount of total variation in a dependent variable to variation in some other processes." (Sayer, 1984: 176). Sayer goes on to warn that it does not explain, or even suggest, causality but merely proposes the plausibility of the variable's contribution to the dependent effect.

This method is used, among others, by Domokos *et al.* (1976) who point to another advantage of the procedure: the identification of multicollinearity. They say:

> "When the explanatory variables are multicollinear, estimates of their associated regression coefficients are not precise and it is difficult if not impossible, to determine the relative importance or influence of the explanatory variable". (page 270)

The type of multicollinearity which is suspected to exist in the present work is defined by Glantz & Slinker (1990: 182) as a structural multicollinearity (as opposed to sample based multicollinearity), which can be, and is dealt with in the regression stage (section 7.3) by altering the model.

Although Camp (1978) uses analysis of variance as a complementary analysis to multiple regression (in the same way as it is done in the present work) the resulting model does not appear to be satisfactory. Metzner (1989) uses it as a sole analysis technique, and Agthe & Billings (1987) use it successfully in differently applied procedures, while Kindler and Russell (1984: 37) recommend it as a 'most commonly used technique for estimation of model parameters'. Lyman (1992) uses this technique to assess variables responsible for peak and off-peak demand according to the influence of variables deployed in each of these conditions. The level of confidence throughout the present research is 99% (0.01), which was judged to be a rigorous enough confidence limit considering the ratio of sample for the population modelled. For a wider discussion on the analysis of variance see Hagwood & Price (1960) and Glantz & Slinker (1990).

As Glantz & Slinker (1990) point out, "analysis of variance is a technique for testing differences between mean values of a variable of interest in the presence of several different (and distinct) [events], whereas linear regression is presented as a way to estimate a continuous linear relationship between a dependent variable and one or more independent variables". (page 273)

4.4.5 Multiple regressions

Having established a preliminary order of the relative significance of the variables which could serve in the microsimulation modelling process, it is necessary to demonstrate that these variables do have a 'continuous linear relationship' with domestic water use (section 7.3). As a matter of fact, the causal or explanatory relationship is not demonstrated in a regression process. As Sanders (1990) puts it:

> "The coefficient of determination (...) is sometimes interpreted as the percentage of variation in the dependent variable caused by the independent variable. This is simply nonsense. It should always be remembered that it is the variation in the dependent variable that is being explained or accounted for (but not necessarily caused) by the *x* variable." (page 557)

There are however, enough reasons to associate two variables with a high regression coefficient (R^2) in a manner which would suggest a relationship of dependence, although the quality of this relationship depends on the assumptions put into the regression model (Moser & Kalton, 1971: 462). In the case of the variable 'number of persons in a household' regressed against 'water use', for example, a causal relationship cannot be proved in logical terms, but there is a clear linear dependence between the two: water use in the household is dependent of the number of occupants. The end product of the regression process provides the measure of strength, or measure of association between DWU and the variables chosen to be modelled by microsimulation (Chapter 8). In order to provide the microsimulation model with a credible set of variables, the conditions have to be satisfied that these variables' association with water use is confirmed. As Dzurik (1990: 226) points out: "The development of a simulation model requires the following:

1. Components: design variables or economic decision points where investment can change the value of the response.
2. Relationships: rules by which the components are operated; rules that specify the physical features of the prototype; rules that govern the response computation.

3. Variables: symbolic representation of elements or components of the system; conditions affecting the system, both external and internal.
4. Time interval: a finite characteristic period of time operating on the system."

In order to satisfy the first and second conditions, the use of the five or six variables with the highest coefficient resulting from the analysis of variance would not be sufficient since it would not indicate the strength of their overall association with DWU. To that end a minimum level of association is set on R^2 = >90%. The reason for this level is the necessity to ensure that when microsimulation, which generalises DWU probabilities from the YW survey into other data sets, is performed the margin of error remains as small as possible.

In early works using regression analysis for water use estimation, such as Berry & Bonem (1974) or Foster & Beattie (1979) the regression coefficient is the final result of the work, since the model is purely a statistical model. An R^2 of 0.76 or 0.54 as was the case in both of these works respectively, merely represents the strength of association between water use and their models, and therefore assesses the success of their works.

Technically and conceptually there exist a whole range of multiple regression techniques which could have been deployed using the data provided. Although time series analysis (performed for example, by Maidment & Parzen, 1984) is excluded by the nature of the data, and on the advice of Carver & Boland (1980) there remains a choice of models. An 'all possible subset regression model', which regresses all independent variables with the dependent simultaneously, and a 'stepwise regression model' are performed in section 7.5 in order to assess the differences between them. Stepwise regression, is

> "a procedure for sequentially entering independent variables one at a time in a regression equation in an order that most improves the regression equation's predictive ability or removing them when doing so does not significantly degrade its predictive ability" (Glantz & Slinker, 1990: 239).

Works by Miaou (1990, 1990a) apply stepwise regression, but in a time series and hence is of limited contribution to the present work's development. However, Domokos *et al.* (1976) performed an 'all at once model' and suggest that this is the optimal solution for a type of problem which the present thesis poses (page 267). A similar technique is recommended by Kindler and Russell (1984: 34-35), and by Dzurik (1990: 152). In the British examples, this type of model was used by Thackray (1978) and Archibald (1983).

Non-linear regression models are excluded due to the assumptions attached to the data, as is the case for log-linear models, which do not appear in any of the works reviewed by the present thesis. For a full discussion on the choice of regression models see Glantz & Slinker (1990), Dougherty (1992), Thomas (1993) and Gilbert (1981).

There remains the issue of multicollinearities. Glantz and Slinker (1990: 181-238) point to the importance of identification and treatment of this effect in general terms, while Domokos *et al.* (1976) points to their occurrences in DWU, and suggests a similar technique, although it is an earlier version which does not take advantage of computing power. In 'centering' technique (Glantz & Slinker, 1990: 204) each observed value of an independent variable is regressed by subtracting its observed mean ($\overline{X}$). This procedure clarifies the real effect of collinearities on the analysis, and the regression coefficient can therefore be judged as sufficiently robust for the variables to be included in a microsimulation model.

4.4.6 Summary

The four statistical techniques used in this section are performed with three main aims. Firstly they are intended to accentuate the specific characteristics of the available data (descriptive analysis), then they are designed to screen the variables which are to be used in the microsimulation modelling (correlation analysis and analysis of variance), and finally, which is the unique contribution of the present work, they are expected to confirm the solidity of the explanatory model as it is used in the microsimulation model.

It is important to note here that for technical reasons explained in section 4.5.1, one of the variables most likely to have been included in the model, the number of toilets, was excluded, whilst the house type, which does not figure prominently in the statistical analysis was modeled instead.

4.5 Microsimulation

The choice of microsimulation in this work (Chapter 8) has two origins. The first is a general dissatisfaction with the methods deployed for the purpose of estimating DWU and forecasting water demand in the past. The second reason is the ability to use this in-house technology at the School of Geography, University of Leeds, which is considered to be one of the more advanced centres in this field today.

The modelling process itself does not form an integral part of the present thesis, but its variables are supplied by the present work, and its results are analysed in Chapter 9. Since not much further explanation is given with regard to this technique in any other part of the work, it is explained in the following sections in more detail than any of the other techniques reviewed in the present chapter.

The uniqueness of the method in which microsimulation is used in the present work stems from its need to define the set of variables which could be modelled. In other works using microsimulation such as Wixon *et al.* (1987) or Duley *et al.* (1988) the variables modelled are determined by their availability (e.g. Wixon *et al.*'s Current Population Survey which provides the variables, page 6), or by the nature of the research (e.g. Duley's household demographic characteristics are defined in terms of maternity, mortality, sex and life expectancy.) Thus the need to choose from a large number of available variables is new to this technique.

4.5.1 Description of microsimulation

Although the basic technique has existed for a long time (e.g. Orcutt, 1957), it is only since the 1980s that its full ability has come to light. Microsimulation, according to Williamson (1992: 62) is a mathematical modelling process by which the micro units (households, in the present case) inside a given geographical area are identified by a set of attributes. The probability of the attributes' aggregate existence in the designated area determines the overall characteristics of this area, and allows the structuring of demand hypotheses relating to these areas based on micro information rather than the traditional macro approach or supply techniques. In other words, rather than deduce or hypothesise on the behaviour of the individual from the total, which is likely to indicate averages rather than marginal utility, this technique actually simulates a total from the aggregation of individuals, thus depicting marginal as well as average utility.

The technique is based on two specific elements: the first is the use of the attributes as a list rather than as a matrix. In this way, a computer programme does not calculate the product of each variable by all other variables, but only variables which possess (or have the likelihood to possess) any of the attributes researched. The advantage of this system is the enhanced computational ability since unlike in a matrix, this method does not necessitate the computation of cells with zero or with values of a negative sign. Thus the variables related to each individual unit researched are arranged in a 'list' and are computed according to their probability (Clarke & Holme, 1987: 146).

The second element is the use of the 'Monte Carlo' sampling technique which generates a ttributes at random, from joint and conditional probabilities. This means that each of the attributes of any variable are independently allocated to any of the cases within the sample, so as to simulate a 'natural' distribution of attributes within the sample (Sanders, 1990). The achievement of the best distribution is made by Iterative Proportional Fitting (IPF) which is repeated runs of an 'algorithm which produces exactly the same number each time it is started with the same seed (Clarke & Holme, 1987: 155). This allows not only the aggregation of the units into a geographical area, but also the construction of hypotheses based on a large number of combinations, and their testing.

To give an example of this technique from the present study, it is assumed that all households in Leeds possess some combination of the 5 attributes which determine water use. However, in order to build a sample for all of Leeds, the known proportions from the YW survey (which contains only 4039 cases) are used as 'seeds' to which independent iterations of random combinations are constantly comparing and adjusting the probability of finding water using utilities in the right proportion for the whole of Leeds' population. The number of runs or iterations is determined by the ability of the 'seeds' (or models, or assumptions, in this case) to merge with the full sample (Williamson, 1992: 64).

In order to achieve a higher calibration of the variables, i.e. a better appreciation of the real distribution, different sources of information concerning the probability of finding any of the characteristics associated with water use are utilised. In the present case, apart from the YW surveys, the General Household Survey and the National Census of Population were consulted in order to calibrate both the profile of the population in the relevant area, and the ownership rate of the applicable utilities. It is the need for comparison with other sources which prevented the use of the 'toilet' variable in the model because it is not available from these publications, and 'house type' was used instead, despite it producing a lower regression coefficient (sections 7.3 and 8.8).

The important point in microsimulation is that it is not the individual observation which is at the end of the process; rather, it is the aggregate of individuals and the ability to manipulate their characteristics in space and time which are the most innovatory aspects of this technique (Clarke & Prentice, 1982: 512). This enables an analysis of the given area by any combination of attributes rather than accepting that an area has an overall average of attributes. For a more comprehensive review of microsimulation modelling technique see Clarke *et al.* (1981).

4.5.2 The advantages of microsimulation

By approaching urban systems in terms of allocation effectiveness, this technique possesses the unique advantage of gauging the effect of policies, which are decided upon with an aggregate, or an average, user in mind, on the individual unit. Reciprocally, it has the capability of producing an image - geographical or any other mode of aggregation, which reflects not only the sum or the average, but the probability of it affecting utility and/or consumption (Clarke & Prentice, 1982: 515).

In the case of DWU, the model's results as they are described in Chapter 8, allow for geographical areas' characteristics to be examined through a series of variables selected through the preliminary processes (Chapters 5 to 7). This enables two types of analysis to be used: the first one is a static analysis, in which the distribution of the attributes in the examined area is described and the pattern which is created for each attribute analysed (Chapter 8). The second type of analysis is scenario building. In this process a set of assumptions related to time are constructed and the attributes attached to the assumptions emerge after running the programme as a possible scenario. The advantage of this tool for policy making is in its ability to project experimental policies into the future.

The final advantage of microsimulation modelling is its ability to transcend geographical boundaries by using the data of the most convenient aggregation for the purpose of the work. In the present work, the data were collected by YW in postal districts. This, however, does not match the aggregation of data in the National Census of Population which is aggregated in wards. It is therefore possible to assess the probability of households water use for the projected area in any form and project it in any other form. This is particularly important when boundaries may define the outcome of a research by aggregating data artificially (Jackson, 1989), and the ability to compare different aggregations of data allows a more 'politically correct' insight into the real meanings of the result (Openshaw, 1990).

4.5.3 The shortcomings of microsimulation

The main shortcoming associated with the use of microsimulation technique is its heavy use of probability projection which requires a very large sample in order to achieve a reasonable confidence limit within the range of the given array of attributes. The practical meaning of this deficiency in the present work is that the number of cases needed to assess water use should exceed the probability array of the water using utilities. Thus the use of 13 water using groups (0-600 in 50m^3 pa intervals) produced the following five variables:

$$(Wu(13)\,|\,OC(6), BD(6), HT(5), DW(2), WM(2))$$

where:
Wu = water use
OC = number of occupants
BD = number of bedrooms
HT = type of house
DW = dishwasher
WM = washing machine

creates an array of 13 X 6 X 6 X 5 X 2 X 2 = 9360 cells which is insufficient for determining the joint probability from a sample of 4039 cases as it produces less than one observation for every two cells required probability distribution

(Williamson, 1994). A reduction in the probability array by reducing the classes of water usage to 7 groups and the use of toilet number instead of house type will mean the array includes 3024 cells only. Such an action in the present case seems to be justified for other reasons (section 7.4) as well, but in general, this sensitivity is a serious drawback.

The other shortcoming of this technique applies to policy modelling in general. It relates to the relatively sophisticated initial requirements in terms of computational technique required where other less demanding methods could function just as well, and to the openness of any result to differing and/or conflicting interpretations.

In the present case there could be some debate over the interpretations of the results regarding spatial distribution of water use in Leeds and whether they were produced by statistical or mathematical modelling. The advantage of the latter is only obvious if the technical know-how allows a rapid and easy construction and manipulation of a model. Simultaneously, an analysis using statistical models such as regression or analysis of variance may produce satisfactory results for other requirements, without the use of highly specialised tools or know-how.

4.5.4 Summary

Microsimulation allows the present work to assess the data from an additional perspective. It facilitates the aggregation of the data acquired by YW by a multitude of geographical and thematic means, and enables the running of scenarios introducing a policy aid tool unavailable by any other means.

The technical aspect of microsimulation is not part of this work. The present work is concerned with two subsidiary aspects of it: the interpretation of the results of the static model and suggestions for prericting techniques.

4.6 Conclusion

This chapter outlines the procedure used in the present thesis. It assesses the use of each technique individually whilst indicating the advantages and flaws in each of them.

Initially the quality of the data is assessed, which determines the course of investigation. The combination of statistical analysis with microsimulation modelling promises to produce unique results which would enable a more detailed and at the same time, wider view of DWU.

The next four chapters carry out these techniques, and their results are analysed in Chapter 9.

5. ASSESSMENT OF PRELIMINARY SURVEY

5.1 Introduction

This chapter corresponds to the survey which Yorkshire Water carried out April 1992. It is used here as a pilot study for the full data set which was collected by the survey carried out in November 1992. The 531 households examined come from the whole Yorkshire Water Area which includes one property from Darlington, and two from County Durham (Figure 5.1). The sample selection was random, but within a sampling frame of properties with water meters. Within this frame, a random selection was made by choosing every one hundredth domestic billing record at the time. This produced 824 addresses, from which 546 valid responses were received. The reasons for some of the responses being non-valid has been discussed in more detail in section 4.3.3 above.

Figure 5.1
Location of towns participating in April 1992 survey

The assumptions which are attached to these data are:

1. All properties in the survey are metered. At the time only 49,000 properties in Yorkshire were metered. These are properties which were either built after 1986, when all new properties in Yorkshire were required by the planning authorities to be fitted with meters, or where households requested the installation of meters (meter optants). It would seem likely that the latter category perceived their total water use as less than the average. In any case, these properties are not likely to be 'representative' of any average, apart from the one which they themselves constitute.

2. These households responded to the questionnaires from YW. The reasons for households not answering the questionnaires are described by Molloy (1989) as a disapproval towards the questioning body.

3. The type of information on households' socio-economic grouping. The questionnaire was designed for purposes other than the present work. No direct reference to any of the households' socio-economic group is made in this survey, and therefore no information of such nature is available in this data set. As a result, it was difficult to link water use to this variable, and proxies have to be used. In the full data set (chapter 6) ACORN classification is attached to some of the households.

4. Information regarding the age of properties. This may be of fundamental importance in the case of leakage detection (see for example Dovey and Rogers, 1993).

5. Households with exceptionally high recorded water use (over $700m^3$). In order to smooth data manipulation, two households which used unreasonably high levels of water, without any apparent explanation (such as high number of persons living in the property, or bedrooms etc.) were omitted. In the full data set, properties of this type are treated differently, as the error which may occur in a data set of over 4000 cases is relatively small. The exact technique is discussed later in this chapter.

This chapter is divided into two parts. The first analyses look at the patterns obtained by applying descriptive statistics. Each highlights particular phenomena and problems which are dealt with in depth in the analysis of the full data set (chapter 6). This analysis allows the assessment of each of the variables as a function in a future model. Some variables are also cross tabulated with other variables, a technique which allows a better appreciation of the quality of the data. The second part discusses in brief the methodological problems that this analysis addresses. Some theoretical issues are developed at this stage, while others are only briefly described.

The order of the investigation is of significance to the constitution of the work. It starts with the most credible data set - locational factors - and proceeds to information the reliability of which can be questioned, such as the number of appliances without a clear definition (e.g. the difference between a bath, a shower or a bath/shower).

5.2 Location

Table 5.1 shows average domestic water use by geographical location. This variable is important in determining exogenous and endogenous domestic water uses, as found by Foster & Beattie (1979: 115) and Williams & Suh (1986). The main factor which might affect water use within a geographical area is climate variation.

Table 5.1
Average DWU (m^3/hh/pa) in selected cities in Yorkshire

	Shffld	Brdfrd	Drlngtn	Dncster	Hudsfld	Harrgt	Hull	Halifax	Leeds	Wakfld	York
Mean	97.06	121.80	98.97	107.96	123.40	132.40	107.19	104.60	102.29	106.34	109.56
Standard Err.	8.75	12.93	13.49	13.80	10.06	12.26	6.50	18.68	7.02	7.91	7.64
Median	89.86	109.45	109.93	97.03	126.21	120.68	99.55	94.37	90.54	102.00	107.67
Standard Dev.	72.14	87.71	40.47	66.17	47.20	63.72	58.54	74.70	65.11	53.04	63.96
Count	68	46	9	23	22	27	81	16	86	45	70

Three important climatic factors are related to water use: temperature, precipitation, and evaporation (Gardiner & Herrington, 1986: 22). However, although within the boundaries of Yorkshire the variations in precipitation are of a magnitude which may cause them to be considered major factors in external water use patterns (Table 5.2), these variations within the region are not related to the water use pattern as it emerges from the survey. Thus, Darlington and Sheffield have a similar water use pattern (98.97 m^3/hh/pa and 97.06 m^3/hh/pa respectively) although the precipitation average in

1992 was different (795mm per annum and 1160mm per annum respectively), while Harrogate and Leeds, who have a similar rainfall average (1126mm and 934mm per annum respectively), differ in their average water use (132.40 m^3/hh/pa and 102.29 m^3/hh/pa). In addition, NERA (1993: 13) points to the relatively small advantage in using detailed climatic analysis with regard to water use in Britain.

Table 5.2
Mean of average annual rainfall in 132 gauging stations in Yorkshire in 1992, in millimetres per annum.

Mean	992.93
Standard Error	24.28
Standard Deviation	279.00
Minimum	592
Maximum	1917
Count	132

Source: Institute of Hydrology (1993)

A comparison with the overall annual average rainfall (1961-1990) of 834mm shows that 1992 was not an exceptional year, although the higher than average precipitation would have probably reduced outdoors water use somewhat. Other exogenous factors, more varied than climatic variations, are the altitude of the location and/or its placement on a slope, which might determine the size and the need for gardening and or landscaping. Figure 5.1 however, shows that there is no significant difference in the altitude of the cities in question. Moreover, there is no evidence in the literature concerning the effect of altitude on water use.

To sum-up, climatic factors mainly affect water use outside the house. These include garden size and type of vegetation in conjunction with the given climatic and soil conditions. Having judged that the variations within Yorkshire cannot conclusively determine any variation of water use, and with the lack of information regarding the outdoors of the properties surveyed, this variable was excluded from all further analyses beyond this chapter.

Regional demographics however, may be more appropriate for explaining variations in water use. Residents of certain geographical areas could be assumed to own, on average, fewer washing machines, and/or more showers than in other areas. Some areas may boast a higher dishwasher ownership and more toilets per property than others, etc.

Several figures become immediately apparent in Table 5.1. The first point to be noted is that whereas Doncaster, Hull, Halifax, Wakefield and York have water use near to the overall average (107.82m^3), Sheffield, Darlington and Leeds appear to have a relatively low average water use, while Huddersfield and Harrogate have a higher than average water use. The exogenous reasons are difficult to detect. Moreover, there is, on the face of it, no obvious endogenous reason which would suggest why households in Huddersfield, for example, use more water than in Leeds. Thus the geographical aspect of the data is, by itself, of very little use. The more useful purpose of the geo-demographic data emerges when microsimulation modelling is performed (Chapter 8).

The second point which should be noticed from Table 5.1 is the wide variation of water uses. For example, the meters reading range is from 3m^3 to 283m^3 in Sheffield, or 47.93m^3 to 292.40m^3

in Harrogate. Variation of such magnitude can point to two observations:

1. It might suggest that a city scale is too wide for the purpose of domestic water modelling (although Foster & Beattie, 1979; Williams & Suh, 1986 and Tate, 1989 produced such models with apparently good results).

2. It might imply the existence of a hidden co-variant in properties with a large variation in minimum and maximum use. For example, a significant difference in the number of occupants; a large number of washing machines, or both.

This last point is highlighted in Table 5.3, where the percentage of occupants per household is cross tabulated by their city. There is a high percentage of households comprising two members in cities where the average water use is higher than the total average, for example in Harrogate. Likewise, the absence of five member households in cities with a higher than average water use, could not provide an explanation for the water use, because other locations where water use was considerably lower (Hull, Darlington or Sheffield) have some or all of these characteristics.

Table 5.3
Percentage of occupants in households by cities in survey

City/Occs	1	2	3	4	5
Brdfrd	23.91	39.13	17.39	15.22	4.35
Drlngtn	18.18	18.18	36.36	9.09	18.18
Dncster	20.83	58.33	4.17	8.33	8.33
Hudsfld	8.70	47.83	17.39	26.09	
Harrgt	25.00	57.14	10.71	7.14	
Hull	28.05	46.34	12.20	13.41	
Halifax	23.53	23.53	29.41	23.53	
Leeds	33.72	39.53	8.14	15.12	3.49
Shffld	29.41	45.59	11.76	8.82	4.41
Wakfld	21.74	36.96	21.74	15.22	4.35
York	19.72	46.48	9.86	14.08	9.86
Total	25.10	43.68	13.24	13.83	4.15

Additional analysis of this type is produced in Table 5.4, where the type of property is cross tabulated with locations. This table shows that in Sheffield there is a low percentage of detached properties which may contribute to its lower than average water use. However, Darlington which has a DWU mean water use below the overall average, has the second highest percentage of detached properties, and no flats which appear to use, on average, least water.

Table 5.4
Percentage of house type by cities in Yorkshire survey

CITY	BG	DD	FM	SD	TT
Brdfrd	12.77	36.17	21.28	19.15	10.64
Drlngtn	18.18	63.64		18.18	
Dncster	25.00	58.33		16.67	
Hudsfld		86.96	13.04		
Harrgt	10.71	57.14	14.29	7.14	10.71
Hull	21.95	42.68	13.41	17.07	4.88
Halifax	17.65	41.18	11.76	23.53	5.88
Leeds	14.94	49.43	13.79	13.79	8.05
Shffld	33.33	33.33	17.39	11.59	4.35
Wakfld	17.39	47.83	17.39	10.87	6.52
York	16.90	46.48	16.90	14.08	5.63
Total	18.47	46.95	14.54	13.95	6.09

BG - Bungalow; DD - Detached; FM - Flat/Maisonette; SD Semi-detached; TT - Through Terraced

5.3 Number and age of occupants

Table 5.5 displays at the average water use by the number of occupants in a household. It is immediately apparent that there is a positive relationship between the number of occupants and water use. This observation, which is supported by other works (Grima, 1972; Archibald, 1983; Russac *et al.*, 1991 and others), is also confirmed in the analysis of the full data (section 6.1), where the exact importance attached to this relationship is determined by correlation with other variables.

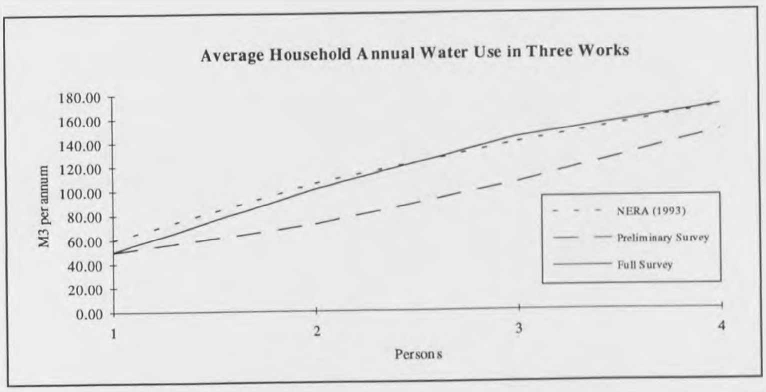
Table 5.5
Average DWU (m^3/hh/pa) per number of occupants

No. of Occupants	1	2	3	4	5
Mean	50.18	104.92	136.22	172.61	187.11
Standard Err.	2.48	3.32	6.11	8.39	11.41
Median	44.88	99.64	129.74	164.15	183.05
Standard Dev.	28.64	50.54	49.61	70.72	52.28
Count	133	232	66	71	21

The number of occupants is a component of a household which is easy to measure, and constitutes the backbone of any database concerning water use. In fact, most water use estimation and projections (e.g. Howe and Linaweaver, 1967; Rees and Rees, 1972; Kindler and Russell, 1984) rely solely on this variable. The ease of obtaining data on this variable and the ability to project scenarios concerning future patterns of growth have rendered the number of occupants the most generally used variable for the purpose of water demand forecasting. The correlation analysis and the analysis of variance in sections 7.2 and 7.3 confirm the eminence of the number of occupants and accords it a high coefficient.

However, as Figure 5.4 shows, the water use per capita in this survey is markedly low in comparison with the full survey (Chapter 6) and with NERA's work which is based on Severn Trent Water data.

Figure 5.4



A related issue is the age of occupants. As Rydz (1978), points out, there are distinct water usage variations between age groups, but the nature of this relationship is difficult to assess on its own owing to its dependence on external factors such as health and income. Hanke & de Maré (1984) and Lyman (1992) suggest that the age factor contributes to the understanding of DWU components, while Russac *et al.* (1993) found that this variable played only a small role in determining DWU characteristics.

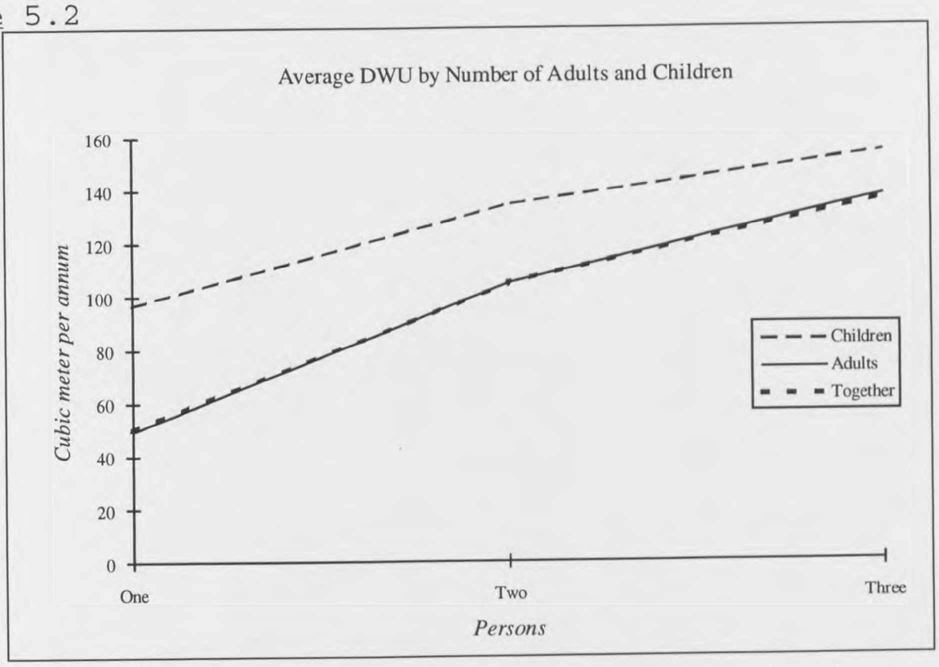
Given that the full database (Chapter 6) does not include the age variable, it is left to this chapter to assess its importance. This is done in two stages: firstly, children as defined by YW, and hence by the present work, as occupants under the age of 14, are cross tabulated with a number of related variables; secondly, in section 7.2, a correlation analysis and an analysis of variance is performed on this variable. The results provides a unique insight into the effects of age structure on water use, although owing to the small number of cases studied, the results serve only as a suggestion as to the possible effect that the inclusion of this variable in the full survey might have had.

As Table 5.6 shows, the number of children is positively related to water use but the ratio in which age affects water use (as a separate variable from a child being just another person) does not necessarily correspond to this rate. Figure 5.2 demonstrates that the water use of a household with children is higher than that of households without children, but the water use by households occupied by adults alone is almost identical to the water use average of both categories together.

Table 5.6
Average DWU (m^3/hh/pa) per number of children under the age of 14 years

No. of Children	0	1	2	3 & Over
Mean	96.72	134.58	153.86	209.71
Standard Err.	2.92	10.61	10.48	24.89
Median	89.45	129.81	148.96	202.78
Standard Dev.	60.43	67.09	74.85	89.73
Count	427	40	51	13

Figure 5.2



When comparing the percentage of children in this survey (15%) to the national average of 31% (OPCS, 1993; page 258, although the age of dependent children is defined there as 'under 16 years old') it becomes apparent that the survey does not reflect the national picture. There does not seem to be a particular bias towards one family size, but the reduced number of children included in the survey may explain the small effect that they have on the average water use.

Table 5.7
Proportion of children under the age of 14 years.

Occs/<14	1	2	3	4	Total
2	2(100)				2
3	27(96)	1(4)			28
4	10(19)	42(79)	1(2)		53
5		7(39)	10(56)	1(5)	18
6		1(100)			1
8	1(50)			1(50)	2
Total	40(38)	51(49)	11(11)	2(2)	104

Note: numbers in brackets represent percentage in row

Having established that the number of children in the survey is lower than the national average, it is important to assess the other related characteristics of this variable. Table 5.7 shows that the largest group of households with children consists of a four person household with 2 adults and two children. The overall percentage of households with two children was just under 50% and that very few families surveyed (13%) had 3 or 4 children.

The number of children may be related to a property's size, which is examined in Table 5.8. However, since the proportion of children used in this survey is low in comparison with the national average, the results obtained do not necessarily explain the correlation between these two variables, although as expected there is a positive relationship between the number of children and the number of bedrooms. The interesting finding of this table is the number of 2 children households who live in properties with zero bedrooms. These properties are by themselves difficult to define (see section 5.4 below and a full discussion in section 6.2), but they are likely to be small properties. The fact is that over 10% of the households which are metered live in these conditions.

Table 5.8
Number of households with children by number of bedrooms

<14 Yr/Bedrooms	0	1	2	3	4	5
1	3	1	4	14	14	3
2	9			17	21	4
3	1			3	6	1
4				1		1
Total	13	1	4	35	41	9

An interesting observation is made when the presence of a washing machine in households is cross tabulated with children. Table 5.9 indicates that the average DWU in properties with children is far higher than that of households with a washing machine, but with no children. This adds weight to the assumption that water using utilities, such as the washing machine (examined below in section 5.5), are related to the characteristics of the occupants - and in particular their age.

Table 5.9
Average DWU (m^3/hh/pa) for properties with an automatic washing machine by age

	<14 yrs	>14 yrs
1	135	59
2	154	120
3	195	144
4	289	210
5		231
Total Average	153	115

Other characteristics of households with children such as the house type or the tenure of the housing in which they reside are not fully investigated at this stage, and are assumed to be better clarified in the correlation analysis (Chapter 7).

5.4 Property characteristics

This section is divided into two sub-sections. The first looks at the type of property in terms of its physical structure, and the second looks at the tenure of the property, thus corresponding more to the occupants' socio-economic profile that the property itself.

5.4.1 Type of property

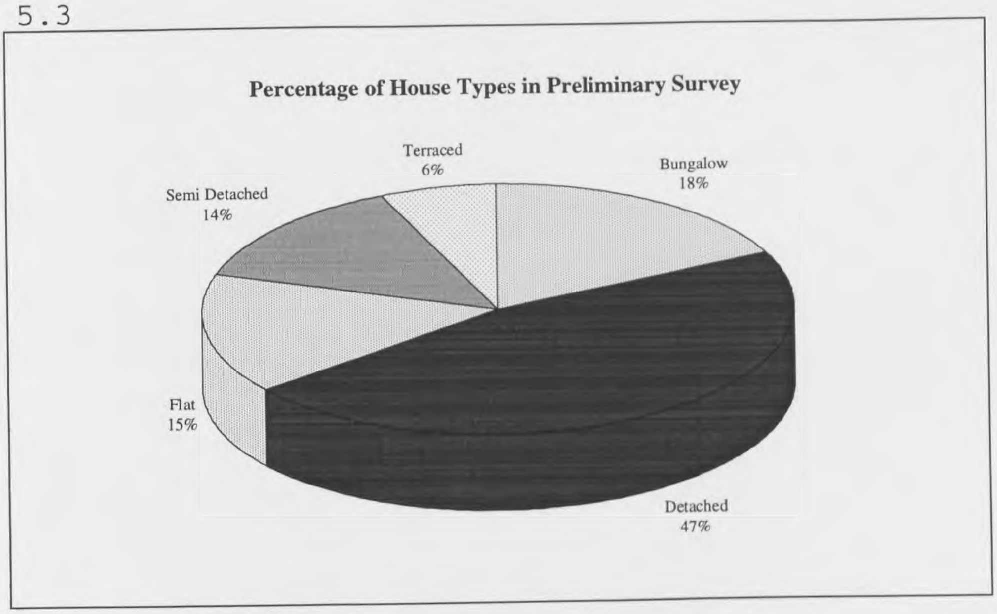
The average water use by household type (Table 5.10) reveals that the dominance of detached properties is not only in their constituting the largest group of household types (over 47% of cases as opposed to 32% on the national scale), but in average water use terms as well.

Table 5.10
Average DWU (m^3/hh/pa) per type of property

	Bungalow	Detached	Flat	Semi	Terraced
Mean	87.82	134.92	61.17	104.83	102.32
Standard Err.	5.86	4.16	4.24	7.95	13.87
Median	82.05	126.91	50.00	94.34	81.77
Standard Dev.	57.37	65.04	38.15	67.49	79.70
Count	96	244	81	72	33

Using 134 m^3 per annum, detached properties use in the region of 20% more water than the nearest categories of semi-detached or terraced properties. What is surprising, however, is the relatively small proportion of semi-detached properties (14%) in what is a 'typical' suburban type of accommodation (Daniel & Hopkinson, 1989). However, this might indicate the age of the properties (which are not indicated elsewhere) since 'semis' are a less common style today than they were 20 or 30 years ago.

Figure 5.3



In conclusion, this category appears at this stage to be a suitable variable for microsimulation modelling on the account of it having distinct characteristics, both in terms of definition of the category (i.e. there cannot be a confusion between them) and the clear DWU pattern in each of them.

5.4.2 Number of bedrooms

Table 5.11
Average DWU (m^3/hh/pa) per number of bedrooms

No. of Bedrooms	0	1	2	3	4	5	6 & over
Mean	118.51	49.73	72.52	106.39	148.30	167.66	251.90
Standard Error	9.77	3.81	3.91	4.42	5.99	19.25	68.97
Median	101.39	43.55	67.11	105.39	136.00	148.82	213.42
Standard Dev.	76.29	26.43	43.04	54.90	66.99	83.90	119.46
Count	61	48	121	154	125	19	3

Apart from 0 bedrooms (Table 5.11), a category which has no particular meaning in the context of the questionnaire, as it could mean a bedsit, a converted loft or simply an unsatisfactorily completed questionnaire, the rest of the table shows a positive relationship between size of property and water use.

The last investigation concerning property's size examines the number of persons who reside in a property. Table 5.12 shows that, as expected, the greater the number of bedrooms, the more occupants reside in the property. However, whilst in the 1 and 2 bedroom properties the distribution is clear with 75% of 1 person and almost 60% of 2 persons households residing in this category, in the 3, 4 and 5 bedroom properties there is no single dominant occupant category. The 2 occupants category retains a majority in all three of these bedrooms categories.

Table 5.12
Percentage of occupants by number of bedrooms

Occupant / Bedrooms	1	2	3	4	5
1	75%	23%	2%		
2	37%	58%	5%		
3	17%	45%	19%	16%	3%
4	10%	40%	16%	26%	9%
5		35%	24%	29%	12%

The role the number of bedrooms plays in the rest of the thesis is heavily influenced by its correlation with the number of persons. It appears at this preliminary stage that this variable is going to be included in the model.

5.4.3 Tenure

Tenure of property is the other category missing from the full survey analysed in the next chapter. It is an important variable because it combines socio-economic characteristics of the occupants with technical specifications which could be attached to the properties themselves.

Table 5.13 points to the overwhelmingly larger average DWU in owner occupied (OO) properties. This type uses over 13% more then privately rented (PR) properties and 26% more than properties rented from the council (CR).

Table 5.13
Average DWU (m^3/hh/pa) per type of ownership

	CR	OO	PR	OR
Mean	81.81	111.51	96.40	93.68
Standard Err.	22.97	2.80	17.89	25.37
Median	45.89	106.05	60.42	45.94
Standard Dev.	100.14	59.71	107.34	101.48
Count	19	454	36	16

However, the sample size for the OO category (84% of the survey's total) is much larger than that of the national average for this category, which is 67% (OPCS, 1993: 254). A cross-tabulation of property's size and type of ownership in Table 5.14 reveals that whilst 50% of council rented properties contain one bedroom only, over 70% of detached properties contain 3 or more bedrooms. This suggests that the larger water use may be related to the larger property size, shown in Table 5.12 to be related to the number of occupants and their age.

