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# CALCULATING THE BALANCE BETWEEN WATER RESOURCES AND WATER DEMANDS

## AN APPROACH USING RISK ANALYSIS

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## SUMMARY

Predicting future need for water resources has traditionally been, at best, a crude mixture of art and science. This has prevented the evaluation of water need from being carried out in either a consistent or comprehensive manner.

This inconsistent and somewhat arbitrary approach to water resources planning led to well publicised premature developments in the 1970's and 1980's but privatisation of the Water Industry, including creation of the Office of Water Services and the National Rivers Authority in 1989, turned the tide of resource planning to the point where funding of schemes and their justification by the Regulators could no longer be assumed. Furthermore, considerable areas of uncertainty were beginning to enter the debate and complicate the assessment. It was also no longer appropriate to consider that contingencies would continue to lie solely on the demand side of the equation.

An inability to calculate the balance between supply and demand may mean an inability to meet standards of service or, arguably worse, an excessive provision of water resources and excessive costs to customers. United Kingdom Water Industry Research Limited (UKWIR) Headroom project in 1998 provided a simple methodology for the calculation of planning margins. This methodology, although well received, was not, however, accepted by the Regulators as a tool sufficient to promote resource development.

This thesis begins by considering the history of water resource planning in the UK, moving on to discuss events following privatisation of the water industry post-1985. The mid section of the research forms the bulk of original work and provides a scoping exercise which reveals a catalogue of uncertainties prevalent within the supply-demand balance. Each of these uncertainties is considered in terms of materiality, scope, and whether it can be quantified within a risk analysis package. Many of the areas of uncertainty identified would merit further research.

A workable, yet robust, methodology for evaluating the balance between water resources and water demands by using a spreadsheet based risk analysis package is presented. The technique involves statistical sampling and simulation such that samples are taken from input distributions on both the supply and demand side of the equation and the imbalance between supply and demand is calculated in the form of an output distribution. The percentiles of the output distribution represent different standards of service to the customer.

The model allows dependencies between distributions to be considered, for improved uncertainties to be assessed and for the impact of uncertain solutions to any imbalance to be calculated directly. The method is considered a significant leap forward in the field of water resource planning.

KEY WORDS:

WATER RESOURCES PLANNING, RISK ANALYSIS, HEADROOM, PLANNING ALLOWANCES, SUPPLY-DEMAND BALANCE

# DEDICATION

This thesis is dedicated to my wife, Maria, and to my children, Sarah and Michael, whose support made this research possible.

## ACKNOWLEDGEMENTS

I am particularly indebted to Dr. Peter Hedges for his tireless support and encouragement, to the late Terry McAllister for offering the support of my employer and to Becci Braithwaite, my secretary, for her unfailing and immeasurable efficiency.

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# CHAPTER ONE - INTRODUCTION

## 1.1 BACKGROUND TO THE RESEARCH

At the outset of this research, the UK water industry had no consistent, meaningful or integrated methodology for developing and utilising water resource planning allowances and, hence, could not evaluate future water resource need in a consistent or comprehensive manner. Over-design results in a waste of economic resources and under-design the commitment of too few resources.

The current levels of inconsistency render both funding by the Office of Water Services (OFWAT) and development approval by the Environment Agency significantly more cumbersome and time consuming than they should be. OFWAT is the UK water industry financial regulator, responsible for assessing water company funding requirements, and the Environment Agency is the UK environment regulator. With water resources development costs in the UK running up to £1,000,000 per megalitre per day then the benefits of more effective and efficient capital planning are obvious.

The overall aim of this research is therefore to produce an integrated methodology for the calculation of future water resource need which is acceptable to Regulators and usable by water resource planners.

Predicting future need for water resources has always been, at best, a crude mixture of art and science. In the early days of resource planning, planners took the view that water was a life sustaining requirement and that demand was growing so quickly that any errors due to over forecasting would be absorbed very rapidly. Indeed, it was seen as sensible to over-predict given the length of the planning process and the consequences of underestimation. These factors led to a planning inertia which persisted for over 100 years eventually leading to the premature development of the infamous Kielder and Rutland reservoirs during the 1970's. The historical background to the calculation of future water resource and/or demand management need is covered in detail within Chapter 2.

Public interest in water resource planning grew rapidly after Kielder and, at the same time, the water industry started to develop more critical internal regulation surrounding water resources planning. Initially the responsibility for resource development approval rested with the water resources departments of water authorities but, following privatisation, responsibility transferred to the National Rivers Authority (NRA) in 1989. The water industry watchdog, OFWAT, was a fledgling organisation at this time.

As the years progressed the pressure exerted by the Regulators, OFWAT and NRA, intensified. This was particularly noticeable during 'periodic price reviews', where the water industry seeks price approval from OFWAT for at least the next five years. Review periods to date have covered 1989-1995 and 1995-2000, with the next Periodic Review, known as AMP3 (Asset Management Plan 3), now very much at the debating stage.

The first Periodic Review, in 1989, focused on putting right the under investment of water companies during the 70's and 80's, particularly on water mains and sewers. Approved water bills for the period 1989-1995 were consequently higher than the rate of inflation for most water companies. The focus would change quite considerably as the industry moved towards its second Periodic Review in 1995.

'Paying for Growth', (OFWAT, $1993_b$), perhaps for the first time, set down abstract rules for the future resource planning process. A selection of extracts illustrates the point.

> "*...New resource developments become more expensive as the most economical opportunities are developed first.... The development of new resources therefore may not be the appropriate response to increases in demand.*"

> "*...First it is necessary to establish whether increased supply is justified in the sense that customers are prepared to pay for the costs of the resources used, including the use of the environment. Present arrangements are scarcely satisfactory....*"

In essence OFWAT was telling the water companies that they must consider a mix of solutions to demand growth, in particular increased evaluation of metering and leakage reduction. Appraisal of preferred solutions would also require an evaluation of environmental costs.

By 1996, the principles within 'Paying for Growth' were enhanced by the UK industry manual on supply expansion and demand management appraisal (UKWIR, $1996_c$).

In addition, OFWAT required companies to submit, each year, demand forecast information and methods. These techniques are audited by independent certifiers and, since 1993 particularly, the requirements for each company to adopt best practice has become progressively more forceful. OFWAT pressurises companies in several ways; first by publishing ranked lists of the quality and confidence assigned to the company's data and methods and secondly, typically during Periodic Review periods, requiring companies to obtain approval from the resource regulator, the NRA until 1995 (now the Environment Agency). This need for approval clearly offered the NRA an opportunity to separately audit demand forecasting and resource planning techniques in a uniquely open manner.

The NRA was also very active between 1991 and 1994 in developing its own strategy for water resource development, again emphasising the need to consider alternatives to resource development and the requirement to consider the real economic costs. The NRA began its on-going research into environmental costing at this point.

Finally, in December 1992, the water companies together with OFWAT and the NRA, drew up an agreed set of guidelines under which water resource issues were to be evaluated for the 2nd Periodic Review. These guidelines, OFWAT (1992), spelled out demand forecasting and source yield assumptions in a very prescriptive way. Notably that:-

> *"... current source outputs will continue ...."*
>
> *"... sources should be considered sustainable"*
>
> *"... no allowance is to be made for climate change"*
>
> *"...allowance for licence reductions would only be made where agreed with the NRA"*
>
> *"... deterioration of water quality should be reflected as an increased treatment cost (rather than as a loss of resource)..."*
>
> *"The NRA will expect applicants for new abstraction licences to prove a need for additional supplies. The NRA will only look favourably on the development of new sources if all existing sources and demand management measures have been developed to their cost effective limit."*

## 1.2 NEED FOR THE RESEARCH

By the late 1970's decades of 'straight-line' demand forecasting and demand growth, coupled with relatively unopposed resource development had left the water industry with weak resource planning. When faced with regulatory pressure it became very clear that the 'factors of safety' previously applied to both demand and to source output would require far more justification than ever before if resource development schemes were to be approved.

The UK Groundwater Forum (1995) made a similar observation on the need to address uncertainty, from the Regulator's perspective:

> *"The precautionary principle is routinely applied to groundwater resources, due to the large gaps in knowledge.... targeting research to reduce uncertainties should help in minimising precautionary decisions"*

Perhaps the most significant demonstration of the need for this research came in January 1999 through the publication of a Ministerial Guideline to OFWAT and the EA on the maintenance of public water supplies (DETR, 1999). The DETR is the Government Department of the Environment, Transport and Regions. A number of extracts serve to demonstrate the Government's position on the issue of uncertainty and headroom and the need to improve its understanding.

