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Modelling of Water Demands and Wastewater Discharges in England and Wales

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MODELLING OF WATER DEMANDS AND WASTEWATER DISCHARGES IN ENGLAND AND WALES

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Preface

Interest in water resources systems has been a critical part of resources and environment related research at IIASA since its inception. As demands for water increase relative to supply, the intensity and efficiency of water resources management must be developed further. This in turn requires an increase in the degree of detail and sophistication of the analysis, including economic, social and environmental evaluation of water resources development alternatives aided by application of mathematical modelling techniques, to generate inputs for planning, design and operational decisions.

In the years of 1976 and 1977 IIASA has initiated a concentrated research effort focusing on *modelling and forecasting of water demands.* Our interest in water demands derived itself from the generally accepted realization that these fundamental aspects of water resources management have not been given due consideration in the past.

This paper, the third in the IIASA water demand series, reports on water demand modelling in England and Wales. As a result of the Workshop on Modelling of Water Demands (Laxenburg, 17-21 January 1977), it is one of several invited contributions to our Survey on Methods for Estimating Water Demands and Wastewater Discharges.

Dr. Janusz Kindler
Task Leader

Abstract

Until 1974 responsibility for demand forecasting lay with a large number of mostly small water supply undertakings and sewerage and sewage disposal authorities. Only since 1974, when 10 large Water Authorities were created, has there been much interest in the formal modelling of water demands and discharges. However, progress is severely handicapped by the shortage of information on how and where the water supplied is used. A lot of attention has been given to trend analysis, but it is becoming increasingly clear that these models are inadequate. Econometric analyses using time series data have some potential, but it seems that the future will see increasing emphasis on modelling the use of water within households and within individual industries. Agricultural demands are relatively small and are unlikely to receive much attention. Sewerage, sewage treatment and effluent discharges have not received a great deal of attention either in modelling work in the past, but the increasing interest in environmental issues will probably result in greater effort being devoted to modelling the effects of discharges.

Acknowledgements

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Introduction

The degree of sophistication of demand modelling techniques applied in any sector of the economy depends primarily on three factors:

i) the importance of the sector under consideration;

ii) the administrative arrangements in the given sector of economy, in particular where the responsibility for demand forecasting and demand management lies;

iii) the data available.

There is likely to be some relationship between ii) and iii).

Figure 1 illustrates the major components of water consumption in England and Wales in 1975. Clearly abstractions for agriculture and "other water supply" are quite small. Direct abstractions by the Central Electricity Generating Board and other industries are less significant than the figures might suggest, because most of this water is returned to watercourses near to the point of abstraction with little change in quality. In the Water Resources Board's national study [1] it was assumed that in 1971 less than 10% of these abstractions had a significant effect on water resources. Therefore it is not surprising that most attempts at demand modelling have concentrated on the public water supply.

In 1960 there were about 900 water undertakings in England and Wales, supplying treated water through the public mains to domestic, commercial and industrial consumers. During the 1960's many of the smaller undertakings were amalgamated, and by 1973 the number had dropped from 900 to 185, serving a population of about 49 million. If the water undertakings were often relatively small the sewerage and sewage disposal authorities were even smaller. In the early 1970's there were approximately 1400 such organizations. From 1963 onwards there were also 29 River Authorities, responsible for water conservation, pollution control, land drainage and certain other tasks, and the Water Resources Board which prepared regional and national plans for the future development of water resources. However, in practice the responsibility for preparing demand forecasts remained largely in the hands of the water undertakings and sewerage and sewage disposal authorities. 1974 saw a significant change in these arrangements. Since April of that year there have been ten multi-purpose Water Authorities, each responsible within its area, which is a single river basin or group of basins, for water supply, conservation of water resources, supervision of land drainage, use of water for recreation, removal, treatment and disposal of sewage, and control of industrial discharges. These Authorities have responsibility for demand forecasting and they are generally large enough to justify the employment of people with particular skills in that field. This, coupled with recent unexpected developments in water demand, has served to increase the water supply industry's interest in demand forecasting techniques. There does not seem to have been the same increase in interest in forecasting the demand for sewerage, sewage treatment and effluent disposal. This may be because in the case of domestic effluents the volume will be closely related to water consumption, while in the case of industrial effluents the main concern has been quality, not volume. The tendency has been to think in terms of controlling the quality by setting discharge standards rather than in terms of simply meeting the demand for disposal.

In the areas of most Water Authorities comprehensive data on consumption are available only since 1960. Records of direct abstractions by industrialists did not start until about 1970. In general very little is known about how the water supplied is used by consumers. It is not even certain how much water is accounted for by domestic consumption, because it is part, and only part, of the unmeasured component. Nor is it generally known how much of the industrial consumption is taken by particular industries. In these circumstances progress in demand modelling is likely to be slow, because it requires not only the development of mathematical techniques but also the collection of a great deal of additional data on water consumption.

The Central Water Planning Unit was set up in 1974 at the same time as the ten Water Authorities. One of the major studies set for the Unit by its Steering Committee was "Demand Forecasting and Waste", one of the objects of this study being the development of improved forecasting techniques. From the start it was envisaged that work would develop through four stages. Initially effort was concentrated on a thorough analysis of time trends in water consumption, in per capita unmetered consumption, metered consumption and in population. It was expected that the next step would be the estimation of the relationship over time between water consumption and the state of the economy, explaining water consumption in terms of such variables as personal income, the index of production, consumer's expenditure, and the ownership of water using appliances, to quote four possible examples. A third potential development was cross section analysis, involving the comparison, at one particular point in time, of demands in different areas and the attempt to explain the differences by reference to social, economic and technological conditions. The results of such studies should improve understanding of why some groups of people consume more water than do others, and the knowledge obtained could then be used in forecasting. However, the ultimate aim of the demand forecasting project was seen as detailed studies of how consumers (both domestic and industrial) actually use water. This approach necessitates obtaining data on the amounts of water taken by individual domestic consumers for specific purposes, while on the industrial side detailed studies of particular industries are required.