Table 5.14
Percentage of bedrooms by property tenure

Bedrooms Tenure	1	2	3	4	5
CR	35%	50%	10%		5%
OO	3%	25%	37%	31%	5%
PR	52%	32%	10%	6%	
UT	80%	7%	7%	7%	

When measuring the number of occupants by property tenure (Table 5.15) the picture does not indicate a conclusive observation. While households with three or more occupants reside mostly in property which they own, households with one and two persons are concentrated mostly in rented accommodation (of both types). This may indicate that rented accommodation has a higher probability of having smaller a household than properties owned by the occupants.

Table 5.15
Percentage of number of occupants by property tenure

Occupants	1	2	3	4	5
CR	42%	42%	5%	5%	5%
OO	22%	45%	14%	15%	4%
PR	50%	42%	3%	6%	
UT	53%	29%	6%	6%	6%

Similarly, the OO category resembles more privately and other rented properties than council rented properties (CR) (Table 5.16). With 52% of detached properties, it compares with the 54% of privately owned properties residing in flats and 59% in other rented housing (mainly housing associations).

Table 5.16
Percentage of tenure categories by property type

Type	BG	DD	FM	SD	TT
CR	45%		35%	5%	15%
OO	17%	52%	10%	15%	6%
PR	14%	19%	54%	8%	5%
UT	18%	6%	59%	18%	

The last observation which is made in regard to property tenure is the ownership of water using utilities discussed in the section below. It is clear from this Table 5.17 that the presence of both utilities in OO properties is overwhelmingly larger than in any rented property. This is taken as an important indicator to socio-economic affiliation, in particular dishwashers which are present in 98% of OO properties in the survey.

Table 5.17
Number of washing machines and dishwashers by property tenure

Tenure	Washing Machine	Dishwasher
CR	16	
OO	440	165
PR	31	2
UT	13	1

In conclusion, tenure of property could potentially provide a useful variable for modelling. However, the absence of this variable from the full survey unfortunately makes it redundant in the present work.

5.4.4 Rateable value

The average rateable value (RV) for all the properties in the survey (notwithstanding the zero values which were included here exceptionally) is £334.80, which falls in the £301-£350 category in Table 5.18. This category uses 94 m^3/hh/pa which is not only less than the overall average (107.82 m^3/hh/pa), but less than the previous category (£251-£300). This discrepancy may suggest that either the properties surveyed are over-estimated for tax purposes, or that the RV does not reflect a linear relationship with DWU. This assumption is strengthened by the lack of a positive relationship between average DWU and RV. In other words, DWU does not increase every time the RV category raises, although the overall trend is positive.

Table 5.18
Average DWU (m^3/hh/pa) by rateable value of property (£)

RV(£)	*0*	*29-100*	*101-150*	*151-200*	*201-250*	*251-300*	*301-350*	*351-400*	*401-450*	*451-500*	*>500*
Mean	101.54	74.16	96.43	99.63	92.00	103.83	94.08	118.61	150.15	146.60	158.87
Stnrd Err.	3.84	16.91	17.52	19.06	19.01	8.31	9.12	9.25	25.22	9.71	11.67
Median	94.49	57.17	70.65	86.49	67.05	112.84	96.73	117.64	108.62	148.19	157.20
Stnrd Dev.	64.67	58.57	78.37	78.58	80.65	53.23	49.13	57.77	109.92	60.63	63.89
Variance	4182.81	3430.65	6141.20	6174.84	6504.53	2833.50	2413.57	3337.52	12083.19	3675.48	4082.19
Count	284	12	20	17	18	41	29	39	19	39	30

RV appears to correspond well to other property characteristics. Thus, the RV of the OO category tends to be in the £200-£400 charge band (Table 5.19), whilst privately rented properties (the other categories did not possess RV) fall under £200.

Table 5.19
Percentage of tenure by RV categories

	Rateable Value (£)					
Tenure	< 100	100- 200	200- 300	300- 400	400- 500	>500
OO	3%	13%	24%	29%	17%	12%
PR	36%	36%	14%	7%	7%	

Similarly, the number of bedrooms (Table 5.20) tends to increase with the RV of a property. In the sample, 65% of 5 bedroomed properties possess a RV of over £400, while 66% of one-bedroomed properties possess a RV of under £200. This suggests that in the case of RV not being found suitable for microsimulation modelling, number of bedrooms could be used as a proxy of its values.

Table 5.20
Percentage of number of bedrooms by RV categories

	Rateable Value (£)					
Bedrooms	< 100	100- 200	200- 300	300- 400	400- 500	>500
1	33%	33%		17%		17%
2	10%	23%	33%	23%	8%	4%
3	3%	20%	30%	29%	12%	5%
4		7%	14%	31%	31%	15%
5			18%	18%	29%	35%

House types, however, (Table 5.21) are not so clearly related to their RV. Although 60% of DD properties possess an RV of over £300 and 87% of SD properties possess an RV of under £300, the other three categories do not reflect any trend. This makes house type an unlikely proxy for RV in the event of this variable being used in microsimulation modelling.

Table 5.21
Percentage of house type by RV categories

	Rateable Value (£)					
Type	< 100	100- 200	200- 300	300- 400	400- 500	>500
BG	2%	23%	26%	28%	9%	10%
DD	5%	8%	21%	29%	22%	15%
FM	8%	25%	8%	38%	21%	
SD	9%	30%	48%	9%		4%
TT		17%	33%	33%		

In conclusion, at this stage RV does not appear to provide a useful variable in DWU modelling.

5.5 Water using utilities

The next set of tables looks at elements of water use inside properties. The toilet is cited by several accounts as the largest water using utility in the house (e.g. National Water Council, 1982; Cameron & Wright, 1990). Table 5.22 indeed shows a positive correlation between the number of toilets and water use. As Thackray *et al.* (1978) point out, in order to measure some of these utilities' correct impact, the estimated frequency of use should be taken into account as well as the quantity of each use, which in the case of most toilets is pre-determined. One example of a technique to assess the frequency of toilet use would include to calculate the number of occupants less the number of children under 3 three years old.

Table 5.22
Average DWU (m^3/hh/pa) per number of toilets

Toilets	1	2	3	4 & Over
Mean	75.17	121.92	140.48	217.76
Standard Err.	3.45	5.49	4.95	23.26
Median	67.59	110.92	135.10	208.71
Standard Dev.	51.76	71.35	54.67	77.13
Count	225	169	122	11

However, the number of toilets could also be correlated to the number of bedrooms. Table 5.23 confirms that households with a larger number of bedrooms have a greater probability of owning a larger number of toilets. This too is related to the number of occupants in larger properties, which is useful for water use estimation.

Table 5.23
Percentage of number of toilets by number of bedrooms

Toilets Bedrooms	1	2	3	4	Cases
1	100%				48
2	78%	20%	2%	1%	121
3	39%	48%	12%	1%	155
4		35%	61%	2%	123
5		32%	53%	11%	18
Cases	203	149	106	7	468
% of Total	43%	32%	23%	2%	100%

Tables 5.24 and 5.25 correspond to two different, yet equally prominent water-using appliances. The positive correlation between water use and the number and existence of washing machines and dishwashers is maintained here. A cross tabulation of washing machines and dishwashers by tenure is performed in sections 6.8 and 6.9 in order to assess the possibility of drawing conclusions on one of the variables in the absence of the other.

Table 5.24
Average DWU (m^3/hh/pa) per number of washing machines*

Washing Machine	1	None
Mean	113.20	59.80
Standard Err.	3.08	7.05
Median	105.01	46.54
Standard Dev.	66.65	53.25
Count	468	57

* *Both automatic and twin-tub*

Although the washing machine's automated and regular water usage make it a relatively easily 'measurable' variable, its frequency of use as well as its volume of usage may be assumed but remain unsafe for modelling without further research.

Table 5.25
Average DWU (m^3/hh/pa) with and without dishwasher

Dishwasher	With	without
Mean	145.50	90.39
Standard Err.	5.29	3.14
Median	138.44	81.55
Standard Dev.	68.63	59.86
Count	168	363

The number of baths (Table 5.25) is often related to the number of bedrooms and hence number of toilets. However, as opposed to toilets, where a minimum frequency and the amount of water used can be estimated reasonably accurately, no such minimum use can be attached to baths or showers.

Table 5.26
Average DWU (m^3/hh/pa) per number of baths

Baths	0	1	2
Mean	60.91	102.35	145.03
Standard Err.	12.02	3.14	7.89
Median	58.83	94.00	131.14
Standard Dev.	38.00	66.23	66.51
Count	10	446	71

As can be seen in the table above, the properties with one bath use on average just over $40m^3$ p.a. more than those with properties which have no bath. Table 5.26 suggests also that there is a positive relationship between the number of baths and the average amount of water used. Table 5.27 indicates two important elements in the case of baths. Firstly, the almost total absence from the sample of properties which possess more than two baths (as rectified in the full survey), and secondly, the positive relationship between the property's size and the number of baths which can be considered a safe assumption.

Table 5.27
Percentage of number of baths by number of bedrooms

Baths / Bedrooms	1	2	3	4	Cases
1	100%				46
2	93%	7%			117
3	91%	9%			153
4	73%	25%	1%	1%	124
5	53%	42%	5%		19
Cases	395	61	2	1	459
% of Total	86%	13%	1%		100%

Table 5.28 looks at the effect showers have on DWU. The expected positive relationship between the number of showers and the average water use is established again. However, since the definition of shower is somewhat vague (as it can be within the bath or a separate unit), there is a danger that it will be calculated twice. Moreover, showers, even more than baths, are prone to be badly assessed for the quantity of water actually used in any wash. It is therefore assumed that this variable is of dubious quality for modelling.

Table 5.28
Average DWU (m^3/hh/pa) per number of showers

Showers	0	1	2	3
Mean	88.00	105.30	145.44	224.98
Standard Err.	5.53	3.81	5.57	48.18
Median	73.97	98.66	142.86	183.81
Standard Dev.	68.23	64.91	51.05	107.74
Count	152	290	84	5

Table 5.29 shows two amenities, sinks and basins, which have a positive relationship to water use. This relationship to water use may, again, be somewhat misleading since both variables are difficult to measure independently in terms of frequency and in terms of quantity used. The links between basins and bedrooms (Pearson correlation coefficient = 0.49) may indicate some potential use for these two variables in the full data base.

Table 5.29
Average DWU (m^3/hh/pa) per number of sinks and basins

	Sinks			Basins				
	1	2	3	1	2	3	4	5 & 6
Mean	99.32	128.90	169.46	78.85	114.02	136.27	179.79	154.21
Standard Err.	3.43	5.19	22.21	3.83	5.72	5.10	16.77	16.42
Median	89.47	127.45	161.23	68.06	109.43	129.35	166.72	156.43
Standard Dev.	67.10	58.76	86.03	57.32	69.08	55.69	73.08	63.59
Count	383	128	15	224	146	119	19	15

5.6 Outdoor water use

Table 5.30 relates to DWU outdoors. YW's data set does not contain any information on the size of the garden which makes these tables of relatively little use. Although the data set does contain the dates on which the measurements began and ended, there is no breakdown into periods (e.g. into four seasons) which would allow the deployment of time series analysis. The positive relationship between water use and the existence of these utilities, is all there is to note about these two variables.

The use of the hose pipe for car washing is also difficult to assess as the questionnaire did not contain a question on the number of cars. Interestingly, there is little difference in average water use between households which possess no hose pipe and those which possess one. There is, however, a considerable difference between households with and without lawn sprinklers.

Table 5.30
Average DWU (m^3/hh/pa) per number of hose-pipes and lawn-sprinklers

	Hose pipes			Sprinklers	
	0	1	2	without	with
Mean	97.26	116.93	136.39	103.59	134.78
Standard Err.	4.08	4.40	8.22	3.13	7.77
Median	81.66	110.38	119.38	95.89	118.65
Standard Dev.	71.21	54.97	66.29	67.12	65.93
Count	304	156	65	459	72

It remains to be seen whether these two utilities can be related to other variables in the survey. Table 5.31 shows that although larger properties possess more hose pipes there are no one bedroomed properties with a hose pipe or a sprinkler and that less than 50% of 3 bedroomed properties and nearly 40% of 4 bedroomed properties do not possess a hose pipe. The even smaller proportion of properties with sprinklers suggests that a vary large sample is needed in order to ascertain conclusively the influence of these utilities on DWU.

The number of hose pipes and sprinklers is cross tabulated with property type (Table 5.32). This table suggests that detached properties and bungalows are, as could be expected, the ones with the greater number of these two utilities. Interestingly, semi-detached properties and terraced properties have well below 50% of hose pipe ownership and a much smaller proportion of lawn sprinklers.

Table 5.31
Number of hose pipes and lawn sprinklers by number of bedrooms

Bedrooms	Hose pipes	Sprinklers
0	24	6
2	39	14
3	74	24
4	76	24
5	11	4
7	1	1
Total	225	73

Table 5.32
Number of hose pipes and lawn sprinklers by property type

Type	Hose pipes	Sprinklers
BG	46	19
DD	136	44
FM	3	0
SD	30	9
TT	10	1
Total	225	73

5.7 Conclusion

This chapter assesses the pilot data in terms of its utility for further statistical analysis. Apart from the familiarisation with the data, this chapter provides an introduction to the technical and methodological problems which are covered by Chapter 6.

This initial descriptive analysis produced three main results:

1. A positive relationship between average DWU and all the variables investigated except RV suggests the *prima facie* viability of modelling technique application.

2. Some categories assessed here are considered, already at this stage, to be too difficult to use as variables in modelling, whilst other variables, which may be considered

useful (e.g. age group or garden size), do not appear in the full survey.

3. The size of the preliminary survey and its geographical distribution does not allow the drawing of firm conclusions from it. The full scale survey which concentrated on Leeds proves to provide a better data base.

The following tentative conclusions are drawn in relation to the variables listed below:

Location - not suitable for modelling in its crude form. Number of occupants - highly suitable for modelling. Age of occupants - suitable, but is not included in full survey. Type of property - appears suitable, but only full survey could indicate suitability for modelling. Number of bedrooms - appears suitable for modelling. Tenure - does not appear very suitable, and does not appear in full survey. RV - does, on the face of it, not appear suitable for modelling purposes, although in combination with other variables might be useful. Toilets - appears suitable for modelling Washing machine - very suitable for modelling, especially with age group Baths - not suitable for modelling. Showers - potentially useful in relation to standard of living, not suitable with reference quantity of water and frequency of use. Sink/basin - potentially poor modelling variables. Hosepipes & lawn sprinklers - good association with house type but poor on actual amount attributed to this variable alone.

The next chapter looks at the full scale survey. The same technique of following each variable at a time is pursued, although greater attention is paid to the variables which appear to have produced clearer results in the present chapter. The results of the next chapter are analysed in Chapters 7 and 8 by a series of inferential analyses and microsimulation modelling.

6. DESCRIPTIVE STATISTICS ANALYSIS

6.1 Introduction

In the previous chapter the preliminary survey was examined. It was suggested there that data availability and the form in which they were collected may affect the possibilities of using it for the purpose of either estimation or modelling. As pointed out in section 4.3.3, the questionnaires for this work were designed by YW for other purposes. The analysis performed hereafter is therefore subject to the limitation which the quality of the information imposes.

This chapter, like the previous one, is concerned with descriptive statistical analysis. Moser & Kalton (1971), Kane (1984) and McNeill (1990) suggest that the correct execution of the descriptive stage is crucial to the full and impartial interpretation of the raw data.

The questionnaires which are the basis for the present analysis were distributed in November 1992 to all properties which have a measured water supply in Yorkshire. The 4039 properties in Leeds answering this category and fulfilling YW criteria for being 'valid' (see section 4.3) for the main data of this work. It should be made clear however, that the pattern of DWU which emerges at this analysis stage does not, and cannot, represent households without water meters. This is the aim of the microsimulation modelling reported in Chapter 8.

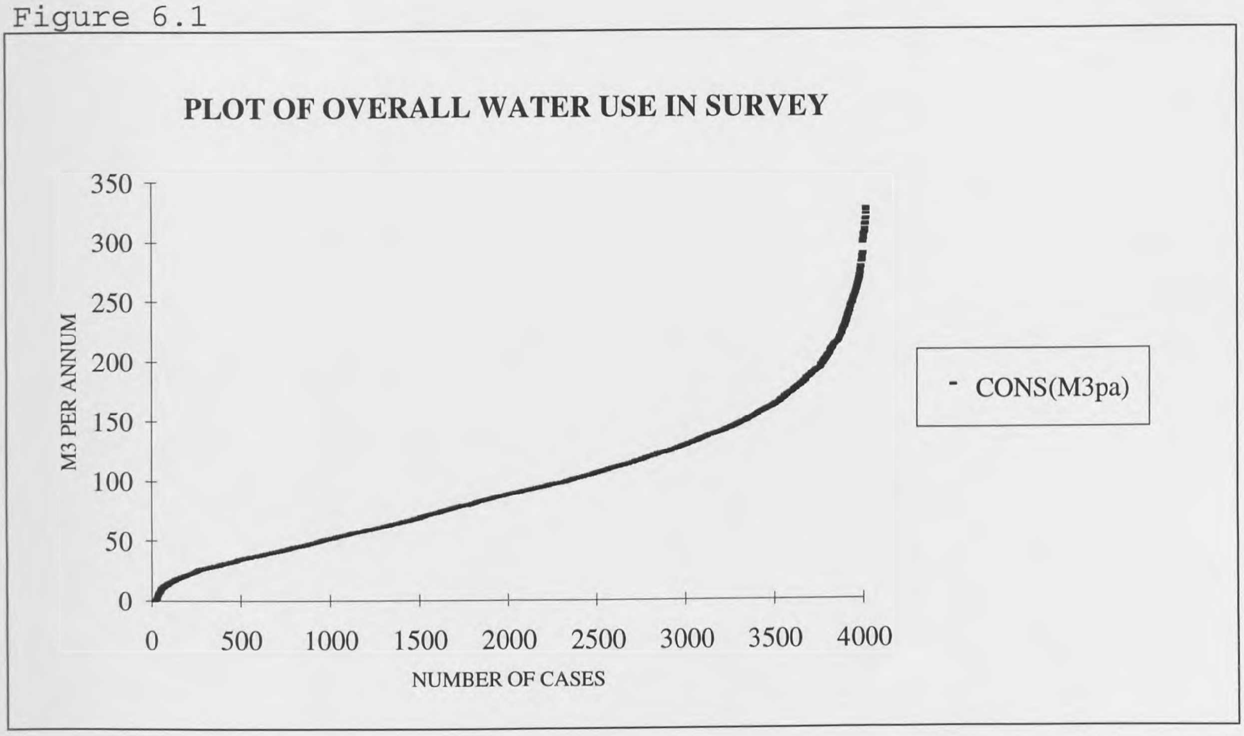
The ACORN classification of the participating households, which was supplied with this data set was not provided in the data set analysed in Chapter 5. ACORN classification is therefore extensively analysed in section 6.12 in the same way age and tenure were treated in chapter 5. The analysis order in this chapter has no particular meaning, as was the case in the previous chapter. Instead, each category is examined in the order of appearance on the data set.

It is important to note that the definitions provided in section 5.1 are applicable in this chapter as well.

6.2 Validity of Data

The data distribution as it was received from YW can be seen in Figure 6.1. For technical reasons, the water use readings in excess of 350 m^3/hh/pa are not plotted in this graph. It suggests that the two ends of the curve (<50m^3 and >200m^3) are indeed extreme situations which allow the majority of the data to be considered as 'normally' distributed.

Figure 6.1



This chapter looks at the average DWU of each category in the questionnaire. Some categories highlight one or more patterns which are used as hypotheses later on in the presentation of inferential statistics in the next chapter. Others just serve as explanatory variables in the development of a model but are not actually included in any further analysis.

One technical comment has to be made at this point:

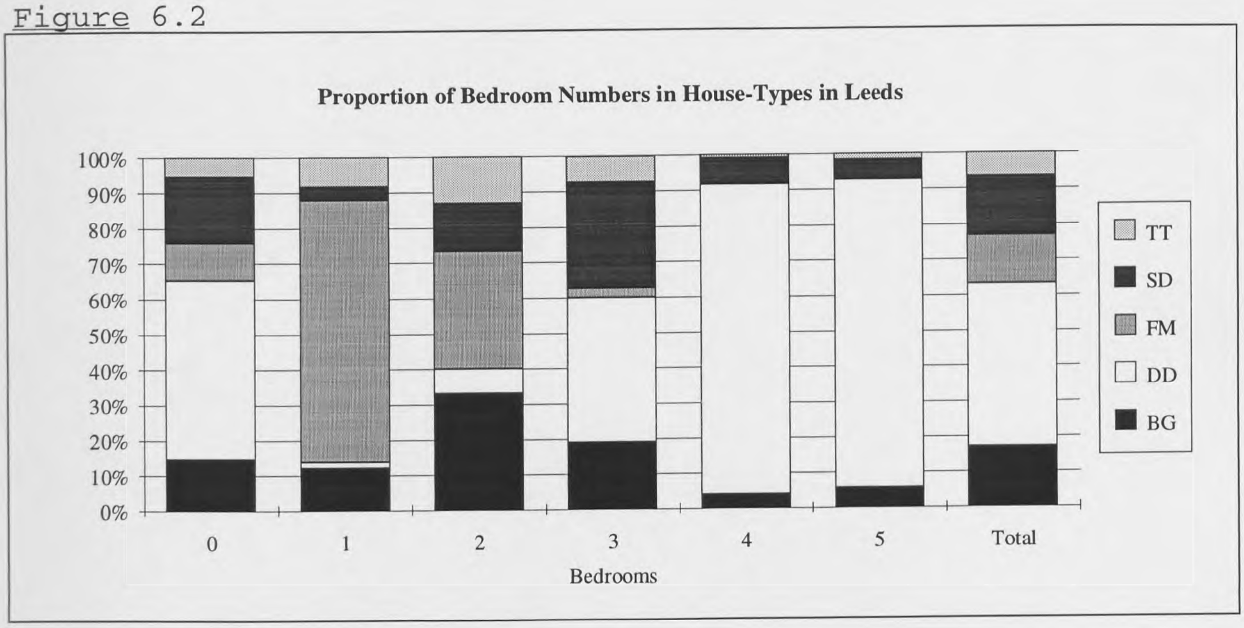
a) As in the pilot study, several observations are not included in the analysis. In this case, exceptionally high water usage may not have affected as a large a sample as this one. However, in some cases occurrences with less than 20 observations (0.5 percent of the sample) were considered to be statistically unreliable and omitted from the analysis.

b) Households with zero occupants and properties with zero rooms appear to pose a more serious problem. Both these categories are discussed in detail in sections 6.4 and 6.5 respectively, but their case is useful in explaining case of zero value. In the case of the occupants the problem may be more easily solved, and may simply constitute properties the owner of which chooses to leave them empty for a variety of reasons. The small number of cases in this group make it unreliable for this work's purpose, but it may, on the other hand, substantiate the plausible explanation given above.

   Zero bedrooms in properties seems to be a less meaningful notion. A property of this type may be composed of studio flats and bedsits which are not classed as bedrooms although they function as such. More probable, however, is the suggestion that both zero value categories include poorly answered questionnaires or represent unavailable data.

The cross-tabulation between the number of bedrooms and the type of house, for example, shows the similarity in proportional profile between the zero bedrooms category and the total, as portrayed in Figure 6.2. The number of bedrooms is also the category for which there is a relatively small number of zero answers - 170 cases (6.5%) compared with for example, ACORN group where 1259 cases (31%!) were zero.

Figure 6.2



Whilst the zero bedroom could mean a studio flat (as noted earlier), it would be highly unlikely for this type of residence to be a detached house. However, Table 6.1 suggests that the distribution of house types in the zero group is not far from the overall distribution (discussed in detail in section 6.3 below). The conclusion must be that zero bedrooms answers are not necessarily studio flats or bedsits.

Table 6.1
Comparison of distribution of zero bedrooms by house type

	BG	DD	FM	SD	TT
Overall	17%	46%	14%	17%	6%
Zero	15%	50%	11%	19%	5%

Alternatively, the number of occupants in the zero bedroom properties was compared with a similar assumption: up to two persons could live comfortably in a bedsit. Above that number it would be unlikely. Table 6.2 shows again that even when allowing for some natural discrepancies, the general picture of the zero bedroom category is not dissimilar to that of the distribution of the overall survey population.

Table 6.2
Cross tabulation of zero bedroom answers with number of occupants

Occupants	1	2	3	4	5
Overall	32%	44%	11%	10%	3%
Zero	40%	35%	10%	6%	2%

A third possibility is to look at the rateable value of properties (Table 6.3) with the assumption that those with a single room could not be valued at the top of the scale (a full discussion on rateable values is carried out in section 6.3). Here the zero value of the rateable value is compared with that of the number of bedrooms. In this case, too, the distribution resembles the overall pattern, which leads to the conclusion that the zero bedroomed properties are more likely to be unavailable data rather than any other category. As can be seen in section 6.3, approximately 30% of the zero bedroom category have a rateable value of over £300, when the overall average rateable value for the whole survey is only £221. If the suggestion is that zero bedrooms signifies a bedsit it would appear to be unlikely to be valued higher than the average.

Table 6.3
Distribution comparison of zero bedrooms by rateable value of property in full data set

RV (£)	0 to 100	100 to 200	200 to 300	300 to 400	400 to 500	500 to 600	600 to 700
Overall	37%	8%	17%	18%	11%	6%	2%
Zero	43%	4%	20%	14%	11%	7%	2%

The next sections examine the results of the averaging and cross tabulating of eleven categories which were judged to be relevant to this work, as a result of the analysis performed in the previous chapter.

6.3 House type

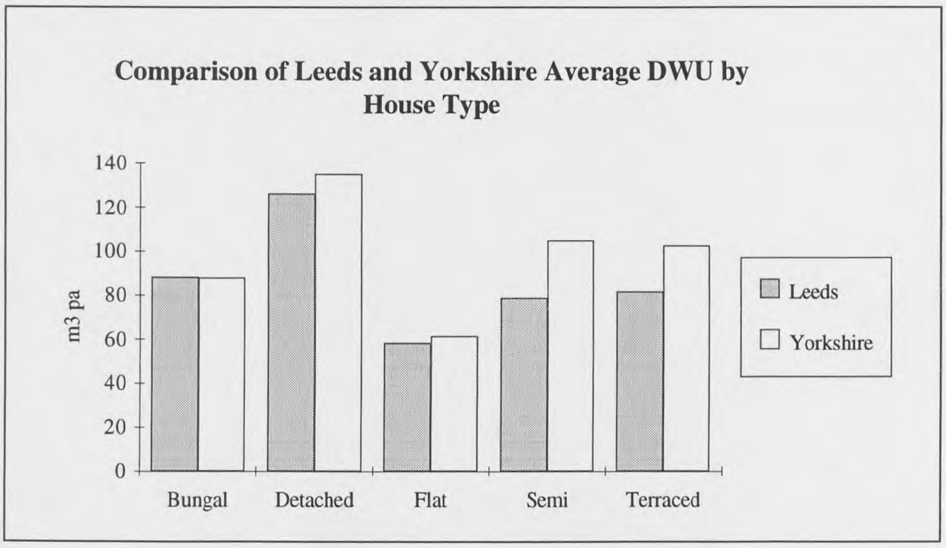
In section 5.4.1 it is suggested that this category may be suitable for microsimulation modelling. With this in mind, the present section assesses the same category with the full data set attained from the full survey.

Table 6.4 looks at the average DWU by different house types. It shows that the average DWU is greatest for detached properties the (DD), and smallest for flats and maisonettes (FM). However, the DD category has the largest number of observations, whilst the number of observations of through-terraced properties (TT) is considerably smaller. The main conclusion from this table alone may therefore be that detached properties in this survey are so overwhelmingly over-represented that any result obtained here will have to compensate for this distortion. A comparison with the preliminary data set (Figure 6.3) shows that in all categories (except the bungalows) the average DWU is smaller in Leeds than in the Yorkshire average. Moreover, even in the DD category where the average is well above the overall average (in both surveys) the average of the Yorkshire survey is higher.

Table 6.4
Average DWU (m^3/hh/pa) by house type

TYPE	*DD*	*BG*	*TT*	*SD*	*FM*
Mean	126.28	88.16	81.38	78.55	58.32
Standard Error	1.70	2.20	2.79	2.02	1.68
Median	115.34	78.05	79.25	66.65	47.795
Standard Deviation	73.70	57.36	45.28	51.94	39.46
Variance	5431.52	3290.63	2049.96	2697.74	1556.93
Count	1887	677	263	660	552

Figure 6.3



The reduced DWU in flats in the full survey, may be attributed to two explanations:

a) Their average size: they do not possess four and five bedrooms at all (Table 6.5), or

b) The lack of garden associated with this type of property.

The difference between terraced properties and bungalows, which have a similar profile, may be explained by water use associated with garden activities. A similar explanation could apply to the difference between the semi-detached and detached properties, although semi-detached have a dominant 3 bedrooms class, while the detached properties have a large 4 bedrooms class.

Table 6.5
Cross tabulation of house type by number of bedrooms

Bedrooms	1	2	3	4	5
BG	4%	48%	39%	7%	2%
DD		4%	31%	55%	10%
FM	34%	59%	7%		
SD	1%	20%	64%	13%	2%
TT	8%	49%	39%	3%	1%
Count	241	947	1336	1105	192
Row%	6%	25%	35%	29%	5%

In order to evaluate these results in comparison to national figures, the average proportion of Leeds properties by type is compared to the whole of Yorkshire (preliminary survey) and the national average (Table 6.6). Whereas the FM and SD categories reflect the national picture fairly closely, there are considerable differences between the TT and DD categories in the three surveys. This may be explained by the proportion of these categories with water meters (as they are in the two YW surveys) compared with the national proportion which incorporates all properties. As meters are installed automatically in new properties (see section 4.3.2) the higher than national proportion of SD and DD could be explained by these types of properties being built in the latter years, as opposed to the other two types.

Table 6.6
Percentage of house type size in three surveys

	SD	*DD*	*TT*	*FM*
National*	19%	32%	29%	14%
Yorkshire	14%	46%	6%	15%
Leeds	16%	47%	7%	14%

* *Source: OPCS (1991)*

In conclusion, it is clear at this stage that the analysis of house type is potentially useful for microsimulation modelling. The characteristics of this criteria are well defined and the distinction between the different categories is clear (there are, for example, no zero values in this category). House types are also easily associated with other characteristics of the property, notably size and age.

6.4 Rateable value

In section 5.4.4 RV was found to be a potentially useful variable in combination with other categories indicating socio-economic characteristics of the property.

Averaging DWU by RV using the full data (Table 6.7), indicates a positive relationship between the DWU and the rateable value of the property. This provides *prima facie* support for the hypothesis stipulated in Chapter 5, that domestic water use is positively related to some socio-economic indexes. This should put the average DWU (99.88 m^3/hh/pa) in proportion to the average property's RV (£221.7). Thus it could be expected to associate properties which are in RV category £201-£250 to have an average DWU. This does not occur, however, and instead this value falls into the £301-£400 per year bracket. As in chapter 5, this puts the suitability of this variable in doubt just because it appears to be unrepresentative of the sample as a whole. This problem is exacerbated when the first category is examined. That the £0 - £50 category has an average water use of the same order as the overall average, may again indicate the seriousness of the zero value, discussed in section 6.2. It is interesting to note that the average DWU decreases until the £151-£200 category and only then (unlike in Table 5.17) does it begin to show a positive relationship with RV.

Table 6.7
Average DWU (m^3/hh/pa) by bands of rateable value

RV (£ pa)	*0-50*	*51-100*	*101-150*	*151-200*	*201-250*	*251-300*	*301-350*	*351-400*
Mean	104.38	93.29	59.76	51.03	57.01	72.88	90.46	106.77
Standard Error	1.79	13.29	8.78	2.73	2.09	2.23	2.55	2.81
Median	94.53	87.52	35.565	39.59	48.21	62.68	83.325	98.75
Standard Deviation	68.53	74.01	78.55	41.70	37.96	41.78	48.58	54.36
Variance	4695.90	5478.01	6170.84	1738.80	1441.15	1745.49	2360.31	2954.81
Count	1470	31	80	233	330	351	362	375

RV (£ pa)	*401-450*	*451-500*	*501-550*	*551-600*	*601-650*	*651-700*	*>700*
Mean	116.53	132.95	145.10	157.06	174.16	189.39	201.50
Standard Error	3.32	4.88	4.65	13.05	12.59	16.24	12.61
Median	110.47	120.61	143.2	130.035	154	188.3	195.065
Standard Deviation	53.88	67.11	59.35	113.76	78.64	98.80	79.75
Variance	2903.55	4503.24	3522.45	12941.37	6184.99	9762.36	6359.62
Count	263	189	163	76	39	37	40

To conclude the section on relationship between water use and rateable value, it seems that this criterion could only be used to support other variables. The measurement itself appears to be unstable. These values may change from time to time and reflect exogenous changes in the property market or tastes rather than the changes in the mode of living inside properties which are responsible for DWU.

6.5 Number of Occupants

From the literature reviewed in Chapter 3 and the discussion in section 5.3 it is possible to assert that the number of occupants is an important variable determining household water use. The present data (Table 6.8, Figure 6.4) seem to accord with this assumption (with the exception of the by now 'established' zero class which does not appear in the calculations). It can be clearly stated that there is a positive relationship between the number of occupants, (ignoring their age due to lack of data), and DWU.

It is however, interesting to note that the average household size in the survey is 2.08 compared with 2.48 nationally and that this average varies in different ethnic groups to reach 4.58 persons per household in the Pakistani/Bangladeshi community (OPCS, 1993). The overall average water use of 99.88 m^3/hh/pa could, therefore, be questioned, especially in Leeds where some areas have considerable ethnic minority communities. This issue is further developed in section 8.4, where the location of this variable and its distribution are discussed in detail.

Table 6.8
Average DWU (m^3/hh/pa) in Leeds by number of occupants

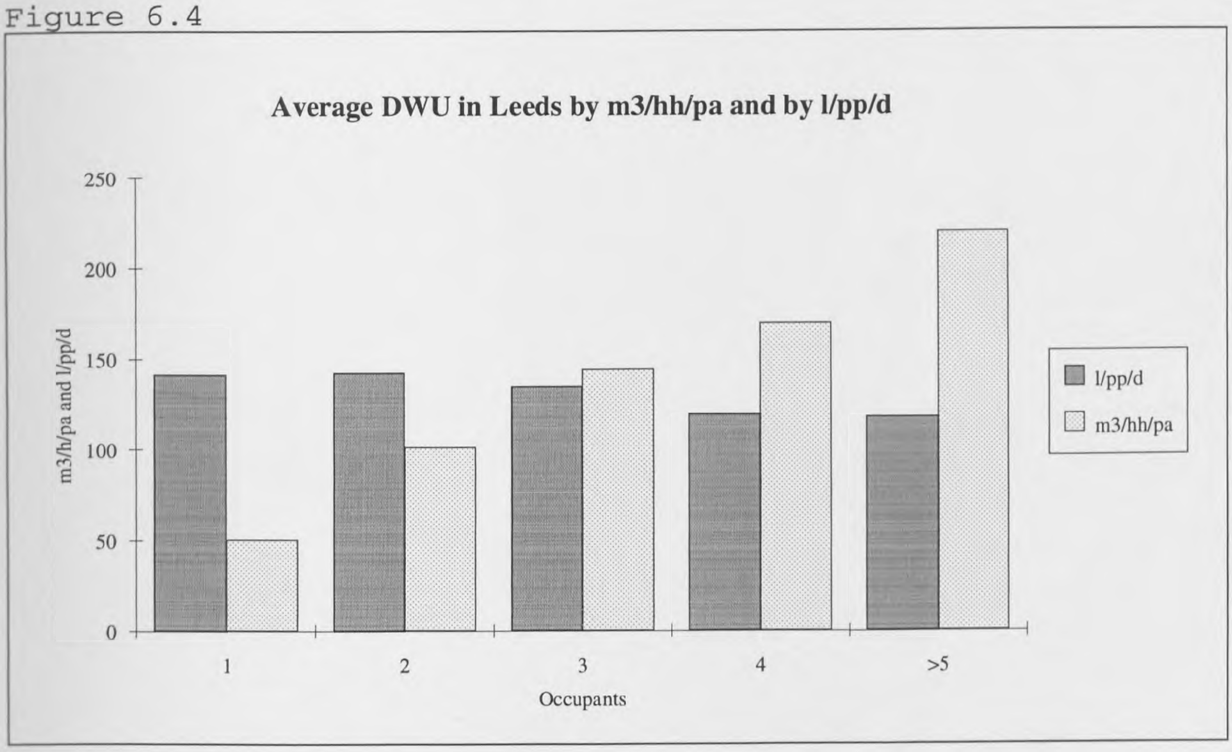
Persons in Household	*1*	*2*	*3*	*4*	*>5*	*Overall*
Mean	50.26	101.09	143.84	169.38	219.74	99.88
Standard Error	1.06	1.06	3.09	3.40	9.17	1.06
Median	43.64	95.055	136.01	159.22	208.59	89.23
Standard Deviation	38.22	44.71	64.52	67.63	105.39	67.49
Variance	1460.67	1999.04	4163.40	4573.30	11106.10	4554.95
Count	1293	1764	437	396	132	4039

The other side of this coin is the water use per person (Table 6.9). As expected, the water use of a person remains fairly constant, although the amount of DWU in households consisting of a larger number of persons allows the individual amount to be slightly lower. This might be explained by activities such as gardening and cleaning which do not necessarily reflect the number of occupants in the household.

Table 6.9
Average DWU per person (l/d) in Leeds

Persons in Household	*1*	2	*3*	*4*	*>5*	Overall
Mean	141.19	141.98	134.68	118.95	117.71	137.29
Standard Error	2.99	1.50	2.89	2.39	4.75	1.24
Median	122.58	133.50	127.35	111.81	112.38	126.24
Standard Deviation	107.36	62.80	60.42	47.49	54.56	79.12
Variance	11525.28	3943.31	3650.11	2255.33	2976.49	6260.00
Count	1293	1764	437	396	132	4039

Figure 6.4



When comparing the average of the full data set to that of the preliminary survey, the averages for households with the same number of occupants is strikingly similar (Table 6.10). This may allow the drawing of the tentative conclusion, subject to the results of the inferential statistics in Chapter 7, that there is a linear relationship between DWU and the number of occupants in the household.