> *"The drought which began in 1995 focused attention on ..... the need for careful and long-term assessment of the balance between supply and demand".*
>
> *"Ministers take the view that necessary costs must be determined from an analysis which incorporates realistic allowance for present uncertainties".*
>
> *"Ministers believe that the (headroom) methodology ..... provides a pragmatic approach to quantifying uncertainty - but that it does not alone provide sufficient evidence to justify the development of new resources".*
>
> *"Ministers recognise, ..... as the methodology suggests, that headroom targets may be justifiably revised by insisting upon better component information, so reducing uncertainty".*
>
> *"The longer term analysis needs to reflect the wide-ranging uncertainties about future demand and availability of supplies, accentuated by the prospect of climate change".*

It is obviously essential for every company to properly understand its balance between water supply and water demand in terms of levels of service and cost to its customers. The value of improved accuracy in resource planning will be worth striving for providing, of course, that the cost associated with doing so is exceeded by the corresponding benefit.

As a final point on the question of research need, it should also be noted that a more correct evaluation of resource need is less likely to lead to excessive prudence, hence less likely to lead to resource development and its consequential environmental impact.

## 1.3 PARALLEL UNITED KINGDOM RESEARCH

Section 2.5.1 discusses UKWIR water resources research during the period 1994 through 1998, noting in particular that four projects have a direct association with resource planning. The most recent project, which considers headroom within the supply-demand balance, was well received by the water companies, by the EA and, more recently, by the DETR. However, the method does not claim to be sufficient to justify a programme of investment to close any imbalance between supply and demand. In this respect, the EA (1998) recommends directly that water companies address reduced uncertainties within the supply-demand balance as a matter of priority.

## 1.4 A REVIEW OF RISK ANALYSIS PRACTICE IN THE WATER INDUSTRY

UKWIR ($1995_b$) commissioned a brief survey of current risk analysis practice in the UK water industry across various water supply asset groupings, the outcome of which is summarised in Table 1.1.

*(Table 1.1)*
*Summary of risk analysis practice in the Water Industry*
*(UKWIR , 1995)*

Note 1 : Derived from all respondents

Note 2 : Derived from the short-list respondents

The methods in Table 1.1, in brief, can be described as:

i) judgement methods involving a single expert opinion or the use of an expert panel (see 2.5.1.4 for further description),

ii) Hazop methods involving a matrix of consequence and likelihood; where risk is the product,

iii) score methods, which rank events using applied weightings, such as operational importance, but without reference to historic or potential failure frequencies,

iv) statistical methods which use the probability of asset replacement within different asset categories,

v) simulation methods, largely referring to resource allocation models, where demands (and sometimes resources) are simulated (see O'Neill, 1985).

At first sight Table 1.1 suggests a fairly widespread use of risk analysis, but the study then goes on to note that only eight of the 26 respondents believed risk analysis to require, as it should, consideration of both consequence and likelihood.

UKWIR ($1995_b$) noted that, although judgement and score based techniques were fairly widely used, they tended to be informal and often limited to available investment budgets. On simulation techniques the study notes that there are a small number of instances where simulation has been used in risk analysis for water resources and recommends further development of the methodology. A more detailed discussion of current methods for evaluating the supply-demand balance is contained within Chapter 2.

UKWIR ($1995_b$) also noted that judgement methods were prevalent amongst smaller water companies. This is not unexpected, since sophisticated methods are usually argued away on the grounds of cost. In this case, the companies argued that engineers had a close intimacy with the asset, well able to judge risk and consequent investment. While this argument has merit, UKWIR ($1995_b$) warn that bias may be widespread with such methods and that staff turnover is clearly critical.

## 1.5 OBJECTIVES AND INTENDED FINAL USE

The overall aim of this research is to address an area of current significant weakness through the production of an integrated methodology for the calculation of water resource need. Within the research, however, the term 'water resource need' is more correctly termed the supply-demand balance, reflecting that resource development is not the only solution to rising demands or falling yields.

Note that the original objectives of this research, presented within Appendix IV, are slightly revised by those which follow. Discussion of both the original and revised objectives is contained within Section 9.7.

i) To review historic research and publications in the field of predicting future resource need.

ii) To review post water industry privatisation research and publications, in particular the projects carried out under the direction of UKWIR (United Kingdom Water Industry Research).

iii) To consider whether forecasting accuracy has improved over time.

iv) To carry out a scoping exercise to assess the full potential range of water resource planning uncertainties. The primary groupings are:-

    - Resource Planning Uncertainty
    - Partial and Pure Uncertainty
    - Physical and Financial Uncertainty
    - Subjective and Objective Uncertainty

v) To appraise, investigate and report on how the spectrum of planning uncertainties might be dealt with in isolation, in particular; the nature and trend of the uncertainty, its likely acceptability by the regulator, and how the uncertainty impacts upon the balance between water supply and water demand.

vi) To investigate how uncertainties can be combined together, in the light of its statistical distribution and dependency, if any, in order to produce a meaningful result at a given level of risk.

vii) To produce an example which demonstrates how companies could financially appraise the benefits of a reduced level of service or the cost of an increased standard.

viii) To produce an example which demonstrates how the uncertainty surrounding the solution to a supply-demand imbalance can be considered.

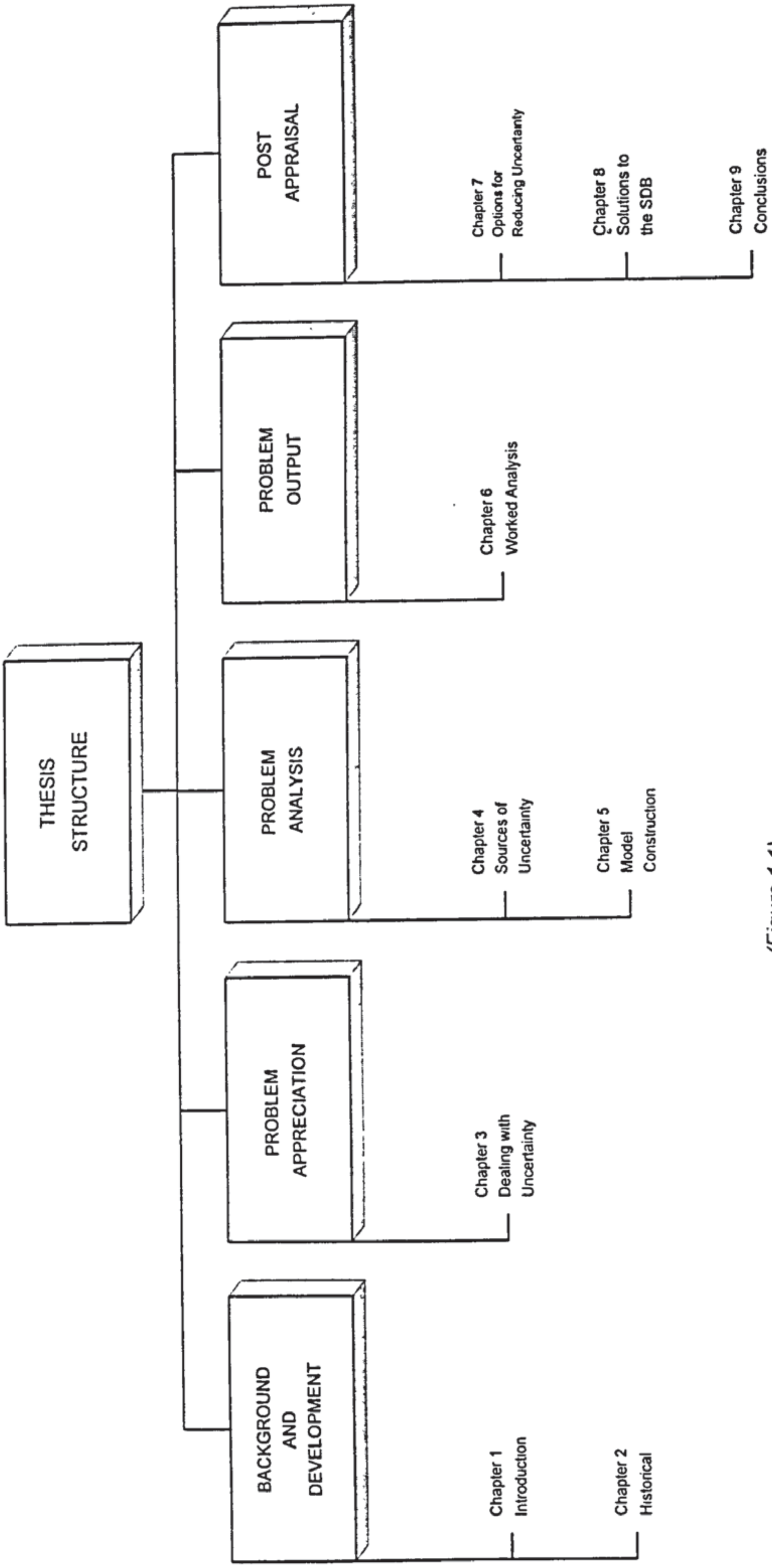
ix) Produce a set of definitions, consistent with and supplementing the Water Industry standard, to cover issues arising from this study, some of which are as yet undefined.