In general the individual Water Authorities have been following the above pattern in developing their demand forecasting techniques. Most have completed careful analyses of time trends, and three are already conducting experiments which involve the metering of individual domestic properties. The major developments in techniques of forecasting the consumption of water from public supplies are described below.

Trend Analysis

Traditionally the water supply industry, when preparing demand forecasts, has relied very largely on the forward extrapolation of recent trends. This method of forecasting has the virtue of being simple and cheap, and in the past it has been reasonably successful, because trends in water consumption have been remarkably stable. For example, a linear equation relating time to total consumption from public supplies in England and Wales over the period from 1961 to 1975 explains 98.8% of the variation in consumption over the period. This trend is illustrated in Figure 2.

One of the weaknesses of extrapolating total consumption is that it fails to take account explicitly of the population projections which are available and which often suggest that in the future population will grow at a different rate from that which has been observed in the past. Therefore it has become the common practice to divide total water consumption into two components, metered and unmetered, and to forecast the latter by extrapolating the trend in per capita unmetered consumption and then multiplying by projected population. As pointed out earlier, unmetered cannot be equated with domestic consumption.

There are two main difficulties in using trend extrapolation. The first is the identification of the best trend equation, of the form of the underlying trend. The second is the implicit, doubtful assumption that past trends will continue unchanged into the future. However stable the trends have been in the past it is possible that future trends could be different because of a change in one of the factors influencing water consumption.

In the case of water consumption the problem of identifying the underlying trend equation is a very real one [2,3]. Figure 3 shows the trend in per capita unmetered consumption since 1961, a trend which seems both stable and simple. The exceptional figures in 1963 and 1964 were attributable to the severe winter weather in early 1963, which caused a large number of bursts and consequently a high level of leakage. Two trend equations were fitted to the data illustrated in

Figure 3, the first linear, the second semi-logarithmic. The estimated regression equations were:

$$PCUM = \underset{(1.29)}{139.87} + \underset{(0.14)}{3.85t} \quad , \qquad R^2=0.9827 \quad ; \qquad [1]$$

$$\log_e PCUM = \underset{(0.0066)}{4.9547} + \underset{(0.0007)}{0.0225t} \quad , \qquad R^2=0.9868 \quad , \qquad [2]$$

where

PCUM = per capita unmetered consumption (litres per head per day)
t = time (1960=0)
and figures in brackets are standard errors.

The two equations cannot be compared on the basis of the values of R^2 because they have different dependent variables, but when they are compared on the basis of the sum of the squared errors the second is preferable to the first. The difference is very small, as Figure 4 shows, yet when these equations are used to project demands they suggest very different figures for 2001, the first giving a figure of 298, the second 357 litres per head per day. This difference is unacceptably large for two equations which fit the past data almost equally well, and the choice between them cannot sensibly be made without giving explicit thought to the economic, social and technological factors likely to influence future demand.

In the case of metered consumption the problem of choosing the appropriate trend is more severe, but at the same time it is more obvious. As Figure 5 shows, during the 1960's there was a steady pattern of growth, but since 1970 the annual changes have been erratic, and in 1975 consumption was still only at the same level as in 1969. The question to be resolved is whether experience since 1970 constitutes merely a temporary halt to the pattern of growth, attributable to economic or other circumstances, or whether there has been a permanent change in trend. If it is assumed that a new trend has been established the implication is that there will be no growth above the 1975 level of about 4700 megalitres a day. On the other hand, if it is assumed that metered consumption will in the near future revert to the rate of growth experienced during the 1960's the projected figure for 2001 is about 7600 megalitres a day. The choice between the alternative projections cannot satisfactorily be made without some effort to understand the reasons behind the recent change in trend, and this means that research on the factors influencing water demand is necessary.

The series of data available is too short to justify attempts to fit more complicated time series models. Even if this were possible it must always be doubtful whether trends will remain sufficiently stable to permit their use for medium to long term demand forecasts. It has been possible to obtain data going back to 1928 for certain geographical areas, though consumption could not be divided between metered and unmetered. In general the long term trend appeared exponential, but there was a suggestion that the rate of growth had slowed down since 1960; consequently the trend was compatible with an S-type curve, implying an eventual upper limit beyond which consumption will not rise. It was found that exponential and S-type curves fitted the past data equally well but the projections of total consumption in 2001 ranged from 350 to 570 litres per head per day, compared with the actual 1975 figure of 308.

Time series methods have also been employed by Owen and Morgan [4] and Sterling and Antcliffe [5] in the type of short term forecasting exercise for which such methods are generally better suited. However, it seems unlikely that forecasting demands for days, weeks or even a few months ahead will ever be very important in the water industry. The distribution system is designed to meet short term peaks and therefore little or no action is required by management if a peak is imminent. A prediction of a water shortage a few months ahead could be useful, but such shortages are attributable not to predictable increases in demand but rather to unpredictable reductions in supply. It would be helpful to be able to predict rainfall a few months ahead, but this would appear to be an impossibility.

In view of the limited need for short term forecasts and the uncertainty attached to long term trends it seems unlikely that time trend analysis of water demands will be developed much, if any, further. At the present time Water Authorities, in preparing demand forecasts, are still relying largely on time trend analysis, but the simple extrapolations are increasingly being modified by subjective judgement to take account of some of the insights given by the types of analysis described below.

Cross Section Analysis

Cross section analysis involves the comparison at one particular point in time of demands in different areas, and the attempt to explain the differences by reference to social, economic and technological conditions. It may well be possible to explain some of the differences in consumption intuitively, but the scope for numerical analysis is limited, whereas from the point of view of demand forecasting numerical analysis is desirable.

Differences in metered consumption are probably explained largely by differences in the "structure of industry", but it is impossible to specify this variable by a number or numbers for inclusion in a regression equation. Similar problems are experienced in cross section analysis of unmetered consumption. Regional differences due to social and economic factors could well be swamped by differences attributable to metering policy and leakage, neither of which can be specified numerically with any precision.