Table 6.10
Average DWU (m^3/hh/pa) in two stages of the work by number of occupants

No. of Occupants	*1*	*2*	*3*	*4*	*5*	*>6 **
Yorkshire	50.18	104.92	136.22	172.61	187.11	416.64
Leeds	50.26	101.09	143.84	169.38	209.83	257.19

** in the full survey there are more categories owing to the larger sample size.*

As with property type, the proportion of household size in the full data set is compared with the preliminary data set and the national average (Table 6.11). Overall, the distribution of the number of occupants in the surveyed household is well balanced.

A somewhat larger number of single person households is compensated by a smaller number of households with three or more occupants. The only observation which can be made at this stage is that the population in the full survey probably contains less children than the other two. This may be deduced from the fact that households consisting of one or sometimes two occupants could normally be considered to have a higher probability of containing adults.

Table 6.11
Percentage of household size in three surveys

Occupants	*1*	*2*	*3*	*4*	*5*
National*	26%	34%	17%	16%	6%
Yorkshire	25%	44%	13%	14%	4%
Leeds	32%	44%	11%	10%	3%

* *Source: OPCS (1991)*

To conclude, the position of the 'number of occupants in the household' variable appears to be strengthened. Allowing for all the safety margins which are applied at the stage of descriptive analysis, the role of the number of occupants remains paramount.

6.6 Number of bedrooms

In the preliminary data set, the number of bedrooms appear to be of importance, but there was also a number of variables which were found to be associated with DWU in a way which could make this category less dominant. Therefore, this section examines the problems related to the number of bedrooms category.

The average DWU (Table 6.12) appears to be positively related to the number of bedrooms. In that respect it corresponds perfectly to Table 5.11. Property size as indicated in this work by the number of bedrooms is important for two reasons. Firstly, it is a reasonable proxy for household income (suggested, for example, by Howe & Linaweaver, 1967, Danielson, 1979).

Table 6.12
Average DWU (m^3/hh/pa) by number of bedrooms

Bedrooms	*1*	*2*	*3*	*4*	*>5*
Mean	54.19	69.95	92.72	126.64	183.65
Standard Err.	2.72	1.35	1.61	1.87	7.02
Median	44.31	62.55	86.04	119.63	165.28
Standard Dev.	42.18	41.57	58.80	62.08	11820.05
Variance	1779.05	1727.91	3457.76	3853.94	12.69
Count	241	947	1336	1105	239

Thus Table 6.13 shows that that the higher the RV, the higher the number of bedrooms would be. This may become useful if this variable were to be used in the microsimulation model, in particular as many of the properties surveyed do not possess an RV (since the introduction of the Community Charge in 1990).

Table 6.13
Number of bedrooms by rateable value of properties in Leeds

	Number of Bedrooms				
RV	1	2	3	4	5
< 100	15%	31%	28%	24%	3%
100 to 200	7%	43%	44%	5%	1%
200 to 300	1%	33%	52%	12%	1%
300 to 400	1%	15%	43%	38%	3%
400 to 500		10%	26%	55%	9%
500 to 600		5%	16%	57%	22%
600 to 700		7%	27%	42%	25%
700 >			16%	37%	47%

The second reason for this category's importance is that bedroom numbers is one of the more 'unbiased' values of the survey: there seem to be little possibility for the customer to respond incorrectly about property size using this measure.

Another advantage of this variable is its possible use in assessing the validity of - the crucial information - the number of occupants. Households with fewer occupants reside, in general, in smaller properties, and vice versa (Table 6.14). Thus no five person households reside in a 1 or 2 bedroomed property, while 93% of 2 bedroomed properties are occupied by households of 1 or 2 occupants.

Table 6.14
Number of occupants residing in number of bedrooms.

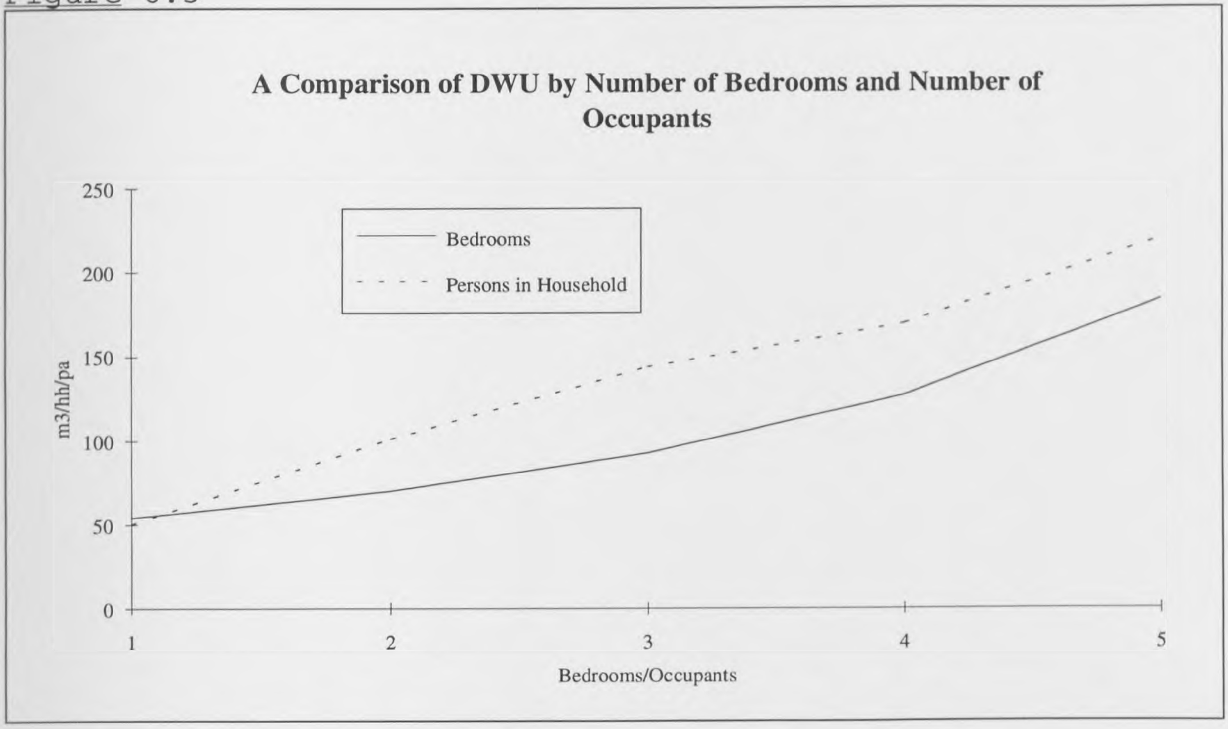
	Occupants				
Bedrooms	1	2	3	4	5
1	74%	24%	1%		
2	49%	44%	5%	1%	
3	31%	48%	11%	9%	1%
4	13%	47%	17%	18%	5%
5	8%	33%	17%	26%	16%

This means that where information is missing on one of the two other variables, there is a good possibility of calculating its probability from the number of bedrooms. It also allows the cross checking of any results in the same way.

When comparing the average DWU by occupants and average DWU by number of bedrooms, the similarity is striking (Figure 6.5). The upper average of DWU by number of bedrooms remains lower than by number of occupants since a number of properties with many bedrooms were omitted from the calculations in this section because they consist of 10 or less observations, which was judged to be too small to draw conclusions.

The fact that the shape of the curve in both these categories is similar may be attributed to the fairly even distribution of household size and property size (Table 6.14 above). The important question, however, is whether in modelling these two categories will produce a similar spatial pattern. The answer to this question is presented in sections 8.4 and 8.7.

Figure 6.5



To conclude the section on the number of bedrooms, this category is identified as an important parameter for the assessment of DWU. There are four reasons for this:

1. The data for this category are readily available from outside sources, and are by their nature very stable in time.

2 It is the closest proxy for house size (in floor surface terms).

3. It can be used as a proxy for a number of other water-using appliances and utilities in the house such as toilets, sinks, etc. (See also section 6.6)

4. The link with number of occupants allows the building of assumptions that could potentially help the early detection of discrepancies and interdependencies.

6.7 Toilets

In chapter 5 the number of toilets was found to be positively correlated with the number of bedrooms, and probably associated with the demographic profile of the household.

Being the largest single water user in the house (Kirby, 1984: 103; WAA, 1988), toilets have to be looked at carefully as their water use involves a large number of interdependencies (Archibald, 1983). The number of the occupants is probably paramount in this respect, but the age, health and occupation of the occupants may be of similar importance.

Considering that the overall average water use in Leeds is 99.88 m^3/hh/pa, it appears (Table 6.15) that the properties covered in the survey with two toilets are the mode. This class is also the largest in term of its size.

Table 6.15
Average DWU (m^3/hh/pa) by number of toilets

TOILETS	1	2	3	4 & Over
Mean	66.71	99.81	136.24	211.27
Standard Error	1.06	1.58	1.97	10.57
Median	57.26	91.33	127.595	185.00
Standard Dev.	42.15	57.77	61.01	130.70
Variance	1776.51	3337.00	3722.46	17081.30
Count	1567	1344	962	153

However, Table 6.16 suggests that toilets, like the type of property and the number of occupants, are closely related to the number of bedrooms. Most properties with 2 bedrooms have only one toilet, whilst the overwhelming majority of 4 bedroomed properties have 3 toilets.

Table 6.16
Number of toilets by number of bedrooms

	Toilets			
Bedrooms	1	2	3	4
1	228	8	1	1
2	668	248	25	0
3	546	577	197	12
4	55	411	576	53
5	4	36	102	33

To conclude, the number of toilets in the household appears to be an extremely useful category for DWU estimation. It remains to be seen whether the inferential statistics confirm this conclusion, and thus whether it can be of use in the microsimulation modelling.

6.8 Baths and Showers

The next water utilities to be looked at are baths and showers. In the questionnaire (Appendix III) a division was made between combined bath/shower and separate baths and showers. For the present purpose it was considered that since bathing patterns and habits and especially the quantity of water related to their use are difficult to monitor (see for example the methodological problem of Archibald, 1983), and because every property has at least one of the three, the category of 'bath/shower' is not treated as being a distinct category in this section.

The existence of bath(s) and their influence on DWU is considered in Tables 6.17 and 6.18. They point to the differences in average DWU between properties with baths and properties with showers. These two tables are not mutually exclusive, which, together with the properties containing a 'bath/shower' could mean that the individual influence of each of the devices is greater.

Properties with no bath use 11% less water than those properties with at least one bath, and properties lacking a shower use 35% less that those with at least one shower. However, it has to be emphasised again, that there is not 44% of the properties sampled without a bath; they do not have a 'bath only'.

Table 6.17
Average DWU (m3/hh/pa) by availability of baths

Baths	*Without*	*With 1 & More*
Mean	93.21	105.11
Standard Error	1.43	1.52
Median	83.535	92.78
Standard Deviation	60.19	72.29
Variance	3623.13	5225.91
Count	1776	2263

Table 6.18
Average DWU (m3/hh/pa) by availability of showers

Shower	*Without*	*With 1 & More*
Mean	83.22	127.64
Standard Error	1.11	1.94
Median	71.88	115.57
Standard Deviation	55.94	75.50
Variance	3128.96	5700.53
Count	2524	1515

Households with either of these utilities use more water than those without them. The smaller difference between the have and have-nots of baths does not necessarily suggest that baths use less water than showers (the literature suggests the opposite, e.g. Water Authorities Association, 1988; Water Services Association, 1992), but rather suggests that baths may only be found in households which have other reasons for using less water. These reasons may be related to socio-economic grouping which will be checked below.

Table 6.19 shows the distribution of dishwashers (used here a as proxy for income level - which is discussed in section 6.10) in 'bath only' households compared with the 'shower only' households. It shows that in households with no dishwasher there is a proportionally balanced number of households with and without a bath (29% - 33%). The same class in the households with a shower only points to a large difference (49% - 14%) in favour of those properties with a shower. This could mean that households without a shower (and consequently are 'bath only' properties) have a lower proportion of dishwashers and hence possibly belong to a lower income group. This hypothesis is developed later (Chapter 7) when, with the help of inferential statistics, the exact function of dishwashers in this study is determined.

Table 6.19
Percentage of dishwashers in households with baths and showers

	Dishwasher			Dishwasher	
Bath	*0*	*1*	*Shower*	*0*	*1*
0	29%	15%	0	49%	14%
1	33%	16%	1	14%	19%

In conclusion, these two amenities appear to be of little use to the present work, in terms of estimating water quantity used. Moreover, the existence of either of these utilities, or both, in all the households surveyed makes them an indistinct tool for modelling purposes.

6.9 Washing Machines

In chapter 5 it was argued that the effect of washing machines on water use appears to be important. A difference of 54% in water use in the present survey (Table 6.20) is a significant difference, although in this case as in the previous category, there is a considerably smaller number of households which do not possess a washing machine. This may reduce the modelling utility of any findings resulting from this category.

Table 6.20
Average DWU (m3/hh/pa) by availability of washing machine

Washing Machine	*Without*	*>1*
Mean	48.43	104.38
Standard Error	2.27	1.11
Median	38.59	93.30
Standard Deviation	40.91	67.50
Variance	1673.88	4555.68
Count	325	3714

The difference in DWU resulting from the existence of washing machines may indicate the age of occupants if the hypothesis that babies and children cause washing machines to work more on average is accepted (see Table 5.9). In order to test this, Table 6.21 cross tabulating the availability of washing machines with the number of occupants in terms of average water use per person in a day. The underlying assumption here, as it was stipulated earlier (section 6.3), is that a household which contains less than two persons is less likely to be composed of at least one child.

However the table's findings are inconclusive. The gap between washing machine owners and non-owners in the 1 and 2 person household is regular, in the 3 persons it is almost non-existent while at the 4 and 5 persons households there are large variations.

Table 6.21
Average DWU (l/pp/d) by ownership of washing machine and number of occupants.

	Washing Machine	
Occupants	0	1
1	109.75	148.61
2	98.64	143.40
3	134.80	134.43
4	39.21	119.09
5	88.20	119.03

The difference between the number of households with and without washing machines and dishwashers deserves comparison with the national average. In Table 6.22 the following points become apparent: whereas the washing machine average in Leeds seems to be fairly similar to the national average, there is a much larger representation of dishwasher owners both in the Yorkshire and the Leeds surveys.

Table 6.22
Percentage of washing machines and dishwashers in four surveys.

	Washing Machine	*Dishwasher*
National*	87%	14%
Yorkshire	89%	32%
Leeds	92%	37%
South-West Water**	78%	6%

* *Source: OPCS (1993)*
** *Source: Hooper (1986)*

In conclusion, the washing machine appears to be a useful and indicative category for the purpose of the present research. Its precise usefulness is determined in Chapters 7 and 8.

6.10 Dishwashers

Households with and without dishwashers are more evenly divided in the sample and can therefore form more distinct spatial observations (see section 8.6). The 43% additional water usage for households with at least one dishwasher (there were 8 households with 2 dishwashers!) is significant for several reasons (Table 2.23).

Table 2.23
Average DWU (m^3/hh/pa) by possession of a dishwasher

Dishwasher	*Without*	*≥1*
Mean	78.43	136.57
Standard Error	1.02	1.96
Median	67.7	124.78
Standard Deviation	51.31	75.58
Variance	2632.71	5712.24
Count	2549	1490

The presence of dishwashers is linked to other categories that may indicate income levels of the household. The higher presence in percentage terms, and the higher rateable value (Table 6.24) suggest that the connection with Table 6.19 which links showers with income is plausible.

Table 6.24
Percentage of dishwashers by rateable value

	Dishwasher	
RV (£)	0	1
<100	72%	28%
100 to 200	92%	8%
200 to 300	83%	17%
300 to 400	55%	45%
400 to 500	35%	65%
500 to 600	19%	81%
600 to 700	6%	94%
>700	9%	91%

Alternatively, Table 6.25 suggests that the higher the status of ACORN group, the higher the probability of owning a dishwasher. ACORN itself is discussed in detail in section

6.13. However, for the present category it is interesting to note that in groups 23-29 which are considered to be poor (see Table 6.32 below) there are no dishwashers, whereas in groups 34-36 which are considered to be affluent there is a considerable proportion of households with dishwashers.

Table 6.25
Availability of dishwasher by ACORN group

	Dishwasher	
ACORN	0	1
23	10	0
27	3	0
28	3	0
29	5	0
34	257	157
35	83	77
36	305	465

In conclusion, dishwashers appear to provide a useful variable to model DWU in both surveys. The proportions of the utility and its distinct attachment to socio-economic groupings make this category a potentially useful variable for modelling.

6.11 Outside taps and lawn sprinklers

Tables 6.26 and 6.27 display the average DWU attributed to outlets outside the house. In Chapter 5 the particularity of the climatic conditions in the surveyed area pointed to the negligible effect which these amenities have on the yearly average DWU. However, when the average water use for properties with and without hosepipes (which differ by 35% on average) or lawn sprinklers (a difference of 31%) is reviewed, the explanations this category of water use may be more useful than previously thought. There might therefore be a case for a seasonal examination of DWU, which may highlight the importance of these utilities.

Although the attributes of the hosepipe are not clearly defined, as its uses are not necessarily related to one particular activity (e.g. car washing, path cleaning, plant watering etc.), the existence of lawn sprinklers may provide more relevant data. Together with information on the climatic conditions during the period which the survey covers, these devices feature strongly in the literature originating from the USA (e.g. Danielson, 1979; Nieswiadomy & Molina, 1991).

Table 6.26
Average DWU (m^3/hh/pa) by possession of hosepipes

Hosepipes	Without	With 1 & More
Mean	78.34	119.95
Standard Error	1.27	1.55
Median	65.765	108.96
Standard Deviation	55.94	71.06
Variance	3129.04	5050.07
Count	1948	2091

Table 6.27
Average DWU (m^3/hh/pa) by possession of lawn sprinklers

Lawn Sprinkler	Without	With 1 & More
Mean	94.45	136.92
Standard Error	1.06	3.69
Median	84.42	122.59
Standard Deviation	62.98	83.72
Variance	3966.93	7008.77
Count	3523	516

The ownership ratio of these two devices deserves a closer examination. Whereas the hose pipe is found in almost half the surveyed households, lawn sprinklers are only in the possession of 15%. This difference may be explained by the wider use of the former. The difference in the average DWU between the two utilities suggests that households in possession of lawn sprinklers use more water. It does not, at this stage, however suggest that this level of water use is entirely the result of using sprinklers themselves. In order to check this further, cross tabulations are needed.

Table 6.28 shows that there is a relationship between the number of bedrooms in a property and the possession of lawn sprinklers. The four bedroom category possesses almost 50% of the lawn sprinklers in the survey, although there is a much smaller proportion of 5 bedroomed properties with the same device (10%). From section 6.6 it can be seen that properties with five bedrooms have a higher average DWU than four bedroomed properties. It can therefore be concluded that although sprinklers do have an effect it is not decisive.

Table 6.28
Number of lawn sprinklers by number of bedrooms

	Bedrooms				
	1	2	3	4	5
Sprinklers	3	38	163	222	47

The occurrence of lawn sprinklers seem to be more frequent in postal areas which are in the outskirts of the city (see Figure 8.1). Over 50% of the sprinklers are situated in four districts: LS16, LS17, LS22 and LS29. These are also the postal districts with more expensive properties (see Table 6.31 below) and with an ACORN classification denoting a higher standard of living .

Table 6.29
Possession of lawn sprinklers by selected postal districts in Leeds

Postal Districts	Sprinklers
LS16	9%
LS17	15%
LS22	12%
LS29	15%

In conclusion, lawn sprinklers and hosepipes may assist in constructing a spatial DWU pattern with seasonal effect. However, with its high dependency on other elements, and with the difficulties in measuring the quantity used (as opposed to spilled, or leaked, for example) it does not appear to be a particularly useful variable in a DWU model for Leeds.

6.12 Postal Districts

In Chapter 5, the locational aspect of water use is explored on a much larger scale, without finding geographical explanation for the differences in average DWU. In small scale data, which the Leeds survey provides, the differences are even more difficult to attribute to any other effect but the demographic profile of the postal districts. Thus when the average DWU is viewed by postal districts (Table 6.30), the variations are not immediately apparent.

The full analysis of this variable is carried out in Chapter 8. However, in the present section some of the fundamental characteristics of the data are explored. Two postal districts are noticed immediately: LS4 and LS5 possess too few cases to be considered statistically reliable.

Table 6.30
Average DWU (M^3/hh/pa) by postal district in Leeds

Postal District	*LS2*	*LS3*	*LS4*	*LS5*	*LS6*	*LS7*	*LS8*	*LS9*	*LS10*
Mean	70.33	70.55	108.27	50.79	81.93	71.81	76.66	31.06	94.55
Standard Error	14.29	11.83	27.67		6.21	8.86	3.97	3.02	8.74
Median	48.55	65.73	76.45		66.115	57.45	64.89	28.14	93.73
Standard Deviation	55.33	45.83	73.21		60.84	58.78	54.33	19.80	56.65
Variance	3061.10	2100.43	5360.40		3701.60	3454.72	2952.08	392.11	3210.1
Count	15	15	7	1	96	44	187	43	42
Postal District	*LS11*	*LS12*	*LS13*	*LS14*	*LS15*	*LS16*	*LS18*	*LS19*	*LS20*
Mean	64.97	101.80	96.30	104.58	81.87	99.87	107.54	*100.53*	112.12
Standard Error	11.86	7.47	4.06	5.69	5.31	2.98	3.64	9.13	6.84
Median	46.44	90.745	90.34	94.47	61.3	87.965	90.755	84.03	94.34
Standard Deviation	76.83	52.83	49.35	67.10	57.97	61.38	83.07	73.58	70.11
Variance	5902.90	2791.04	2435.38	4502.46	3361.08	3767.39	6901.04	5414.24	4915.66
Count	42	50	148	139	119	424	520	65	105
Postal District	*LS21*	*LS22*	*LS23*	*LS24*	*LS25*	*LS26*	*LS27*	*LS28*	*LS29*
Mean	91.94	113.85	112.03	117.80	109.93	97.11	101.11	89.63	106.49
Standard Error	5.66	4.24	6.64	5.53	4.99	7.41	2.77	4.55	3.18
Median	73.65	104.87	100.35	110.22	98.55	84.32	93.56	83.6	95.76
Standard Dev.	61.70	66.59	61.91	62.29	66.37	87.07	50.32	54.83	72.80
Variance	3806.49	4434.27	3833.38	3879.56	4404.44	7581.50	2531.73	3006.06	5299.32
Count	119	247	87	127	177	138	329	145	523

As the geographical pattern of water use by itself does not offer much explanatory power, it needs to be linked with other categories in order to be of use. For that purpose Table 6.31 provides additional insight into the structure of these postal districts. RV fails to add any plausible explanation to the average DWU in Leeds. It does not correspond to the 'inner-outer city' pattern.

LS24, for example, is on the eastern edge of Leeds (see Figure 8.1) with a low average RV (£221), while LS8 which is fairly central has an average RV of £328. Similar results are obtained in other cross tabulations chosen not to be displayed here as the evidence they provide is not sufficient to attach more significance to locational factors.

Table 6.31
Average RV (£) by postal districts (in ascending order)

Postal District	Average RV (£)
LS03	52
LS04	134
LS11	158
LS12	212
LS24	221
LS06	223
LS13	231
LS07	236
LS27	241
LS09	248
LS10	260
LS25	260
LS15	271
LS26	292
LS19	302
LS28	321
LS21	323
LS08	328
LS18	331
LS23	335
LS20	361
LS17	372
LS16	377
LS29	378
LS22	394
LS14	414

To conclude, the use of postal districts seems better to represent the end result of the model rather than being potential variables. It is therefore not developed further at this stage. In Chapter 8 this issue is fully explored.

6.13 ACORN classification

The ACORN classification is utilised by YW and other water and sewage companies as an assessment tool for DWU. It is one of the roles of this work to find out whether this approach provides an adequate answer to the water industry's requirements in the future, or whether a radical change, namely a new computation technique, should be adopted.

This category was not supplied in the preliminary survey, and is not dealt with in any other part of the present work, except for the review of related literature in section 3.7, and therefore deserves closer examination at this point.

ACORN was created in 1997 by Richard Webber at the Centre for Environmental Studies, Liverpool. The acronym stands for 'A Classification of Residential Neighbourhoods', and is built around the premises that "people who live in similar neighbourhoods are likely to have similar behavioural, purchasing and lifestyle habits." (CACI, 1992: 3)

The advantage of ACORN is in its "ability to identify buying power" (Chisnall, 1985; 280) and thus identify target areas for marketing campaign and catalogues and mail shots. The major problem in using ACORN is its two spatial classifications. The information on household characteristics is gathered from the national Office of Census in enumeration districts (EDs) whilst it is necessary, for practical reasons, to convert it into postcodes (normally postal sectors). In the process of conversion the 'hard level data' is diffused by about four times in order to fit into the postcode spatial area. (CACI, 1992: 5) This process causes two effects: firstly, it increases the probability of erroneous identification of an area; and secondly, "it results in people 'swapping' back and forth between classification types from one year to the next". (*ibid.*)

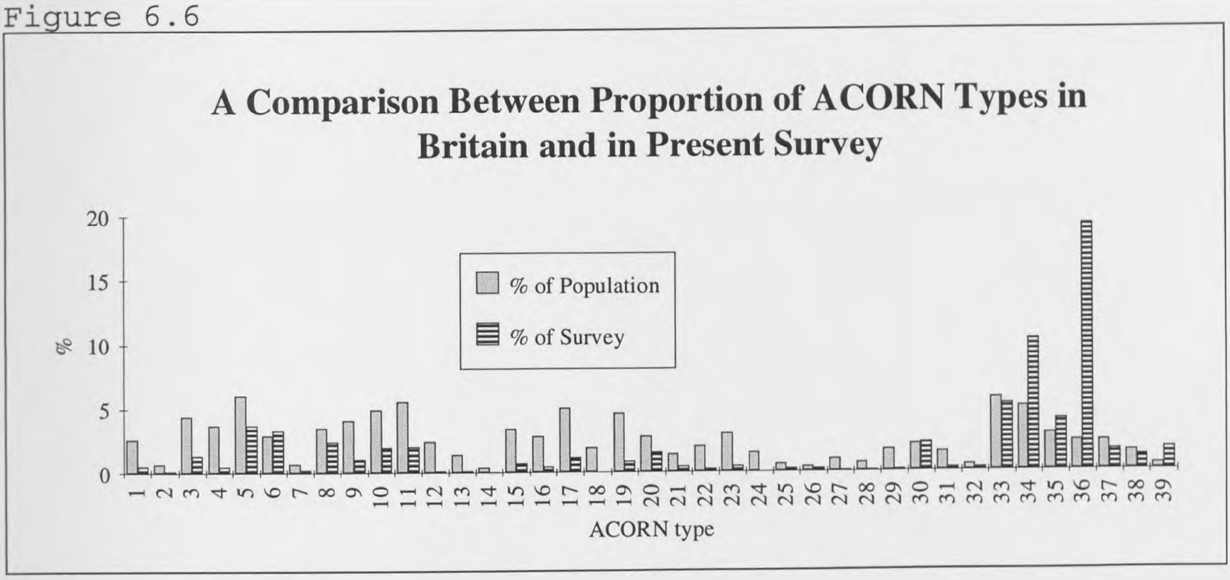
Table 6.32
The structure of ACORN classification with present survey's sample proportion

Group	Type	Description	% of Population	% of Survey
A Agriculture area	1	Agricultural village	2.6	0.54
	2	Areas of farms and small buildings	0.7	0.12
B Modern Family Housing	3	Post-War functional private housing	4.4	1.36
	4	Modern private housing, young families	3.7	0.50
	5	Established private family housing	6.0	3.69
	6	New detached houses, young families	2.9	3.29
	7	Transient workforces, living at their place of work	0.7	0.22
C Older Housing	8	Mixed owner occupier and council estates	3.5	2.40
	9	Small town centres and flats above shops	4.1	1.04
	10	Villages with non farm employment	4.9	1.93
	11	Older private housing, skilled workers	5.5	1.96
D Poor Old Terraced	12	Unmodernised terraces, older people	2.4	0.12
	13	Older terraces, lower income families	1.4	0.12
	14	Tenement flats lacking amenities	0.4	0.02
E Council Estates (better off)	15	Council estates, well off older workers	3.4	0.69
	16	Recent council estates	2.8	0.45
	17	Better council estates, younger workers	5.0	1.11
	18	Small council houses, often Scottish	1.9	N/A
F Council Estates (less well off)	19	Low rise estates in industrial towns	4.6	0.82
	20	Inter-War council estates, older people	2.8	1.56
	21	Council housing, elderly people	1.4	0.45
G Council Estates (poorest)	22	New council estates in inner cities	2.0	0.22
	23	Overspill estates, higher unemployment	3.0	0.45
	24	Council estates with some overcrowding	1.5	N/A
	25	Council estates with greatest hardship	0.6	0.22
H Multiracial Areas	26	Multi occupied older housing	0.4	0.25
	27	Cosmopolitan owner occupied terraces	1.0	0.07
	28	Multi let housing in cosmopolitan areas	0.7	0.07
	29	Better off cosmopolitan areas	1.7	0.12
I High Status Non-Family	30	High status non-family area	2.1	2.20
	31	Multi-let big old houses and flats	1.5	0.22
	32	Furnished flats, mostly single people	0.5	0.25
J Affluent suburban	33	Inter-War semis, white collar workers	5.7	5.22
	34	Spacious inter-war semis, big gardens	5.0	10.25
	35	Villages with wealthy older communities	2.9	3.99
	36	Detached houses, exclusive suburbs	2.3	19.11
K Better Retirement	37	Private houses, well off older residents	2.3	1.58
	38	Private flats, single people	1.5	1.11
	39	Unclassified	0.5	1.73

Source: : CACI (1993)

From the right hand column of Table 6.32 it can be seen that there are two area types missing from the survey: categories 18 and 24. The first type is a localised phenomenon for Scotland, and the second is either not common in Leeds, or does not have meters installed in it. The overall comparison can be better appreciated in Figure 6.6, where the % of ACORN types in the population is clearly higher in all types except for classes 34 to 37, which have an overwhelmingly disproportional representation in the YW survey.

Figure 6.6



(Table 6.33) portrays a complex picture. There is no apparent pattern, except for the lack of households apart from type 13 which has an average DWU of more than 150 m^3/hh/pa. As in the property type, the size of the sample for certain types should be approached with care, and not too much should be concluded from this sample alone.

The 'zero value' (not eliminated here for demonstration purposes) reflects again an average close to the overall DWU average (99.88 m^3/hh/pa), as do area types 6 and 17. These two areas, although not belonging to the zero category, have an average less than 5 m^3/hh/pa from the overall average.

Table 6.33
Average DWU (M^3/hh/pa) by ACORN groups in Leeds

ACORN Group	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Mean	103.31	109.09	170.69	88.36	88.83	89.28	100.61	124.50
Standard Error	1.87	11.31	37.75	7.77	15.89	5.00	4.44	14.64
Median	94.38	104.72	131.44	80.4	64.62	66.45	92.93	115.87
Standard Deviation	66.44	53.04	84.40	57.59	71.06	61.07	51.23	43.92
Variance	4414.53	2813.13	7123.88	3316.99	5049.38	3729.50	2624.88	1929.17
Count	1259	22	5	55	20	149	133	9

ACORN Group	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Mean	85.19	79.31	109.81	79.23	66.27	158.42	182.29	87.53
Standard Error	5.52	8.43	8.17	4.56	25.85	35.12		10.99
Median	80.02	60.855	97	79.11	58.6	153.1	182.29	79.895
Standard Deviation	54.33	54.65	72.17	40.56	57.81	78.54		58.16
Variance	2951.78	2986.61	5208.70	1644.99	3341.57	6168.01		3382.48
Count	97	42	78	79	5	5	1	28

ACORN Group	*16*	*17*	*19*	*20*	*21*	*22*	*23*	*25*
Mean	142.10	103.15	55.03	76.13	77.09	78.32	77.09	78.32
Standard Error	11.05	9.40	8.20	6.34	15.90	11.67	15.90	11.67
Median	152.08	91.67	39.81	63.65	48.81	73.19	48.81	73.19
Standard Deviation	46.87	63.02	47.12	50.32	67.44	35.01	67.44	35.01
Variance	2196.74	3972.15	2220.20	2531.68	4547.75	1225.40	4547.75	1225.40
Count	18	45	33	63	18	9	18	9

ACORN Group	*26*	*27*	*28*	*29*	*30*	*31*	*32*
Mean	87.56	38.16	79.04	56.16	81.56	75.20	54.39
Standard Error	14.93	20.74	40.68	14.93	6.04	14.35	14.58
Median	93.43	19.60	64.04	51.31	60.11	70.78	38.64
Standard Deviation	47.20	35.92	70.45	33.38	57.01	43.04	46.10
Variance	2228.06	1290.46	4963.55	1114.06	3250.65	1852.11	2125.51
Count	10	3	3	5	89	9	10

ACORN Group	*33*	*34*	*35*	*36*	*37*	*38*	*39*
Mean	77.81	97.10	108.95	115.54	77.22	62.71	120.79
Standard Error	3.79	3.34	6.35	2.56	6.20	6.70	14.77
Median	61.03	81.94	94.47	103.09	61.88	54.43	94.82
Standard Deviation	55.01	67.87	80.63	71.02	49.62	44.92	123.61
Variance	3026.12	4605.93	6500.98	5043.24	2462.20	2017.75	15279.21
Count	211	414	161	772	64	45	70

The data are divided according to a sophisticated classification described in Table 6.32. There are eleven groups, divided into 38 types of residence plus one residual unclassified category.

However, from the affluent areas (types 33-38), only two have a moderately higher average, whilst the five properties in type 13 and the one property in 14, for that matter, which are described as 'Older terraces, lower income families' and

'Tenement flats lacking amenities' respectively, have an average DWU much higher than any other area type. A cross tabulation, as displayed in Table 6.25 produces reasonably satisfactory results, but the inability to attach these results to DWU effectively makes this exercise futile. This indeed was the conclusion reached by Russac *et al.* (1991) who attempted to use this classification in a more practical manner (discussed above in Section 3.7).

To conclude the discussion of this category, it appears that not much use can be made of this technique. The two inherent faults in the method mentioned earlier, together with the unclear price elasticity of demand for water, make the assumptions on which it is based (areas with 'buying power') largely irrelevant to DWU patterns at present.

6.14 Conclusion

At this stage of the analysis six variables appear to be suitable for microsimulation modelling. They are: house type; number of occupants; number of bedrooms; existence of washing machines; existence of dishwashers and number of toilets. The classes of each of these variables are shown in Table 6.34.

Table 6.34
The six variables and their classes to be used in the model

Variables	**Classes**				
Occupants	1	2	3	4	5
Bedrooms	1	2	3	4	5
House Type	TT	FM	SD	TT	DD
Toilets	1	2	3		
Washing Machine	0	1			
Dishwasher	0	1			

The microsimulation model thus calculates the probability of any given household being attributed with any of these six variables according to their geographical location, i.e. their postal sector, postal district or the ward to which they belong. The final choice of the variables which is explained here is produced in the next chapter by application of inferential statistics.

The value of water used for the present work was calculated by Yorkshire Water Plc. on the basis of m^3 per household per year. However, despite the emergence of the importance of the number of persons, all figures on the database will continue, for the sake of simplicity, to be calculated in m^3 per annum.

a. The variables were limited to their credible sample size. Thus households with more than five occupants or more than five bedrooms were rounded to the level where a sample size of less than 10 (0.25) would not be calculated. A similar procedure was carried out for dishwashers and washing machines: households with more than one of these appliances were omitted from the calculations.

b. The second procedure was the grouping and categorising of the two continuous variables, water use and rateable value. Water use was categorised into 13 groups of $50m^3$ beginning at 0.

In the next chapter these findings are submitted to inferential statistical analyses which should determine rather more conclusively the variables suitable for modelling.

7. INFERENTIAL STATISTICS

7.1 Introduction

Following the descriptive statistics in Chapters 5 and 6, this chapter concentrates on the crucial element: an inferential statistical analysis of DWU. This analysis is required in order to establish the relationship between the variables selected in the previous section and water use. It should be noted however, that the regression analysis is not a pre-condition for microsimulation modelling (Chapter 8). Indeed, in some respects microsimulation actually replaces regression analysis, by providing a tool for establishing causality by its ability to predict (Birkin & Clarke, 1988). Microsimulation modelling was used by Williamson (1992) for example, to locate community care needs for the elderly. By using this type of modelling Williamson avoided the use the regression analysis which is, by definition, a statistical model.

However, in the present case the problem is different. The aim of the work at this stage is to distil a set of variables that could eventually be used in a microsimulation model in order to reduce the calibration process in the latter. Several preconditions have to be met before a regression analysis is performed:

a. Availability of information. As pointed out earlier (Chapter 4), the information for this work was gathered by YW for purposes other than this work. As a result, there are a number of variables (e.g. age structure of household, economic status and garden or lot size) which are absent from both questionnaires. Other questions were put in a manner that does not allow the drawing of clear explanatory conclusions (e.g. are shower, bath and bath/shower mutually exclusive?), while some further categories do not seem to provide any useful information for the purpose of this work (e.g. date of opening and closing meter reading in the first survey, and the YW serial number of each case in the second survey).

As a result, a method had to be devised which would allow the assignment of attributions to 'valid' variables only, from the limited choice available.

b. Hierarchisation of variables. As explained earlier, the real test of the validity of the variables is the microsimulation model, in particular the running of different scenarios. However, from the total of 19 variables provided there are some which are clearly of greater importance, (e.g. the dependent variable - water use, or the independent variable - number of occupants), while other independent variables remain in the grey area that makes them valuable only under certain circumstances, for example in combination with one or more other variables. In any case, a small number of variables will remain of little use for the purpose of this work (e.g. meter positioning).

The initial way to measure the utility of any category for the purpose of microsimulation (or any other modelling), is to associate or correlate each of the independent variables with the amount of water used (the dependent variable). The variables which obtain a high correlation coefficient could be assumed to provide a higher degree of explanatory power than those which obtained only a low coefficient. However, correlation coefficients, by their nature, do not provide an indication of causality and this, in fact, is the type of relationship that this stage seeks.

For this purpose, a analysis of variance is carried out, measuring which of the 18 independent variables in Table 7.1 has a strong explanatory power in relation to the dependent variable DWU. Before providing a detailed technical account of the method used at this stage, it is useful to consider in the first place the hypothetical results of this analysis.

The other important element of this thesis is the regression analysis, which ought to attribute the selected variables the conjoint relationship with DWU. The aim of this procedure is to regress all variables against water use and to find the six variables with the strongest explanatory power for use in microsimulation modelling. For this purpose, a threshold had to be fixed. It was postulated that the variables with a strong regression coefficient (R^2>90%) would emerge at the end of the process. The reason for that choice of that number of variables is to allow the microsimulation model to be run on PCs with a limited computing power, as explained in section 4.6.3.