## 1.6 THESIS STRUCTURE AND RESEARCH METHODOLOGY

This research is divided into five sections, each with one or more chapters, moving through areas of background, appreciation, analysis, output and appraisal. An abstract schematic of the thesis structure is shown in Figure 1.1.

The bulk of the original research will be in Chapters 4, 5 and 6 involving scoping and analysis, leading through to Chapters 7 and 8 which consider ways of reducing uncertainty and how to introduce solutions, such as uncertain resource development, into the methodology.

For the reader's convenience, a definitions and abbreviations section is included as Appendix 1.



*(Figure 1.1)*
*Thesis Structure*

# CHAPTER TWO - RESOURCE PLANNING: HISTORY AND DEVELOPMENT

## 2.1 INTRODUCTION TO CHAPTER

Resource planning is not a new science, for engineers have been constructing new resources based on forecasts of demand since the earliest days of water supply. In Chapter 2 the history and development of resource planning is over-viewed from the beginnings of the recognised water industry in the UK, in the latter part of the nineteenth century, to the present day.

Note that there are several works which describe the historical and social development of water resource planning in the UK in detail and that this chapter is by no means exhaustive. For further reading see Hassan (1998) and Parker *et al* (1980).

The discussion follows through a number of identifiable phases:-

i) the period from the 1850's up to 1976 when economic and health needs took clear priority over environmental issues; when water was seen as cheap and environmental issues considered insignificant,

ii) between 1976 and 1989 when population growth fell, industrial output went into decline, environmental pressures increased, funding constraints (through external financing limits) were tighter and greater emphasis was placed on the importance of accurate demand forecasting,

iii) the simultaneous culmination of environmental pressures and industry privatisation resulting in the creation of the National Rivers Authority in 1989. At the same time the economic regulation of the privatised industry was in its infancy,

iv) developments instigated through UKWIR (United Kingdom Water Industry Research) beginning in 1993, coupled with the pressures to develop environmental appraisal techniques and the 'Paying For Growth' debate forming part of the second periodic review in 1994 (OFWAT, 1993),

v) key external events in the UK water industry, particularly the reaction to the summer of 1995.

## 2.2 EVOLUTION OF THE WATER INDUSTRY

Water supply examples can be found which go back thousands of years. Even in more recent centuries there are examples of local distribution systems, often constructed with pipes made of hollowed out tree trunks. Until the industrial revolution these systems would have been fed under gravity thus restricting supplies to those below the level of the source. It was reported by Smith (1972) that, in 1846, ten of the 190 local authorities in Britain had their own waterworks, but for the rest of the country water carts were the primary source for domestic use.

During the early to mid nineteenth century, following decades of water-borne disease, numerous local private waterworks were formed. These water companies provided the first supply which was available to the public at large at an affordable price.

Many years later local councils accepted responsibility for the provision of water supply within their areas and by 1950 there were 950 separate water supply organisations in England and Wales, each acting independently. The number of organisations would reduce to 187 immediately prior to the 1974 re-organisation of water management which succeeded the 1973 Act (MacLean, 1993).

The first major change in the structure of the UK water industry came with the passing of the 1945 Water Act which gave water companies the power to develop water resources subject to a satisfactory technical report and public enquiry. Up to this point applications were made directly to parliament; a long-winded process which meant that water companies tended to increase their planning horizons so that they would not have to go to Parliament too often. The 1945 Act also provided for the setting up of a Central Water Advisory Committee to advise the Minister on the proper use of water resources.

The next major change came with the 1963 Water Resources Act which set down the responsibilities of the newly formed River Boards for the conservation, utilisation and regulation of water resources. These boards were eventually to evolve through various stages into the Environment Agency of today.

The 1973 Water Act saw major consolidation of the Industry, reducing the number of organisations to ten Water Authorities (taking in the river boards and publicly owned water suppliers) together with 29 private Water Companies. Apart from mergers of small companies and the devolution of water resource regulation, the situation in the UK is much the same today. In 1973, the private water companies became agents for the Water Authorities with respect to the supply of water and it was not unusual for water authorities to carry out corporate planning functions on behalf of the companies; typically including demand forecasting and resource planning.

In 1989 the water industry was privatised and regulated involving the removal of traditional financing constraints, floating of water authorities on the stock market and creation of the fledgling Office of Water Services (OFWAT). The first periodic review, of prices and performance, instigated by the Department of the Environment (DoE) took place in 1990 which gave the water industry the opportunity to remedy areas of under-investment. Industry prices were set for the next 10 years although were subsequently reviewed in 1994.

In 1991 the new Water Resources Act replaced the water resources sections of the 1989 Water Act, and, in 1995, the Environment Bill provided for the creation of the Environmental Agency, bringing together water, air and waste management functions under a single umbrella. The Environment Agency effectively combined the previous functions of the NRA together with transferred duties for air pollution and waste management.

## 2.3 FROM 1850 TO THE WHITE ELEPHANTS

Throughout the period from the early days of the water industry in the 1850's through to 1976 there was no standard demand forecasting methodology within the water industry and forecasts concentrated on extrapolating past trends. On this basis the Water Resources Board predicted a doubling of water demand between 1970 and the end of the century (Hassan, 1998). This demand growth did not materialise, largely due to recession, resulting in severe premature development of resource schemes. (Parliamentary Office of Science and Technology, 1993). This section describes some of these early developments.

For detailed reading of other developments perceived to be premature, particularly Carsington Reservoir, see Parker *et al* (1980).

### 2.3.1 The 1922 Order - South Staffordshire Water

Examples of early resource planning up until the 1945 Act coincide with private Acts of Parliament, each of which sought to develop resources over extended time horizons, typically up to 25 years. The rate of growth of schemes during the period from 1900 to the 1970's was such that the emphasis was on sufficiency of resource rather than cost or environmental impact. It was considered that over-estimation of planning margins, even large ones, would be absorbed within only a very few years of demand growth. Rapid demand growth over the period 1900 to 1970 is shown in Figure 2.1 for South Staffordshire Water. South Staffordshire Water is a company located in the Midlands region of England and supplies around 2% of the UK population.

In the early years of the water industry demand growth was driven almost entirely by the ease of access to a water supply from the existing population. It was not until the mid 1960's that the primary driving force became growth in per capita consumption partly due to increased personal hygiene, in part associated with hot water heating systems, and increased acquisition of automatic washing machines.