There is the added difficulty in cross section analysis of obtaining regional or sub-regional social and economic statistics. Water Authority boundaries are based upon river catchments and bear no particular relationship to the economic planning regions for which social and economic statistics are normally published. Census data are collected for quite small geographical units and could almost certainly be aggregated in such a way as to refer to Water Authority areas or even to Water Authority Divisions, but the range of these statistics is quite limited. On the whole the scope for cross section analysis seems severely limited by the lack of appropriate numerical data.

Econometric Analysis of Metered Public Water Supply

At the Central Water Planning Unit linear regression analysis has been employed to estimate statistical relationships between water consumption and a number of possible explanatory variables, using annual data for the period from 1961 to 1974. It should be emphasized from the start that regression analysis may indicate correlation but it cannot guarantee causation. Ultimately, of course, it is causation in which we are interested, and therefore the method of analysis described in this section of the paper could never be considered the final word, particularly as it has only recently been tried for the first time.

From 1961 to 1974 a simple time trend explained about 95% of the variation in metered consumption. The basic aim was to find an equation or equations either including or preferably excluding a time variable, which explained a higher proportion of the variation in metered consumption than did time alone. Figure 5 shows clearly that the scope for improving on the simple time trend was very limited for the period from 1961 to 1970 and the success of the exercise depended largely on whether suitable explanations could be found for the erratic behaviour of consumption from 1970 onwards.

Initially the relationship between metered consumption and the index of industrial production was examined in some detail. This index performed better than did time alone but only marginally so, and it only partially explained the change in the rate of growth in metered consumption from 1970 onwards. Between 1961 and 1970 industrial production rose at an average compound rate of 3.0% per annum and metered water consumption rose at a very similar rate, 3.2% per annum. From 1971 to 1974 metered consumption hardly rose at all while industrial production continued to rise, albeit at only about half its previous rate. The instability through time of this relationship between metered consumption and industrial production suggests that it cannot be used with any degree of confidence for demand forecasting. Either the index of industrial production is an inappropriate measure of output or there must be some additional variable influencing metered consumption.

In view of these results a number of alternative measures of output were considered and so were alternative measures of employment, investment, climate and the price of water. First of all metered water consumption was regressed on each variable individually, secondly each variable was included alongside time in a regression equation, and finally all possible combinations of output, employment, climate, investment and price were considered. In view of the fact that most of the variables were correlated with time many of the equations were also estimated in terms of first differences. Overall it appeared that the best equations were those with two explanatory variables, output, and employment in the service sector.

Examples of the estimated equations are:

$$M = \underset{(0.917)}{4.649} + \underset{(0.0020)}{0.04968}MAN - \underset{(0.0000724)}{0.0003142}NXMAN \quad , \qquad [3]$$

$$R^2=0.9856 \quad ;$$

$$\log_e M = \underset{(1.89)}{5.577} + \underset{(0.0377)}{0.9420}\log_e MAN - \underset{(0.208)}{0.8655}\log_e NXMAN \quad , [4]$$

$$R^2=09865 \quad ;$$

$$\Delta M = \underset{(0.0249)}{0.05123} + \underset{(0.0067)}{0.03028MAN} - \underset{(0.000105)}{0.002427NXMAN} , \quad [5]$$

$$R^2 = 0.6792 \quad ;$$

$$\%\Delta M = \underset{(0.55)}{1.16} + \underset{(0.132)}{0.5403\%\Delta MAN} - \underset{(0.317)}{0.6225\%\Delta NXMAN} \quad [6]$$

$$R^2 = 0.6325 \quad .$$

where

M = metered potable plus non-potable consumption (million cubic metres a day)
MAN = index of output in manufacturing industry (1970=100)
NXMAN = employment in the non-manufacturing sector
Δ = means "change in"
%Δ = means "percentage change in"
and figures in brackets are standard errors.

The variables representing employment in the service sector performed well in this analysis because the period of rapid growth in service sector employment occurred at the same time as the period of slow growth in metered water consumption. This could be pure coincidence, though a causal relationship is plausible, because many establishments in the service sector have unmetered water supplies. It is felt that the possiblity of a causal relationship must now be subjected to more rigorous testing.

Econometric Analysis of Unmetered Public Water Supply

From 1961 to 1974 a simple time trend explained about 99% of the variation in total unmetered consumption, leaving very little scope for improvement by the introduction of further variables. In these circumstances the main aim of the analysis was to find an equation which did not include a time variable but which nevertheless fitted the past data as well as the simple trend equations. The variables considered were gross domestic product, personal disposable income, average weekly earnings of wage earners, consumers' expenditure, climate, population, the number of dwellings, and service sector employment. Population, the number of dwellings and income proved to be so closely related to each other that it was not possible to include more than one of them in any equation; of the three the number of dwellings proved the best. When combinations of the various explanatory variables were examined the best equations were those including the number of dwellings, summer rainfall, and employment in the non-industrial sector:

$$\underset{}{U} = \underset{(0.538)}{-7.067} + \underset{(0.0000446)}{0.0007587D} - \underset{(0.000317)}{0.001397SR} \qquad [7]$$

$$+ \underset{(0.0000948)}{0.0003427NXIP} \;, \qquad R^2=0.9962 \;;$$

$$\log_e U = \underset{(0.61)}{-15.98} + \underset{(0.085)}{1.480\log_e D} - \underset{(0.0168)}{0.06653\log_e SR} \qquad [8]$$

$$+ \underset{(0.137)}{0.4480\log_e NXIP} \;, \qquad R^2=0.9963 \;;$$

$$\Delta U = \underset{(0.0898)}{-0.05681} + \underset{(0.000339)}{0.002045\Delta D} - \underset{(0.000305)}{0.001054\Delta SR} \qquad [9]$$

$$+ \underset{(0.000177)}{0.0003256\Delta NXIP} \;, \qquad R^2=0.6201 \;;$$

$$\%\Delta U = \underset{(1.06)}{-1.091} + \underset{(0.617)}{2.315\%\Delta D} - \underset{(0.0155)}{0.05871\%\Delta SR} \qquad [10]$$

$$+ \underset{(0.258)}{0.5193\%\Delta NXIP} \;, \qquad R^2=0.6921 \;,$$

where

U = unmetered consumption (million cubic metres a day)

t = time (1960=0)

D = number of dwellings
SR = summer rainfall (millimetres)
NXIP = number employed in the non-industrial sector
and figures in brackets are standard errors.