Table 7.1
List of independent variables of the full survey supplied by YW in alphabetical order.

Categories
ACORN (classification)
BATH (number of)
BEDROOM (number of)
CODE (Postal District)
DISHWASHER (existence)
HOSE PIPE (number of)
OCCUPANT (number of)
OUTSIDE TAP (number of)
POSITION (of meter)
RV (in £ per year)
SHOWER (existence)
SINK (number of)
SPRINKLER (existence)
TOILET (number of)
TYPE (property)
WASHER (washing machine)
WASHBASIN (number of)
WASTE DISPOSAL (existence)

By a strong regresion coefficient the figure of $R^2 = 0.9$ within confidence limits of 99% (0.01), was decided upon, for the cumulative effect of the total of variables chosen. However, there are still conditions to be met before this process could begin. The conditions are divided into two categories:

1. Those which would correspond to the assumptions and accumulated knowledge on the subject; and
2. Those which would satisfy the statistical technique employed.

7.2 Validity of data

The first condition relates to Chapter 4 which presents the general assumptions, conditions and hypotheses that accompany this work. Accordingly, it was decided that there is no reason to include in the analysis the coefficient of possible explanatory variables which were absent, which do not figure prominently in other works, or which were found to be of little use in Chapters 5 and 6 .

Thus, inferential statistics is only performed on variables that seem to have some *a priori* explanatory power with respect to water use. The variables which did not meet this criteria are sinks, wash-basins, outside taps or, as classified in the pilot study, the separate categories of automatic and twin-tub washing machines. These utilities and appliances can be used in a large variety of ways and in a large number of combinations such that their individual contribution to DWU has been found to be low in any model previously devised, except as one component of a miscellaneous category of "other uses" which was discussed in section 3.6 (see for example Archibald, 1983; Hall, 1988 and WAA, 1989).

The second condition to be met before a full inferential statistics analysis can be carried out is more technical by nature. It consists of tests that must be carried out in order to confirm their suitability for this type of analysis. The importance of these tests lies in their ability to validate any result obtained. Two such tests are carried out: 'standard score' (or Z scores), and the 'normal probability plot'. Their results are discussed below.

The standard score is used to assess the normality of the distribution of the data, similar to the test carried out in section 6.2. It is defined as the difference between the mean of a set of data and the value of a given observation divided by the standard deviation. It can be derived from equation

7.1, that the mean of the standard normal curve is 0 and the standard deviation is 1.

$$Z_i = \frac{X_i - \overline{X}}{S} \qquad 7.1$$

The transformation of the data into standard normal score allows each variable to be plotted against its Z score, and if the pattern obtained portrays a straight line, the distribution of the data is normal and the different variables are suitable for regression modelling. Figure 7.1 demonstrates the normality of the dependent variable which is used in the regressions by the virtue of being a straight line.

Figure 7.1
Standard score of DWU used in regression for in Leeds

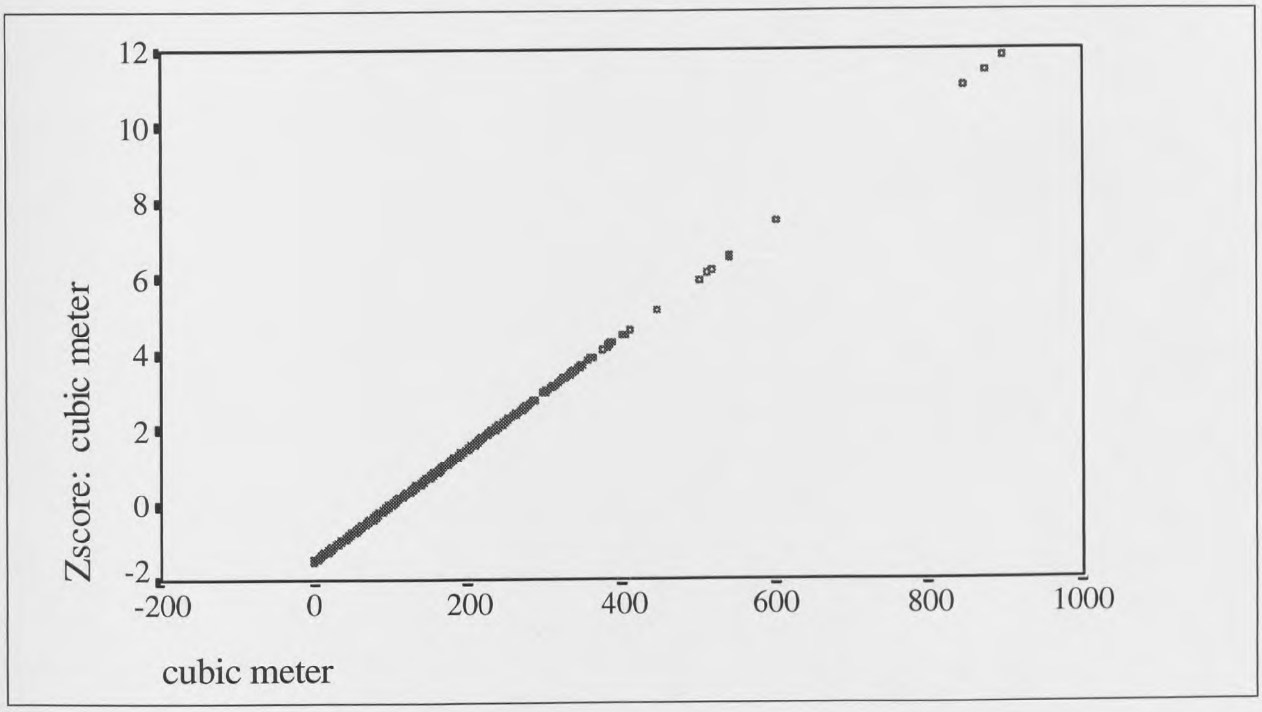
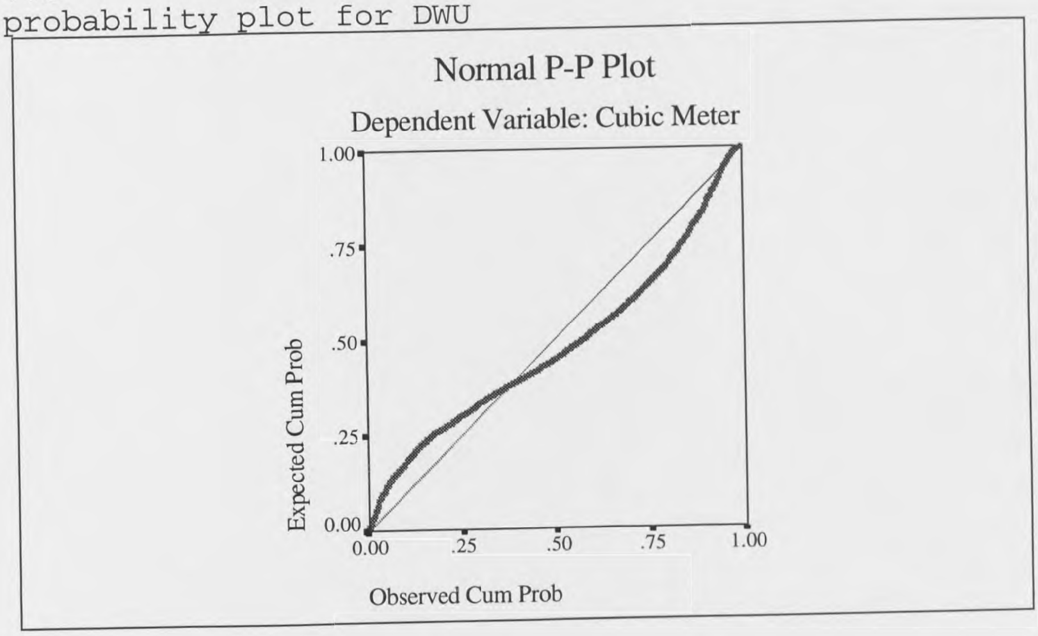


Figure 7.2 fulfils the conditions for a regression analysis by means of a probability plot. As can be seen, the distribution of the residuals (the dots) has the typical 'S' shape on both

sides near to the diagonal straight line which denotes the 'perfectly' normal distribution.

This process is described by Norušis (1992: 181): "Each observed value is paired with its expected value from the normal distribution. (The expected value from the normal distribution is based on the number of cases in the sample and the rank order of the case in the sample.)" Norušis continues to say however, that "it is important to remember that whenever the sample size is large, almost any goodness-of-fit test will result in rejection of the null hypothesis. It is almost impossible to find data that are exactly normally distributed", which is the straight line (page 183).

<u>Figure</u> 7.2
Normal probability plot for DWU



A final explanation is due in respect of the two variables transformed from alphanumeric to numerical data: the postal code and house type. In the case of the postal code, any statistical manipulation does not seem to pose any particular problem. Each postal district (e.g. LS19) is transformed into a number from 1 to 28 as there are 29 postal districts in Leeds, but no residential properties in LS1.

For 'house types', the order of transformation was made by assigning numbers from 1 to 5 according to the alphabetical order of the types, obtaining the results as shown in Table 7.2.

An important point in this reclassifying system is to ensure that the figures attached to the classes are not treated as values, which may influence any result obtained.

Table 7.2
Re-coding of house types

BG	1
DD	2
FM	3
SD	4
TT	5

A last point of reminder is that the dependent variable for all subsequent calculations is DWU in cubic-meter-per-household-per-annum (m^3/hh/pa), which is henceforth referred to as 'the dependent variable'.

7.3 Correlations

Following the tests for the validity of the data, a simple correlation (Pearson, two tailed) between DWU (m^3/hh/pa) and the explanatory variables was performed within 99% confidence level. Table 7.3 shows the correlation levels between all the dependent variables and water use in descending order. Six variables are temporarily earmarked at this stage for the model. The threshold of 0.35 was chosen arbitrarily as it fitted the number of variables required for the microsimulation modelling, as was explained earlier.

Table 7.3
DWU (m^3/hh/pa) correlation to categories in YW survey.

Category	Correlation
1. OCCUPANT	.648
2. TOILET	.517
3. WASHBASIN	.460
4. DISHWASHER	.414
5. BEDROOM	.395
6. SHOWER	.384
7. OUTSIDE TAP	.340
8. HOSE PIPE	.322
9. SINK	.270
10. WASTE DISPOSAL	.235
11. WASHER	.232
12. SPRINKLER	.213
13. BATH	.189
14. RV	.186
15. POSITION	.107
16. ACORN	.012
17. CODE	-.050
18. TYPE	-.186

Not surprisingly, the number of occupants in a household is most prominent in this list (0.648). As it is noted in Chapters 5 and 6, and is demonstrated later, this is undoubtedly the most tightly correlated category to DWU. Inter-correlation between occupants and number of bedrooms produced only 0.399, while the correlation of occupants with other variables such as number of toilets did marginally better (0.419). This allows the drawing of the tentative conclusion that the relationship between the number of household occupants and DWU is relatively free from inter-dependencies and, although some relationship may exist, its influence on DWU does not appear, at this stage, to be important.

The number of toilets correlated to DWU is also referred to in the previous chapters, although as it transpires below, it proved difficult to use in the microsimulation model due to difficulties in projecting the number of toilets on the general population. This issue is discussed in section 4.5.2. 'Wash basin' numbers in the household is another category with a relatively strong correlation to DWU. Its own correlation with the number of bedrooms produced a ratio of 0.433, which highlights the same problem as for the 'toilet' category, above.

The 'dishwasher' is an item which appears from the previous chapters to be useful for the purpose of this work. While the distribution is fairly even in the Leeds survey, where 37% of households own a dishwasher, its high water usage - 50 litres per usage (Water Services Association, 1992) and its high purchase price make it a useful variable for modelling purposes and Table 7.3 only strengthens this notion.

The last two categories that displayed an important level of correlation are the number of bedrooms and the number of showers. These categories which display an 0.315 correlation coefficient between them, do qualify to be included in the model. However, there are methodological problems highlighted in section 6.7 which cast a doubt on the exact definition of showers in the questionnaires.

Rateable value can be used, as could house type in other cases, as a proxy for income, although judging from the poor correlation of these two categories with DWU, this indicator may not be solid enough.

The number of showers is highly correlated to the number of wash basins (0.513), as one is often found in any bathroom in any house. The number of bath tubs does not necessarily reflect this component since it is customary in recent years to include in addition to a '*master*' bathroom which contains a bath tub, an '*en suite*' shower/toilet room which contains a wash basin. In any case, a distribution of 37% of the households with at least one shower (Water Services Association, 1992) provide a more clear-cut distribution for modelling than the 99% of households with one bath.

The reasons for the other variables' poor association with the DWU may be rooted in a variety of reasons. Some, like ACORN groups or enumeration districts may concern an over-generalised population (as explained in section 6.3); the meter position within the property may influence DWU in relation to leakage detection and other unaccounted-for water losses, which are not counted by the meter, and therefore cannot be modelled. The full correlation matrix can be seen in Appendix V.

7.4 Analysis of variance

The following section describes how the analysis of variance is carried out with two aims in mind. Firstly "it is used to describe tests which generalise the difference of means tests" (Norcliffe, 1982; 157). "It considers the effects of one nominal source of variation - the explanatory variable - on a continuous 'response' variable" (*ibid.*). The other aim of

ANOVA (as the one way analysis of variance is also called) is to compare the variances of the samples - or the 'variance ratio test'.

For the purpose ANOVA, the use of *F* distribution is applied. The F distribution is governed by two parameters (F and F_{crit}) which are composed of two variances and their degrees of freedom. The aim of this test is according to Dougherty (1992) to measure: "If F is greater than F_{crit} you reject the null hypothesis and conclude that the 'explanation' of [the dependent variable] is better than is likely to have risen by chance" (pp 110). In other words, this analysis allows for the assumption that given the objective and subjective conditions and limitations in which the test was carried out, the variables tested in an analysis of variance cannot be associated between themselves by chance - within the confidence limit set prior to the test.

When the *F* test was performed with 99% of confidence, all the variables, including 'ACORN' classification ($Fcal5.40>Fcrit1.59$) and 'code' (postal districts) (6.15>1.79) showed strong explanatory power (*F* was significant) and the null hypothesis was rejected. As in correlation analysis, this result does not indicate causality, but it does reject the hypothesis of accepting coincidence as an explanatory element. For the full details of the results obtained from this procedure see Appendix VI.

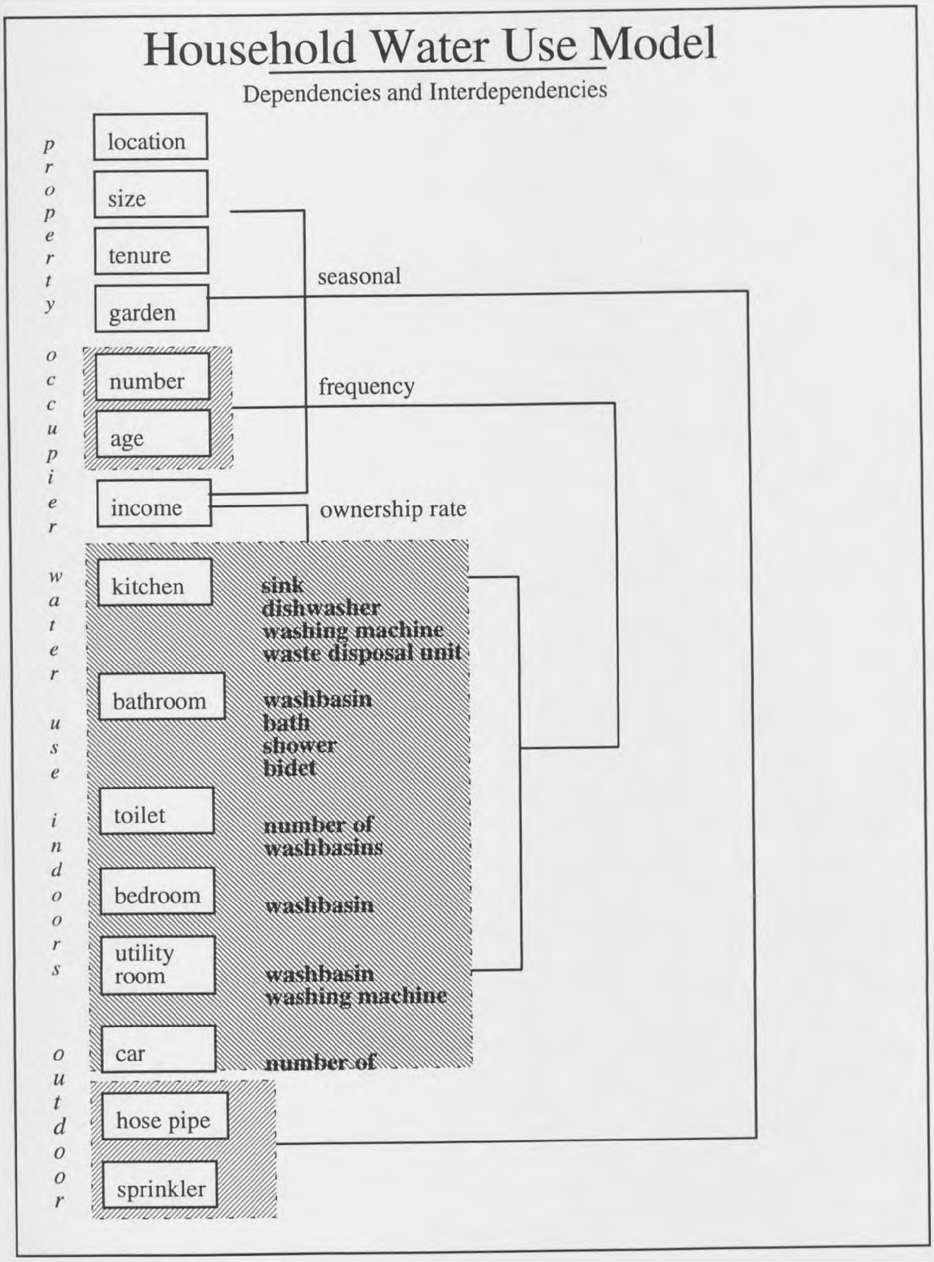
The other part of ANOVA is carried out as part of the regression analysis described in the section below.

7.5 Regression analysis

Figure 7.3 shows the interdependencies between the different variables affecting DWU. It shows the relation between variables which produce the interdependencies within and outside the house. These are divided into four main components: property, occupant, DWU indoors and DWU outdoors. The interaction between these groups is of three main types: frequency of use, ownership rate and seasonal effects. The reconstruction of a model depicting the ensuing association between the components within these groups is the task of the in the following chapter.

The relationship between house size and number of occupants is self explanatory, and section 6.5 and 6.6 examine this closely. As are the number of bedrooms and number of bathrooms and bathrooms with baths & showers, the garden size etc. However, the relationship between income and the size of property or availability of utilities is far from being clear cut. Moreover, the locational effects on DWU are not only in the realms of income group as ACORN grouping may (unsuccessfully) suggest. The location of a property determines, amongst others, the type of property it is, its size, but also the size and nature of the garden. All these interdependencies are also concerned with the frequency of use (which is sometimes called intensity of use, see for example Williams & Suh, 1986).

Figure 7.3



With six tentative variables in mind, a linear regression of DWU is performed against each of the independent variables. Three types of linear regressions were performed. Firstly, a least square bivariate regression against each independent variable separately; secondly, a linear regression which entered all independent variables together against water use at once, and in the third instance, a stepwise linear regression was carried out.

The model used for the regression is loosely based on Kindler & Russell (1984) and consists of a single explanatory equation 7.2.

$$WUs_i = N_i(a_1 \ldots a_n) + (e_r, e_d) \qquad 7.2$$

<u>Where</u>:

	WUs_i	=	water use in household i
	N_i	=	number of persons in the household i
	a	=	utilities and appliances in household i
	e_r	=	statistical random error
	e_d	=	error of data

This equation is based on the premises stipulated earlier and assumes an *a priori* use of the number of occupants in the household as the function coefficient. This is related to Kindler & Russell's (1984) notion of obtaining an 'anchor variable' which can be relied upon to resolve such an equation in an algebraic way. This equation also attributes equal weight to all the utilities and appliances within and outside the property. It does not include any economic or socio-economic element, nor a coefficient for it. The error term is divided into two parts which are affected by each other and can therefore be dealt with separately. The statistical random error term is compensated automatically in the regression coefficient, while the error resulting from inaccurate or erroneous data is the constant, often referred to as 'noise'.

Noise in DWU is made up of one or both of the following categories: data collection and erroneous data (Moser &

Kalton, 1971: 378). A technique used to treat 'noisy data' is used by Kher & Soroshian (1986). It comprises a complicated non-linear first order lag model which is introduced into a mathematical iterative model. The use of a mathematical model in principle resembles the microsimulation modelling which is performed in Chapter 8 and uses the variables obtained in this chapter. Microsimulation models are not concerned with the data collected from one source only, and hence the relatively little preoccupation with noisy data at this stage.

Table 7.4 which is the result of the first type of regression, does not prove that the number of occupants, for example, is a better explanatory variable for DWU than the existence of a washing machine ('washer'). It does however provide two subtle pieces of information. Firstly it confirms many of the results obtained by the test for correlation in section 7.2. This is not surprising as the calculations for the two procedures are of a similar nature.

Table 7.4 should therefore not be interpreted as a hypothesis test which would eliminate all variables below a certain level of explanatory power (for example 0.2) as was done in the correlation analysis earlier. It should only be assumed that these variables which have a strong coefficient in this manipulation have a linear relationship with DWU, as opposed to other, non-linear relationships. The cumulative effect of the variables past bedrooms shown on the right hand side of table 7.4 is R^2 = .01429 which points to the relatively little contribution which these variables make.

Table 7.4
Regression coefficients of DWU (m^3/hh/pa) of selected independent variables and their cumulative coefficient.

Variable	R^2	Cumulative R^2 (in ascending order)
OCCUPANT	.41944	0.41944
TOILET	.26755	0.49276
WASTE DISPOSAL	.23528	0.50051
WASHBASIN	.21172	0.50552
DISHWASHER	.17161	0.51120
BEDROOMS	.15574	0.51182
SHOWER	.14757	0.51290
OSTAP	.11583	0.51871
HOSE PIPE	.10386	0.52043
WASHER	.07865	0.52129
SINK	.07265	0.52134
SPRINKLER	.04542	0.52205
BATH	.03590	0.52395
RV	.03447	0.52416
TYPE	0.0285	0.52425
POSITION	.01142	0.52597
CODE	.00251	0.52608
ACORN	.00014	0.52611

For example, the rateable value (RV) features low in both tables: it is 14th variable in the correlation ratio, and the 14th in the regression model fit. The reasons for both these ratings are the nature of the data: a large number of residents in a house of low rateable value are not necessarily low water users. Alternatively, a property with a very high value may only accommodate one person who does not use much water.

When a regression was performed with all 18 independent variables at once, the resulting R^2 was 0.524 whereas the regression coefficient including only the six calculated together produced an R^2 = 0.51. The addition of the 12 variables admittedly produces a higher coefficient, but the disturbances (multicollinearities, discussed in section 6.6) which some of the additional variables may have in them could cause new problems. It is for that reason that the stepwise regression process was carried out on the five most likely variables.

In this process the ordering of the variables is done automatically, where the variables with the largest F_{enter} (i.e. the nearest to a pre-defined upper F value threshold) are added one by one. The algorithm of each variable entered performs a backward elimination, and checks whether its addition eliminates the effectiveness of the previous variable (Glantz & Slinker 1990, pp 265). The result of the stepwise linear regression (F_{in} = 0.5; F_{out} = 1.0) of all 18 independent variables produced an R^2 of 0.523 (Table 7.5), which is not better than the regression performed to all variables simultaneously. Among the seven variables rejected in the process (Table 7.6) are however both the number of bedrooms and the type of property which were included in the model.

Table 7.5
Cumulative R^2 Stepwise regression coefficients in ascending order.

Variable	Cumulative R^2
OCCUPANT	0.41944
TOILET	0.49276
OSTAP	0.50225
DISHWASHER	0.50951
WASHBASIN	0.51419
WASTE DISPOSAL	0.51756
BATH	0.51954
HOSE PIPE	0.52150
WASHER	0.52261
SPRINKLER	0.52339

Table 7.6
Variables not included in stepwise regression.

Variable	Beta In	Partial	Min Toler	T	Sig T
ACORN	5.29E-04	0.00073	0.363612	0.046	0.9631
BEDROOMS	0.010329	0.012001	0.342767	0.762	0.4463
CODE		-0.02632	0.365775	-0.987	0.3235
RV	0.018408	0.022275	0.356405	1.414	0.1575
SHOWER	0.026857	0.030097	0.343477	1.911	0.0561
SINK		-0.01549	0.358625	-0.549	0.5832
TYPE	0.00474	0.006322	0.358938	0.401	0.6883

As can be appreciated from table 7.7, two variables 'TYPE' and 'BEDROOM' do not posses a high *B* or *t* coefficients. Their inclusion in the final variables ows more to the modelling process as described in section 4.5.4, than to their strong regression coefficients.

Table 7.7
All the variables in 'all at one' regression and their coefficients B*.

Variable	B	SE B	Beta	T	Sig T
ACORN	-.027938	.058241	-.006643	-.480	.6315
BATH	4.560362	1.244631	.043085	3.664	.0003
BEDROOMS	**.415803**	**.776418**	**.007431**	**.536**	**.5923**
CODE	-.100712	.105015	-.010483	-.959	.3376
DISHWASHER	**9.162446**	**1.927155**	**.066140**	**4.754**	**.0000**
HOSE PIPE	5.361376	1.794390	.041979	2.988	.0028
OCCUPANT	**30.635061**	**.808899**	**.494064**	**37.873**	**.0000**
OUTSIDE TAP	6.403963	1.618165	.056435	3.958	.0001
METER POSITION	6.195576	1.642707	.045410	3.772	.0002
RV	.014468	.005606	.043193	2.581	.0099
SHOWER	3.090248	1.542251	.028383	2.004	.0452
SINK	-1.835605	1.936526	-.011846	-.948	.3432
SPRINKLER	5.993144	2.363411	.030006	2.536	.0113
TOILET	**7.552838**	**1.422616**	**.103347**	**5.309**	**.0000**
TYPE	**.638962**	**.715869**	**.010807**	**.893**	**.3721**
WASHER	**8.236067**	**2.795156**	**.033962**	**2.947**	**.0032**
WASHBASIN	5.252657	1.138960	.076150	4.612	.0000
WASTE DISPOSAL	9.914340	2.220173	.055747	4.466	.0000
(Constant)	-29.850367	6.207718		-4.809	.0000

* **Bold** variables were eventually selected.

In essence, those stages only confirmed what was known from the previous procedure: that the total explanatory power of these variables does not fully cover DWU in Leeds. However, it provided some additional insight into the nature of the data.

Although the results may seem straightforward, the choice of variables for the microsimulation model could not be made out on the hierarchisation of the regression coefficient (B) alone (Table 7.5). The reasons for this are divided into two categories. Firstly, there are those variables with low coefficients. Thus ACORN, CODE, and RV all consistently, throughout the analysis produced coefficients which do not appear to contribute to the modelling of DWU.

Some variables that may have a strong coefficient, but there is no information on the availability of these variables in all the population of Leeds (as opposed to those with metered water supply), which is needed for microsimulation modelling. Thus the ownership details of number of toilets or wash basins, both of which display strong regression coefficients, are not openly available from official data sources (e.g. OPCS), and the probability of their ownership could not be calculated satisfactorily from the present survey.

7.6 Comparison with other results

All the works examined in this section are reviewed in previous chapters but particular points which were not highlighted then can now be understood with additional depth.

Typically, the problem faced by the British researchers is the lack of accurate information on the present DWU. This is pointed out earlier as the result of the lack of meters and as a result of this the absence of reliable literature on this topic. The common element in these works is their being based on metering of some properties from which an attempt was made to draw conclusions on wider patterns of domestic water use.

As a result of this condition there is little discussion in British works on the precise statistical technique which should be used for this purpose. Instead, the debate circles around be used for this purpose. Instead, the debate circles around technical points related to civil engineering (e.g. Thackray *et al.*, 1978; Brandon, 1984 and Bell 1986), and the averaging of household components water use (e.g. Hall *et al.*, 1988, Russac et al., 1991). There is some literature on water demand forecasting (e.g. Gardiner & Herrington, 1986), but it is concerned more with forecasting techniques than actual measurements of water used. The present work allows the introduction of the household components' characteristics which are comparable with other sources, such as the National Census of Population. However, Thackray *et al.* (1978) had the advantage over the present work of having the questionnaire designed by the authors. There are therefore components and variables which had to be inferred or even hypothesised upon in the present work, while Thackray *et al.* used primary data.

The technique used by Thackray *et al.* (1978) to assess external water use was by linear regression analysis, while for the independent components within the household, an analysis of variance was performed. The reason for this, they say (page 55), was the insufficient number of reliable observations for a full regression analysis. Thackray *et al.*'s analysis of variance conformed to 75% of their component water use in Malvern and 77% in Mansfield. The results of their regression analysis appear to be confirmed by works which are reviewed later. When regressing RV against overall average water use they obtained $R^2 = 0.63$ which was not the case when an individual household's water use was regressed. In that case the coefficient was 0.03 only. The other regression performed included with all the independent variables together, and obtained an $R^2 = 0.61$. (See also section 3.6).

Archibald (1983) explains Thackray's *et al.* (1978) relatively weak result compared with Clouser & Miller (1980) who obtained $R^2 = 0.82$ to 0.89, by the fact that the price variable which is absent in the UK is crucial for that type of regression. He points out that this is especially apparent when outdoors water use is a substantial part of the total water use, as is the case in many parts of the USA (pp 183).

Hanke & de Maré obtained an R^2 of 0.259 only, from a regression where apart from the number of occupants, the other variables included the <u>actual</u> income for each household (obtainable from the Swedish Census Bureau) and a breakdown of the household into children and adults. A similar result was obtained by Jones & Morris (1984) for a work with similar premises, albeit not with such accurate information on income, as their work was carried out in the USA, where such information is not available for reasons of civil rights.

The most important conclusion from these two works is that of the explanatory power of socio-economic variables which were not obtainable in most other works. The explanatory power of the income related variable was therefore assumed to have particular importance. In Grima's words: "price [of water] is the most important policy variable" (1972: 112). However, the Swedish example, as well as Jones & Morris and the benchmark work on this topic by Howe & Linaweaver (1967) failed to substantiate the underlying assumption which would stipulate that if the price of water was of high magnitude, income would have a significant coefficient in the estimation of DWU. Three reasons are suggested here to be the essence of this failure:

1. Inaccurate information on real income. This reason may have two sub-explanations: outdated information, or confusion over the exact meaning of 'real' income, as opposed to gross, indexed etc. income.
2. The sample size and/or the model used to evaluate the link between income related variables and DWU were either insufficient or faulty.
3. There is no causal or explanatory link between water use and household's income.

In terms of policy rather than prediction and water use estimation, it is pointed out in section 2.3.4, that there is apparently no tool which could control DWU other than the price mechanism. The regression coefficient for the price of water-per-unit-of-use, (a variable which is not included in the present work for reasons explained earlier) obtained diverse results depending on the location and season in which the survey was carried out. The range of this coefficient is between R^2 = 0.47 in the winter and R^2 = 0.60 in the summer (Gibbs, 1978), while Carver & Boland (1980) did not prove the advantage of a seasonal model where R^2 = 0.44 and a non-seasonal model obtained R^2 = 0.97. A conflicting conclusion was reached by Metzner (1989) who obtained an R^2 = 0.97 using time series as opposed to component analysis.

Another British work which has not been discussed so far is by NERA (1993), which produced water demand analysis for YW using household size patterns and ACORN grouping. Checking the relationship between water use and these two variables they regressed each of the variables at a least square regression (LSR) and at log-linear regression. Their regression coefficients in both cases are considerably lower than obtained by the present work in several respects. Initially their linear regression R^2 coefficient for the number of occupants (Household Size) was 0.316 while their logarithmic R^2 was 0.426. For ACORN groups their R^2 was 0.016 and 0.021 respectively. In other words, the household size variable contains useful parameters for the estimation of domestic water use, whilst ACORN classification does not (pp 12).

7.7 Multicollinearity

The reason for the results in the present work being lower than in most works reviewed here appears to be related to multicollinearity.

In the case of time series analysis discussed in section 3.5, the problems are, according to Domokos *et al.* (1976), twofold: firstly that they violate one or more of the assumptions allowing this type of extrapolation; and secondly that it does not explain the complexity of multicollinearities between variables. The first problem, Domokos *et al.* argue, can be solved relatively easily by mathematical manipulation of the relationship between the dependent and independent variables.

The condition for collinearity is that two independent variables produce, when regressed together, a high linear regression coefficient which depends on them being regressed together, thus hiding their real independent linear value. Although this problem is most common in time series, it can easily appear in any multiple linear regression of the sort performed here. Domokos *et al.* note that the complications with multicollinearity are mainly of four types (pp 270):

1. When the explanatory variables are multicollinear, estimates of their associated regression coefficients are not precise and it is difficult, if not impossible, to determine the relative importance or influence of the explanatory variable.
2. Explanatory variables may be omitted because the imprecision resulting from the multicollinearity prevents their influence from being detected.
3. Unless an explanatory variable is not correlated with the other explanatory variables, its estimated regression coefficient depends upon which other explanatory variables are included in the regression equation.
4. If several explanatory variables are each correlated with the predicted variable, they are likely to be correlated with each other. In fact, if the correlations between each of several explanatory variables and the predicted variable are high enough, the explanatory variables must be correlated with each other.

Examples for each of these cases can be found in the YW data on which this work is based. It should be remembered that at all times the dependent variable is water use.

The first problem is easily identifiable in a number of variables e.g. the relationship between the number of occupants, the number of bedrooms, the rateable value and the ownership of washing machines.

OPCS (1993), for example, point to an overall average of 0.50 persons per room in Britain (page 57). There are however 24% of households with between 0.50-0.65 persons per room and 19% with between 0.66-0.99 persons per room (ibid.). It must be noted that 'rooms' in the General Household Survey, are not necessarily bedrooms. Nevertheless, the variations within these categories allows a wide range of multicollinearities between the number of occupants and the number of bedrooms. The correlation (Pearson, two tailed) between these two variables in the present data is 0.399 (see also section 7.2). However, when a third component, the washing machine, for example, is added, the correlation between it and bedroom number dropped down to 0.236 and the correlation between washing machine and the number of occupants was 0.224, suggesting that washing machine ownership might be more strongly related to bedroom number, but not overwhelmingly so more than the number of occupants.

In a matrix position, which microsimulation model ultimately is, a situation like that might result in a perfect (exact linear dependence) collinearity with one or more ('multi') of the independent variables, but it may also result in any other form of interdependency which would be difficult or even impossible to detect. For a comprehensive discussion on this topic see Glantz & Slinker (1990).

To give another example from the present data, interdependencies between the number of bedrooms, the number of baths, and the rateable value of a property may be of a linear nature - the higher the RV, the more bedrooms and the more bathrooms (and baths) there are. However, it may also result in a situation where the higher the RV the more bedrooms (in a linear fashion) there are, but the number of baths does not increase linearly, and instead, once one or two bathrooms have a bath tub, any additional bathroom will contain a shower only. In such a case the matrix relation of baths, for example, is with more than two variables: the RV and bedrooms number in correlation with socio-economic or age group. Yet, this is the type of data which is rarely obvious, and in the present case the most available variable of that kind is the ACORN classification. This particular variable was omitted from the analysis earlier as it failed to show significant explanatory powers. Evidence from other works (Russac *et al.*, 1992 and NERA 1993) also suggests that it is a poor indicator for DWU.

The second complication of multicollinearity as highlighted by Domokos *et al.* above has two levels: the first concerns the technical aspect of omitting variables, and the second concentrates on the conceptual problem of the same process. In the present work a number of variables were chosen for their explanatory ability concerning water use. At the descriptive statistics stage the notion of correlation between water use and each independent variable was explored, even if it was not explicitly expressed. However, it is pointed out by Domokos *et al.* that strong collinearities might have hidden a potentially efficient explanatory variable. Thus the immediate effectiveness of the rateable value, for example, did not appear important at that stage and on the strength of that performance alone would probably have been omitted from further manipulations. It was not omitted immediately due to the fact that other works (Grima, 1972 and Russac *et al.*, 1992) initially found it to be a potentially robust explanatory variable.

Conceptually however, there are other ways in which a variable could be omitted from a model due to a collinearity which 'hides' its explanatory powers. When a model is designed (e.g. microsimulation) there are variables which are more suitable for its purposes than others. Simultaneously, there are inherent multicollinearities in the data which would be activated in such a model and distort any result obtained. In some cases, area units may be used as an indicator of socio-economic groups (as a proxy for income) while the index for the classification may already include RV. In such situations the real explanatory essence of RV would be either hidden or even omitted as a result of its too 'obvious' closeness to other explanatory variables.

The third type of complication is directly related to that class of manipulation. Domokos *et al.* (1976) point out the problems of the collinear relationship between independent variables themselves to the extent that the construction of the model would be based on false or erroneous premises. In the case in hand, the regression coefficient for the variables of a socio-economic nature, such as RV or ACORN groups, themselves composed of different elements, reveals a degree of multicollinearity which would hide explanatory powers of other variables.

This is also the main issue of the fourth and last complication. It is a problem recognised in many forms of regression techniques (Taylor 1977: 218), however it is given a special emphasis here. Domokos *et al.* argue that multicollinearities should be assumed to exist between all independent variables related to one predicted variable. This is not difficult to identify in the present data. In the questionnaire, explanatory variables are all (deliberately) linked to DWU. Thus, all eighteen independent variables are linked to each other by their explanatory power over DWU, which was found in this work to be a function of a multitude of elements. Multicollinearities between the variables could therefore be assumed to be inherent characteristics of their relationship.

Grima (1972) found similar problems when attempting to model DWU in Canada. His model (equation 7.3) includes apart from the number of occupants, and the property's value, the price of water ($/gallon) and a constant:

$$WUa = K + V + Np - P - F \qquad 7.3$$

Where:

WUa = annual water use;
K = constant;
V = value of property;
Np = number of persons;
P = price of water, which has a negative sign; and
F = fixed bill for billing period (minimum charges).