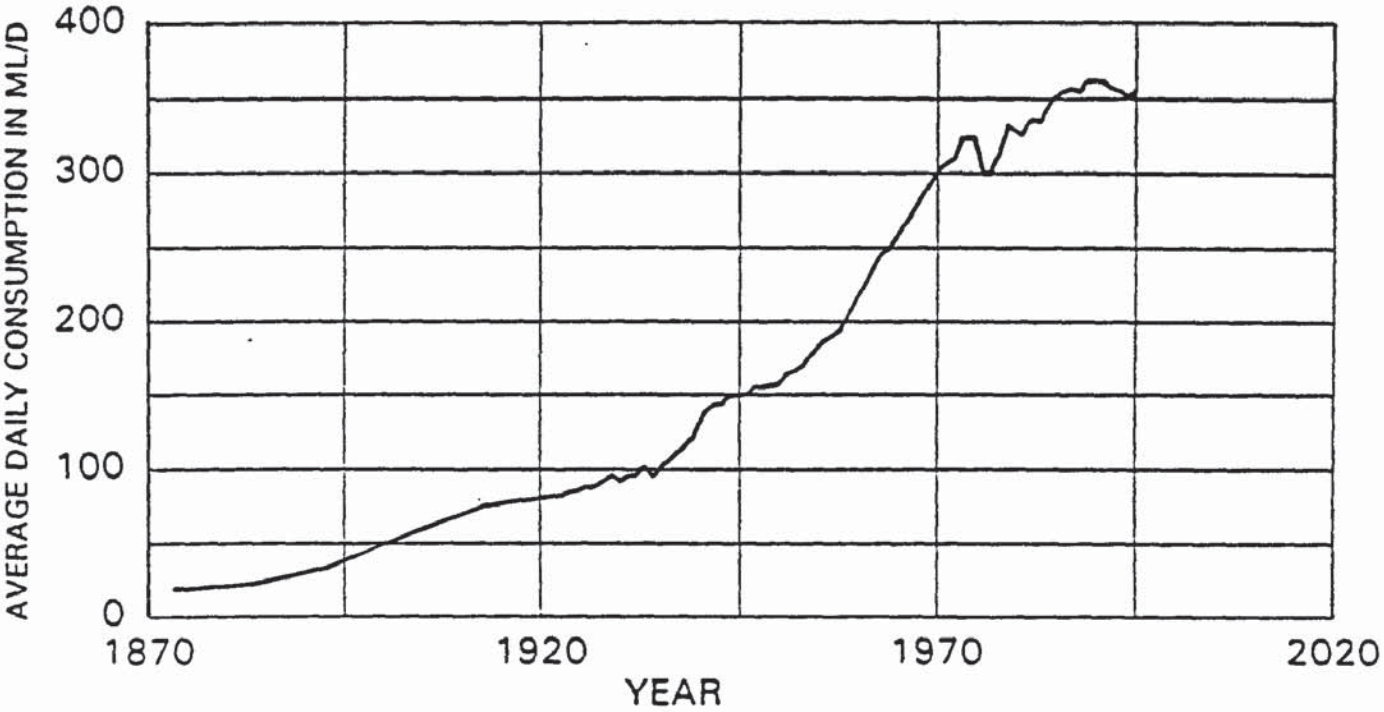
An example of an early Parliamentary submission by South Staffordshire Water was that made in 1922 when the Company applied for approval for six new borehole developments. The planning horizon spanned 12 years from 1922 to 1934 and projected and predicted a growth in average demand of 36% and a growth in peak 14 day demand of 38%. The submission is shown in Figure 2.2.

Forecasting at this time was at its most elementary with no breakdown of total consumption, even into industrial and domestic components. Resources were designed to handle consumption during peak fortnight on the basis that storage had little value when spread over 14 days.

Actual outturn demand is shown as a solid line showing the extent of outturn forecasting error.

A demand forecasting surplus would normally be mitigated given that the sources to be developed, as shown along the bottom axis of Figure 2.2, were small groundwater developments which would have had the benefit of low planning inertia and low investment. However, it is interesting to note that the 1922 Act of Parliament which permitted these developments acted as a form of momentum ensuring development and the dates of source development closely match those intended, leaving a resource surplus. In addition the outturn yields were around 30% higher than expected, resulting in a considerable supply-demand surplus.

It is also interesting to note that 1921 saw a significant reduction in average day consumption, almost certainly due to a tail off in post war reconstruction. A more appropriate "straight line" might have been projected through 1911 and 1921 in Figure 2.2 resulting in a 1936 estimate of 23 mgd, an increase of exactly half that of the parliamentary submission.



*(Figure 2.1)*

*Growth in average day consumption 1873 to 1995*

*for South Staffordshire Water*

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(Figure 2.2)
Forecast of demand showing proposed source developments and outturn demands
South Staffordshire Water (In Parliament) 1922

This observation shows that the sensitivity of straight line projection, even over a relatively short horizon, can make nonsense of long run planning decisions. With incremental low cost investment this could be significantly mitigated but as the industry consolidated and used up its aquifer and surface water stocks, it moved towards grander schemes, colloquially referred to as "white elephants", many of which have gone down in folklore.

The Kielder, Shrewsbury and Rutland developments have been described by various authors as less than justifiable. These three schemes are discussed briefly in Sections 2.3.2 through 2.3.4.

### 2.3.2 Shrewsbury

The Shrewsbury Water Order was an application to abstract water from the river Severn at Shelton to meet the future needs of the Shrewsbury Corporation. The application was particularly unusual in that other water undertakers were the main objectors.

The justification used to support the application is a particularly remarkable example of prudent planning.

In 1961 The South Staffordshire Water Company, the Wolverhampton Corporation, Birmingham Corporation and others were in the process of promoting a private bill for the provision of a regulating reservoir on the river Clywedog, a tributary of the River Severn. The Clywedog Reservoir, 11,000 million gallons capacity (50,000 megalitres), was to be a major financial venture for all those involved and it appeared that the Shrewsbury Water Order in 1961 was an attempt to secure abstraction rights from the river, which would of course benefit from the future provision of river regulation, but without proportional payment for Clywedog.

In the following text Mr. Risbridger is the Engineer for the Birmingham Corporation opposing the application: Mr. Sabido represents Shrewsbury. A Queen's Counsel carries out questioning. The text is extracted directly from the written transcript of the Shrewsbury Water Order Enquiry (Ministry of Housing and Local Government, 1961).

Figure 2.3 indicates the exaggerated implications of the arguments put forward by Shrewsbury in support of their application. A brief critique follows Figure 2.3.

Q *Now, Mr. Risbridger, have you sought to prophesy the future needs of Shrewsbury ?*

A *Yes, I have, within very wide limits obviously......... I have taken the upper limit at about the rate of 4% compound, which is I think a rate of increase no Undertaking in the Country has ever experienced.. I am quite certain this rate of increase cannot be maintained.*

Q *If that rate of increase were maintained, when would Shrewsbury be requiring 10 mgd ?*

A *By the year 1997.*

Q *Mr. Sabido talked about industrial supplies and on the grounds that he required a million for industrial supplies at the present day he thought he ought to budget for another three-quarters of a million in respect of future industrial users. What do you say to that ?*

A *I don't think I would like to dispute that.*

Q *You are content to accept that ?*

A *It only needs one very great factory to come in and you are landed with it.*

Q *Mr. Sabido takes another gulp of the river by adding a peak demand factor of 40%. What do you say to that ?*

A *In Birmingham, we have provision to meet a peak load of 40%, but we do not design all our plant to give 40% peak load, it is much less than that, because we have storage from which to balance the peak load.*

Q *Mr. Sabido goes on to add 2 mgd. in respect of the outside areas, as we term them ? What did you discover concerning these outside areas ?*

A *I found that the total consumption was 680,000 gallons per day, and I also looked up the resources from which that sum was derived, totalling altogether 684,590 gallons of resources, of which they appear to be using all but 4,590.*

Q *So in your opinion, would you add in this extra 2 mgd. for the outside areas ?*

A *Well, if I thought I could get away with it I might if I was in Mr. Sabido's position.*

Q *What if you were in the Minister's position ?*

A *If I was in the Minister's position, I should want to ask them some rather searching questions. I should want to ask them, for instance, what are they going to do with the existing sources.*

Q *Anyway, Mr. Sabido was able to convince himself that there ought to be a provision to the tune of 2 million gallons in respect of this item and brought his total maximum demand up to 9, and then he adds yet another million at the end. What do you say about that last million ?*

A *That is another million for luck.*

Q *He is a prudent man ?*

A *Very prudent indeed.*

The enquiry demonstrates how only 30 or so years ago the process of resource planning focused on sufficiency at all costs. Accuracy of the forecasts are appraised only in terms of industry norms and even the objector agrees that he would make the same proposal *"if he thought he could get away with it".*

It is worth making brief comment on the inclusion of contingencies in the application. It is easy to understand Shrewsbury's need to make allowance for a single factory because they could not cope with demand if it happened, as Mr. Risbridger agrees. However, does the argument extend to allowing for, say, two factories ? Clearly the issue is one of risk and cost. In the case of Shrewsbury they would be unwise to take the risk of a single factory development but would be unable to afford to provide a buffer for a factor of, say, 5 mgd. A 1990's water authority could absorb these events without undue concern simply due to their magnitude, thus suggesting that planning allowances will invariably reduce, the larger the organisation becomes. This relationship is shown in Figure 2.4.