In view of the multicollinearity attributable to the fact that population, income and the number of dwellings all exhibited a clear time trend, it seems likely that the coefficient of the variable representing the number of dwellings includes a component attributable to factors such as increasing income and population. Therefore these equations can only be used for forecasting if it is probable that the relationship between population, income and the number of dwellings will remain unchanged.

One possible way of removing the influence of population is to use per capita rather than total unmetered consumption as the dependent variable. When this was done the most useful explanatory variables were the average number of residents per dwelling and, once again, summer rainfall and employment in the non-industrial sector.

The econometric analysis described above has achieved some measure of success, in that equations have been found which explain more of the variation in past consumption than does time alone. However, with the short series of data available it is possible that some of the correlations discovered are coincidental, and even if the correlations are genuine there is no guarantee that causal relationships useful for forecasting have been established. However, the results certainly suggest potentially useful lines of enquiry for the detailed studies of how water is used.

Detailed Studies of Industrial Water Use

To date there have been very few detailed studies of water use in particular industries. Such studies are extremely difficult, the principal reasons being:

i) industrialists do not like to spend time completing questionnaires;

ii) they are reluctant to disclose information about their production methods;

iii) given the wide variety of product mixes and production methods it is difficult to design a questionnaire which is applicable to all firms.

The first in-depth study was that of water use in fruit and vegetable processing [6]. A questionnaire relating to current water utilization practices was sent to firms with interests in the canning and freezing of fruit and vegetables, and attempts were made to explain the differences in the volume of water taken per ton of raw material processed. The analysis consisted of a series of bivariate regressions, multiple regression not being attempted. Relationships were found between water use and water supply charges and between the degree of recirculation practiced and the total water costs per 1000 gallons. There was no clear relationship between water use per ton processed and size of the factory. In fact it was clear that water consumption varied a great deal from plant to plant and there was no obvious explanation as to why the differences should be as large as they were. Statistical regression analysis was not really very satisfactory because of the high level of unexplained variance.

A similar conclusion emerged from a study of the use of water in the textile industry. The report [7], published in 1973, explains in considerable detail how water was used, what technical processes were available and where economies in water use might be made, but the only element of formal mathematical modelling was an attempt to establish the price elasticity of the demand for water. The initial aim was to build a production function model to explain how the relative usage of the various factors of production changes when prices change, but the statistical relationships which emerged from the analysis did not permit this. However, a significant relationship was found between water usage and the price of water.

A recent study of water use in the food industry [8] gives a great deal of information about the volumes of water used in different processes in different product groups, but the study did not involve mathematical modelling of the production process or of the inter-firm variations in water use.

There are possibly some individual large firms which, for their own management and planning purposes, have developed models of water use within their own plants. However, the author of this paper is not personally aware of any such models, and certainly none have been described in published reports. In the industrial sector mathematical modelling of water demands seems to be confined to the limited cross section regression analysis undertaken by Herrington [6] and the Textile Research Conference [7]. This approach seems to have limited potential because so much of the variation in water use between firms remains unexplained.

There is now a great deal of interest in pursuing studies of industrial water demand. However, before models of individual industries can be incorporated into a formal demand forecasting framework, it will be necessary to know how much water is used by each industry. Unfortunately such information is not generally available. Some Water Authorities are now starting to rectify this by classifying both abstractions and metered public supplies according to the Standard Industrial Classification. Gradually the stock of information is growing but it will probably have to grow a good deal more before it can be incorporated into a satisfactory, formal numerical demand modelling and demand forecasting system.

Detailed Studies of Domestic Consumption

In preparing forecasts of unmetered water demand most Water Authorities have started by extrapolating per capita unmetered consumption, but some have also attempted to break consumption down into a number of components and to forecast each component separately. The second method is normally used as a check on the first, to ensure that projecting past trends does not give wholly unrealistic forecasts. Even at the present time the division into components is largely a matter of guesswork but research is proceeding to provide improved data.

The first task is to split unmetered consumption into its major components, namely household, commercial, miscellaneous and leakage. At present, on the basis of a few metering experiments and a considerable number of night flow readings it would appear that household consumption is of the order of 100 to 120 litres per head per day, commercial consumption is up to 20 litres per day per head of resident population, miscellaneous consumption is negligible, and leakage is probably between 60 and 90 litres per head per day.

In order to divide household consumption into further components one Water Authority has already metered about 1000 households and studied in detail their use of water. The participating households kept daily diaries to record their water using activities and they also read their own meters daily. Similar experiments each covering towards 1000 households are being actively planned by two other Water Authorities. The basic aim is to identify, for each possible water-using appliance:

i) the percentage of households owning the appliance;
ii) how often the appliance is used;
iii) the volume of water consumed each time the appliance is used.

The empirical information on these items is expanding all the time and it will probably not be long before the component method of forecasting is in common use. At the Central Water Planning Unit all of the empirical information currently available has been drawn together and has been combined with a certain amount of, hopefully intelligent, guesswork to indicate the orders of magnitude of the various components of domestic water consumption [9]. Then some thought has been given to the position as it may be in the year 2000 and this suggests that consumption may well not grow as rapidly as a simple extrapolation of past trends would indicate. It seems that future effort in the field of domestic water consumption will be devoted largely to the further development of models involving the estimation of individual components of water use.

Agricultural Water Demand

Figure 1 shows that in England and Wales agriculture appears to be a relatively small use of water and accordingly it has not received much attention in research on water demands. The figure of 300 megalitres a day includes all abstractions for purposes of irrigation but does not include much of the water abstracted for other agricultural uses. There has been research on crop responses to irrigation and there are also linear programming models of the agricultural sector, but the two have not been put together in a mathematical model to show how water demand would respond to different situations and conditions.