This equation is based on economic premises, as opposed to the conventional models in the field which rest on engineering supposition. The assumption which underlies this equation is that any information which in the equation is also available to policies formulators. Thus the value of properties and the price of water seem to be the main components of the model. The coefficients obtained in regressions (equation 7.4) lean heavily on the number of persons, but the size of the constant leaves much doubt as to the explanatory power of this mode.

$$WUa = 114.04 + 0.34V + 21.08Np - 1.76P - 0.13F \qquad 7.4$$

As expected the 'economic variables' have a small coefficient, and hence a small margin of usage as policy tools. The highest R^2 achieved by this model was 0.52.

In order to detect any disturbances to the model, Grima regressed the variables in their logarithms form. The above model subsequently acquired the following values (equation 7.5):

$$\log WUa = 114.04 + \log 0.34V + \log 21.08Np - \log 1.76P - \log 0.13F \qquad 7.5$$

However the R^2 obtained in this process was only 0.56, which allows the assumption that this method does not provide a satisfactory answer for estimating DWU.

The conclusion of this example is that Grima may have looked in the wrong direction. The problem in Grima's model was that it ignored the nature of the interdependencies between the different components of DWU which create multicollinearity. This is where the present work is performing an additional test.

The test which is performed in this work to determine levels of collinearity between the selected variables consists of measuring their variance inflation factors (VIF) and their Eigenvalues. It is not necessary to introduce the details of the statistical calculations needed to obtain these values. Suffice it to say that both in VIF and Eigenvalues, the higher the value resulting from the test between two variables, the higher the possibility of collinearity between them. The full result of the tests carried out on the six variables concerned is displayed in Appendix VIII.

The VIF analysis on the six variables does not disclose any strong collinearities between them. However, in the Eigenvalue test there appears to be an underpinning spurious relationship not only between the expected variables of 'house type' and 'number of bedrooms', but also of 'washing machine'. This result does not alter the main thrust of the conclusions as they appear so far: the variables appear to provide reasonable answers insofar as their individual coefficient is concerned, but their ensemble is not adjusted to this type of analysis (Taylor 1977). In other words, the condition for considering the variables safe for microsimulation modelling is set as >90%

regression coefficient of all six variables, whereas in the model used in the present work so far the R^2 only reaches 53.2%

The next step was therefore to manipulate the data into a situation where these discrepancies would be reduced. The technique involves the centering of the individual data, or in other words the regression is not performed with the 'native' dependent variable, but a variable which is written "in terms of its deviation from the means of the associated independent variables" (Glantz & Slinker, 1990; pp 200). They add that "although centering results in different values for the regression coefficients because they are written in terms of the derivation from the means of the associated independent variables, the resulting equation represents the same mathematical function as we would obtain by fitting the original equation using the uncentered variables" (ibid.)

The results are dramatic (Appendix IX). The regression coefficient of $R^2 = 0.997$ seems to straighten the discrepancies which marred the process so far. However, the conclusion as to the reasons why the regression coefficient only explained approximately half the water use remains. The conclusion arrived at is of a statistical nature, and it merely demonstrates that by using the measurement of the mean of the intervals between the expected and observed points of water use as a dependent variable, the five independent variables provide a satisfactory explanation.

7.8 Conclusion

In this chapter the most important part of the analysis is carried out. The aim of this analysis was from the outset to produce a set of variables which could serve the purpose of modelling with a high level of confidence. From past works it was assumed that the highest level of accuracy, of the available variables, centred around the 50% mark, although in some works originating in the USA, higher coefficients were obtained through the use of non-linear regressions and with the use of a wider range of variables and techniques than were available in this work.

The importance of this process was in its provision of a integral set of variables to be used in the microsimulation model. In the conditions under which this model operates it was required that the variables used be of a high explanatory power. The technique of regression analysis was therefore chosen over other techniques, such as correlation or the analysis of variance, due to its attachment of a causal element as a link between variables. Thus it was not enough to point to a strong link between water use and any independent variable. The strength of the regression analysis provides a direct, if not causal link between them (Wallis, 1979).

Several methods of regression were tried and their merits and shortcomings compared with results of similar works carried out previously in this country and abroad. The problem of multicollinearity was widely discussed as it proved to be the major stumbling block for the production of an approved set of highly correlated variables. The manipulation of the dependent variable served as a useful solution which can now be used in the more comprehensive modelling.

However, due to technical problems discussed in section 4.5.1, the variable depicting the number of toilets which should have been included in the model, was replaced by the house type variable. The consequences of this change are difficult to assess as there is presently no other model of this nature in existence.

In the next chapter these variables are introduced into the microsimulation model and the spatial implications of the existence of each of the variables in all households within a given area is analysed.

8. EVALUATION OF MICROSIMULATION ANALYSIS FINDINGS

8.1 Introduction

This chapter assesses the relevance and importance of Williamson's (1994) findings on formulation of domestic water management policy in Leeds. There are two main aspects in which these results are reviewed: firstly their contribution to the better understanding of DWU patterns in Leeds; and secondly, highlighting the weak points of the statistical analyses carried out in Chapters 5, 6 and 7.

The premises on which this chapter rests are that the distribution patterns and the pattern of DWU as they appear in Williamson's model are 'correct'. This assertion has two sides: firstly, that if there are any technical errors in construction of the model (conceptual or computational) it is beyond the scope of the present work to discover them; and secondly, that the picture which emerges from the model corresponds better to actual DWU if only for the reason that the model deals with the population in general and not only with households surveyed by YW.

Following an overall review of Williamson's results, each of the variables analysed in the report is compared with the results obtained in the present work. The assumptions and variations in findings are highlighted and finally conclusions are drawn.

8.2 Data comparison

8.2.1 Sources of data

Yorkshire Water's 1992 surveys and Williamson's works provided the present work with two sets of data upon the basis of which a discussion is carried out in chapter 9. However, in the process of research, both Williamson and the present work needed to consult other sources of information.

The present work compares any result obtained in relation to DWU quantities with published works on similar topics. Some figures concerning ownership rate and distribution patterns are compared with the OPCS in order to put the findings of the YW survey in proportion. In Williamson's works (1993 and 1994) there is no comparison of results in term of DWU as no such work has ever been carried out beforehand. However, the comparison of ownership rate and distribution patterns carries a heavier weight as it is an integral process of the microsimulation modelling (see section 4.5).

8.2.2 Correspondence between the two works.

Only six variables out of 18 supplied by YW were used by Williamson. Five of them were used in a limited fashion in order to calibrate national data collected elsewhere, while a crucial role was assigned to the sixth variable, water use. The six variables were household size, number of bedrooms in properties, property type, existence of washing machine, existence of dishwasher and water use.

All the variables suffer from a major bias as they are drawn from the survey which covered metered households only (Chapters 5 and 6 detail the implications of this phenomenon). The spatial distribution in both works does not match: Williamson's findings were projected into ward boundaries whereas the data collected by YW was assembled by postal districts (PDs) (see Figures 8.1 and 8.2).

Although a method could be devised to convert the latter into the former or vice versa, it is considered to be of little relevance for the following two reasons:

1. The use of the original borders as used in the survey produce different overall patterns than the ward configuration. This can point to discrepancies and / or hidden issues which ward boundaries, defined for political reasons (they are in effect constituency zones) may have ignored.

2. Policy formulation requires a wide scope of the area (as opposed to tactical/operational decisions), and the difference in borders should not hinder this process.

8.2.3 Reliability of data and analysis

Chapter 6 discusses in depth the reliability of the data supplied by YW. These comments are also appropriate to the data used by Williamson, but whereas his work uses this data for calibration purposes only, there is a need to re-evaluate the reliability of all data in the present work.

Figure 8.1
Postal Districts overlaid on Wards in Leeds

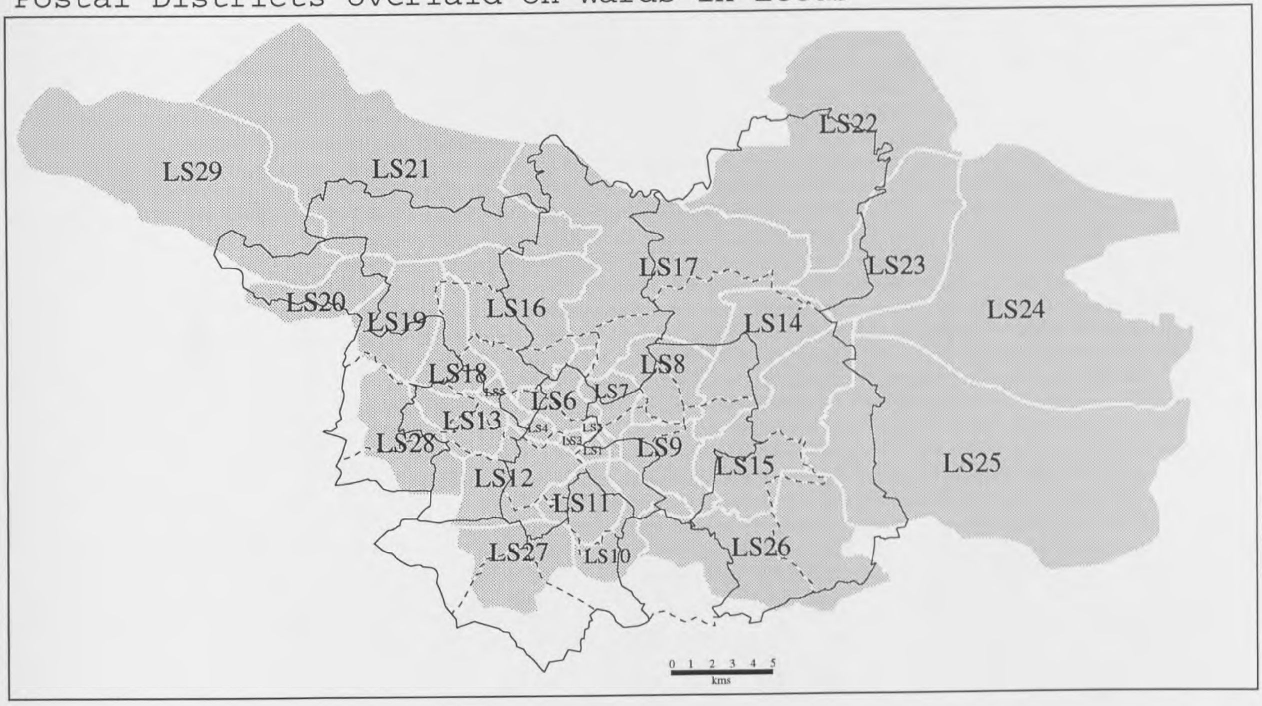


Figure 8.2
Wards overlaid on Postal Districts in Leeds

Williamson treats the variables in the YW survey as *a priori* biased, because they are not based on systematic sampling as is the General Household Survey, for example, or from the whole of the UK population as is the National Census of Population. The first task of this evaluation of reliability is therefore to assess whether there is a problem in the use of one survey (YW) as a modifier of another (OPCS).

As Williamson points out (section 5.2), the number of observations in the YW survey does not allow him to reach the level of confidence required for a Monte Carlo sampling (which is explained in section 4.5.1), where the minimum for the establishment of conditional probability is at least one observation for every two cells. As an alternative, Williamson chose to run a two stage cross-tabulation. The first stage was a crude estimate of the joint probability distribution, and the second stage consisted of fitting the now 'known' or 'scaled' joint probabilities from the first stage to the five modelled variables by means of the Iterative Proportional Fitting (IPF) technique (Williamson, 1992: 64). This technique consists of the repetitive comparison of randomly generated figures with a 'base' model which was produced at 'stage one' cross tabulation. It ceases to iterate either when the number of iterations commands run out, or when the new set of figures fits the preliminary model to the degree which was pre-determined.

As a result of this dual manipulation, a 'best' estimate of DWU is obtained. Although the new figures are more adjusted to the national profile than the crude YW data, there are still some parts of this technique which raise doubt as to the validity of any results.

The criticism is twofold: firstly, Monte Carlo models treat joint probabilities for an independent occurrence although there are clear indications of interdependencies between the occurrence of variables in the present case (section 7.7). Molloy (1989: 112) says that

> "a simulation mimics a stochastic process in time so that the outputs of a simulation are themselves random variables....It is a disadvantage if you wish to make a statement about the modelled system's average behaviour based on the observation of the simulation."

This criticism is relevant in one way or another to any model, and is treated as an inevitable drawback of all isomorphic models (Wilson, 1981: 29), of the microsimulation type.

The second point concerns the number of iterations required in order to achieve a satisfying result. A distorted picture may emerge if iterations are halted before the results reach an optimal point. The choice of ten iterations in Williamson's work appears to have reached a satisfactory level of adjustment (see Table 10 in Williamson, 1994) and is therefore eligible for the purpose of policy assessment in Chapter 9.

The data sources used in the two works do therefore suggest that any result obtained by these two different approaches are compatible, at least in terms of the data's reliability.

8.2.4 Assumptions

As in any other form of modelling there is a whole set of assumptions related to the accuracy and validity of the model compared with the 'real world', but when taken into account these arguments should not hinder the use of this tool (Openshaw, 1990). Williamson's work is underlined by a series of assumptions, the details of which need not be discussed here. This section provides a general description of some of the more relevant assumptions, and explains how they differ from the assumptions of the present work.

The first assumption which could be identified in Williamson's work is the geographical nature of DWU. By attributing water use to demographic-economic variables only, there is a whole set of variables which are not investigated, such as property's size (e.g. in square yards), garden size, altitude and the nature of soils. Williamson assumes therefore that DWU is primarily concerned with the type of information supplied by YW. In this respect, microsimulation does not differ from the present work.

The second assumption embedded in Williamson's work concerns the nature of the relationship between the occupants of a given household, and their propensity to use water. Unlike in the present work, the use of water in Williamson's work is referred to as 'demand' which has several implications (see section 3.2). Firstly it implies that a household would use less water if its price were more expensive. Conversely, this assumption can stipulate that households would use more water than they did in this survey, if water were cheaper or altogether free. This assumption allows however, the introduction of a negative relationship between water and price, which in turn allows both statistical and mathematical models to obtain 'reasonable' results. Again, however, the assumptions of both works are identical.

Finally, there is the implicit assumption that the typical population of YW's surveyed customers corresponds to the two additional data bases used by Williamson, i.e. the National Census of Population and the General Household Survey. In other words, this approach supports the belief that there is nothing particular about households with water meters apart from the fact that they possess a water meter. This argument may indeed hold true, but until such time as it is verified, it must remain an untested proposition.

Alternatively, it is argued in the present work that there are specific characteristics attached to metered households, even if their specifications cannot yet be verified, and any conclusion drawn from the metered household sample does not necessarily correspond to any other type of population. This last assumption is contained in Williamson's work, but is absent from the present one.

8.2.5 Conclusion

The additional sets of data used by Williamson and the basic assumptions embedded in the modelling process do not have the same implications as do the manipulation of the data.

In Williamson's work, the deployment of water using utilities from the YW survey is performed in the first stage only. In the second stage the model consults data bases on a national scale in order to calibrate its findings. For the present work however, the YW survey is the sole source of information and provides the basis of the present comparison. The rest of the chapter therefore compares each of the variables used by Williamson with their 'crude' form in the YW data set. Each section is divided into parts: the first describes the variable's distribution in both works. The second compares the assumptions underlying the variable in each work. Thirdly, the difference in the findings are discussed, and finally, each variable's analysis is concluded.

8.3 Water use pattern

8.3.1 Description - Average

The aim of both Williamson (1994) and the present work is to estimate domestic water use in Leeds. As this chapter is concerned with a comparison of results, it is important to assess the differences in the main variables first.

As Table 8.1 shows, the distribution of water use in Leeds PDs is as would be expected. If the PDs with less than 100 cases were to be removed in order to increase the confidence limits of the sample, there remain eight PDs above, and eight below the average water use level. The geographical distribution (Figure 8.3) which the PDs create does not appear to indicate any particular pattern.

Table 8.1
Average DWU in Leeds by PDs

PD	Average
LS09	31.06
LS05	50.79
LS11	64.97
LS02	70.33
LS03	70.55
LS07	71.81
LS08	76.66
LS15	81.87
LS06	81.93
LS28	89.63
LS21	91.94
LS10	94.55
LS13	96.30
LS26	97.11
LS18	97.74
LS16	99.87
Average	99.88
LS19	100.53
LS27	101.11
LS12	101.80
LS14	104.58
LS29	106.49
LS17	107.54
LS04	108.27
LS25	109.93
LS23	112.03
LS20	112.12
LS22	113.85
LS24	117.80
Total	99.88

[shaded] - Postal Codes for which sample is less than 100 cases (1.5% of sample)

The first comment concerns the relatively large number of PDs with low sample size which are included in the class below the average water use. Apart from three PDs (LS19, LS12 and LS23), all other high water users have a sample size larger than 100 cases, which reinforces the suspicion that the meter ownership rate in some PDs is related to their DWU pattern. As is pointed out in section 8.2.2, the existence of meters in households may signify additional household characteristics apart from meters simply being there.

The second comment concerns the locations of the PDs with higher than average DWU (Figure 8.3). Apart from two (LS4 & LS14), all other PDs with higher than average DWU are in the outskirts of Leeds. This picture may be misleading as some areas on the edge of the Leeds districts are, in fact, rural areas which include isolated farms and villages as well as suburbia. The importance of this phenomenon for policy formulation purposes is discussed in Chapter 9. It is interesting to note that the west of Leeds (LS20 down to LS27) which borders Bradford and includes some 'high class' residential areas (e.g. Horsforth) is not a planned growth area for Leeds. The same is true for the south of the city, where Wakefield's boundaries limit Leeds' sub-urbanisation in this direction. The north and the north-east of Leeds remain the growth areas (Leeds City Council, 1993: 123). This may explain the existence of more meters related to new properties. However, as Table 8.2 shows, the installation of meters in new properties did not occur in the expected area mentioned above, but mostly in the centre, the south and the east of Leeds.

Table 8.2
Percentage of households with meters installed in new properties: Leeds PDs

Post Code	New
LS16	6%
LS08	8%
LS17	8%
LS20	11%
LS29	18%
LS07	20%
LS18	20%
LS19	25%
LS22	30%
LS15	34%
LS23	36%
LS14	40%
LS21	40%
LS04	43%
LS12	44%
LS26	46%
LS28	46%
LS06	48%
LS25	67%
LS24	71%
LS10	76%
LS13	78%
LS11	86%
LS27	93%
LS09	95%
LS02	100%
LS03	100%
LS05	100%
Total %	36%

- Postal Districts with low sample (<100)

Meters in new properties, although only 36% of the present survey, constitute the largest group of installation type. Since a comprehensive installation of meters in existing properties is not currently considered as a viable option by the water industry, although it may happen in the future (OFWAT, 1992: 12), new properties are, and have to be, assumed as the largest provider of growth in metered properties in Britain.

Figure 8.3

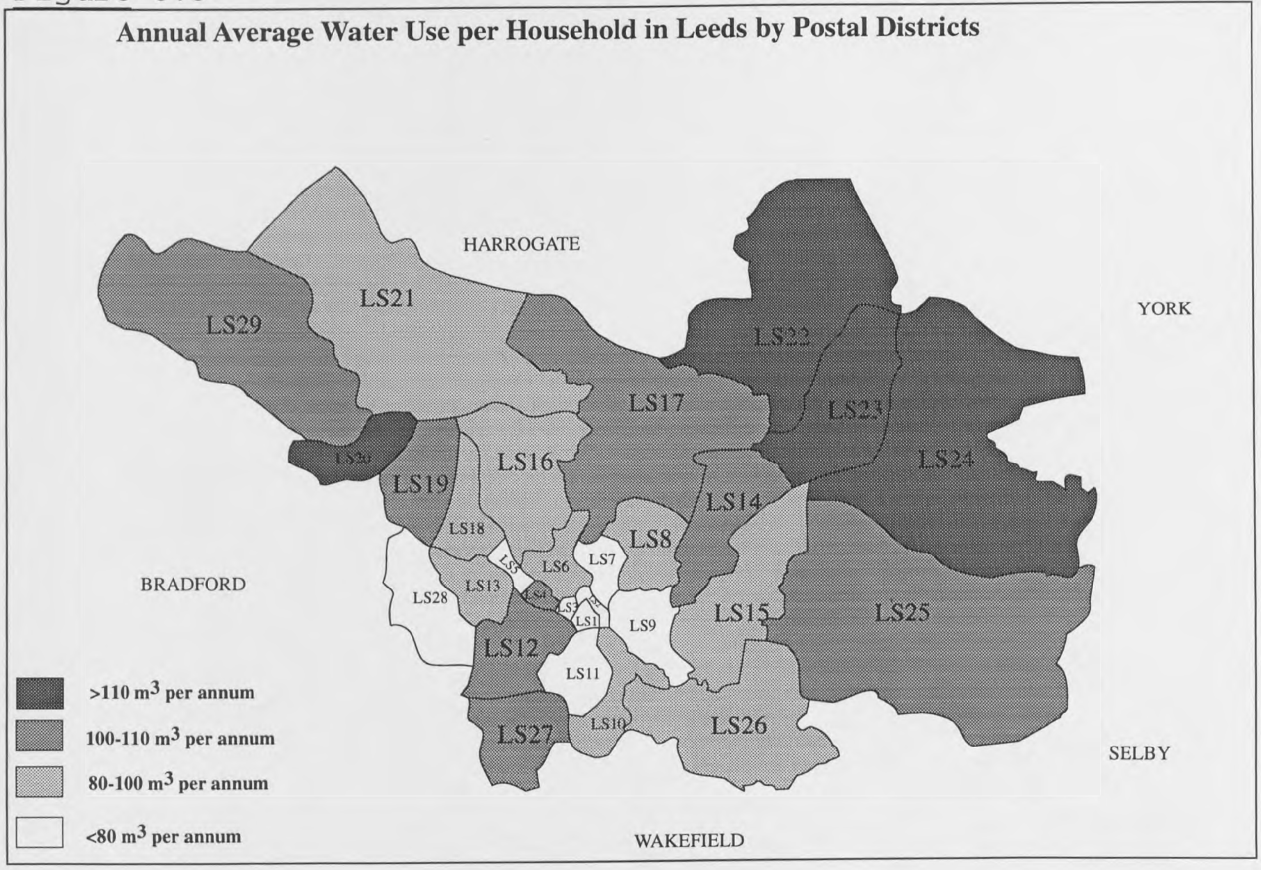
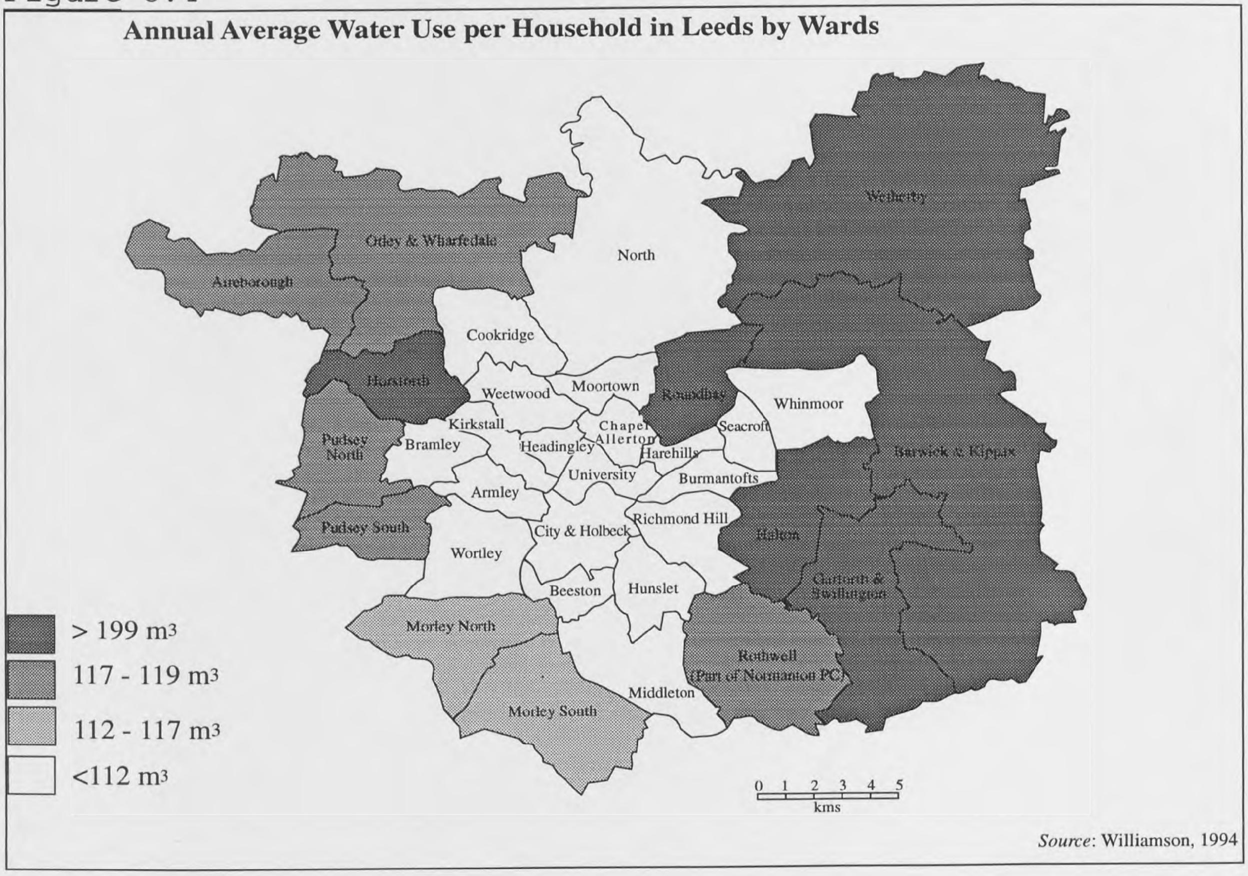


Figure 8.4



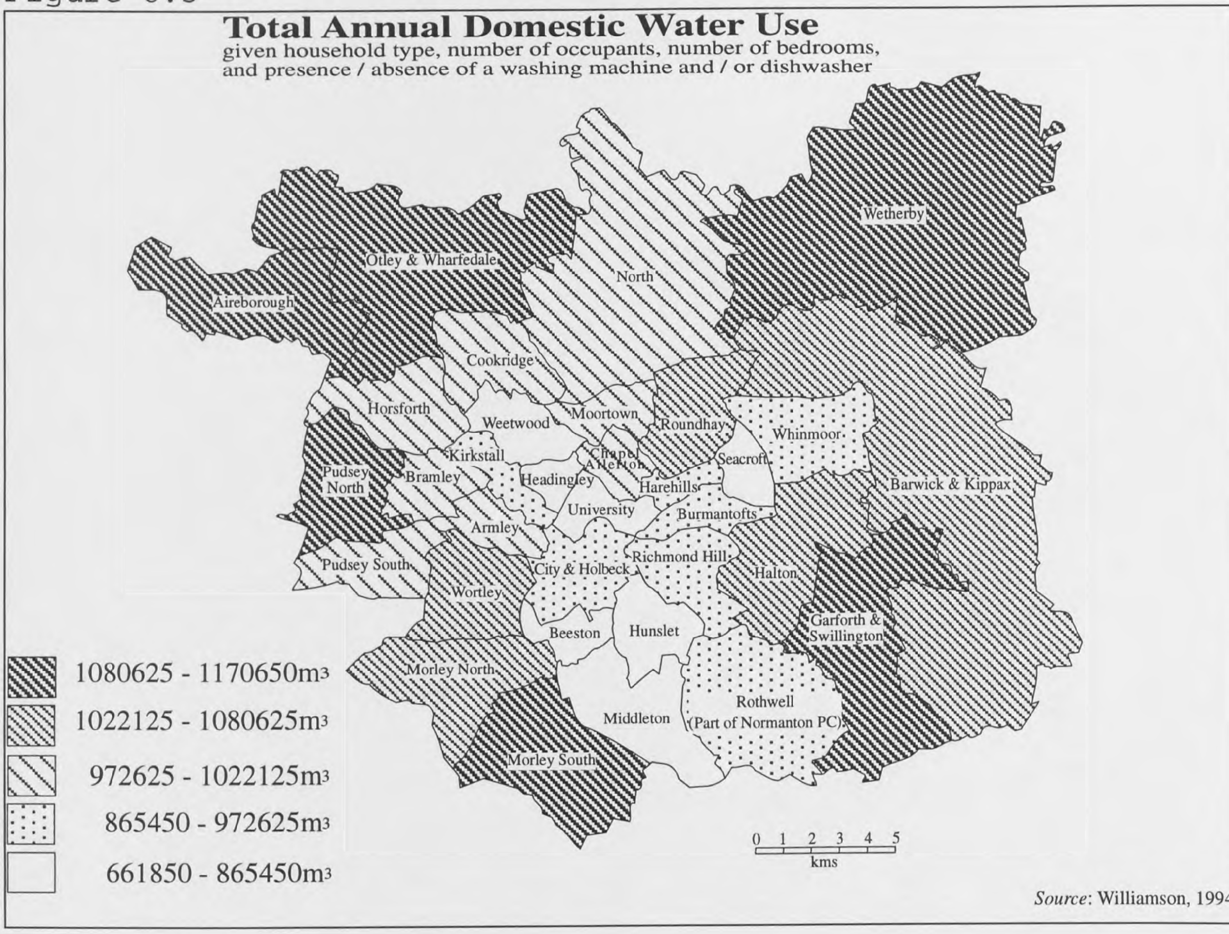
Source: Williamson, 1994

In Williamson (1994) the pattern of average DWU is found to be somewhat different. The eastern areas of Leeds are the heaviest water users (Figure 8.4) as opposed to the north eastern in the YW sample. Horsforth ward is also a high water user, again unlike the corresponding PD - LS19 (see Figures 8.1 and 8.2 for overlapping areas). So far the comparison between the two works reveals a similarity, but they are not identical. This may be attributed to their common data base, namely the YW water use survey.

8.3.2 Description - total amount

Figure 8.5, taken from Williamson's work, describes the total (not average) amount of water used annually by each household in any PD. It shows a more fragmented water use pattern than the average DWU pattern which does not correspond to the present work's results. This map is the most important element in the validity of present work. This is because it is the one result which cannot be estimated with precision by statistical means, since the total of the population includes a majority of non-metered households, the conclusions reached by the combination of the two works is of a highly practical nature to the water company.

Figure 8.5



Williamson found six wards in the highest water users category (1,080,625 - 1,170,650 m^3 pa): Morley South (LS27), Pudsey North (LS28), Aireborough (LS20, LS29), Otley & Wharfedale (LS21, LS19), Wetherby (LS22) and Garforth & Swillington (LS15, LS26). The figures in brackets are the postal districts to which each of the wards roughly correspond.

8.3.3 Assumptions

Interestingly, the total water use pattern matches, in broad terms, the areas of average DWU in YW's survey. Five possible conclusions might be drawn from this similarity:

1. That the YW data is decisive enough to determine the outcome of any mode of research.
2. That the two types of administrative borders contain a population of similar profile.
3. That the classification of water use level is of a similar order.
4. That the similarity in results is a coincidence.
5. That there is a fundamental error in either or both works.

For practical reasons it is assumed that the last two assumptions are false. The other three propositions however, have to be looked at carefully.

Concerning the first assumption, the quality of the data is examined several times over in this work (e.g. Chapters 6 and 7), including its bias and other shortcomings. Moreover, the limitations of the techniques used to manipulate the data in all stages have been described in detail, and their merits and shortcomings discussed. It seems therefore that that there is no reason to assume that any part of either works has ignored any major possible influence of that type.

The second conclusion deserves an even closer look. Administrative boundaries can affect the outcome of any research since their fixing is initially usually done with particular aims (Taylor & Hudson, 1971; Openshaw, 1990). However, the suggestion that administrative units were designed to reflect water use patterns is absurd. It can therefore only be the derivation of some other pattern which emerges from the existing boundaries. The most convenient classification with which to associate water use pattern would of course be the socio-economic grouping, which in turn, might reflect profiles of population with differing economic-political interests.

In theory therefore, there is a possibility of similarity between the population within the two different boundaries. However, a different work is needed in order to conduct a thorough investigation of each of the wards and PDs involved. Microsimulation modelling allows for the disaggregation of any given spatial unit into smaller, more homogenous units (e.g. enumeration district [ED]). Results of this type of work, currently undertaken by Williamson are excepted to show that the similarities between the two types of spatial units could not be responsible for any similarities in the outcome of the research.

The third possible conclusion is also discussed elsewhere in this work (Chapter 4). Although there are reasons to favour classifications of water use in ways other than the ones performed in this work, there is no reason to believe that another classification, (by 10 m^3/hh/pa for example) would produce radically different results, if at all. To conclude this point, it is argued here that even if there is any correlation between the class size of water use in both works, it cannot, by itself, explain the similarity.

8.3.4 Conclusion

The patterns of water use by themselves do not reveal any substantial differences between the two works examined. Therefore, the reasons for the apparent similarity are assumed not to be related to the dependent variable DWU alone.

As pointed out in section 8.2 the real comparison is however between the 'true' pattern as it appears in the microsimulation model, and the biased YW sample. The fact that there is a similarity between the average DWU in the YW model and the total DWU in the modelled pattern is accepted as proof for the robustness of the data on which the present work is based.

8.4 Household size

8.4.1 Description

Household size, or number of occupants, is referred to in Chapters 5, 6 and 7 as the single most important variable affecting DWU. Table 8.3 shows that there are almost twice as many PDs below the average as there are above it. However, when the 13 postal districts with a low sample are ignored there are seven PDs in each category. Figure 8.6 reveals that the households occupied by a number of persons over the average (2.08) are encircling the city from the north east to the south west. Two PDs are exceptional, LS14 and LS20. These two PDs are the ones just over the average line (2.12 and 2.14 respectively), and have other features, notably using more water than the average PDs. These PDs are also over the survey's average of the 'washing machine' and 'dishwasher' categories which are discussed in sections 8.5 and 8.6 below.

Table 8.3
Average number of persons per household in Leeds PDs.

Postal District	Average Persons
1. LS05	1.00
2. LS03	1.13
3. LS09	1.21
4. LS02	1.53
5. LS07	1.64
6. LS11	1.69
7. LS08	1.71
8. LS06	1.84
9. LS15	1.89
10. LS28	1.94
11. LS17	1.95
12. LS04	2.00
13. LS16	2.02
14. LS18	2.02
15. LS19	2.02
16. LS21	2.04
17. LS29	2.04
Average	**2.08**
1. LS20	2.14
2. LS23	2.17
3. LS26	2.18
4. LS22	2.23
5. LS10	2.29
6. LS13	2.32
7. LS27	2.35
8. LS24	2.50
9. LS25	2.55
10. LS12	2.56

[shaded] - Postal Districts with small sample (<100)

8.4.2 Assumptions

Williamson's work, as pointed out above, is concerned with the whole of the population in the study area rather than the YW survey alone (Figure 8.7). His initial estimate (1993; section 3.2, Table 10) portrays a similar pattern. There may be several reasons for this outcome. It could be related to the property's size (see section 8.7), but it may also be the result of a different class interval. One indicator of the classification issue is the difference between YW survey's average of 2.08 persons per household, compared with the Leeds average which ranges between 2.53 and 2.33 persons per household (Leeds City Council, 1993: 117). This too may highlight the particularity of the household type with meters.

However, Williamson's work lacks an overall singular assessment of household size in the city's wards. This makes his result in terms of household size, which is indeed incorporated in the joint probability, difficult to interpret.

Figure 8.6

Average Number of Persons per Household in Leeds by Postal Districts

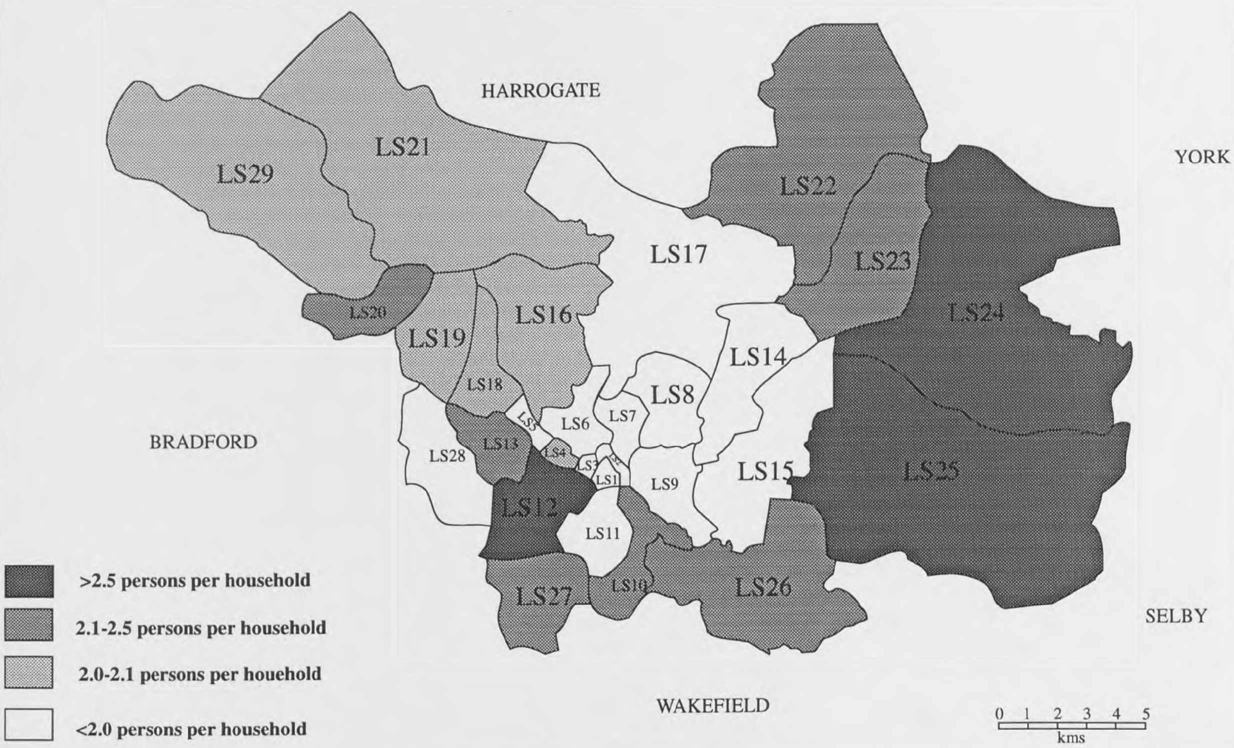


Figure 8.7

Average Number of Persons per Household in Leeds by Wards

Source: Williamson, 1993

8.4.3 Comparison

The differences between the two works in this category represents the crucial test for the model. Whereas it can be questioned whether quantities of DWU are correctly derived from one data source or another, the use of National Census data for this variable in the microsimulation makes this model unassailable. With this in mind, it is interesting to note that although the YW sample is not 'wrong' in that it does not contain household sizes in the places they do not exist, it simply lacks certain classes.