This observation is referred to again in Chapter 5.

As to the final outcome of this enquiry, the Water Order (1962) permitted an abstraction of 6¼ mgd. This quantity was subsequently considered insufficient (West Shropshire Water Board, 1971) and the Borough of Shrewsbury became a constituent member of the Clywedog Joint Authority, increasing its powers of abstraction to 8½ mgd.

### 2.3.3 Rutland Water (1970): A Reassessment in 1982

In the 1980's the Water Industry began to question the development decisions made in the 1970's in the light of a tail off in demand growth. Herrington (1982) critically evaluated the Rutland Water development, noting a number of interesting observations which add value to

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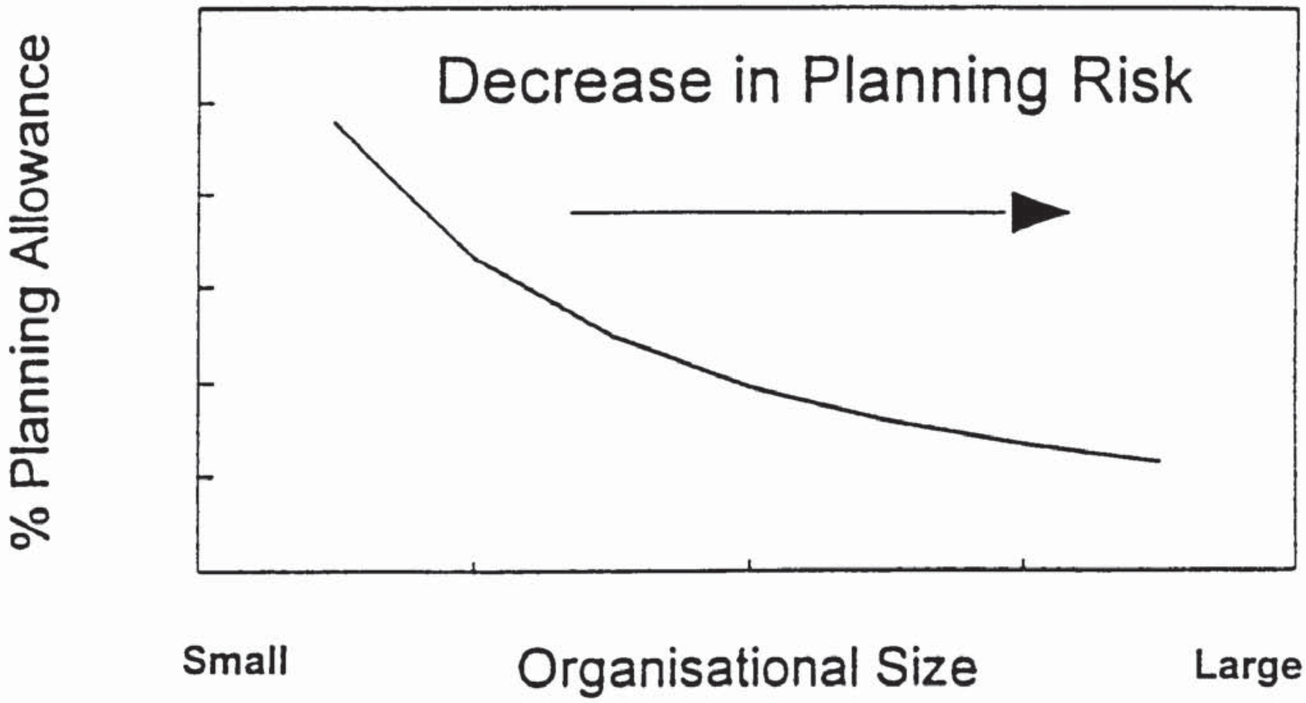
*(Figure 2.3)*
*Forecast of demand by Shrewsbury Water Corporation for the 1961 Water Order*
*(extracted from Ministry of Housing and Local Government, 1961)*



*(Figure 2.4)*
*The postulated relationship between planning margin and organisational size*

both the historic and current context of how uncertainty was, and perhaps should not have been, dealt with.

Herrington (1982) reports that one of the leading engineering witnesses for the Rutland scheme stated in his submission:-

> *"In an area where reservoir sites are scanty and demand is high and future demands are going to grow, one wants to put in a reservoir as large as the Country can accommodate."*

Herrington (1982) suggests the priorities of the 60's:-

> *"At the end of the 1960's no proposed reservoir had been seriously contested on the grounds that need had not been established..... engineers called the tune and accountants picked up the bills."*
>
> *"Over insurance has been presented as prudent housekeeping...."*

## 2.3.4 Kielder Reservoir

The Kielder saga has been debated *ad nauseum* in the UK but a discussion of historic resource planning would not be complete without mention of it.

There has been considerable debate on the errors of judgement made during planning of the Kielder scheme. Pearce (1982) was particularly condemning.

Leaving the politics aside, however, the Kielder experience is a classic example of how rapid growth prior to a forecast, a trend based forecasting method and extraordinarily long lead times can lead to errors of disproportionate magnitude and schemes which develop an almost unstoppable planning momentum. One answer to the problem is improved forecasting, including scenario analysis, coupled with incremental resource development. However, in 1970 this may have been much easier said than done and Brady (1985) argues for the firmly held convictions for the Teesside economy in the late 1960's, anticipating imminent, rapid and sustained growth. Conversely, in Hassan (1998), Gray (1994) describes the scheme as "*one of the most serious manifestations of the incorrect forecasting of the late 1960's*".

The potential impact of long lead times on forecasts can be seen in the paper by Gardiner (1986), from which Figure 3.1 has been extracted. The graph shows how the demand forecasts changed year on year until the scheme was developed; giving a difference between the 1967 and 1981 forecasts of 422 Ml/d; almost half the total projected increase.

Aston University

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*(Figure 2.5)*
*Kielder reservoir planning:*
*Northumbrian Water demand forecasts 1967 to 1981*
*(after Gardiner, 1986)*

## 2.4 FROM 1976 TO 1989

1976 is proposed as a change point in UK planning methodology because, for many companies, the 1975/6 drought halted the seemingly endless rise in demand which had been seen for decades. It may have been this downward distortion that catalysed the need for improved forecasting methods or it may have been the influence of a new generation of forecasters. Certainly in the latter part of the 1970's and early 1980's significant new methodologies were introduced, and welcomed, by the industry at large. Some of the most notable works were by Archibald (1983), the CWPU (1973), Herrington (1973) and Rees (1971).

Archibald (1983), for example, tidied up the state of the art in demand forecasting at that time, drawing on the observations made by Thackray *et al* (1981) from the Malvern and Mansfield studies and setting down the component methods for both domestic and industrial use forecasting that remain in common use today.

Two papers, Archibald (1983) and Thackray and Archibald (1981) effectively became working framework methodologies for demand forecasting across much of the water industry, remaining in use until UKWIR (1995$_a$) produced the Composite 'Demand Forecasting Methodology' with associated software.

A number of relevant events and developments during the period 1976 to 1989 are discussed in Sections 2.4.1 through 2.4.5.

### 2.4.1. Shropshire Groundwater Scheme (1979)

The Shropshire Groundwater Scheme is a supplementary form of river regulation for the River Severn during dry years in which Clywedog reservoir, at the head of the Severn Catchment, is unable to sustain prescribed flows at Bewdley. As abstraction from the river began to increase during the 1960's and 1970's the river Severn became progressively more likely to need support.