Sewerage, Sewage Treatment and Effluent Discharges

Very little has so far been said about the demand for sewerage, sewage treatment and the discharge of effluents. In fact these have not received anything like as much attention in formal demand forecasting exercises as have the demands for water. This could be partly because the demands can be met at the local level more readily than can the demand for potable water, and consequently there has been less need for strategic plans and the associated strategic demand forecasts.

In the case of domestic effluents future volumes have usually been estimated by extrapolating past trends, while making some allowance for changes in expected trends in population growth. In the case of trade discharges to public sewers and industrial discharges direct to watercourses Water Authorities are able to control demand to a considerable extent through the operation of discharge consents and this may explain why it has not been found necessary to prepare and publicize forecasts.

One major modelling exercise which involves effluent discharges is a research study of the River Tees. The object of the study is to model the quality of the water in the Tees estuary, taking into account the discharges, and to examine how different quality standards might be achieved, with particular reference to pricing. The study is composed of two components, a water quality model and an abatement cost model. The former relates the quality of the estuary to the distribution of sources of effluent discharged and to effluent quality. The abatement cost model will calculate the additional cost of achieving alternative levels of water quality. The first step is to specify the quality required, and four alternatives are being considered:

i) no deterioration from present levels;
ii) quality suitable for coarse fish;
iii) quality suitable for migratory fish;
iv) quality associated with the best technical means of abating pollution.

The second step is to collect information from industry to determine how much it would cost to achieve each of the four qualities. The third step is to show what costs would be if the quality of the estuary were controlled by the imposition of different types of effluent charges and standards. The study is nearing completion but at present only early descriptions of the project [10] have been published.

The Situation in Scotland and Northern Ireland

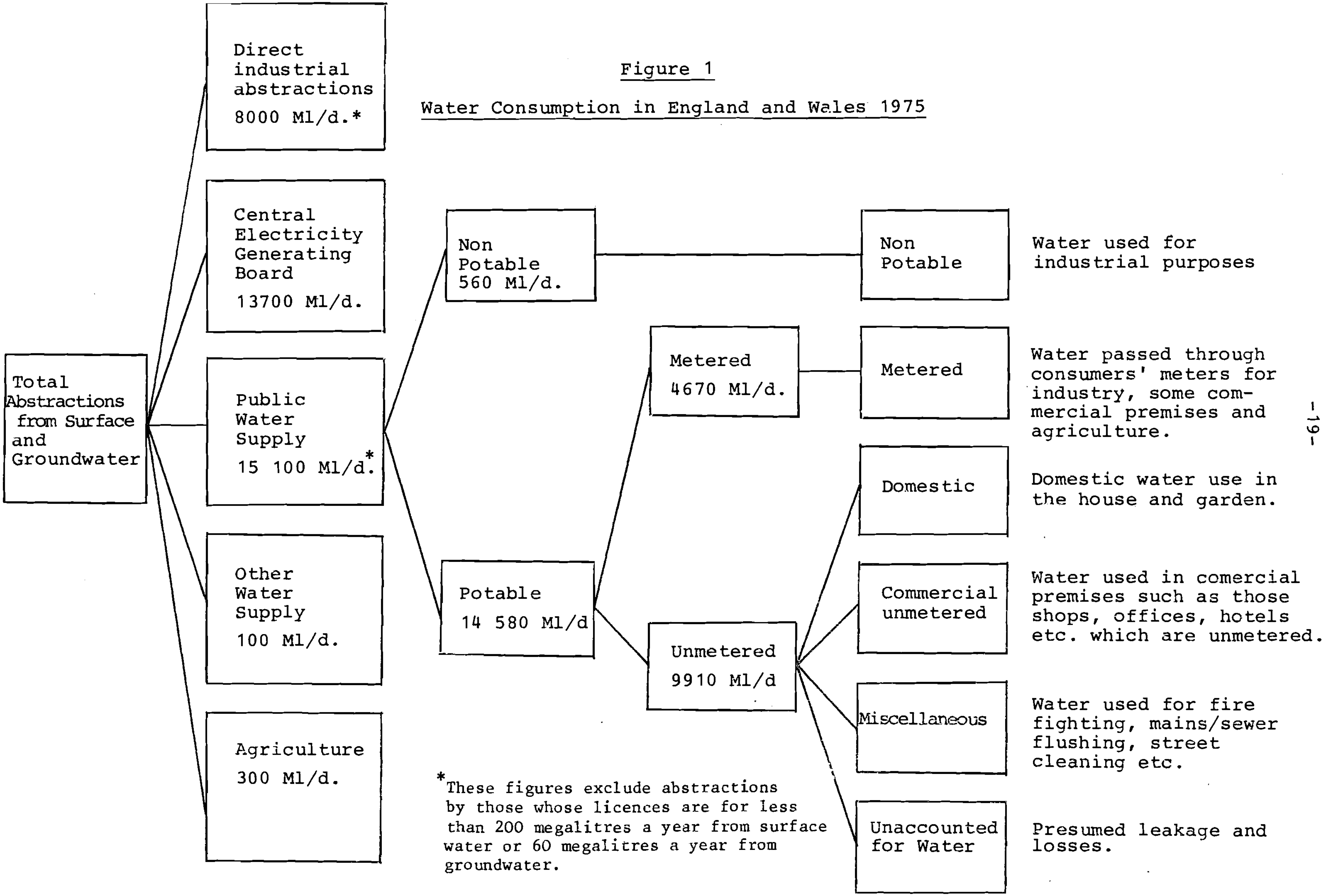
This paper has so far dealt only with England and Wales. In Scotland and Northern Ireland the administrative arrangements for water supply, sewerage, sewage treatment and effluent disposal are different, but not so different as to affect significantly the state of demand modelling. In general demand forecasts have been based on simple extrapolation of past trends, but increasingly, interest is being shown in more detailed studies of water demand. Econometric models have, as far as is known, not been used.