The centre and the north of Leeds have, according to the YW survey, very small average household size. There is however, a tendency of PDs on the east of the city to be occupied by larger households than those on the south and the west. In Williamson's (1993) work this tendency is also apparent. However, as opposed to the 'U' shaped pattern larger households create with the YW data, in Williamson's model there is a clear concentric pattern with the smallest households in the centre and the largest in the suburbs.

8.4.4 Conclusion

On the basis of this variable alone, the YW data appears to portray a reasonably accurate picture of the household size distribution in Leeds. There is a discrepancy in the north of the city, but as the model does not attribute a particular weight to this variable it is likely to be compensated by other variables.

8.5 Washing machine availability

8.5.1 Description

The spatial distribution of washing machine ownership according to the YW survey, produces a pattern with some resemblance to the average DWU pattern.

Table 8.4
Percentage of washing machine in Leeds PDs (in ascending order)

Postal District	Washing Machine
LS02	27%
LS03	40%
LS11	55%
LS09	74%
LS07	77%
LS06	81%
LS08	89%
LS10	90%
LS14	90%
LS17	90%
LS18	90%
LS21	90%
LS19	91%
LS26	91%
Average	**92%**
LS28	93%
LS29	93%
LS16	94%
LS13	95%
LS20	95%
LS23	95%
LS25	95%
LS12	96%
LS15	96%
LS24	96%
LS27	96%
LS22	97%
LS04	100%
LS05	100%
Cases	3702
Row %	92%

[shaded box] - Postal Districts with small sample (<100)

Higher than the average washing machine ownership, which stands on 92% of households, are again the PDs in the east and north east of Leeds (Figure 8.8), although LS20 (covering roughly the area of Aireborough Ward), and some southern PDs are included in the same category.The latter cases do however, fall within the category of PDs with a low sample size, and as pointed out above (section 8.4) are not considered to be statistically safe (Table 8.4).

Williamson's projection of washing machine ownership has several aspects. Whilst it calculates probabilities of washing machine ownership given other probabilities the present case looks at the 'washing machine only' probability (Figures 8.8 and 8.9). The difference between the two works are not remarkable, despite the fact that here too, Williamson's work covers the population as a whole. Eastern wards of Leeds (Elmet, Barwick & Kippax) together with one southern ward (Morley North) and two in the west (Horsforth, Pudsey North) have the highest percentage of washing machine ownership in Leeds. In addition some of the northern wards of Leeds have a high percentage of such ownership.

Figure 8.8

Percentage of Households Owning a Washing Machine in Leeds by Postal Districts

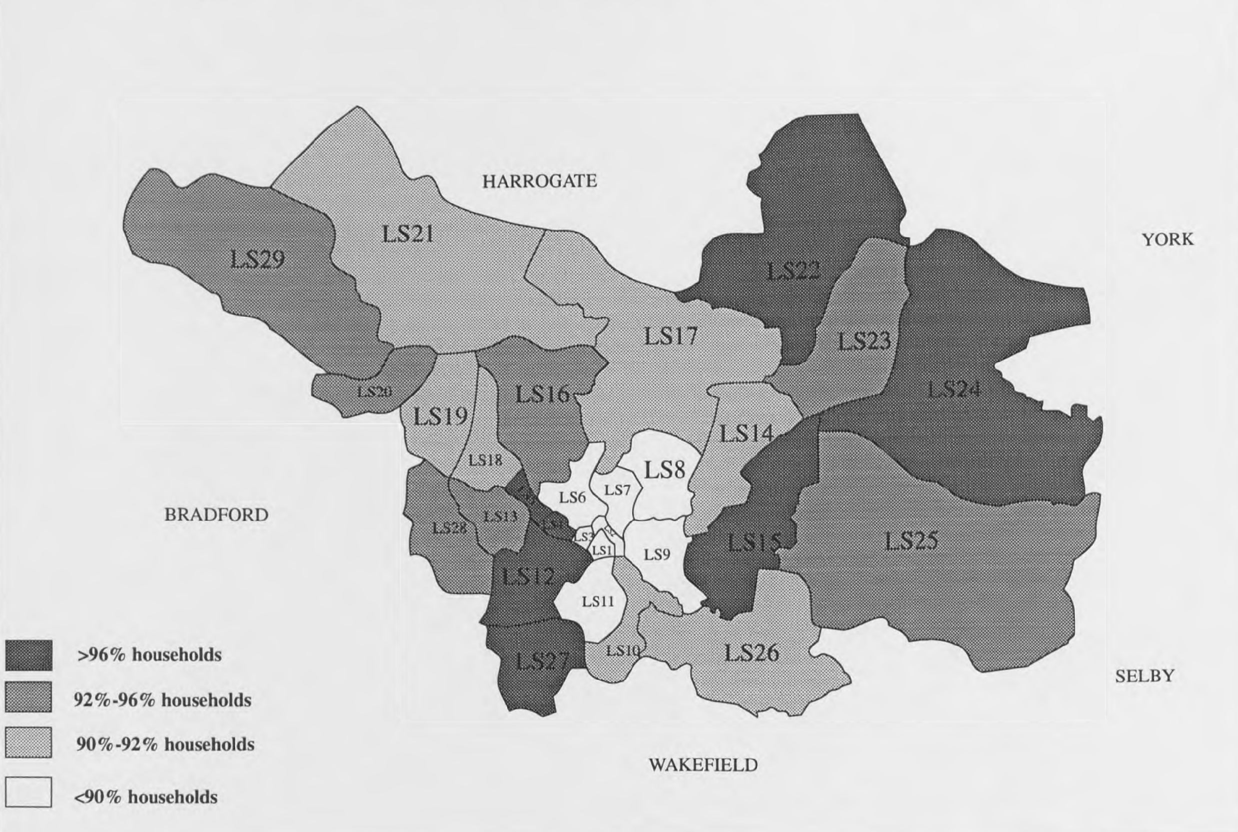
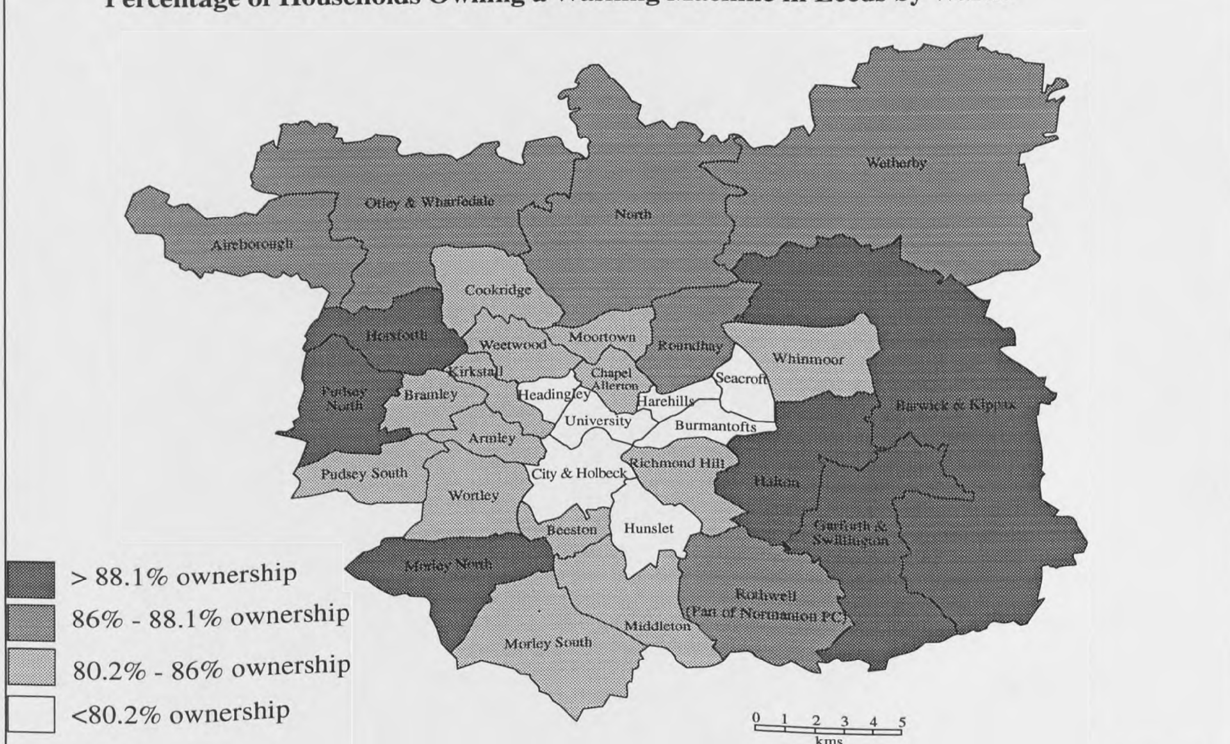


Figure 8.9

Percentage of Households Owning a Washing Machine in Leeds by Wards



Source: Williamson, 1993

8.5.2 Assumptions

Washing machine ownership is introduced to the present work as one proxy for standard of living, the other being the dishwasher (see sections 5.5 and 6.8). In this respect, the findings of both works confirm this assumption: the areas with high washing machine ownership tend to be the ones with high average DWU (section 8.3), and with other particular elements related to the standard of living. Accordingly, Williamson found that the probability of finding a washing machine in a 'professional' household is 95% whereas in council rented housing with an economically inactive head of household it is 38% (1994, section 3.2).

8.5.3 Variations

The difference between the two works may be attributed to the difference in borders, difference in classification and, of course, the different projections. The first and the last arguments are discussed in detail earlier in this chapter (section 8.2), but the second argument needs to be discussed here.

The lowest washing machine ownership percentage in Williamson's work is 72.7% of households and the highest is 90.1% of households, with three groups between them (1994, section 3.2). This, compared with the national average of 87% of households (OPCS, 1993), suggests that the two upper classes in Williamson's work (86% to 90.1%) are in the same category as the average ownership rate found in the present work. It would therefore appear that the results obtained by both works do represent a compatible comparison, and the conclusions obtained are valid.

8.5.4 Conclusion

Although it is difficult to assess the impact of washing machines alone on DWU the similarity in the findings in the two works suggests that there is good reason to attribute to this utility some explanatory power. However, the regression analysis (section 7.5) and the conclusive results from Williamson (1994, section 5.3) suggest that this utility's effect alone may be misleading if not erroneous. Of greater importance is the additional effect of combined elements in the household.

8.6 Dishwasher availability

8.6.1 Description

There is little correspondence between the pattern of dishwasher distribution in Leeds in the present work and Williamson's work.

In the present work all the households with higher than average dishwasher ownership per household (which stands on 36% of households) are in the postal districts in the north of Leeds (Figure 8.10). They are all in suburbs villages or rural areas, where in some cases the ownership rate is over 50% (e.g.

LS17, LS20, LS22, LS23; Table 8.5)Williamson's spatial pattern of dishwasher ownership is more complex (Figure 8.10).

Table 8.5
Percentage of dishwashers in households in Leeds PDs

District	% Ownership
LS02	
LS03	
LS05	
LS09	2%
LS10	5%
LS11	5%
LS07	7%
LS06	10%
LS04	14%
LS12	14%
LS13	20%
LS27	21%
LS15	25%
LS28	27%
LS26	28%
LS08	30%
LS25	32%
LS18	36%
Average	**37%**
LS19	37%
LS14	38%
LS21	38%
LS16	42%
LS24	42%
LS29	49%
LS17	51%
LS20	51%
LS22	53%
LS23	55%

(shaded) - Postal Districts with low sample (<100)

Although the north of the city is still characterised by households with high dishwasher ownership, there are five other wards, in the west and the south-east of the city that have a high percentage of dishwasher ownership as well. These are Horsforth, Pudsey North, Morley North, Halton and Garforth & Swillington.

Figure 8.10

Percentage of Households Owning a Dishwasher in Leeds by Postal Districts

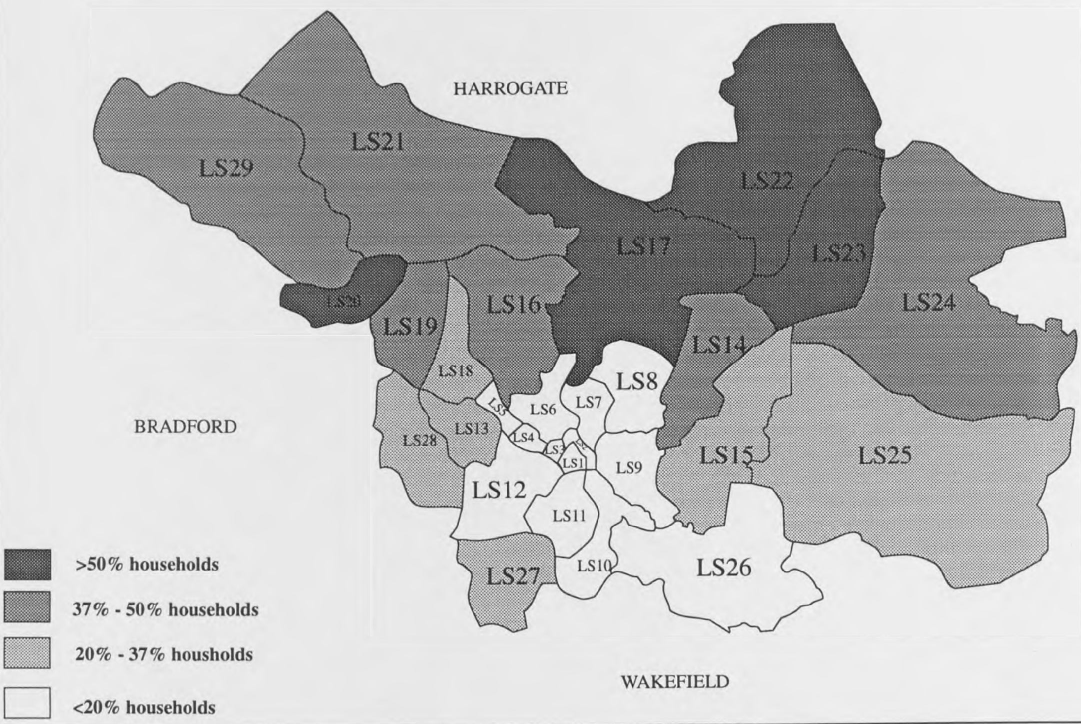
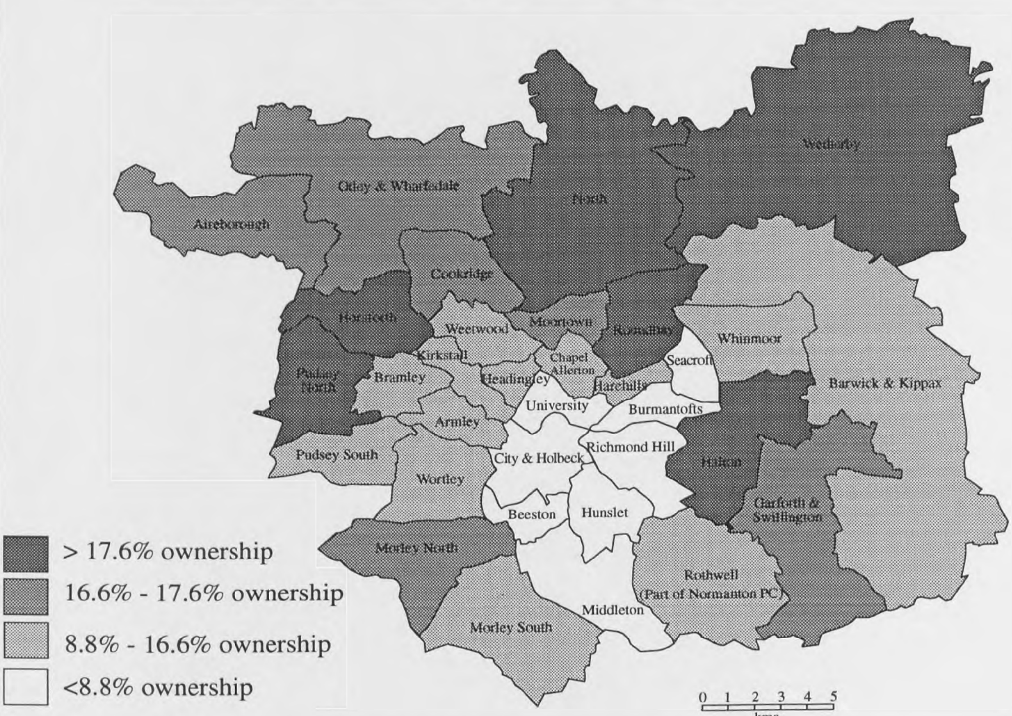


Figure 8.11

Percentage of Households Owning a Dishwasher in Leeds by Wards



Source: Williamson, 1993

8.6.2 Assumptions

Sections 5.5 and 6.10 deal with the assumptions which append to the existence of dishwashers in a household. Consequently, this variable was found to be the best proxy for the socio-economic classification, and more precisely, an indicator of wealth as it is considered to be a luxury utility found in a relatively small proportion of households.

This assumption seems to hold true for both works. Williamson (1994; Section 3.2) points to the probability of finding a dishwasher in a household whose head is a professional as being 35%, whereas in a household where the head is economically inactive the probability is just 0.6%.

These underlying assumptions suggest that any significant difference in the findings of both works should be the result of a different interpretation. The spatial distribution of these utilities is therefore, considered to be not as strong in the YW survey sample as it is in reality, and the contribution of this variable to the present model is not as substantial as the statistical analysis may have suggested.

8.6.3 Variations

The differences between the two works are attributed to similar elements, as were the differences in the spatial distribution of washing machines (section 8.5). These elements are: the difference in classification, in boundaries, and the magnitude of projection.

As discussed in section 4.3, the YW survey produced a distorted picture of several utilities, including dishwashers. In the second stage of his work (1994; section 6), Williamson modifies the water use pattern according to the joint conditional probability of possessing several water using utilities. The results of these probabilities in terms of individual components are never disclosed in the report, but the comparison with the present work adjusts the picture somewhat.

8.6.4 Conclusion

Williamson (1994) gives the two electrical water using utilities (washing machines and dishwashers) considerable weight in his estimation of domestic water usage probability. This corresponds however, only partially with the present work's findings (Chapter 7), where although the dishwasher is attributed with a relatively high regression coefficient (0.45), the washing machine obtains a lower one (0.22). This suggests that the distribution of dishwashers in Leeds corresponds to the pattern of DWU.

8.7 Number of Bedrooms

8.7.1 Description

The descriptive analysis in the present work (Figure 8.12) suggests that households with a larger than average number of bedrooms (the average being >2.93 bedrooms per property, Table 8.6) are located in the north of the city, mostly in areas which include rural land and suburban patterns. None of the other 'outskirts' postal districts in the east or in the south-east of Leeds are included in this category.

The number of bedrooms is only referred to in Williamson (1993). In section 3.2 of that work (Figure 8.13 in the present work), the picture which emerges is that of the larger properties being concentrated in the north and east of Leeds, while the smaller properties are in the south of Leeds.

8.7.2 Assumptions

The assumptions in both works do not differ radically. For Williamson (1994) the number of bedrooms is included as part of the joint conditional probability for DWU. This means that it has no more weight than any of the other variables. The fact that the present work has identified this variable as one of the stronger indicators for domestic water use, does not alter either results.

The underlying assumption in both works is that the number of bedrooms is a rough indicator of other units in the property size including garden size, which may be of greater interest, although it is not widely discussed in the present work. The relationship between the number of bedrooms and the garden size does however, provide scope for further research.

Table 8.6
Average number of bedrooms per household in Leeds PDs

Postal District	Average Number of Bedrooms
LS03	0.93
LS09	1.21
LS02	1.33
LS11	1.76
LS10	2.50
LS06	2.54
LS07	2.57
LS15	2.58
LS13	2.62
LS12	2.64
LS27	2.67
LS28	2.67
LS14	2.73
LS08	2.82
LS21	2.86
LS25	2.89
LS26	2.92
Average	***2.93***
LS19	2.97
LS18	2.98
LS04	3.00
LS24	3.02
LS17	3.06
LS29	3.15
LS22	3.27
LS20	3.32
LS23	3.32
LS16	3.33
LS05	4.00

[shaded] - Postal Districts with low sample (<100)

8.7.3 Conclusion

The differences in this variable between the two works are too large for a conclusive judgement on either the quality of the information which this variable provides, or the usefulness of this variable as an indicator of DWU. The essentially different spatial distribution pattern suggests that a large number of hidden components within this variable merit a closer examination.

Figure 8.12

Average Number of Bedrooms per Property in Leeds by Postal Districts

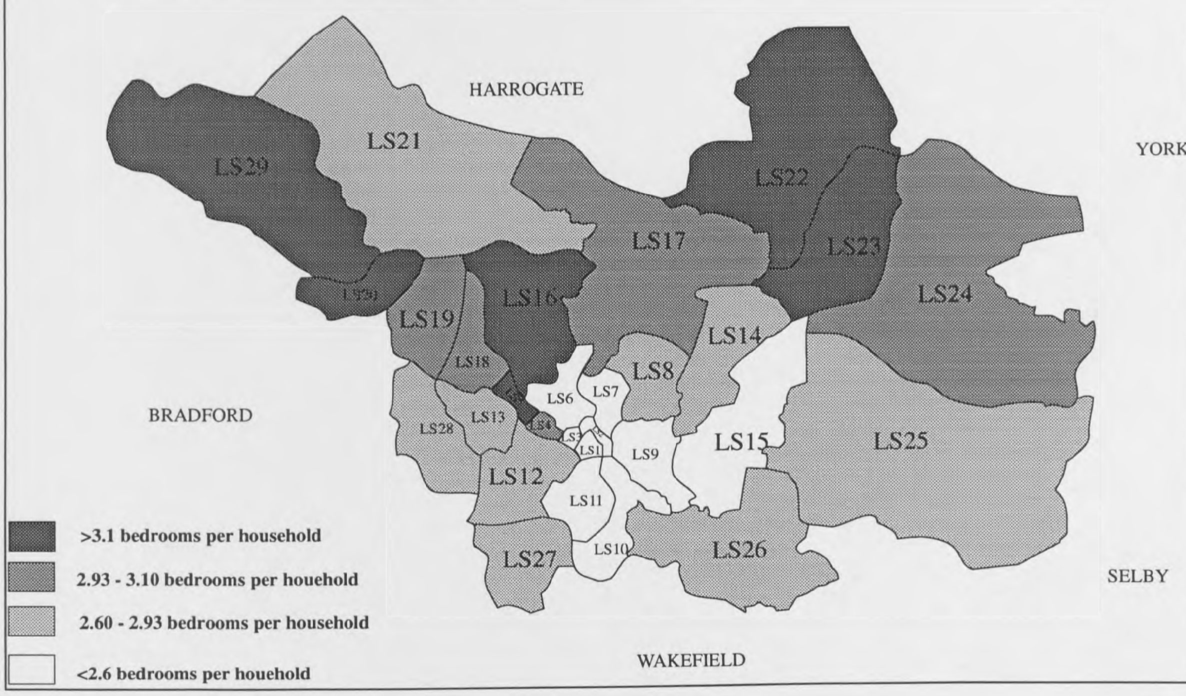


Figure 8.13

Average Number of Bedrooms per Property in Leeds by Wards

Source: Williamson, 1993

8.8 Household type

8.8.1 Description

Figures 8.15 and 8.14 show that detached properties (DD) and bungalows (BG) have a similar distribution pattern in Leeds. They mostly exist in the east and the west of the city, while the north, the centre and the south have a lower percentage of this type of property. The other three categories each portray a different pattern. The 'flat and maisonettes' (FM) category (Figure 8.21) depicts an almost mirror image of the detached properties. The 'through terraced' (TT) properties (Figure 8.19) are distributed with no apparent coherent pattern. There is a concentration in the south and in the centre and there is one postal district in the south east (LS25) and one in the north west (LS29) which are predominantly TT properties. Semi-detached (SD) properties (Figure 8.17) are concentrated in the centre, the south and the south east of the city.

As can be seen in Table 8.7, whereas the 'low sample size' are concentrated in the urban PDs, they vary between the lowest percentage groups in the DD and BG categories, to the highest percentage in the other three. This should highlight the importance of the microsimulation modelling for this variable, as it allows a better adjusted estimation.

Table 8.7
House types percentages in Leeds PDs

PD	DD	PD	BG	PD	FM	PD	SD	PD	TT
LS02		LS02		LS04		LS03		LS03	
LS03		LS03		LS05		LS05		LS05	
LS09		LS04		LS25		LS09		LS24	
LS06	8.33%	LS05		LS20	0.95%	LS22	3.24%	LS15	0.84%
LS07	13.64%	LS11		LS15	3.36%	LS21	3.36%	LS08	1.60%
LS04	14.29%	LS06	3.13%	LS24	4.72%	LS14	5.76%	LS20	1.90%
LS10	16.67%	LS10	7.14%	LS22	5.67%	LS29	7.27%	LS22	2.02%
LS11	16.67%	LS13	8.11%	LS27	6.08%	LS11	9.52%	LS26	2.17%
LS12	24%	LS07	9.09%	LS16	6.84%	LS24	10.24%	LS17	2.69%
LS08	26.74%	LS23	9.20%	LS19	7.69%	LS20	12.38%	LS19	3.08%
LS15	31.93%	LS09	9.30%	LS23	8.05%	LS23	12.64%	LS16	3.30%
LS13	34.46%	LS08	10.70%	LS29	8.60%	LS02	13.33%	LS23	3.45%
LS27	43.47%	LS21	10.92%	LS26	8.70%	LS17	13.65%	LS18	3.53%
Total %	***46.72%***	LS27	13.07%	LS12	10%	LS28	15.86%	LS28	5.52%
LS14	44.60%	LS16	15.57%	LS13	10.81%	***Total %***	**16.34%**	LS21	5.88%
LS17	45.38%	LS12	16%	LS28	11.72%	LS25	16.38%	LS12	6%
LS28	45.52%	***Total %***	***16.76%***	LS18	11.76%	LS18	17.65%	LS14	6.47%
LS18	49.41%	LS17	16.73%	***Total %***	***13.67%***	LS16	17.69%	***Total %***	**6.51%**
LS19	50.77%	LS26	17.39%	LS06	16.67%	LS19	18.46%	LS02	6.67%
LS21	51.26%	LS18	17.65%	LS10	16.67%	LS15	18.49%	LS07	6.82%
LS25	51.41%	LS14	18.71%	LS17	21.54%	LS26	18.84%	LS25	9.60%
LS26	52.90%	LS29	19.31%	LS14	24.46%	LS13	24.32%	LS29	10.13%
LS29	54.68%	LS24	19.69%	LS21	28.57%	LS27	24.32%	LS09	11.63%
LS16	56.60%	LS19	20%	LS08	30.48%	LS08	30.48%	LS11	11.90%
LS20	63.81%	LS20	20.95%	LS07	31.82%	LS10	38.10%	LS27	13.07%
LS24	65.35%	LS28	21.38%	LS11	61.90%	LS07	38.64%	LS04	14.29%
LS23	66.67%	LS22	22.27%	LS09	79.07%	LS12	44%	LS06	16.67%
LS22	66.80%	LS25	22.60%	LS02	80%	LS06	55.21%	LS10	21.43%
LS05	100%	LS15	45.38%	LS03	100%	LS04	71.43%	LS13	22.30%
Total	1887		677		552		660		263

[shaded] = <100 cases in sample

In Williamson (1993) the wards with a high percentage of detached properties appear in the north and the east of the outer city (Figure 8.16). A high proportion of semi-detached properties (Figure 8.18) are generally in the south east outskirts of Leeds, but also in two wards (Weetwood and Moortown) nearer the centre.

Figure 8.14

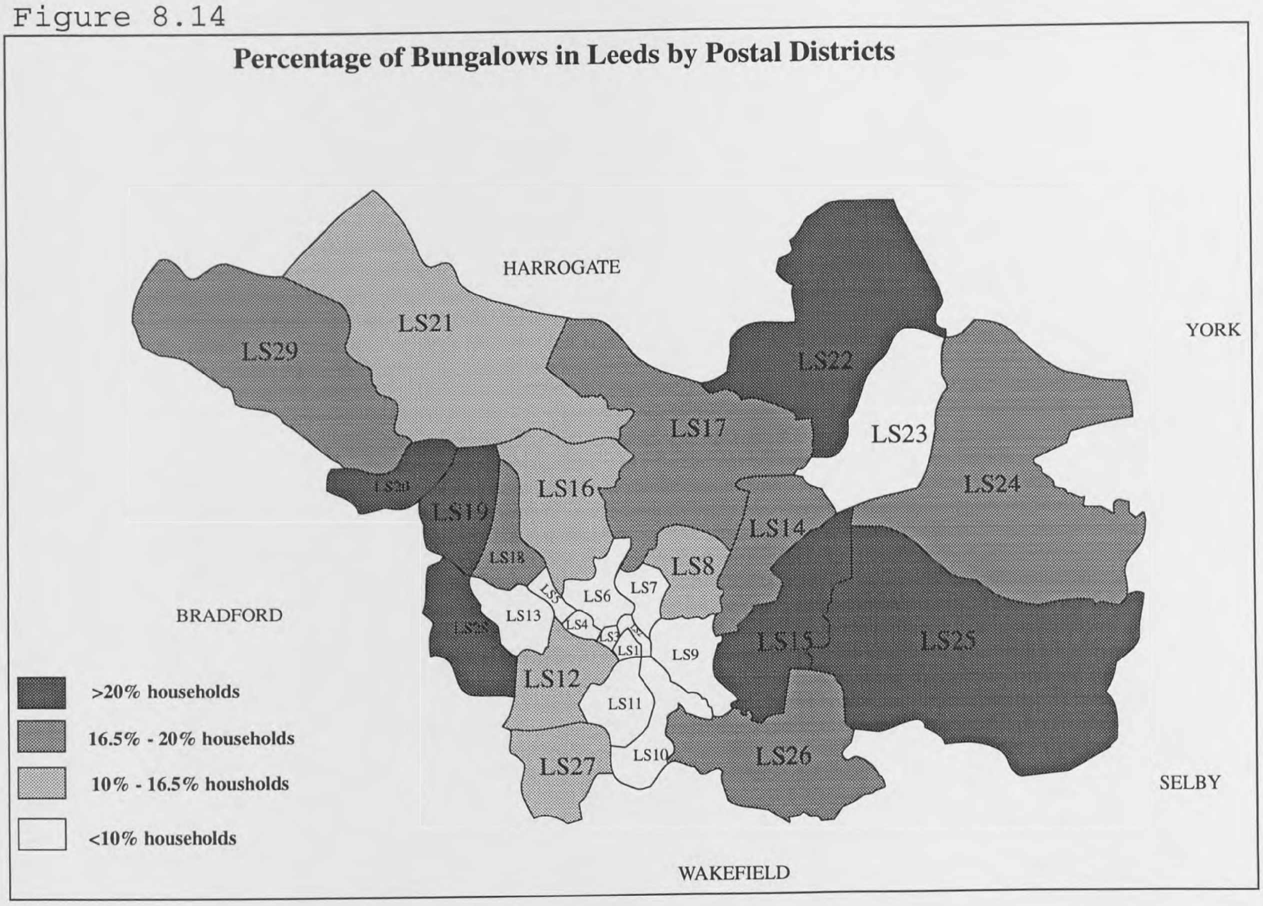


Figure 8.15

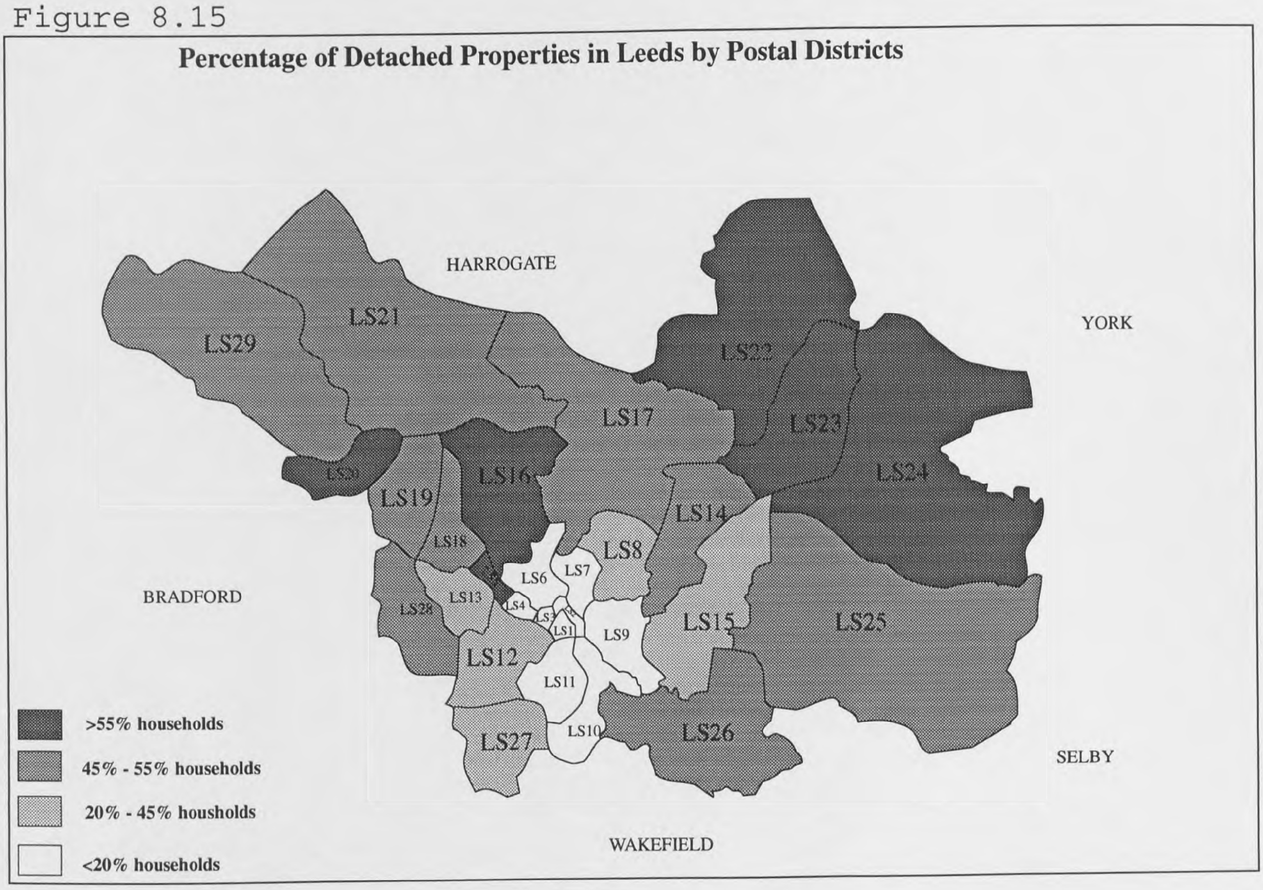
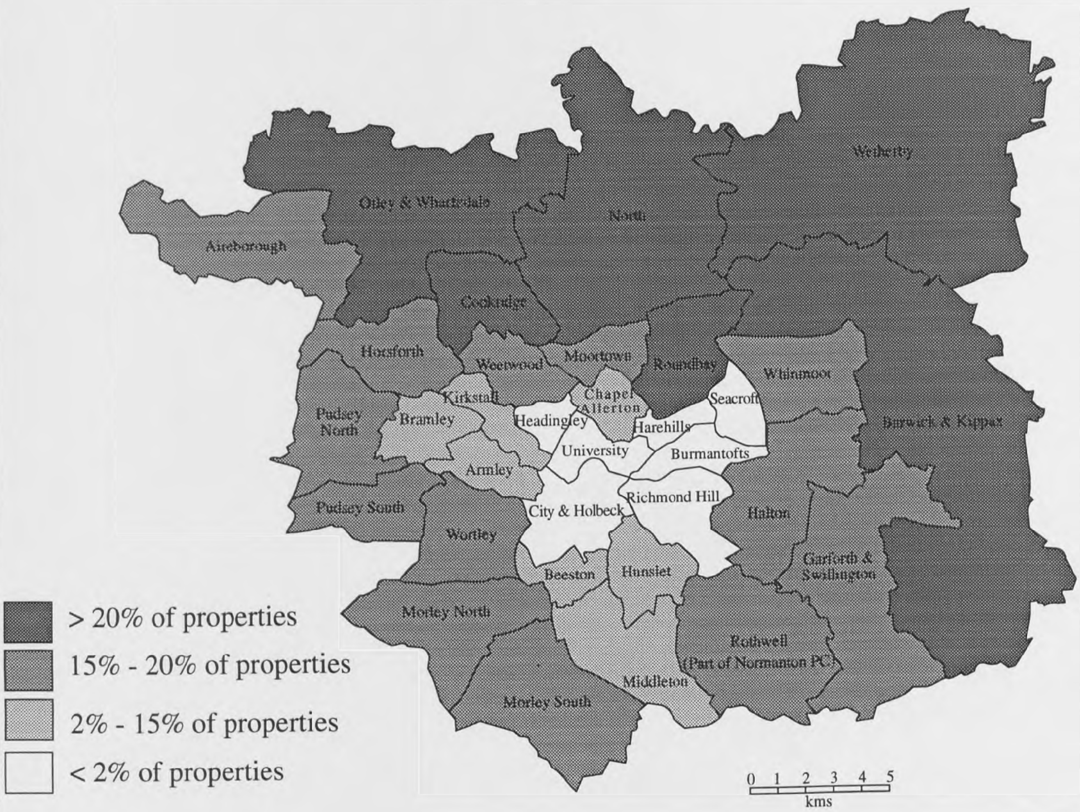