Various water undertakers sought to justify development of the Shropshire Groundwater Scheme to a public enquiry in 1979, including the Bristol Waterworks Company and the South Staffordshire Waterworks Company (Salop County Council, 1979). Some of the more interesting features of the submission which demonstrate partly prudent, but also evolving, behaviour of the time, are as follows:

i) the applicants applied upper and lower limits to the demand forecasts, sensibly to demonstrate scenarios. However, it was not clear what the lower limit was for or, more importantly, how likely the upper and lower limits were,

ii) an attempt at forecast plausibility was made by comparing the 1979 'moderate' forecast with the rapid rates of growth during the 1960's and 70's,

iii) a reduction in resource availability of almost 15% was made to total source output to allow for transmission capacity limitations and reduction in yield during a drought (of unknown severity). The 15% appears to have been arbitrary,

iv) resource need was based on peak week demand by the addition of 10% to the average day demand. The benefits of allowing strategic service reservoir storage to fall were ignored over peak week,

v) one of the applicants, Bristol Water, most encouragingly forecast future demand without use of historic trends. It was therefore a pure forecast without recourse to projection. The forecasts were also very conservative at less than 1% growth per annum,

vi) planning allowances appeared to be absent from the planning process except that an arbitrary 15% was added to demand for peak week while ignoring storage potential. In addition deployable yield was calculated to be that available in a *'3 dry year, 75% rainfall situation'*. It is not stated how severe these events were,

vii) one of the other applicants, Severn Trent, provided a detailed submission of demand forecasts insofar as assumptions are given for each of the various components of the forecast; measured, unmeasured, per capita, population, leakage, etc. The forecasts are also bound by upper and lower limits which are equally well explained, but without comment as to their likelihood. The preferred estimate was also noticeably much closer to the upper limit than the lower limit. The closeness of the upper and lower limits obviously adds confidence to the forecasts but it does little in terms of providing for planning allowances.

Despite the extensive evidence suggesting inadequate justification of demand growth the perceived need for the scheme would subsume objections.

### 2.4.2 North West Water - Report on Planning 1978

The North West Water Report on Planning (1978) may not be unique in terms of foresight but it is certainly evidence of rapid water industry change towards more thorough and sophisticated forecasting methods. Only a very few years after straight line extrapolation was commonplace this planning document takes both a detailed and pragmatic look at major influences on demand growth evolving the critical skill of combining judgement and science.

The forecasts examine structure plan proposals, Office of Population Census Surveys (OPCS) population projections, variation in domestic consumption with household occupancy and detailed appraisal of economic expectations. Most notably the report also highlights areas where the forecasts are particularly uncertain, such as leakage levels, and forecast ranges have been produced based on upper and lower limits. A 'preferred' forecast bisects these limits. The North West Water forecasts are reproduced as Figures 2.6 and 2.7. To quote the North West Water (1978) document directly *"the forecasts now rely rather less on extrapolating past trends than used to be the case in earlier exercises."*

Figure 2.6 shows the main constituents of domestic demand; garden watering, washing etc. Forecasts would have been derived from market research into appliance ownership levels and frequency of use.

The use of scenarios displayed in Figure 2.7 is useful for 'what-if' analysis but invariably the scenarios were only used to fine tune the position of the preferred forecast. Probabilities would not have been assigned to the span of possible outcomes.

For the evaluation of future water resources need, North West Water compared their preferred demand forecast with their 1 in 50 year source yield. They then made a deduction of 40 Ml/d (1.7% of demand) to provide for source outage due to remedial work and pollution incident. This again represents a thoughtful balance between science and judgement.

### 2.4.3 Yield Assessment of Water Resources 1977 through 1980

In January 1977 the Central Water Planning unit (CWPU) carried out a detailed study of methods for calculating the yield of surface water sources. The report observes that although source reliability is commonly stated in terms of return frequency (e.g. once in 50 years) it would be more appropriate if reliability were to be expressed in terms of duration, frequency and intensity of restrictions on customers.

(Figure 2.6)
North West Water Authority : Constituent elements
of Water Demand, Forecast to 2001

Illustration removed for copyright restrictions

(Figure 2.7)
North West Water Authority : Demand forecasts
to 2001 Scenarios

The CWPU note that failure means the emptying of a reservoir or the drawing down of an aquifer to a minimum acceptable level. In practice, however, the water supplier intervenes, often prematurely, to protect the reservoir by introducing demand restrictions and seeking drought orders. The effect of this is that the period of restriction tends to be longer than it might have been although the severity of the restriction is attenuated. The customer acceptance would also probably be higher hence the reservoir 'reliability' is increased. It is also expressed in terms which are more readily understood.

Specifically on the question of uncertainty the CWPU (1977) make two observations on how yield changes with time. The first is that yield reliability is based on historic data and is therefore empirical. Hence, as time goes on and more data becomes available the calculation of yield will inevitably change. The second point is that outage allowances tend to be high at the beginning of an asset's life as teething problems are sorted out. Outages will increase again as the asset beings to deteriorate towards the end of its working life. This relationship is shown in Figure 2.8.

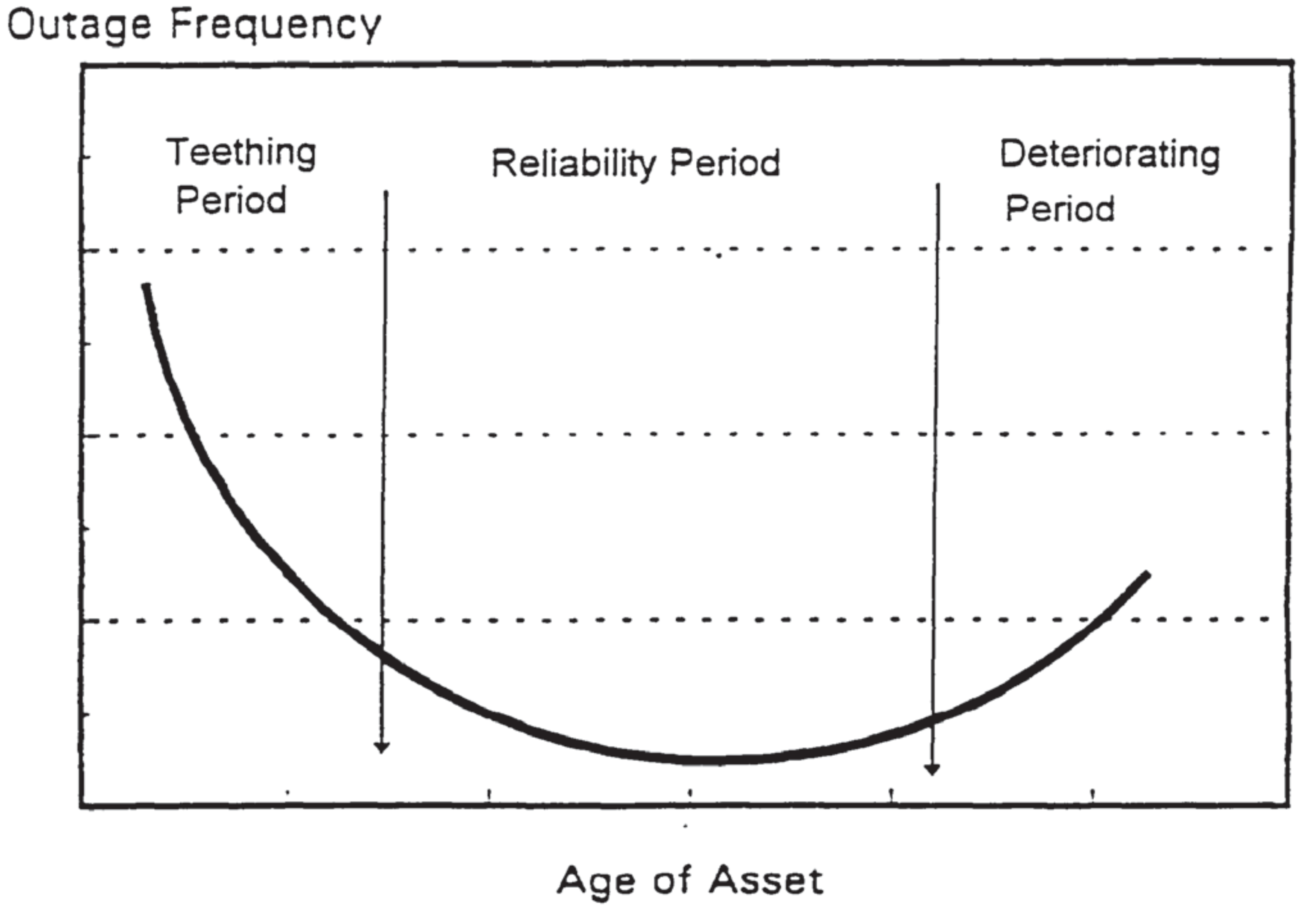
Clark (1980) expanded on the work by the CWPU on the question of source reliability noting that evaluating future need for water resources involves a trade-off between the supply-demand balance and the required level of service.