Conclusions

It is only within the last few years that demand modelling has received a great deal of attention within the water industry. Even now in formal modelling work attention is focused entirely on public water supply, rather than on direct abstractions by industry or the discharge of effluents. Since the re-organization of the water industry in England and Wales in 1974 trends in water consumption have been carefully studied, and the use of econometric models has been examined. Household consumption is being examined in detail, with a view to establishing the major components of domestic use, but mathematical models of water use within industrial processes have not yet been developed.

Figure 1

Water Consumption in England and Wales 1975



*These figures exclude abstractions by those whose licences are for less than 200 megalitres a year from surface water or 60 megalitres a year from groundwater.

Figure 2

Total Water Consumption from Public Supplies in England and Wales 1961-1975

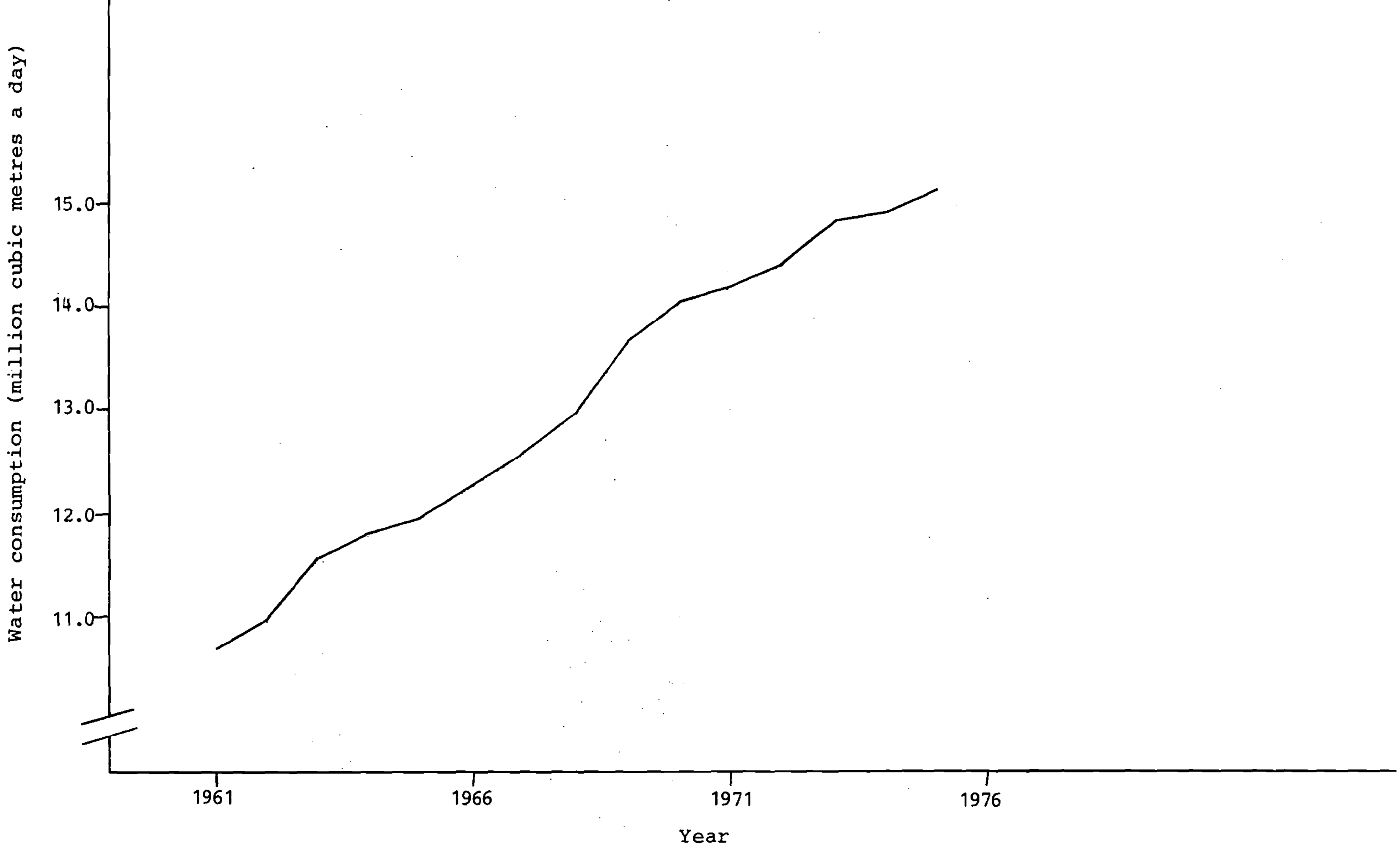


Figure 3

Per Capita Unmetered Water Consumption in England and Wales 1961-1975

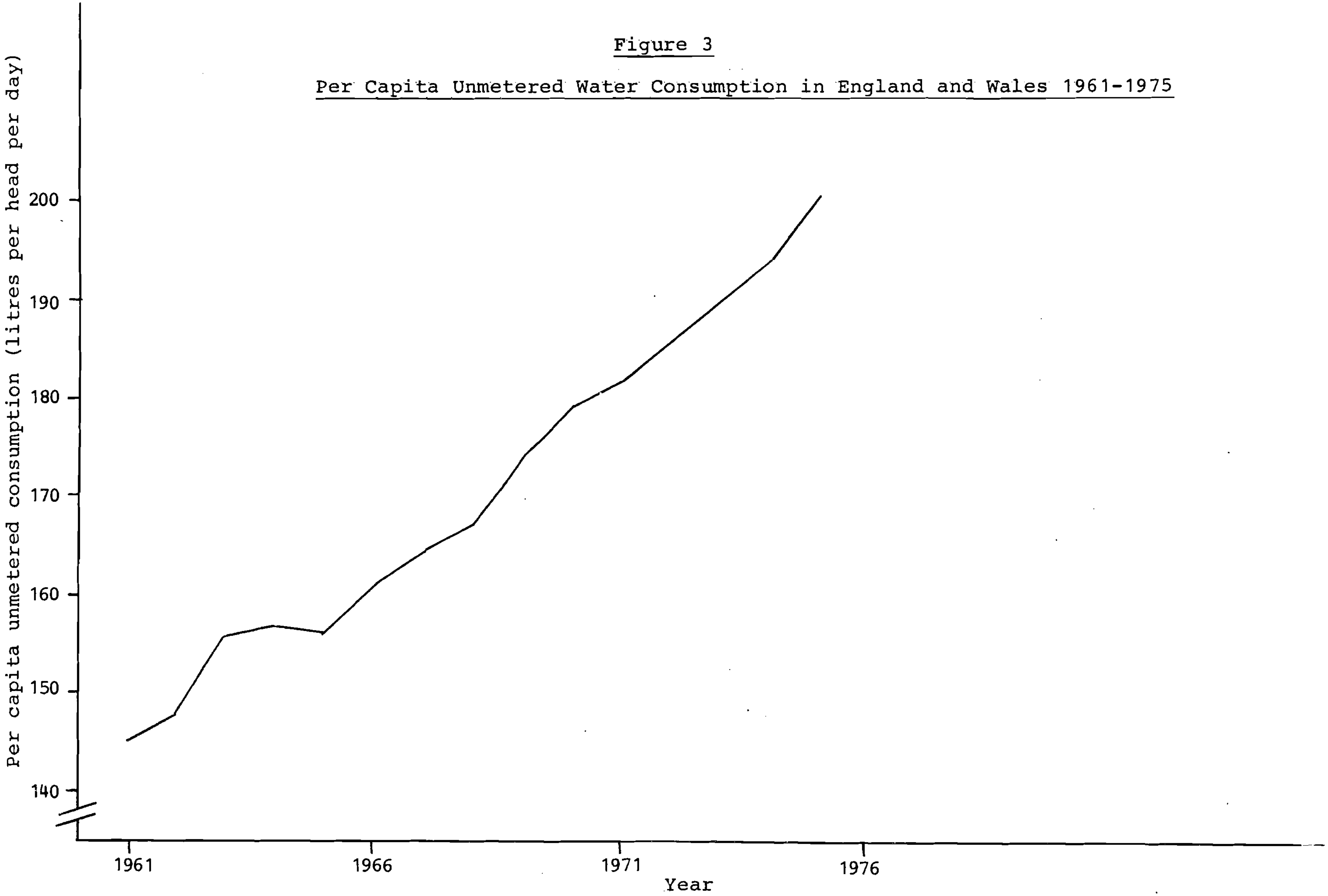


Figure 4

Alternative Trends in Per Capita Unmetered Water Consumption in England and Wales 1961-1975