Figure 8.16

Percentage of Detached Properties in Leeds by Wards



Source: Williamson, 1993

Figure 8.17

Percentage of Semi-Detached Properties in Leeds by Postal Districts

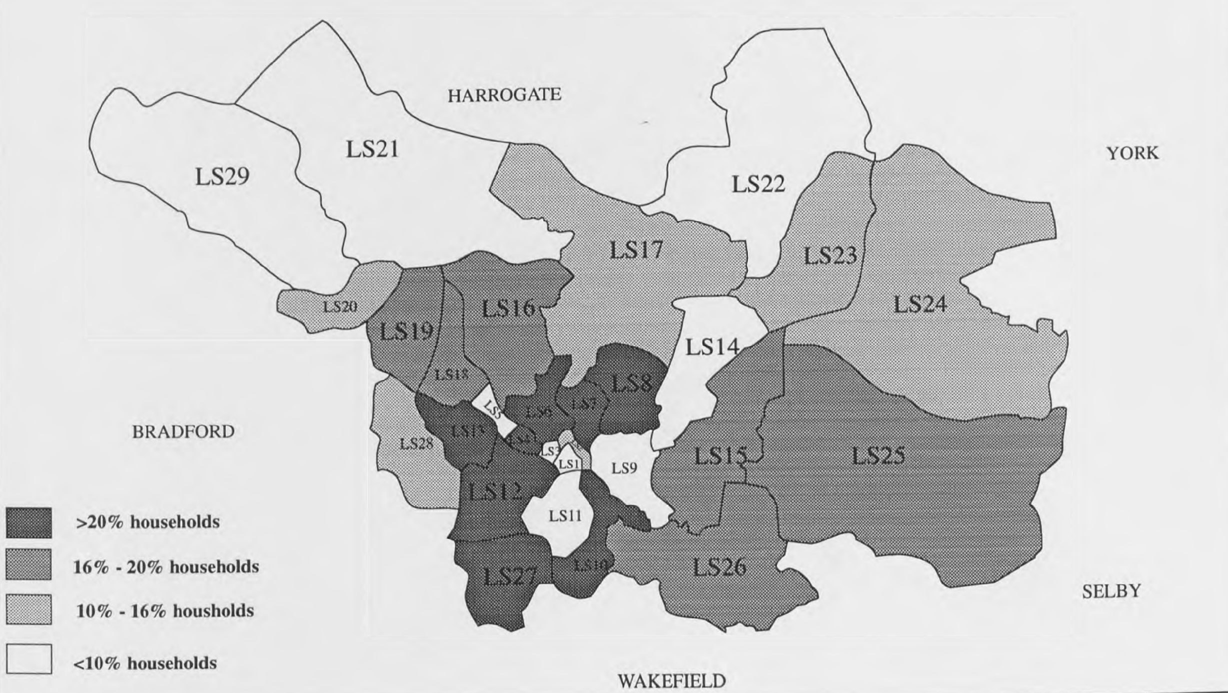


Figure 8.18

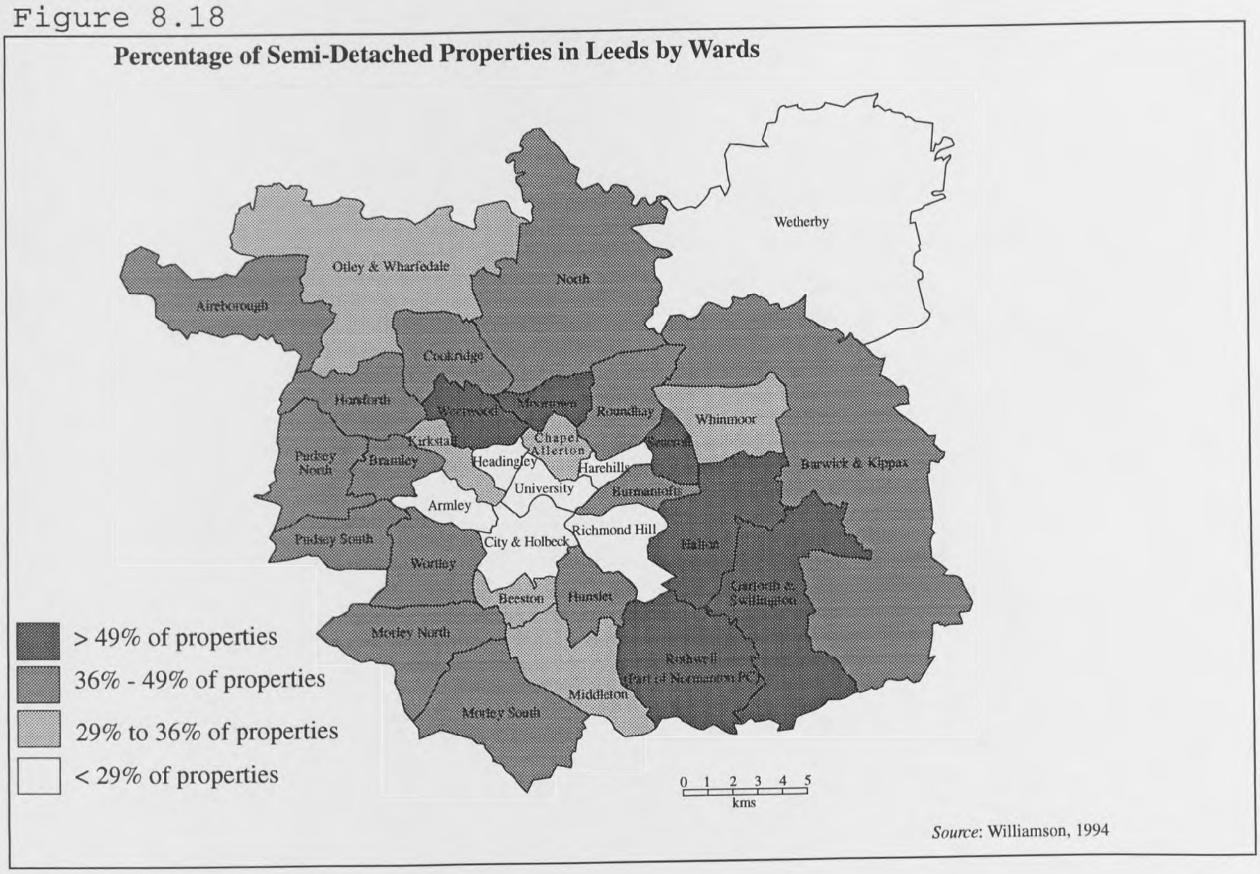


Figure 8.19

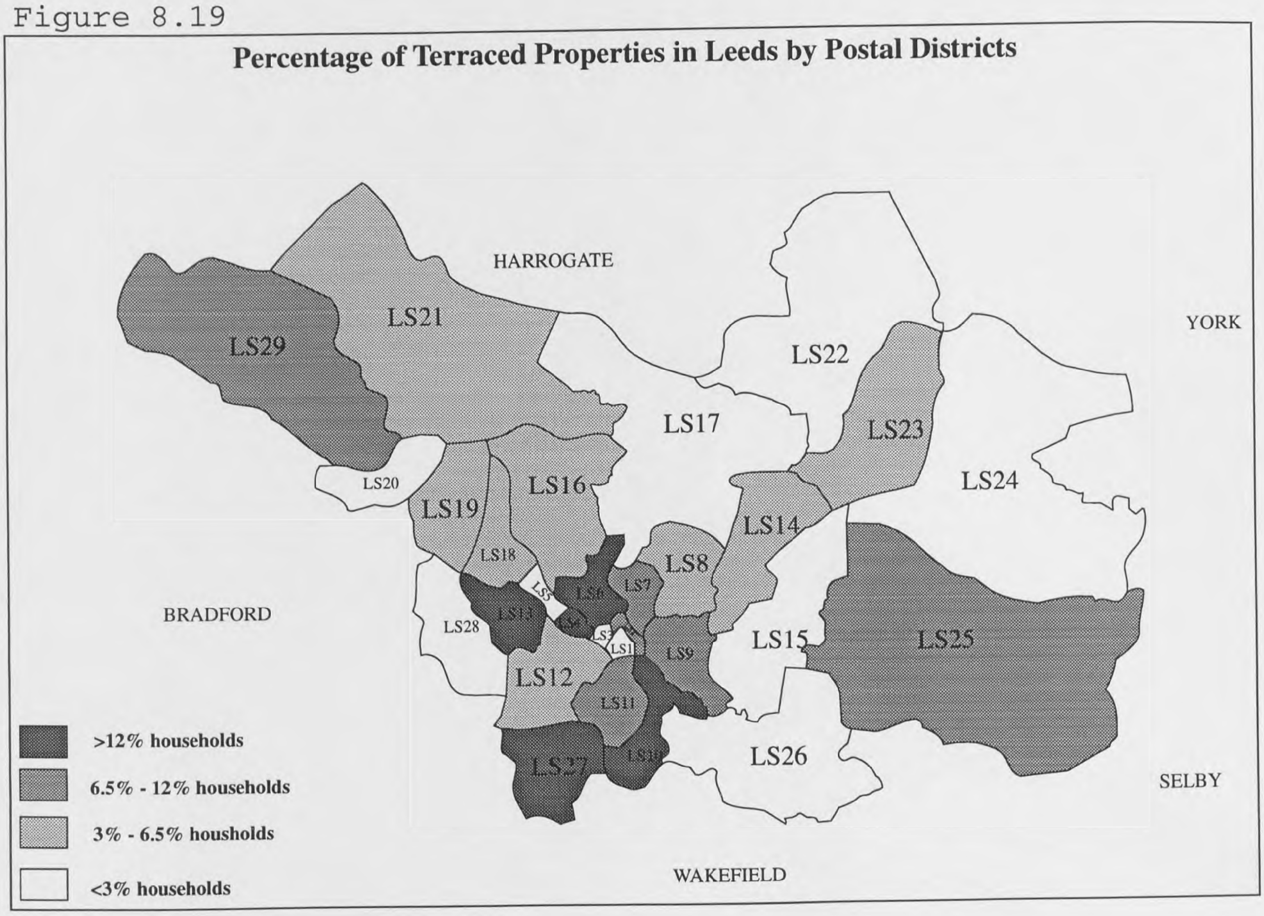
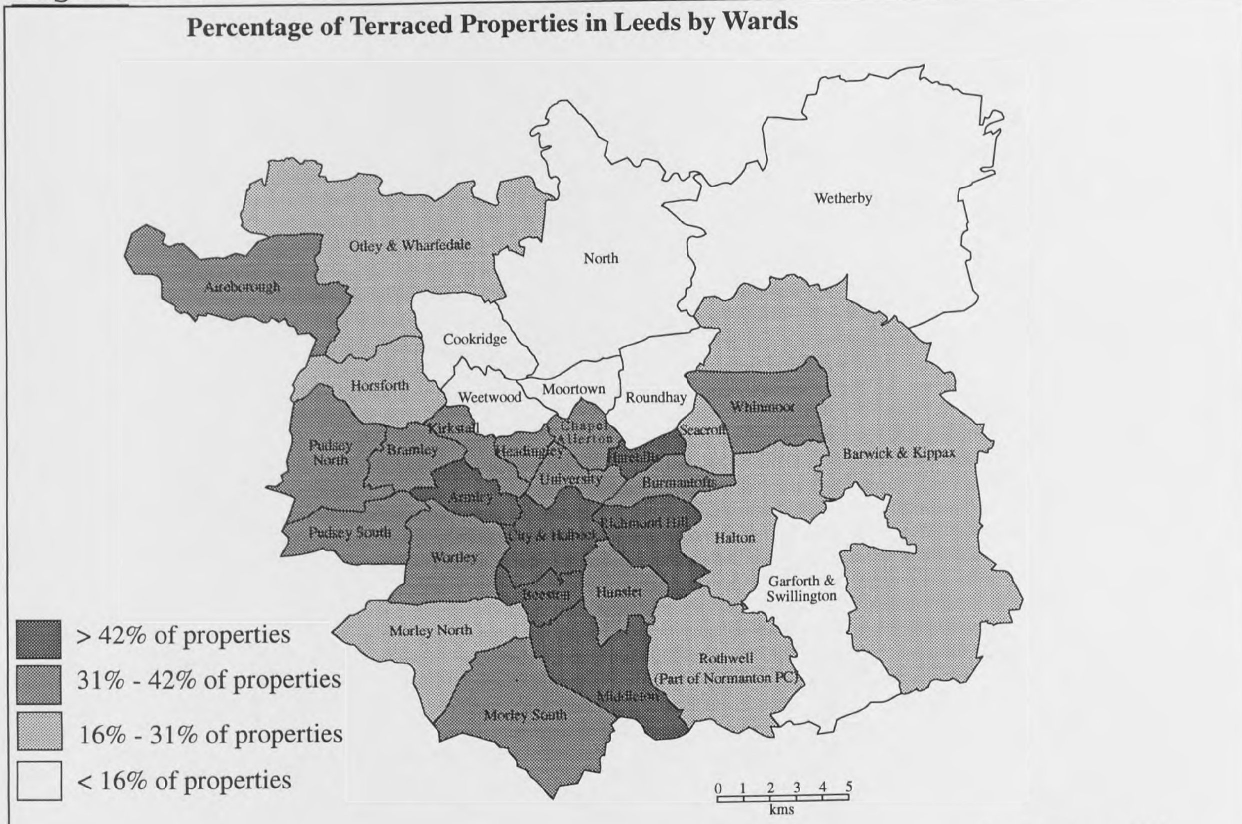


Figure 8.20



Source: Williamson, 1994

Figure 8.21

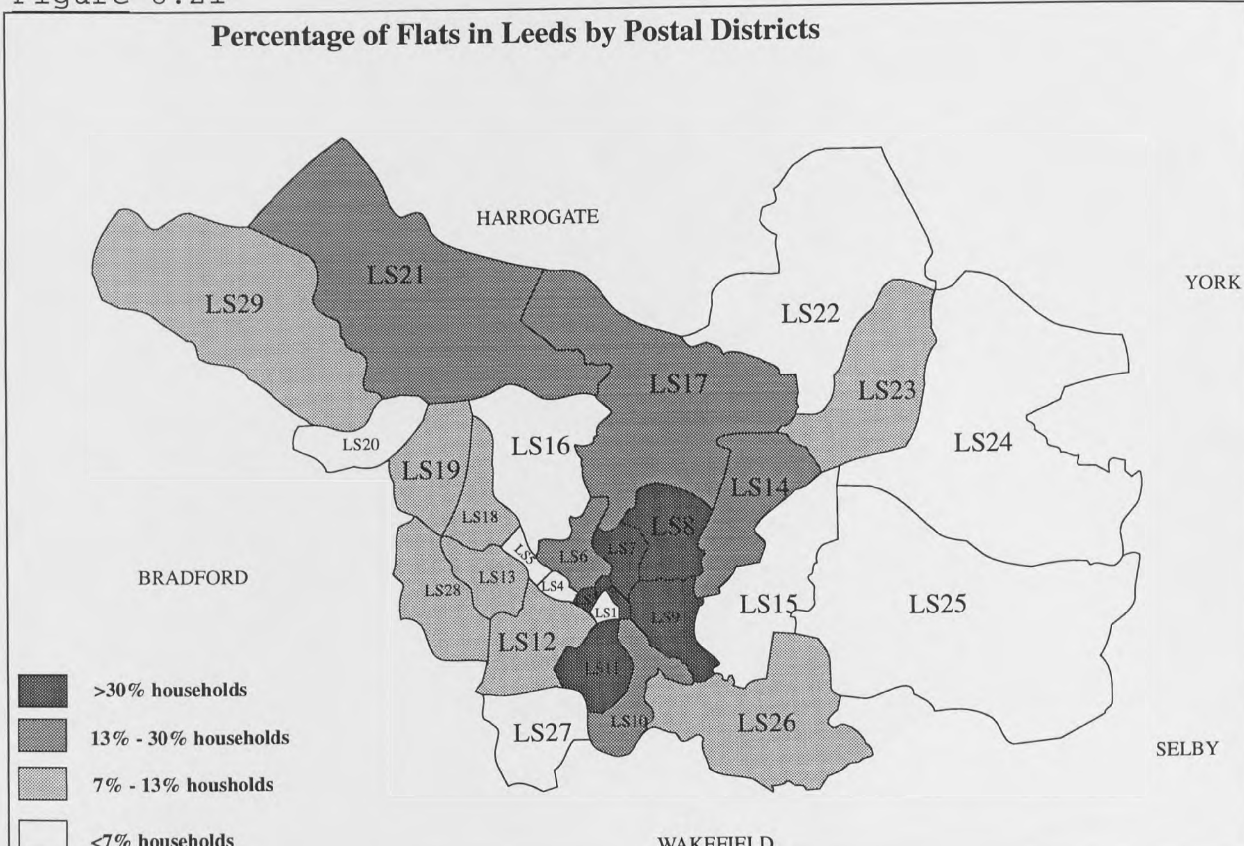
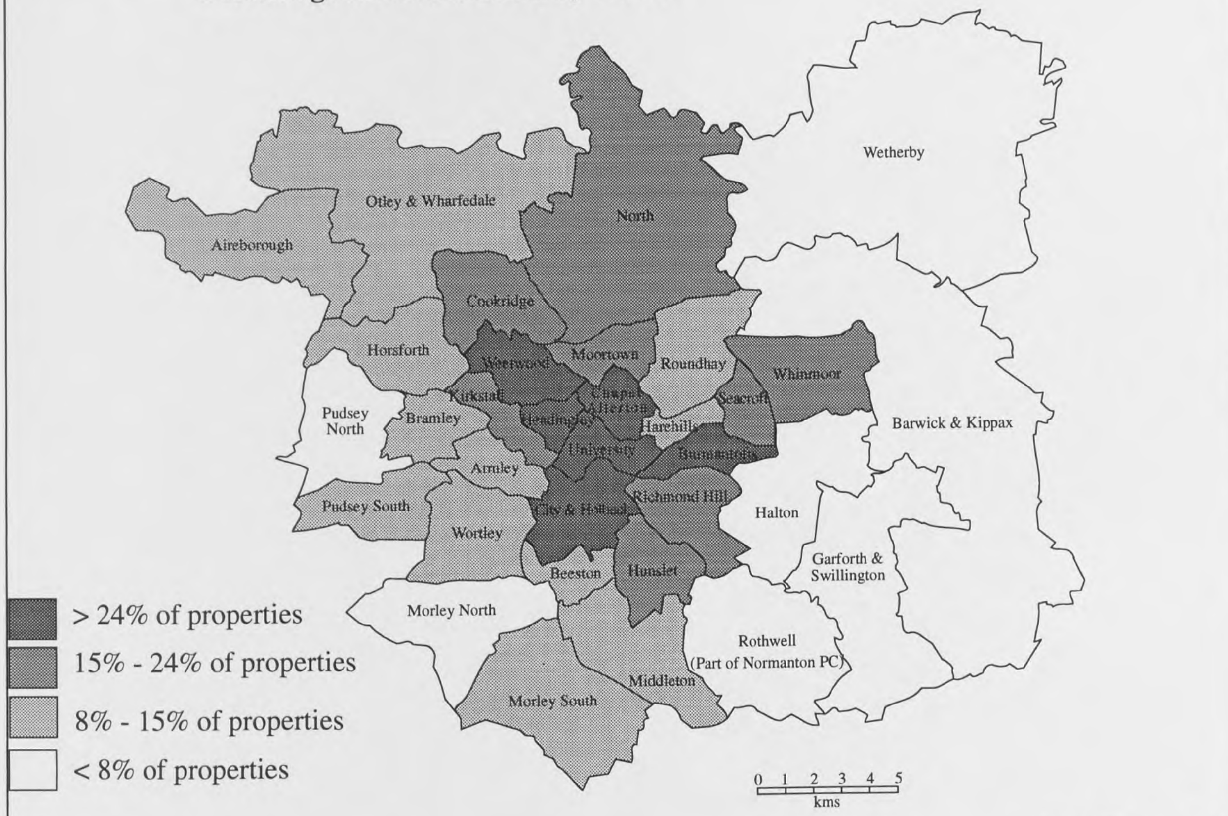


Figure 8.22

Percentage of Flats in Leeds by Wards



Source: Williamson, 1994

A higher proportion of terraced households (Figure 8.20) is in the centre and the south of Leeds; whereas flats and bedsit categories (Figure 8.22) (Williamson did not include maisonettes or bungalows in his work) are concentrated, as could be expected, in the city centre wards.

8.8.2 Assumptions

The present work does not attribute much significance to house type distribution for three reasons. Firstly, it is assumed (section 6.5) that the variations in number of occupants, number of utilities and indeed shapes and sizes of the properties themselves do not allow the drawing of any conclusive evidence from this variable alone. Secondly, the regression analysis in section 7.5 confirms this preliminary observation and the regression coefficient for house type is low (-0.02). Thirdly, there are a number of definitions which can apply to each of these categories. Thus, for example, a bungalow is also a detached property and a terraced house can be a 'through terrace', a 'back-to-back' or a 'cottage'. Each of these sub-categories has, no doubt, its particular characteristics with the attached DWU profile.

In Williamson's work the property type variable is used exhaustively for two reasons. Firstly it is assumed that on preliminary results of the present work (Chapters 5 and 6) that this variable could yield better results than it actually did. Secondly, this variable is easily available from the National Census of Population or the General Household Survey used by Williamson.

8.8.3 Variations

There are relatively small differences between the two works in representing property type profiles in the two spatial units. These modest variations are attributed to the three explanations offered earlier for the other variables - boundaries, class and projection mentioned in section 8.2. As regards the house type variable however, the complexity in the definition of the variable itself adds to the possible different interpretation of the two works.

Williamson points out that "the picture is far from clear with every ward containing at least 2% of each property type" (1993, section 3.2), and also that there are possible contradictions between the proportional and the overall number of properties.

8.8.4 Conclusion

House type appears to be the one variable which does not add much explanatory power to DWU modelling. The combination of the absence of a coherent spatial pattern with a low coefficient in regression, are only exacerbated by the lack of cohesion in the definition of the variable itself.

The absence of resemblance between any of the house type spatial patterns (either of the present work or of Williamson's) and the average or total DWU patterns (Figures 8.4 and 8.5) only reinforces the sense of uselessness of this variable. The somewhat closer pattern of DD to DWU pattern on the PD figure demonstrates this point well.

8.9 Summary and conclusions

This chapter compared the results obtained by Williamson (1993 and 1994) with the results of the descriptive analysis carried out on each of the PDs in Leeds. Throughout the comparison the nature of each of the variables is assessed in terms of its spatial distribution, the assumptions which underlie each variable and the conclusions which can be drawn from it.

This comparison had three aims: firstly, it confirmed the dominance of some of the variables over the others. Secondly, it helped in identifying the usefulness of the variables' effectiveness for the formulation of policies, and thirdly, it laid the foundation for a further analysis stage, where 'what if' scenarios can allow a deeper and more sophisticated analysis.

The chapter did however produce one important result. It showed clearly that variables which proved to be highly explanatory in the regression analysis obtained a spatial distribution pattern very similar to those observed by Williamson's model. This closeness confirms the usefulness of the results obtained earlier in this thesis.

The next chapter examines the implications which the findings of these two works could have on policy formulation, both in terms of pricing water and it terms of providing an adequate level of service for the population.

9. DISCUSSION

9.1 Introduction - summary of main findings

The present work looked at domestic water use in two stages. In the first stage data provided by YW which included 22 details of 4039 households in Leeds was statistically analysed in order to determine the main components of water use. The second stage used these components to model the distribution on the overall population, and as a result to model the DWU pattern for Leeds. The first stage was needed in order to produce the variables which could safely be modelled by microsimulation technique.

The use of regression technique to determine the variables to be modelled in microsimulation is unique to this work. In previous works, the variables modelled are self evident. Thus the 'age' variable is imperative, when modelling demographic patterns in general (Clarke, 1986) or community care for the elderly (Williamson, 1992). Similarly, 'road length' and 'road width' provide inevitable variables for road transport modelling (Öberg, 1976). In the case of domestic water use however, the variables which produce the variations in DWU are unknown.

The results of the regression analysis consist therefore of six independent variables which were concluded to be the most influential over DWU (the dependent variable). These six are: the number of persons in the household, the number of bedrooms in the property, the existence of a washing machine, the existence of a dishwasher, the property type and the number of toilets in a property. Their use for the purpose of modelling was therefore considered to be safe in methodological terms. AS pointed out in section 4.5.1, there was a problem with the use of 'number of toilets' since no backup information was available on the national frequency of this variable, which made it impossible to calibrate the microsimulation model. The 'toilet' variable was therefore omitted and replaced by 'property type', which obtained a much weaker coefficient. The six final variables produced an R^2 of 0.99 (section 7.7) which meets the standard set out in section 4.4.5.

The microsimulation model itself re-affirms, in a certain way, the conclusions reached by regression analysis. Annual average DWU is highest in the areas where the number of occupants in a property is highest; there is a similarity in the patterns of washing machine and dishwasher ownership and average DWU in Leeds. The patterns obtained by the microsimulation model correspond well to the pattern obtained by sample alone (Chapter 8), which suggests one of two things: either that the survey carried out by YW covers a representative population; or that the bias of the sampled population in the YW survey was transferred to the microsimulation model. However, since this model obtained most of its household composition data from sources other than the YW survey, it can be safely concluded that the first hypothesis holds true, and the survey covers the population well, which means that the model corresponds to the actual DWU pattern.

9.2 Discussion and analysis

9.2.1 Introduction

Having determined the characteristics of individual household water use and the spatial distribution of these characteristics in the research area, the implications of these findings for the operations of the Government, the regulators and the water companies themselves can be examined.

As is pointed out earlier (Chapter 2), the results of a modelling exercise such as that undertaken in this work cannot assign imperative indicators for one type of action or another. Instead, these results suggest a set of variables, technical as well as conceptual, which should enable the assessment of any given policy carried out by any of the bodies responsible for DWU supply.

The present chapter ties together the background of the water industry's activities (Chapter 2) with the results of the analyses in Chapters 6 to 7, and with the outcome of the microsimulation modelling which is discussed in Chapter 8.

Two main results emerge from the present work. They are the identification of the variables responsible for differences in DWU, their coefficient (Chapters 5 to 7), and their geographical variability (Chapter 8). Primarily, the effect which the number of occupants has on domestic water use was re-affirmed. This finding is supported by other works (e.g. Archibald, 1983 and NERA, 1993), as well as by the descriptive statistics, Chapters 5 and 6 of the present work, the regression analysis (Chapter 7) and the microsimulation modelling (Chapter 8). Corresponding variables (i.e. type of premises and household utilities) and their relationship were found to be useful in assessing different policy options for the WCs.

The second set of findings relates to the spatial distribution of DWU in Leeds by average and total water use using microsimulation technique. Following suggestions made by Walsh (1993), Leipnik *et al.* (1993) and McKinney *et al.* (1993), the implications of these findings could contribute to formulation of policy either by the water companies or by the regulator.

9.2.2 The main variables

The average number of occupants in a household can be translated into an area's total by using several techniques. This work found that it is not particularly useful to assess or even measure the total number of occupants in an area and multiply it by an average water use per person, as has been the procedure in the past. For a full discussion on this subject see Kindler & Russell (1984, Chapter 2), or Dzurik (1990, Chapter 5).

The necessity for a new technique is not immediately apparent. Historically, it seems, the water industry has always been able to fulfil all its statutory and other requirements, including those imposed by growing demand. 99.9% of the population is connected at present to the water grid in one way or another, and cases of dangerous diseases as a result of shortage of water or even low water quality are rare. Hose pipe bans in certain areas in summer months, and the water contamination at Camelford, in 1985 are two exceptions which prove the rule. Moreover, the techniques used by practitioners in the water industry seem to provide senior management with all the information needed to run their businesses. The question therefore is: why introduce a new, unproved estimation technique? Why re-invent a system which seem to have worked and is still working? The answer suggested here is divided into three parts.

a) The change in the status of water companies since privatisation has required them to produce a much more accurate account of their activities. This duty is to their shareholders first and foremost, but they also need to satisfy their customers that their management is effective. The accountability to a regulator who requires efficiency in performance is another outcome of privatisation which raises the need for a new technique of assessing domestic water demand. The decision-making parties in this sector could not continue in a situation where the industry accounts for the production and delivery of its core product only in terms of 'more or less', sometimes within a 10% margin either side. The main reasons for this imprecision are twofold: firstly, the inability to measure exactly the amount actually withdrawn by households owing to the absence of measuring devices (meters); and secondly the absence of any reliable information regarding leakage from the system.

Water resources have, for a long time, been considered as unlimited in this country. It is now becoming clear that as a result of three factors: the first pertain to the natural limits of a closed system, the second factor concerns the costs involved in disrupting the natural equilibrium of the water cycle and the third factor is associated to climatic change or the global warming theory.

The first factor is the natural limits of a closed system, such as the water cycle, to grow infinitely. It is becoming clear to managers of the industry that some regions in the UK will not be able, in the near future, to provide an adequate service for their domestic customers all year around unless new reserves are found. This is particularly the case in the South West, where overall demand for 2011 is expected to be up 24%; and the East of the country (up 22%). Table 9.1 points to this fact clearly: only one area considers a reduced demand (North West Water) while the average increase for England and Wales is 12% . The need to be more economic with the amount of water withdrawn, even temporarily, from the cycle has grown.

Table 9.1
Projected increase in water demand to the year 2011 (million/litres/day)

NRA Region	1990	2011	% Change
Anglian	1839	2343	22
Northumbria	1114	1218	9
North West	2550	2446	-4
Severn Trent	2398	2573	7
Southern	1324	1577	16
South West	493	598	18
Thames	4032	4723	15
Welsh	1216	1417	14
Wessex	861	1135	24
Yorkshire	1457	1587	8
England & Wales	17248	19617	12

Source: Water Services Association (1993)

The second factor is the growing awareness that unchecked usage of water disturbs the natural equilibrium which maintains the quality of water in the cycle at a stable standard (McDonald & Kay, 1988). Thus the need to treat water as it is being withdrawn for use, and to re-treat it once again when it is returned to the cycle increases the costs involved with the supply of water in direct relationship to the amount withdrawn. The limits are therefore in the amount of available water for domestic purposes rather than a simple total amount. It is because there is no separation between the supply for domestic, industrial or agricultural use, that water standards have to be maintained at a high level at all time (Brandon 1984, Chapter 4).

The third factor which may affect the supply of fresh water is the perception of an imminent climate change which has driven many academics to the conclusion that there is a need for new contingency plans (Mitchell, 1989, Chapter 5). These comprise both the understanding of global warming, finding alternative resources which could be affected as a result of such warming, and simultaneously the understanding of the exact pattern of water usage.

b) The second need for a new approach to water use assessment, forecasting and modelling relates to the present cost of producing water. As water appears to turning into a scarce resource, whether this perception is exaggerated or not, the need for investment in its preservation is growing. With this need comes the requirement for a better, more efficient use of this resource. As noted above, the treatment of water and sewerage has become more sophisticated and as a result, more costly. The value added to each unit of water thus becomes important enough to be measured precisely. In other words, until recently, a resource planner in a water company could have estimated the amount invested in the treatment of water in gross terms (as in Brandon , 1984, Chapter 6). However, with the importance attributed to the quality of water consumed and discharged these costs have become considerably higher both in terms of the energy required to perform the treatment and the chemicals themselves (Stewart, 1993).

c) The last argument for the need of a new method for water use estimation is the change in the accountability of the privatised water companies. Being a nationalised industry, as the WSCs were until 1989, meant that they were accountable directly to the Government and hence to Parliament. Privatisation has changed the position radically. The terms 'efficiency' and 'equity', often used to describe the joint goals of utilities are in effect, incompatible (Veljanovski, 1993). A nationalised firm is concerned primarily with the welfare of its customers, and any considerations of economic performance should be secondary (Brown & Silby, 1986).

Having to satisfy only the management of a nationalised industry for decades, there are now new responsibilities, first and foremost to the shareholders. This situation produced annual accounts for a firm the size of YW, that cannot account for the deliveries of their main product more accurately than ±10% (at best) as a result of un-accounted for losses from the system (YW, 1994).

These three reasons demonstrate that the need for assessing DWU beyond the 'average water use per person per time unit' is real. The tools available to policy makers are two: a more accurate total demand estimation and a sensible tariff structuring. The first tool is the focus of many discussions on the subject. Works by Hanke & Mehrez (1979) and Archibald (1983) carried out in different locations in the world, achieved different results concerning the average water use per person, yet the reasons for these discrepancies were never investigated. In other words, the question: 'why does one person in Western United States use on average more water than one person in Derbyshire' was never asked.

Total demand estimations are still performed using regression analysis where past trends are used to extrapolate future demand, usually by indicating three possible future scenarios (high, middle and low demand). Thus works by Rees & Rees (1972), Brandon (1984) and Bell (1986) show total water use only as a function of per-person averages over time. The problem with this type of work lies in the underlying assumptions and in their rounding-up of information. For methodological reasons, the former problem is discussed in section 9.3 below. Rounding-up of 'units per person' may create the problems usually associated with the aggregation of rounded numbers which in turn are rounded again. The advantage of such a procedure is its simplicity; the disadvantage is in its being inaccurate. In the eyes of some writers (e.g. Gibbs, 1978; Charney and Woodard, 1984) this is the essence of the argument between those who measure price elasticity of water in terms of average price and those who measure the price elasticity of marginal price.

The result of the present work suggests that the use of 'a person's' average water use is not a sufficiently accurate variable for DWU estimation. The addition of two or more variables (depending on geographical location) add considerable weight to any estimation. In Britain, for example, the additional coefficients of 'washing machine' and 'dishwasher' ownership and the 'number of toilets' in the property increase the estimation accuracy by over 10% (Chapter 7). The same coefficients do not necessarily apply to the Western USA, where Metzner (1989) and Nieswiadomy & Molina (1989) suggest that swimming pools and lawn size account for a bigger DWU proportion than any other, after per capita use. Crude estimation of DWU anywhere could continue to be performed using the old, well tested regression analysis but its accuracy could be enhanced considerably by adding some secondary independent variables.

In addition, the accuracy of DWU estimation can be even more refined if a seasonal, or peak element is introduced. Although the present work does not develop this subject, it is obvious from the works of Billings & Day (1989), Bland (1986), Martin & Kulakowski (1991) and Maidment & Parzen (1984) that variations between years and seasons do contribute to the change in water use. It is also useful to note that Major & Lenton (1979) point to the importance of seasonal variations to the junior regional managers, but not so much to the senior management. The concern over a possible climate change may prove this last point wrong.

The second aspect where the addition of independent variables to the demand function can be useful is in the structuring of tariffs. Some information on the availability and proportion of ownership of utilities and amenities in the house is usually available in one form or another. In the present work, the General Household Survey was consulted. Others, such as Dun & Larson (1963) and Hanke & de Maré (1982) extracted similar information from other sources in the USA and Sweden respectively. The advantage of using additional independent variables is their adaptability to become proxies for income or other socio-economic grouping, and hence for price elasticity estimation. A number of works looking at this subject e.g. Foster & Beattie (1979) and Opaluch (1984) failed to achieve a satisfactory estimation of overall water use in relation to its elasticity.

Thus for example, the number of persons in the household was shown in the present work to be positively related to the ownership of a washing machine. Similar results are obtained, although with a somewhat less substantial statistical validity, from the addition of age composition of the household and the type and tenure of the property. As in the estimation of total water use discussed above, tariff structuring by disaggregating 'occupants' to more than one category allows the estimation of the effect any given tariff structure on different segments of the population. Thus estimations obtained from the works of Harris (1992) and Waterstone (1993), could be re-evaluated.

Although price elasticity of water is not tested in the present work, there are several indications of the magnitude of this in compatible areas of the USA. Thomas & Syme (1988) and Weber (1989) produced a reasonably accurate estimation of such elasticities in the eastern and north-eastern states of the USA. The results of the present work could be used in similar models to identify household types characterised by more than one variable for targeting pricing policies. Scenarios of DWU could, therefore, be produced not only by number of occupants and ownership rates, but include different price structures and their effect on the total demand.

So far the discussion has involved the results of the present work concerning DWU, methods for its calculation and the improvements which the use of certain techniques could produce. It is argued here that the additional variables attached to the main component of DWU, i.e. number of occupants, can provide a much improved indicator to the amount used at present and the amount that will be required in the future. These advantages can be used to better assess the total quantity of DWU in any area, by providing more accurate information. The additional variables can also be used to assist in the construction of more equitable and technically feasible tariff structures. The next section looks at the spatial element of employing the methods of analysis used in the present work.

9.3 Spatial modelling

9.3.1 Introduction

Spatial aspects of DWU are used to demonstrate the descriptive, the predictive and the scenario-building abilities which the technique used in the present thesis could be developed into. The main features of the techniques, namely regression analysis combined with microsimulation are a) the ability to describe the present characteristics of any given spatial unit in terms of DWU with maximum precision, and b) the ability to predict future changes in DWU patterns with a high degree of accuracy through the ability to run scenarios. These scenarios can incorporate global economical changes, cultural phenomena, life cycles or any other element which may affect water usage.

A 'what if' scenario could look at how DWU would shift according to the three components of the model: the economic conditions (e.g. any standard of living index); the demographic condition (the size and age profile of the population in the area); and the climatic conditions comprising of average rainfall and temperature. All these data are available from other sources (e.g. OPCS, Institute of Hydrology)

The model could estimate the total DWU for this ward for any time horizon required. It could incorporate elements of price elasticity which would portray total DWU when price is structured with some social considerations (i.e. with an ascending block structure) or solely with operational considerations (i.e. descending block structure). Such a model could be modified by changing any of the assumptions, including the scale area investigated. Any results obtained from this model could later be modified by running a subsequent model with one or more different assumptions, thus simulating different scenarios.

One simple hypothetical example would include DWU simulation for the Headingley ward five years from now, with the assumptions of the present rate structure, regional economic and climatic conditions unchanged. One scenario would assume the population size and profile unchanged, while the other scenario (the 'what if' scenario) would simulate a growing population but with a similar age profile. By changing the value of population number DWU would shift and allow a more accurate prediction for small geographical areas.

9.3.2 Present DWU characteristics

British researchers such as Thackray *et al.* (1978), Archibald (1983) Russac *et al.* (1991) and Dovey & Rogers (1993) assess actual DWU in Britain by a variety of means. All these works' results were useful, but owing to their relatively small sample size could not be safely generalised over a larger population. Any pattern of spatial distribution which the surveys displayed could not have been substantiated with sample sizes of 853 properties as in the case of Archibald or 969 properties in the case of Russac *et al.*. In other countries where metering is not practised, such as in parts of the USA or Canada, components of DWU are also a common topic of research.

Grima (1973), Carver & Boland (1980), Maidment & Parzen (1984) and Smith (1988) who look at municipal water use in North America draw conclusions on DWU without ever investigating the micro spatial level. In an economic system where the price of water is determined according to its average cost (as is the case in Britain), there seems to be little apparent interest in the micro distribution of water use patterns (Howe & Linaweaver, 1967). However, the new structure of the industry may require such a level of precision, such as the present work suggests. Three main advantages of the technique used in the present work are pointed out: it can be used as an aid for determining charging methods (see the metering debate, section 2.3.7); it could be deployed in the composition of tariff structure (section 2.2.4); and finally, it could establish more precisely the amount of water lost through leakage and other losses from the system. The full debate concerning substitutes for water charges by RV before April 2000 is fully described in section 2.3. The present work contributes to the methods mentioned there at least two and possibly three more ideas.