In a typical resource yield analysis a surface reservoir output would be defined in terms of a return period or risk of failure such as 1 in 50 or 2%. The defined yield would be the constant abstraction which causes failure at this level of frequency. The point made by Clarke (1980) is that water undertakers tend to over-react to droughts, introducing both demand management and seeking reduced compensation flows before it is clear how severe the drought actually is. In many cases, it is argued, the outturn drought turns out to be less severe than the design drought. In addition, the impact of restrictions, lower demand and reduced compensation flow tend to reduce strain on the reservoir thus increasing storage and the ability of the reservoir to cope with even more severe droughts; trading off levels of service to the customer.

This appreciation of the relationship between supply, demand and levels of service was innovatory for the time.

### 2.4.4 Risk Analysis Before UKWIR - An Example from South Staffordshire Water - 1986 (unpublished)

In 1986, South Staffordshire Water produced statistical distributions for variables influencing the supply-demand balance. A Monte-Carlo simulation program was written in FORTRAN to calculate frequency distributions for different levels of resource shortage.



*(Figure 2.8)*

*Change in source outage frequency with life of asset*

A logic diagram extracted from a Company resource plan in the early 1990's (South Staffordshire Water, 1992) is reproduced as Figure 2.9, showing the stages involved in deriving the supply-demand balance.

Early simulation models developed by South Staffordshire Water (1992), considered the interaction of the following elements:-

i) the effect of climate on average day and peak consumptions,

ii) the effect of demand restriction during severe climatic conditions,

iii) the effect of uncertainty in assessing the level of leakage,

iv) the effect of uncertainty in forecasting leakage target levels,

v) the statistical variation in surface water yield,

vi) loss of supply caused by: plant/mains failure, system and source pollution, routine maintenance, etc. (Planned and Unplanned),

vii) the trend in consumption peaking factors with time.

### 2.4.5 Other Developments : 1976 - 1989

In the Summer of 1985, Paul Herrington and Vince Gardener, representing the University of Leicester, obtained ESRC funding for a workshop on demand forecasting. The event was particularly significant in that forecasting techniques had evolved considerably over the previous 8-9 years while, at the same time, the Industry had still to go through the process of privatisation. This timing meant that there was much to discuss and that participants were still keen to offer free flow of information between companies. This free flow dried up very soon afterwards.

Fifteen papers were presented or posted at the workshop which were later published in a compendium volume (Gardiner and Herrington, $1986_b$), which is referenced by individual authors in the pages which follow. The various papers, in this unique compendium, explore demand forecasting techniques ranging from hourly forecasting to long term planning.

*(Figure 2.9)*

*Logic diagram for calculating the supply-demand balance*
*South Staffordshire Water Resource Plan 1992/3*

There are several observations within the compendium which deal specifically with the question of uncertainty although the paper by Gardiner and Herrington (1986) is the most notable.

Gardiner and Herrington consider that the greatest challenge to forecasting is in successfully combining analysis and judgement, noting that there is only a very weak correlation between information volume and forecast accuracy. The same paper also notes that demand forecasting should not avoid the issue of choice of service. As such, risk analysis should be employed to associate both demand and source provision at appropriate levels of probability.

The Gardiner and Herrington paper proposes risk analysis by simulation and quotes it as a possible way forward where sufficient demand information is made available. Although the comment refers specifically to demand forecasting the view is insightful. The paper also criticises the practice of adding arbitrary allowances to forecasts to allow for uncertainty, while noting that unsophisticated resource planning is often a fact of life.

Resource planning activity between 1976 and 1989 focused in particular on the demand side of the supply-demand balance, in particular the industry's inability to predict any of its demand components well.

An early reference to planning margins, although not of the type more generally associated with the supply-demand balance, was made by Thackray (1977). Thackray made the point that planning margins were often added to demand profiles simply to allow for possible delays during construction. This aspect adds an interesting new dimension to the uncertainty issue which will be referred to again in Chapter 4.

Research during the 1970's and early 1980's tended to concentrate on uncertainties within unmeasured demand on the basis that this was the element least well understood. In 1982 the National Water Council (NWC) summarised these studies, reporting particularly on the handful of appliance use and demographic studies which had been undertaken.

Turton (1985) also touched on the issue of uncertainty observing that:

> *"Information on Water Authority Policies should be kept under review - will leakage programmes be 100% successful ? - A gambler would not bet on some of the planned outcomes."*

Finally, it is interesting to reflect in hindsight on the ability to predict accurately. Steinberg (1982), for example, noted that the prevailing recession would last until 1996 based on 'Kondratieff Cycles'. Kondratieff, a 19th century analyst, observed a staggeringly consistent relationship between economic boom and bust cycles, forecasting economic booms beginning in 1849, 1896, 1945 and 1997.

There are sound logical reasons for business cycles which are beyond the scope of this work but, as part of the database of information supporting forecasts of water demand, they may in future be given more than superficial attention, particularly since industrial consumption forecasting is one of the most uncertain of all the demand components.

## 2.5 PRIVATISATION OF THE WATER INDUSTRY IN ENGLAND AND WALES AND ITS EFFECTS UPON RESOURCE PLANNING

Privatisation of the UK water industry in 1989 brought substantial change in the way the industry was regulated. Funding needs, through OFWAT, would now be critically assessed, and water resource need, through the EA (then NRA), would require substantial proof.

For reference a calendar of events covering the period 1985 to 1989 (Maclean, 1993) is presented as Table A1 of Appendix III.

By 1993, the effects of regulation and continued growth in water demand, (particularly peak demand), had reached a point where the industry needed to focus its research needs in support of more robust resource planning.

In 1993 the national water industry water resources group was formed, responsible for promoting research into areas of water resources where a greater understanding is required. The national water resources group was a body of representatives, typically water resources managers, who were employed by individual water companies but collectively acted on behalf of the water industry through the Water Services Association (WSA) and Water Companies Association (WCA).

The resources group fed proposals through UKWIR, the industry research co-ordinator, for tendering and project management. Each project had a water industry steering group typically made up of a team leader, representatives from the water industry and representatives from the Environment Agency and from OFWAT. The first UKWIR project was commissioned in April 1994.

### 2.5.1 UKWIR Supply-Demand Balance Research 1994 to the Present Day

As at September 1998, UKWIR had commissioned approximately 15 water resources projects, each project, typically of £30,000 value, taking between six and 12 months to complete. Of those commissioned to date, four have been directly associated with the supply-demand balance. These are:-

i) **The Calculation of Outage Allowances - April 1994 to March 1995**

This project reviewed the industry approach to how companies make allowance in their calculation of resource need for loss of source water during source outage. Outage allowances are a small subset of planning allowances on the supply side of the supply-demand balance. Chapter 4 discusses outage allowances further.

This project introduced the '@ Risk' package to the water industry as a software system to analyse problems involving uncertainty.

ii) **Sufficiency of Water - April 1995 to July 1996 (UKWIR, 1996,)**

This project was commissioned with the intention of producing a methodology which calculates whether a company has sufficient current water resources. The resulting research used decision trees as a technique.

iii) **Calculating the Impact of Demand Restriction - September 1996 to April 1997 (UKWIR, 1997)**

This project began with the objective of deriving a technique for converting methods of demand restriction, such as a hosepipe ban, into an equivalent saving in resource need.

iv) **Headroom - April 1997 to January 1998 (UKWIR, 1998)**

The Headroom project very much parallels this research, in that it is intended to provide a tool for measuring the uncertainty within the supply-demand balance, although the application is fundamentally different. Specifically, the Headroom methodology claims not to be sufficient to accompany an application for water resource development.

Outage allowances and Headroom are both considered in more detail within 2.5.1.3 and 2.5.1.4.

UKWIR also commissioned research into groundwater yield assessment and demand forecasting over the period 1993 to 1998. Both of these studies were key elements of the supply-demand jigsaw and are discussed in more detail in 2.5.1.1 and 2.5.1.2.