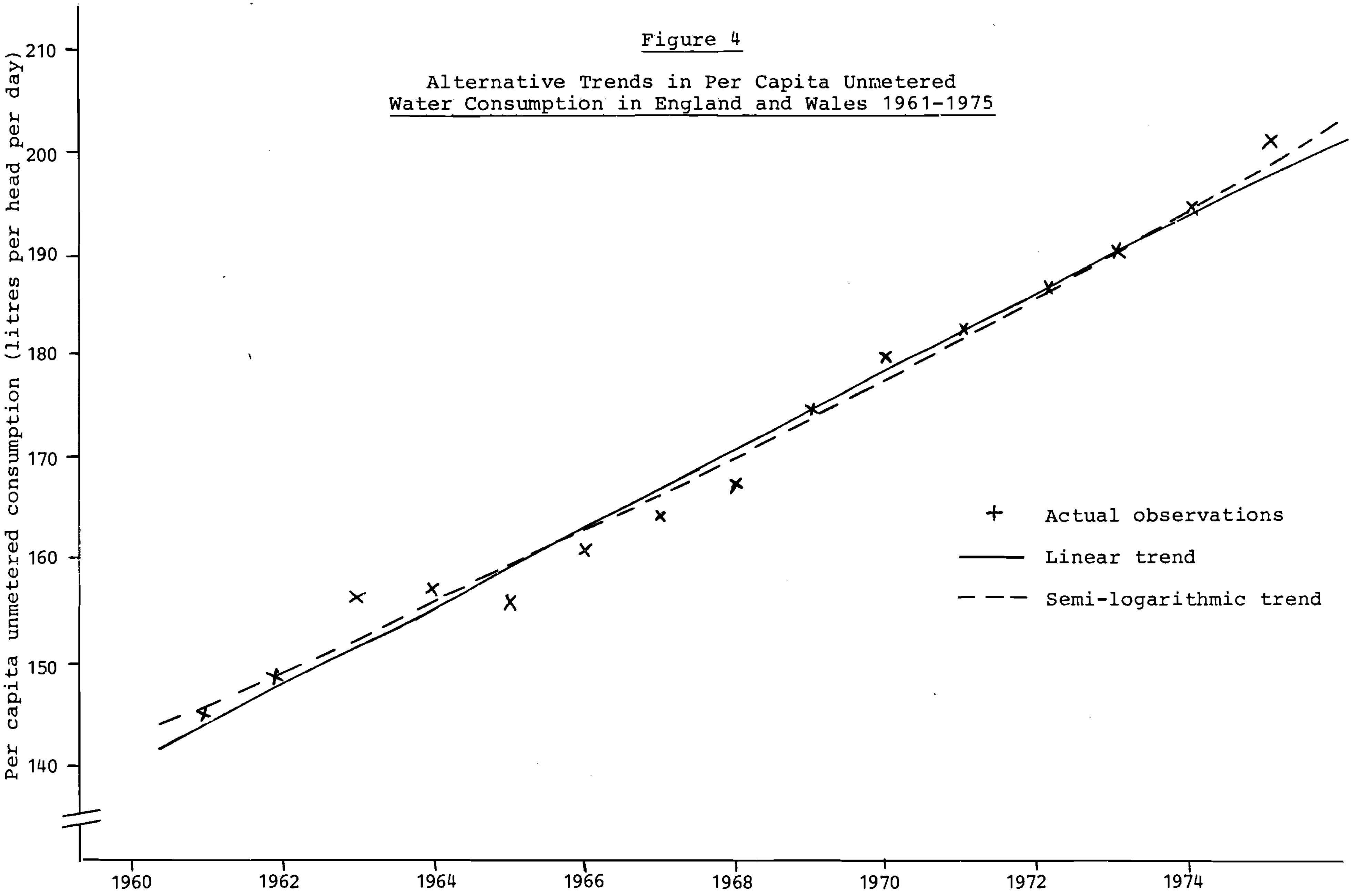
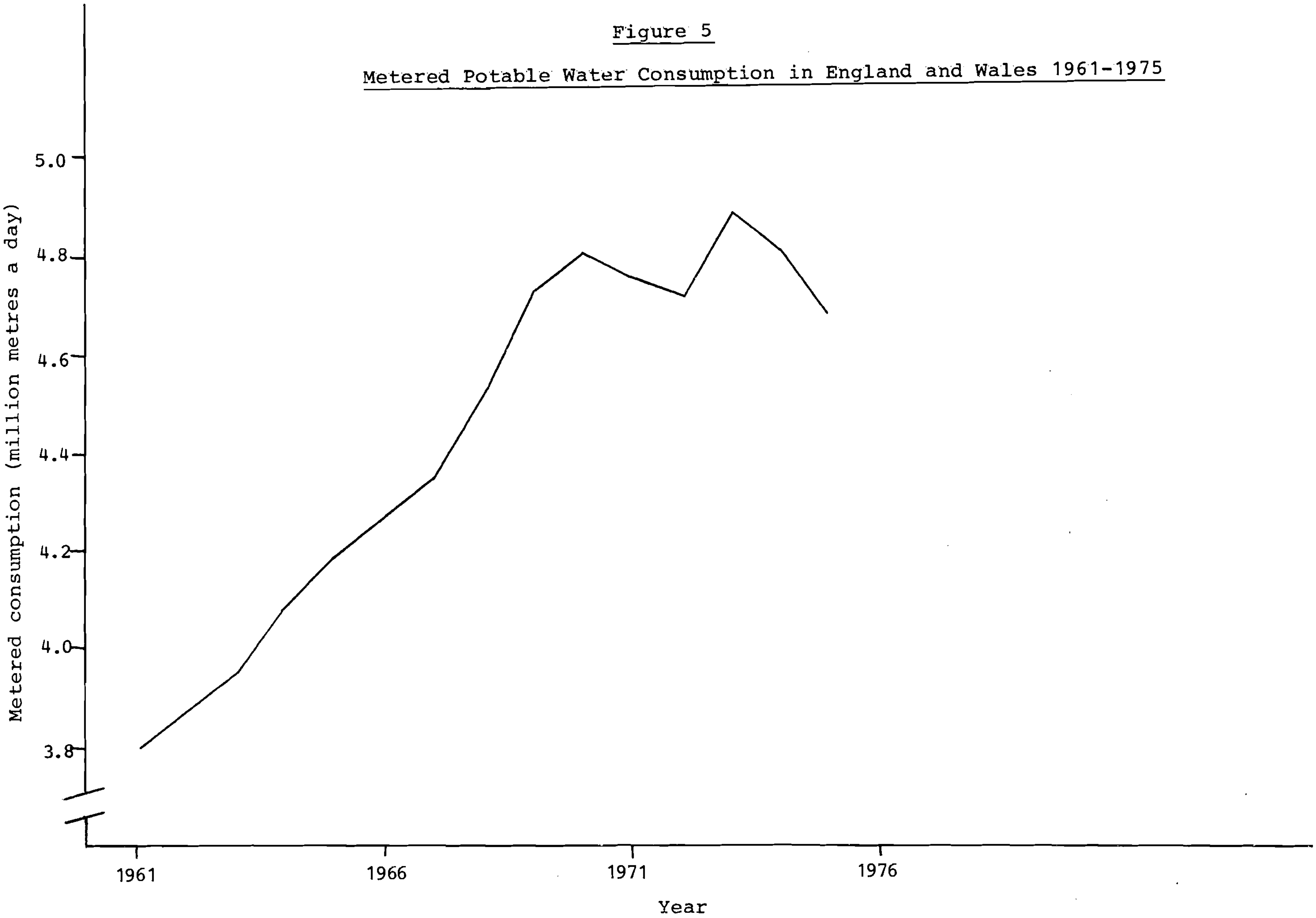


Figure 5

Metered Potable Water Consumption in England and Wales 1961-1975



References

[1] Water Resources Board, *Water Resources in England and Wales*, Her Majesty's Stationery Office, London, 1973.

[2] Central Water Planning Unit, *Analysis of Trends in Public Water Supply*, Reading, February, 1976.

[3] Central Water Planning Unit, *Public Water Supply in 1975 and Trends in Consumption*, Technical Note 19, Reading, July 1977.

[4] T.J. Owen and N.B. Morgan, *A Water Consumption Model for the Central Water Planning Unit*, Scicon, London, 1976.

[5] M.J.H. Sterling and D.J. Antcliffe, *A Technique for the Prediction of Water Demand from Past Consumption Data*, Journal of the Institution of Water Engineers, Volume 28, No. 8, November, 1974.

[6] P.R. Herrington, *Water Use in Fruit and Vegetable Processing in the UK*, University of Leicester, Water Demand Study, Progress Paper A5, September, 1971.

[7] Textile Research Conference, *The Use of Water by the Textile Industry*, July, 1973.

[8] W.E. Whitman and S.D. Holdsworth, *Water Use in the Food Industry*, Leatherhead Food Research Association, December, 1975.

[9] Central Water Planning Unit, Annual Report for 1976/77, Appendix 4.

[10] C.K. Rowley, B. Beavis, and D.J. Elliot, *Studying Industrial Discharges to the River Tees*, Water, No. 3, April, 1975.