Firstly, there is a possibility of allocating any postal sector (PS) or enumeration district (ED) an individual water use value. Each spatial unit is estimated to possess the characteristics that are attributed to an amount of water. Households within this spatial unit therefore need not be charged according to the average water use of the larger geographical area to which they belong. Under such a method each small geographical area (SGA) would possess its own value which could be changed either as a result of notification from the residents themselves or by the use of artificial data updating techniques such as SYNTHESIS (Birkin & Clarke, 1988). It should be noted here that the results of the SGAs microsimulation modelling in Leeds will be published by Williamson (1995) in the coming months.

The second suggestion is that the banding of SGAs be based on an independent banding system created by the water company and not on the Council Tax as suggested by Langdon (1994). This system would correspond both to the exact area profile and to the actual DWU pattern as opposed to proxies derived from other sources and transferred onto larger areas. The number of bands in such a system is not limited, and could vary to reflect the variation of DWU in different communities. In addition, areas where DWU can be determined as more seasonally sensitive (e.g. where properties possess large lawns) could be charged by seasonal bands.

The possibility of simulating even smaller areas, such as an individual household is presently ignored. This is so not only for technical reasons, but it involves equitable questions which may prevent such a system ever to operate. The problem is that simulation models do not account for unexpected variations which occur in real life (Kindler & Russell, 1984: 45). Thus for example, a household which was absent for a long time from the property would be charged according to the average annual use; or a property which changed hands would be charged by the characteristics of the previous owner etc. Such cases would raise not only the equitable aspects, but perhaps even more importantly, incur considerable legal costs.

Another possibility, related to the second proposal, suggests that in SGAs where meters are installed, water would be charged not by a uniform average price, but by blocks (see section

2.2.5). Thus SGAs with a high density of population with relatively low income (e.g. inner cities) would pay a lower sum for any unit used, while others in a neighbouring SGA, where a similar water use pattern may be attributed to more prosperous features such as a lower density but with higher income, could be charged at a higher price per unit.

Although the composition of tariff structure is discussed elsewhere in this work (sections 2.2.4 and 3.5), there are additional options for tariff structure related to the spatial distribution. As part of the debate on whether to introduce a uniform price or a block structured price the spatial distribution of water use can be helpful. A regression analysis of SGAs could determine their price elasticity and consequently compute an overall pattern which could suggest the method to use. Such a decision would be aided by the aggregation of the micro characteristics typical to each SGA rather than being inferred from assumptions associated with larger geographical areas as is the case at present.

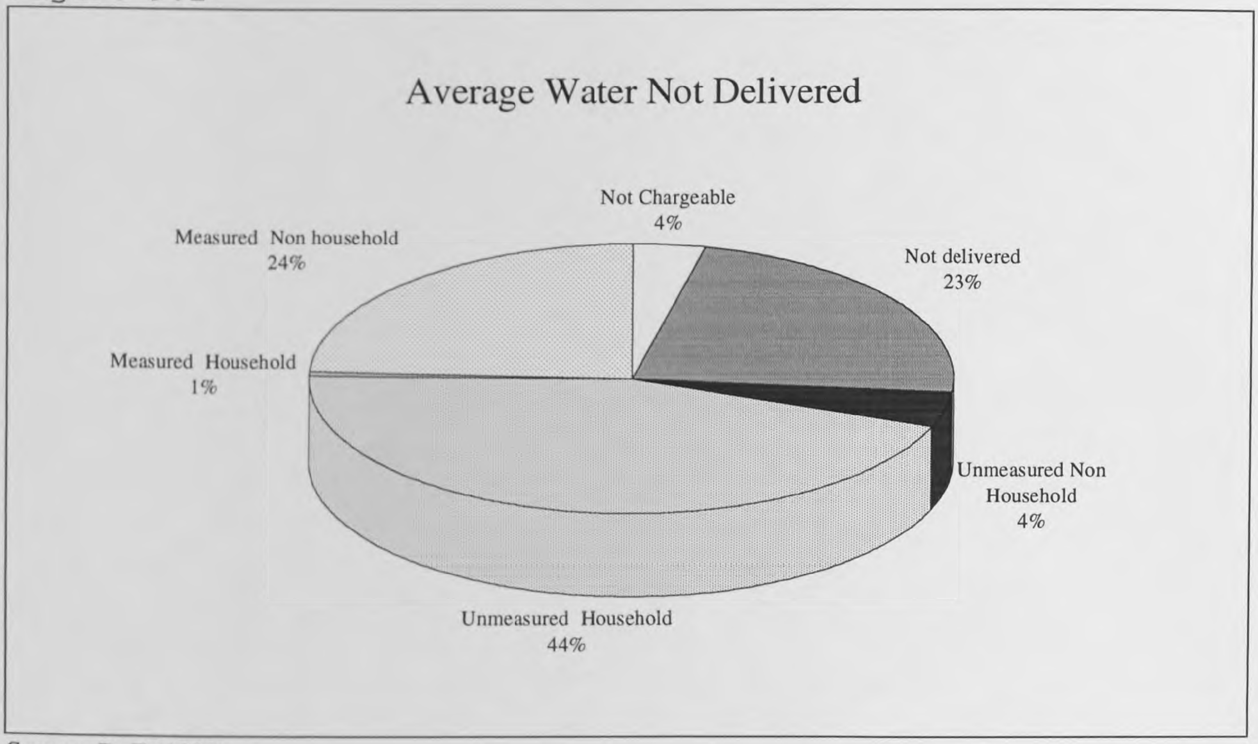
The second possibility is to use microsimulation in order to run price elasticity scenarios with assumptions drawn from the regression analysis of previous works. Results obtained by Weber (1989) for example, could provide estimates of price elasticities based not only on water use pattern, (which the regression technique can do) but on a whole range of other elasticities. Price of other utilities, such as electricity or retail price of water using electrical goods could be attributed to the SGA from other data sources such as private market research firms or population censuses.

Finally, microsimulation could determine the scale of any block rates, if such a tariff structure was to be used. In certain works, such as Brownstone *et al.* (1988), Amerheim & Macintosh (1988) and Williamson (1992) such scales are constructed for other purposes: in Amerheim & Macintosh the scale was entries into the labour market, in Brownstone *et al.* it was housing demand and in Williamson the scale was of assistance for the elderly. In all these works the principle issues concern equity in an allocative system, in much the same way as it concerns the present work. A similar principle could, therefore, be applied in the case of water use, making sure that if such a political decision is taken, it can be performed in the most equitable way. Soi far works in this area, e.g. Martin & Kulakowsky (1991) failed to assess the precise effects of block rates on income groups. They estimated that they did not have the tools to carry out such a complicated task.

The last advantage of the method used in present work for estimating actual DWU is its ability to ascertain water losses from the system with a higher accuracy and reliability than is possible at present (see also discussion in section 5.2.3). The proportion of water loss from domestic properties can be appreciated from Figure 9.1. In particular the unmeasured household sector stands out as the largest single element for water not delivered. This proportion could, of course, be much larger as the amount actually used in unmeasured properties is unknown.

There are three possible advantages which the present work can offer in this domain. Firstly, by subtracting the exact figures from the amount supplied, any loss could be indicated with greater accuracy. Such figures are critical in particular since the planners of the industry cannot presently point to the amount lost in respect of domestic use (Haughton & Hunter, 1994: 166). Other works concerning leakage such as Dovey & Rogers (1993) and GMAP (1992) point to the lack of actual usage information as a primary cause for the inconsistent figures attached to water losses.

Figure 9.1



Source: DoE (1992)

The second advantage which the present work could introduce to leakage control is the ability to identify the link between the spatial distribution of households with their precise water usage pattern. The comparison of a modelled supply pattern with the amount actually supplied could detect lost water within an SGA. Such a system depends, of course, on accurate measuring of supply areas (or nodes), which is not always achieved (Brandon, 1984, Chapter 12). Even if not precise, the use of this technique would alert the management to the possible area of water loss.

In the third instance, a predetermined figure of water loss could be attached to each household's water use. This figure, which could be calculated as an integral part of DWU could vary according to attributes which would be attached to the SGA in which the household is located. The length of the mains, their age and other characteristics (material, type of soil etc.) together with water pressure in them could be associated with specific SGAs and hence increase the ability to detect potential areas of risk. Another aspect of water loss estimation is discussed in section 9.3.3 below.

But by far the most important role which the method used in the present work offers the water industry is the freedom in the aggregation data. In essence, the technique offers the possibility of using data collected, as is the present case, for billing purposes (i.e. in PDs), and re-aggregate it in the form which would fit the actual water network (Nodes).

Properties whose details were collected in postal sectors, for example, could be regrouped in EDs, for demographic predictions, in PSs for economic evaluation or into nodes for engineering purposes. This would contribute to the ability to cross tabulate information from different sources, which in turn would enable the micro-data attached to individual properties and associated previously with billing only, to be used in the context of the water supply network.

So far the advantages of using microsimulation to assess the present water usage pattern has been described. It points to the advantage of using micro-data in SGAs as a means of substituting other mechanisms of charging, pricing and leakage control. The next sub-section examines new ways to increase the ability to predict future DWU pattern which include the methods used here.

9.3.3 Future demand modelling

The ability to prognosticate fine variations in DWU is another advantage of the techniques used in the current work. Whereas the technique used both in Britain and elsewhere at the moment consists of extrapolation from past trends (see Brandon 1984, or Bell, 1986), microsimulation allows the construction of spatially related scenarios which incorporate variations that stem from locational pattern. The two noticeable advantages of this method are firstly the ability to run scenarios based on series of assumptions and secondly, to bring together the cyclical nature of water processes. These include, apart from the natural seasonal cycle, also human life's cycle and rhythmic changes of urban development patterns.

The seasonal cycle is often treated in terms of 'peak' and 'off-peak' periods (see for example Lyman, 1992). However, between these two points in time lies a wide area of DWU which is often ignored for lack of technical ability. In other words, it is assumed that peak season is the target of water planning objectives, since this is the maximum which the system has to satisfy. This peak corresponds to the lowest period in natural irrigation and the highest in temperature and is therefore of important implications for agriculture as well as for domestic gardening (Gouevsky & Maidment, 1984). Conversely, the period when water usage becomes less prominent corresponds to the rainy season, when temperatures are lower. Most models which look at these phenomena treat DWU in all periods with what can be described as a binary approach. The resulting DWU prediction often oscillates between peak predictions, and tends to be higher than the eventual level (Gysi, 1981).

However, the present technique allows peak and off-peak DWU patterns to correspond to effects other than climatic variables. The attributes which determine any SGA's DWU could include for example, a variable describing the size of the lot which is easily translatable into garden size. Billings & Day (1989) and Renzetti (1992) point to the positive relationship between peak DWU and garden size in the USA, which is also observed in works of Thackray *et al.* (1978), Archibald (1983) and Russac *et al.* (1991). Thus peak demand of an SGA with average garden size would probably vary considerably compared with that of a neighbouring SGA with small or no gardens at all.

Moreover, the phenomena of annual cycle has demographic aspects as well. Summertime, with which peak water demand is usually associated, is also the period in which most holidays are taken. Thus some areas lose a considerable proportion of the population for some part of this season, while other areas have to cope with additional demand. The pattern of DWU for each SGA can perhaps not be exactly pinpointed in time, but by attributing SGAs a specific social index, independent from the more sweeping ones such as ACORN (Russac *et al.*, 1991), a sounder prediction could be made in this respect as well.

Related to this topic is the notion of the biological life cycle. As the works of Hanke & de Maré (1984) and Lyman (1992) show, the age of occupants has a clear effect on DWU pattern and this, in turn, can be translated into a variable which can be adjusted in time. Each SGA could be simulated to undergo the life cycle of its population profile which would eventually alter its water usage pattern (along with other behavioural patterns). However, life cycle is not only a human phenomenon. It is now that leakage from old mains is more frequent than in newer ones known (Dovey & Rogers, 1992).

The last advantage in the use of the present technique is its ability to incorporate features of urban redevelopment. In the 'classical' method of water prediction the size of population, which is the main water use element, rarely falls. This is so because on an urban scale, even if cities lose population in real terms (London lost between 1971 -1981 about 814,000 people; Armstrong & Taylor, 1985:105) the effects on DWU does not vary radically. For the purpose of the YW survey, the population of West Yorkshire grew regardless of whether it lives in the city centre of Leeds (LS2) or in a rural area near Wetherby (LS22). Moreover, patterns of average DWU have been shown in the present work to be higher in the suburbs than in the city centre (see Figure 8.4), so that out-migration from cities could actually increase demand. In addition, many areas in city centres (e.g. Leeds) have undergone regeneration in the past five years, which changed many former industrial districts into residential areas (e.g. The Calls). In these cases too, the ability to disaggregate SGAs, combined with the ability to introduce a cyclical element into the development of urban areas, could produce a more accurate picture of DWU.

This section has looked at the potential of spatial pattern of DWU modelling using techniques tested in the present work. The advantages of this technique emerged in two aspects: the accurate estimation of present water use where there is no other way of generating such data; and the ability to predict future water use beyond the limits of linear regression technique. These two aspects rely on changes which occur at the micro-level of water use - the household - and its non-linear aggregation. The ability to combine separate data sources as well as the introduction of cyclical element into the model could increase the ability to assess and to predict DWU without a need for further technical devices such as meters.

9.4 Further development

9.4.1 Introduction

In view of the results obtained in this thesis, there are several ideas which could be developed by further research. This section tries to foresee possible avenues for such research, and in the process highlights limitations and shortcomings of the path chosen by the present work. For technical reasons the section is divided into two parts. In the first part the present work is discussed in hindsight, whilst in the second part developments which could be made on the basis of the present work are presented.

These two approaches to the epilogue could also be described in lighter terms. The first approach asks of the work 'what would be done differently if the project was to be restarted now?', whilst the second approach asks 'where and how far could the conclusions drawn from this work lead?'. The former resembles a list of complaints, while the latter is perhaps an imaginary journey.

9.4.2 Hindsight comments

The comments concern three subjects where a similar type of research could have been conducted differently. In the first instance a more accurately targeted questionnaire would have been used. As pointed out in Chapter 4, the questionnaire was designed and carried out by the finance department of YW for purposes other than the present research. As such, some of the questions which might have produced a more concise result were never asked. One such question concerns the age structure of the household. As it is mentioned several time in the present work, there is ample evidence, not least in the preliminary survey (Chapter 5), that this variable affects DWU pattern.

The second question which should have been added to the questionnaire concerns the age of the property. This is discussed by Dovey & Rogers (1993) and is probably just as relevant to the part of England in which this research was carried out. The third question which would be included in the questionnaire is the size of the garden and its nature. As complicated as such a question may initially seem, five categories of the type of 'no garden', 'front and back large garden', 'small front, large back garden', 'front drive, back garden'; and 'front garden, back yard' might have helped considerably. Of course, a more technical question on this subject, such as the size of the garden in square yards or the nature of the vegetation in it, is also possible. An odd question, but one which may have produced surprising results, would concern the existence and size of swimming pools and/or Jacuzzi baths (see Renzetti, 1992).

A comment which is related to the questionnaire, although it is not an additional question is the spatial units in which the information was gathered. Had the information been gathered in wards rather than postal districts, it would have been easier to compare the two parts of the work. Additionally, the annual average DWU could have been broken into quarters or monthly averages. DWU by period is easily available to YW, and its inclusion may have enabled the assessment of seasonal variations on the overall average.

Finally a question should probably have been asked about the economic status of the household. Again, a simple format question such as the number of employed persons living in the household could be satisfactory in order to avoid a large number of no answers.

The second comment relates to the manipulation of data collected by these questionnaires. Rather than model the present water use, a more challenging programme would have been to assess past DWU pattern. In such a system the results could have actually been tested, at least insofar as the total amount supplied is known. Such a technique would identify an erroneous model on the overestimating side, and in the case of too little use, the area concerned could be tested in smaller units (EDs). Parts of this comment are already being performed as part of the next stage of the present research project.

The third difference from the present work would involve a more thorough data gathering technique of the type currently carried out by Anglian Water Plc. Over 2000 properties representing the widest available profile of the region's customers are connected to telemetric water meters with regular (over twice a day) individual logging of six taps in each property. Such a survey would have eliminated the need for the first part of the present work, and microsimulation modelling could be performed on a much safer ground. Although it is unlikely that the funds necessary for an investment of such a magnitude would have been given to the present work, it could have undoubtedly increased the value of its findings considerably.

9.4.3 Proposal for further research

Two ideas for furthering research into DWU are proposed here. The first concerns the effect of price and pricing policies on water use in England; and the second compares DWU patterns in two or more European countries.

The first proposal has a sound literary basis for research as the topic is exhaustively discussed in the literature originating from the USA and elsewhere (e.g. Clemenz, 1991; Martin & Kulakowsky, 1991; and Nieswiadomy, 1992 from Poland). As the debate over the advantages and shortcomings of privatisation of the water industry gathers momentum with the possibility of a new Government in 1996, such a research may be of high political value. Additionally, a comparison between DWU pattern and other utilities such as electricity and gas could be performed using price as an anchor. A third possibility for such an investigation would be the modelling of DWU pattern with other, apparently not related, utilities such as health care or transport. A study of that nature could concentrate on the relationship and trade-offs in the consumption of different utilities using cost benefit analysis or other econometric models.

The second proposal has a wider geographical scope. Research similar to the present work was carried out in other countries in the past. The USA, Canada, Holland, Sweden and Poland all produced at least one work on this topic, and there are, no doubt more works which were not traced by the present thesis. The objectives of such a work could be manifold. A comparison of standard of living (e.g. GNP) on DWU and the cultural aspects of DWU are only two such examples. Of course, climatic effects would have to be taken into account, but it would probably not be the main thrust of such work.

9.5 Summary and conclusion

This chapter summarised the main findings of this thesis, developed the policy implications which these findings may have, and proposed avenues for further investigation. A wide range of uses for the findings is discussed and some of the implications of such uses elaborated.

Overall, the use of regression analysis together with microsimulation for DWU modelling is presented as a successful technique to achieve allocative efficiency with social equity. The proposals for further research incorporate this technique with the technological and political landscape of the near future.

10. CONCLUSIONS

10.1 Summary of thesis

Domestic water use in Leeds is the main subject of this work. In the process of discussing it, a whole range of issues more or less related to the task in hand are touched upon. These issues cover the whole spectrum between engineering, economics, statistics and simulation modelling. In order to achieve an order in this vast array of disciplines, the thesis begins with a general introduction which describes the reason for the thesis, its aims, the problems which are expected to be faced and the approach which is adapted in order to solve them.

The second chapter provides the background which is necessary for the understanding of the issues involved in this research project. This chapter is divided into two main parts: the economics of DWU and the historical and political issues which are related to DWU in Leeds. The importance of this chapter is in its being a constant point of reference throughout the thesis. Almost every economic policy and historical development is being explained at this stage which allows the following chapters to concentrate on the technical aspects.

In the third chapter the literature on DWU is reviewed. The range of the topics which this subject covers allows the division of the chapter into four parts, each corresponding to a different approach. These approaches are described as the social policy, the engineering, the economic and the component analysis. It is noticed that each of these approaches uses a terminology which characterises its attitude to DWU in general.

Water demand, withdrawals, requirements of water needs and consumption, all depict an approach far beyond their etymological context. The term 'water use' was chosen to describe the action investigated by this research, with its associated abbreviation DWU for domestic water use.

Being aware of how this subject was previously tackled, the approach and methodology adapted for this thesis is described in Chapter 4. The validity of the data supplied by YW is assessed, a range of statistical techniques are displayed and the most appropriate set chosen to perform the most important part of the thesis; the selection of the components which would be modelled. In the final part of this chapter the fundamental principles of microsimulation modelling are explained, followed by a brief discussion on the advantages and disadvantages of this technique.

The next two chapters perform a descriptive statistic analysis of the two data sets provided by YW. In Chapter 5 the preliminary survey is analysed. This survey contains a relatively small sample but its performance allows initial attention to be drawn to the prominent variables, and to some of the methodological problems in assessing others. Two variables: age of occupants and tenure of property, which do not feature in the full survey were analysed in greater depth than the others. Chapter 6 investigates each component separately, while highlighting not only its association with DWU, but with the other components of the household. A series of cross tabulation and a comparison with other sources allowed an initial selection of six variables suitable for modelling.

Inferential statistics performed in Chapter 7 help to finalise this list of variables. In a series of correlations and regression analyses the five most eligible variables together with one which was found to be more readily available for modelling purposes are selected. Their performance in regression analysis complied with the precondition set out in Chapter 4, which allowed the microsimulation model to rest on safe ground. However, for technical and methodological reasons explained in section 4.5.1, one of the variables which produced a high sign in all stages of the statistical analyses (number of toilets) had to be replaced by lesser variable, namely house type.

Microsimulation modelling itself is not an integral part of this thesis, but the results of this model are analysed in Chapter 8. In a set of maps comparing the crude data from the survey with the maps resulting from the modelling process the advantages of this technique become clear. However, the overall pattern of DWU only confirms the assumptions which were pronounced in the previous chapters, allowing for a mismatch as a result of the choice of a lesser variable.

In the ninth chapter these results are analysed and discussed as part of a full DWU policy. The implications of the findings and of the technique which was used in this work are put forward as a most useful combination of policy tools for the water industry management. In the concluding sections of this chapter, proposals for further research in two related subjects are discussed.

10.2 Conclusion

This thesis highlighted the problems associated with the assessment of DWU. Technical, methodological and conceptual problems were exposed, analysed and solved through a set of rigorous techniques. First and foremost, the combination of statistical analyses with the powerful tool of microsimulation modelling came into effect.

The thesis portrayed the methodological problems which works on this subject had to endure in the past, while pointing to the difficulties which arise when analysing the data. The similarities with as well as the variations from the previous works produced the theoretical foundation on which the basis of this thesis is constructed.

The components of DWU were identified through a set of descriptive and inferential statistics. The components most responsible for DWU were finally determined to be the number of occupants in the household, the number of bedrooms in the property, the number of toilets in the property, the existence of a washing machine, and the existence of a dishwasher. The type of property was eventually added to the microsimulation model for technical reasons, instead of the number of toilets.

With the use of this model, assumptions were used to construct a variety of scenarios which could test a whole set of future applications for this model. Thus, capital investment could be targeted in areas where demand is likely to grow; price structuring could reflect the geographical diversity of customers' dispensation; and the detection and calculation of water lost from the system by leakage or otherwise could be better pinpointed.

Future uses of the technique deployed in this thesis are suggested to include the testing of the implications of DWU on global environmental change such as the warming of the atmosphere, or local economic scenarios such as a rise or depression in the standard of living. The predictions for future requirement of this, the most precious of resources, could henceforth be executed with greater precision than ever before.

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Appendix I
Questionnaire number 1, April 1992 (see page 143)

Yorkshire Water

DOMESTIC CONSUMPTION SURVEY

SPECIMEN

A. Information about your house

1. Is your house
   - rented from Council ☐
   - rented from private landlord ☐
   - owner occupied ☐
   - other ☐

(please tick one box)

2. Is your house
   - semi-detached ☐
   - terrace/townhouse ☐
   - detached ☐
   - flat/maisonette ☐
   - bungalow ☐

(please tick one box)

3. Number of bedrooms — No. ☐

B. Appliances and fittings in your house

Appliances/fittings	No.
Washing machine - automatic	☐
- other	☐
Dishwasher	☐
Electric sink waste disposal unit	☐
Outside tap	☐
Hosepipe	☐
Lawn sprinkler	☐

(please enter number in appropriate boxes)

Appliances/fittings	No.
Toilets	☐
Sinks	☐
Washbasins	☐
Baths	☐
Showers	☐

(please enter number in appropriate boxes)

C. Number of people in your household

	No.
- Under 14 years of age	☐
- 14 years of age and over	☐

Please Return In The Envelope Provided To: Yorkshire Water P.O. Box 52 Broadacre House Bradford BD1 1BR.

Thank you for your co-operation

Tariff Development 2
February 1992

Appendix II
Accompanying letter for questionnaire number 1, (see page 144)

Yorkshire Water

@ML1OCNAM25A
@ML2OCNAM25A
@ML1BILAD30A
@ML2BILAD30A
@ML3BILAD30A
@ML4BILAD30A
@ML5BILAD30A

FINANCE DIRECTORATE
PO BOX 52 BROADACRE HOUSE
VICAR LANE BRADFORD BD1 5RQ
Tel: 0274 374445

Your ref:
Our ref: C/MB/990

@TODAYDAT19

Dear Customer

Consumption Survey

I would like you to take a few moments to help me complete a survey of households receiving measured water supplies.

We base our plans to supply the future requirements of customers like yourself partly on present demand for water and partly on our estimates of how our customers` needs will change over the coming years. Allowances are made for the expected changes of a growing population and also the different ways water is being used. Careful planning for instance, helps us to cope with such things as the lower than average rainfall experienced in the Yorkshire region over the last three years.

It is important that we use up to date information if we are to be confident in our forecasts. The results of this survey will help me to review if there has been any change in the present relationship between water consumption and for example, types of houses or number of appliances.

I should be most grateful if you would complete the enclosed questionnaire and return it to me in the prepaid envelope provided. Your reply will be treated in the strictest confidence.

Thank you for your assistance.

Yours faithfully

Stuart Hallas
Income Control Manager

Appendix III
Questionnaire number 2, November 1992 (see page 145)

Yorkshire Water

A3

Household Water Usage Survey

SPECIMEN

Description of your House
(please tick one box)

Semi Detached	✓
Terrace/Townhouse	
Detached	
Flat/Maisonette	
Bungalow	

Information about your House
(please enter number)

	Number
Number of people in your household	
Number of Bedrooms	

Information about Fittings and Appliances
(please enter appropriate number)

Fittings in your House

	Number		Number
Toilets		Washbasin (Bathroom)	
Sink (Kitchen)		Bath and Shower	
Bath only		Shower (Cubicle)	

Appliances in your House

	Number		Number
Washing Machine		Dishwasher	
Electric Waste Disposal Unit		Outside Tap	
Hosepipe		Lawn Sprinkler	

Please Return in The Envelope Provided to: Yorkshire Water, P.O. Box 52, Broadacre House, Bradford BD1 1BR.

Thank you for your assistance

Appendix IV
Letter Accompanying questionnaire number 2, November 1992 (see page 145)

Yorkshire Water (A4)

Customer Services
PO Box 52, Broadacre House,
Vicar Lane, Bradford BD1 5RQ
Telephone (0345) 828889
Fax (0274) 309468

SPECIMEN

Date: 3rd October 1994

Dear Customer,

Household Water Usage Survey

I am writing to our metered household customers to ask for their assistance.

We are aiming to build up more detailed information than we have at present regarding levels of household water consumption and how this is affected by different factors. This is to assist with our long term planning and to help give customers advice on water consumption.

I should be grateful if you would spare a few moments of your time to complete the enclosed questionnaire and return it in the reply paid envelope provided. This information will be treated as confidential.

Thank you for your help.

Yours faithfully,

Phil Crossley
Customer Communications Manager

Ok
4/10/94

APPENDIX V
Pearson correlation matrix (see page 240)

- - Correlation Coefficients - -

	ACORN	BATH	BEDROOMS	CODE	DISHWSHR	HOSEPIPE
ACORN	1.0000	.0206	.1512	-.0534	.1462	.1167
BATH	.0206	1.0000	.1278	-.0181	.1540	.0566
BEDROOMS	.1512	.1278	1.0000	-.0451	.3614	.3288
CODE	-.0534	-.0181	-.0451	1.0000	-.0523	-.0315
DISHWSHR	.1462	.1540	.3614	-.0523	1.0000	.3338
HOSEPIPE	.1167	.0566	.3288	-.0315	.3338	1.0000
OCCUPIER	-.1067	.1142	.3991	-.0383	.3238	.2329
OSTAP	.1687	.0731	.3566	-.0393	.3431	.5688
SHOWER	.0577	.3279	.3155	-.0345	.4103	.2581
SINK	.0659	.1375	.2821	-.0325	.3037	.2696
SPRNKLER	.0424	.0412	.1807	-.0068	.2289	.3638
TOILET	.1438	.2695	.5398	-.0472	.5529	.3849
TYPE	-.1589	-.0695	-.1764	.0595	-.2462	-.2577
VALUE	.5977	.1623	.3458	-.1011	.3634	.2632
WASHER	.0096	-.0132	.2357	-.0211	.2139	.2266
WSHBASIN	.0915	.2800	.4334	-.0338	.4480	.3331
WSTDSPSL	.1858	.1363	.1410	-.0424	.3615	.1640
M3PA	**.0118**	**.1895**	**.3946**	**-.0501**	**.4143**	**.3223**

	OCCUPIER	OSTAP	SHOWER	SINK	SPRNKLER	TOILET
ACORN	-.1067	.1687	.0577	.0659	.0424	.1438
BATH	.1142	.0731	.3279	.1375	.0412	.2695
BEDROOMS	.3991	.3566	.3155	.2821	.1807	.5398
CODE	-.0383	-.0393	-.0345	-.0325	-.0068	-.0472
DISHWSHR	.3238	.3431	.4103	.3037	.2289	.5529
HOSEPIPE	.2329	.5688	.2581	.2696	.3638	.3849
OCCUPIER	1.0000	.2333	.3089	.2148	.1491	.4190
OSTAP	.2333	1.0000	.2970	.2823	.2841	.4393
SHOWER	.3089	.2970	1.0000	.3108	.1736	.5813
SINK	.2148	.2823	.3108	1.0000	.1515	.4460
SPRNKLER	.1491	.2841	.1736	.1515	1.0000	.2348
TOILET	.4190	.4393	.5813	.4460	.2348	1.0000
TYPE	-.1305	-.3197	-.2821	-.1841	-.1473	-.3251
VALUE	.0124	.3384	.2562	.2242	.1166	.4011
WASHER	.2237	.2126	.1443	.1278	.0930	.2181
WSHBASIN	.3612	.3602	.5101	.4323	.2244	.7284
WSTDSPSL	.0998	.2059	.3083	.2227	.1272	.3362
M3PA	**.6476**	**.3403**	**.3842**	**.2695**	**.2131**	**.5173**

	TYPE	VALUE	WASHER	WSHBASIN	WSTDSPSL	M3PA
ACORN	-.1589	.5977	.0096	.0915	.1858	.0118
BATH	-.0695	.1623	-.0132	.2800	.1363	.1895
BEDROOMS	-.1764	.3458	.2357	.4334	.1410	.3946
CODE	.0595	-.1011	-.0211	-.0338	-.0424	-.0501
DISHWSHR	-.2462	.3634	.2139	.4480	.3615	.4143
HOSEPIPE	-.2577	.2632	.2266	.3331	.1640	.3223
OCCUPIER	-.1305	.0124	.2237	.3612	.0998	.6476
OSTAP	-.3197	.3384	.2126	.3602	.2059	.3403
SHOWER	-.2821	.2562	.1443	.5101	.3083	.3842
SINK	-.1841	.2242	.1278	.4323	.2227	.2695
SPRNKLER	-.1473	.1166	.0930	.2244	.1272	.2131
TOILET	-.3251	.4011	.2181	.7284	.3362	.5173
TYPE	1.0000	-.3117	-.1117	-.2441	-.1032	-.1856
VALUE	-.3117	1.0000	.1288	.3172	.3696	.1891
WASHER	-.1117	.1288	1.0000	.1652	.0878	.2318
WSHBASIN	-.2441	.3172	.1652	1.0000	.3074	.4601
WSTDSPSL	-.1032	.3696	.0878	.3074	1.0000	.2353
M3PA	**-.1856**	**.1891**	**.2318**	**.4601**	**.2353**	**1.0000**

(Coefficient / (Cases) / 2-tailed Significance)

APPENDIX VI

Analysis of Variance of Unique 18 Independent Variables against Water Use
Confidence Interval = 99%. (See page 242)

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F
ACORN	849685	35	24276.720	5.539
Residual	17543222	4003	4382.519	
Total	18392907	4038	4554.955	
BATH	1256614	4	314153.593	73.954
Residual	17136292	4034	4247.965	
Total	18392907	4038	4554.955	
BEDROOMS	3317312	4	829328.038	245.158
Residual	12908880	3816	3382.830	
Total	16226192	3820	4247.694	
CODE	707424	26	27208.620	6.154
Residual	17552665	3970	4421.326	
Total	18260089	3996	4569.592	
DISHWSHR	3166159	1	3166158.712	840.540
Residual	15176497	4029	3766.815	
Total	18342656	4030	4551.528	
HOSEPIPE	1601702	1	1601702.260	396.242
Residual	16096172	3982	4042.233	
Total	17697874	3983	4443.353	
OCCUPIER	7196594	4	1799148.509	724.680
Residual	9903414	3989	2482.681	
Total	17100008	3993	4282.496	
OSTAP	1522695	1	1522694.875	401.842
Residual	14713792	3883	3789.285	
Total	16236487	3884	4180.352	
POSITION	225879	2	112939.259	25.091
Residual	18167028	4036	4501.246	
Total	18392907	4038	4554.955	
VALUE	3401719	13	261670.657	70.256
Residual	14991188	4025	3724.519	
Total	18392907	4038	4554.955	
SHOWER	2500865	4	625216.285	165.058
Residual	15268820	4031	3787.849	
Total	17769686	4035	4403.887	
SINK	1396569	2	698284.691	165.689
Residual	16878749	4005	4214.419	
Total	18275318	4007	4560.848	
SPRNKLER	844714	2	422356.894	97.140
Residual	17548193	4036	4347.917	
Total	18392907	4038	4554.955	
TOILET	4052134	3	1350711.397	441.845
Residual	12191232	3988	3056.979	
Total	16243367	3991	4069.999	
HOUSE TYPE	2751817	4	687954.242	177.431
Residual	15641090	4034	3877.315	
Total	18392907	4038	4554.955	
WSHBASIN	3478322	4	869580.562	248.530
Residual	13775169	3937	3498.900	
Total	17253492	3941	4377.948	
WSTDSPSL	973649	1	973648.962	226.415
Residual	17321571	4028	4300.291	
Total	18295220	4029	4540.884	

Appendix VII
Stepwise regression matrix (see page 248)

Stepwise regression of m3pa on 5 predictors, with N = 4039

STEP	1	2	3	4	5
CONSTANT	16.271	-9.681	-5.643	-13.819	-15.240
occupier	40.16	32.41	31.60	31.19	30.91
T-RATIO	54.01	42.33	41.34	40.50	39.30
toilet		21.80	17.46	17.16	16.43
T-RATIO		24.15	17.07	16.76	14.90
dshwashr			16.2	15.5	15.4
T-RATIO			8.72	8.32	8.22
washer				10.7	10.1
T-RATIO				3.81	3.60
bedroom					1.37
T-RATIO					1.80
S	51.4	48.1	47.6	47.6	47.5
R-SQ	41.94	49.28	50.22	50.39	50.43

<u>Best Alternative</u>

VARIABLE	toilet	dshwashr	washer	bedroom
T-RATIO	38.40	18.80	4.62	2.20

VARIABLE	dshwashr	bedroom	bedroom
T-RATIO	28.92	12.62	2.73

APPENDIX VIII

See page 260

* * * * M U L T I P L E   R E G R E S S I O N * * * *

Equation Number 1   Dependent Variable.. M3PA   cubic meter

Block Number 1. Method: Enter
BEDROOMS DISHWSHR OCCUPIER TOILET TYPE WASHER

Variable(s) Entered on Step Number
1.. WASHER
2.. TYPE
3.. OCCUPIER
4.. DISHWSHR
5.. BEDROOMS
6.. TOILET

Multiple R	.71027
R Square	.50448
Adjusted R Square	.50374
Standard Error	47.54395

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	6	9278865.77970	1546477.62995
Residual	4032	9114041.09294	2260.42686

F = 684.15292   Signif F = .0000

------------------------ Variables in the Equation ------------------------

Variable	B	SE B	Beta	Tolerance	VIF	T
BEDROOMS	1.375479	.762533	.024583	.661686	1.511	1.804
DISHWSHR	15.186771	1.874939	.109627	.670907	1.491	8.100
OCCUPIER	30.924414	.786572	.498731	.763720	1.309	39.315
TOILET	16.168581	1.128315	.221239	.515586	1.940	14.330
TYPE	-.751043	.696198	-.012703	.886380	1.128	-1.079
WASHER	10.015137	2.818241	.041298	.910007	1.099	3.554
(Constant)	-12.754122	3.805008				-3.352

------ in -------

Variable	Sig T
BEDROOMS	.0713
DISHWSHR	.0000
OCCUPIER	.0000
TOILET	.0000
TYPE	.2808
WASHER	.0004
(Constant)	.0008

Collinearity Diagnostics

No	Eigenval	Cond Index	Variance Proportions Constant	BEDROOMS	DISHWSHR	OCCUPIER	TOILET	TYPE	WASHER
1	5.87985	1.000	.00105	.00256	.00655	.00415	.00252	.00343	.00203
2	.60561	3.116	.00302	.00004	.49568	.00001	.00348	.05156	.00258
3	.20068	5.413	.00150	.03339	.38380	.17967	.04210	.33179	.00000
4	.12687	6.808	.00579	.07999	.03369	.81407	.10413	.05963	.02883
5	.08803	8.173	.01338	.15512	.01087	.00114	.11821	.19903	.51900
6	.06998	9.166	.00374	.71337	.04197	.00045	.62941	.01034	.00241
7	.02898	14.245	.97152	.01553	.02744	.00051	.10014	.34422	.44516

APPENDIX IX
Centred multiple regression (see page 260)

* * * * M U L T I P L E   R E G R E S S I O N * * * *

Equation Number 1   Dependent Variable.. UMCI_1   99% U CI for M3PA mean

Block Number 1. Method: Enter
BEDROOMS DISHWSHR OCCUPIER TOILET TYPE WASHER

Variable(s) Entered on Step Number
1.. WASHER
2.. TYPE
3.. OCCUPIER
4.. DISHWSHR
5.. BEDROOMS
6.. TOILET

Multiple R	.99971
R Square	.99942
Adjusted R Square	.99942
Standard Error	1.15987

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	6	9349164.60495	1558194.10082
Residual	4032	5424.26696	1.34530

F = 1158246.57302   Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
BEDROOMS	1.080698	.018603	.027083	58.094	.0000
DISHWSHR	15.444561	.045741	.156329	337.655	.0000
OCCUPIER	31.277743	.019189	.707315	1629.979	.0000
TOILET	16.542882	.027526	.317405	600.988	.0000
TYPE	-.581560	.016984	-.013792	-34.241	.0000
WASHER	7.216476	.068753	.041726	104.962	.0000
(Constant)	-6.398238	.092826		-68.927	.0000

End Block Number 1 All requested variables entered.