### 2.5.1.1 Groundwater Yield

Aquifers may typically store hundreds of years of supply, unlikely surface reservoirs, and if pumps are set deep enough, holes are drilled deep enough and head losses though the aquifer and borehole wall are low enough, then licence quantities may be achieved for decades, regardless of rainfall. Indeed, if the licensed yield is available, particularly if consistent with local demand for water, then the question of hydrogeological capability may never arise.

However, if borehole output, by virtue of hydrogeological capability, falls below licensed yield the resource planner is immediately concerned that source reliability has been reduced. This is usually due to one or more of three reasons:-

i) Aquifer decline due to low recharge (short to medium term),

ii) Aquifer decline due to mining the resource (permanent),

iii) Decline in borehole efficiency, due typically to clogging or coating of the walls.

From the above, cause (ii) requires a reduced pumping rate, (iii) may require remedial action whereas cause (i) represents a statistical event analogous with a defined reliable yield of a surface water scheme. However, applying a return period concept to groundwater is complicated by long duration antecedent conditions in the aquifer. This issue is referred to again in Chapter 4.

UKWIR ($1995_c$) made inroads into the evaluation of groundwater yield, producing a systematic and easy to follow methodology, although they were resigned to accepting that yields could not be assigned likelihoods. Instead they determined that a current yield and minimum historic yield (drought yield) were the only values possible and that the supply-demand balance should include the minimum historic figure for planning purposes.

The UKWIR methodology, summarised in graphical form is shown as Figure 2.10.

Illustration removed for copyright restrictions

*(Figure 2.10)*
*Example of a summary diagram : drought condition, average demand*
*(from UKWIR, 1995.)*

#### 2.5.1.2 Demand Forecasting

In July 1995 UKWIR published their demand forecasting methodology which served to standardise the inconsistencies in forecasting methods and offered 'best practice'. (UKWIR, $1995_a$). Notably, this UKWIR study is itself a significant source of reference and bibliography for demand forecasting research, citing a large number of UK and international studies. Other embedded references and bibliography into demand forecasting, to both UK and international studies, can be found in Herrington (1987) and UKWIR/EA ($1997_a$).

Mention is made in the UKWIR report of demand forecasting in other European Countries, observing that little is available which improves upon UK techniques. The French methodology, for example, uses highly sophisticated auto-regressive models but without explanatory variables. They therefore remain extrapolative rather than causal, relying on the usually dangerous assumption that the future will be an extension of the past.

The methodology in UKWIR ($1995_a$) is essentially the same component methodology discussed in section 2.4.2 but described in detail and in a consistent manner. New to the issue of dealing with uncertainty, however, was the question of *'base year'*. Component forecasts are not made in the absence of trends, or current values, hence the issue arises of whether current component values are typical, and, if not, how demands can be normalised. This is particularly important if weather parameters have been abnormal. The UKWIR document does not say, unfortunately, how *'normalisation'* can be carried out. This issue is referred to again in Chapter 4.

The methodology also incorporates the use of Maximum Likelihood Estimation (MLE). Since all demand components must add up to the water put into supply (top down) then adjustments to each component (bottom up) are made based on relative accuracy and magnitude. This concept also serves to demonstrate, albeit obvious, the point that improvements in accuracy should focus on the largest components.

An example is shown in Table 2.1.

Calculation of components in Table 2.1 gives a remainder for distribution losses of 68.76 Ml/d. Night flow analysis gives a figure of 71.59 Ml/d for distribution losses. The difference (2.83 Ml/d) must, therefore, be allocated between all the components according to relative perceived accuracy.

Table 2.1 reconciles the difference of 2.83 Ml/d between the total of demand components and the distribution input figure. Most of the difference is allocated to the distribution losses figure because of its high level of uncertainty (20%), resulting in an adjusted value of 69.81 Ml/d.

| Demand Component | Estimate Ml/d | 95% Variation | Range Ml/d | % of Total | Adjust | Revised Estimate |
|---|---|---|---|---|---|---|
| Measured Household | 6.02 | ± 0% | 0 | 0 | 0 | 6.02 |
| Unmeasured Household | 191.76 | ± 3% | 11.51 | 25.32 | -0.72 | 191.04 |
| Measured Non-Household | 72.82 | | 0 | 0 | 0 | 72.82 |
| Unmeasured Non-Household | 11.3 | ± 10% | 2.26 | 4.97 | -0.14 | 11.16 |
| Other | 6.1 | ± 25% | 3.05 | 6.71 | -0.19 | 5.91 |
| Distribution Losses | 71.59 | ±20% | 28.64 | 63.00 | -1.78 | 69.81 |
| Distribution Input | 356.76 | ±0% | 0 | 0 | 0 | 356.76 |
| | | | 45.46 | 100 | -2.83 | |

*(Table 2.1)*
*Example of Maximum Likelihood Estimation*

The reconciliation item of -2.83 Ml/d shown at the bottom of the "Adjust" column in Table 2.2 would be expected to reduce year on year as component estimation improves. "Range" in Table 2.1 is calculated by applying the 95% variation to the estimate.

The UKWIR methodology also offers advice on the extent of sampling needed for given levels of component accuracy, based essentially on the Central Limit Theorem (Kvanli et al, 1989), and quotes expected metering under-registration based on UK national metering trials.

#### 2.5.1.3 Outage Allowances and DG1

In 1994 the newly formed UKWIR undertook to improve upon the much misunderstood and inconsistently applied level of service measure of water resource availability, DG1, and embarked on the four studies described briefly in 2.5.1. DG1 ("Director General 1") was intended to measure, as an index, the fraction of supply over demand. A figure greater than one would thus indicate an adequate level of service. However, the measure did not define either 'supply' or 'demand' sufficient to avoid considerable inconsistency of application. In addition a DG1 less than unity meant that all a company's customers were at risk of water shortage, making DG1 an "all or nothing" standard.

Dealing with the full suite of planning allowances was seen by UKWIR as too major a first step, concluding that attention should be given firstly to defining and calculating outage allowances. The concept of planning allowances is shown for the supply side in Figure 2.11.

The UKWIR project began by scoping existing practices with regard to planning allowances, concluding that 39 of the 43 utilities were still applying simple adjustments to the supply-demand balance in much the same way as had been carried out for many decades before. Of the more complex techniques the study concluded that a risk simulation would provide a meaningful and practicable method of deriving outage allowances.

Outages were considered to be legitimate when due to pollution, temporary deterioration in water quality and system failure and probability of events was defined in terms of least, most and maximum credible outage in days, thus describing a triangular probability distribution for sampling.

The next stage of the evolution of the DG1 measure was to commission a study to redefine it, seeking to make it consistent for both internal planning and external reporting uses. The methodology for DG1 (subsequently re-titled "Sufficiency of Water") was quite straightforward, involving event trees, but it did not explore sources of uncertainty.

### 2.5.1.4 Headroom

Headroom is defined as *"the buffer between supply and demand to cater for the uncertainties in water resources planning and help ensure that the water company chosen level of service is achieved"* (UKWIR, 1998). The Headroom project, in the face of an urgent need to provide a usable method for planning in advance of the third periodic price review in April 1999, sought to provide a practical method rather than a theoretically robust one.

In total, ten sources of uncertainty were considered within the project. These uncertainties are assigned scores which are then combined applying the assumption that the square of variances is representative of overall risk.

The ten sources of uncertainty within the Headroom project are:-

(Figure 2.11 )

Terms used in the definitions of the output of an active source or group of active sources. (After UKWIR, 1995)

**Supply Topics**

Vulnerable Surface Water Licences
Vulnerable Ground Water Licences
Single Source Dominance
Bulk Transfers
Time Limited Licences
Gradual Pollution causing a Reduction in Abstraction
Uncertainty of Climate Change on Supply

**Demand Topics**

Accuracy of Sub-component Data
Demand Forecast Variation
Uncertainty of Climate Change on Demand

The summary score sheet and conversion curve are shown as Figures 2.12 and 2.13 respectively. The conversion curve converts the score into a percentage to be added to demand. The derivation of scores was substantially concluded by using an expert panel approach, where a panel of five expert water resource engineers debated and agreed through concensus the relative importance of each source of uncertainty.

The project has been applied widely by water companies as part of the third periodic price review.

## 2.5.2 Other Research: 1990 to the Present Day

Other than the four specific UKWIR supply-demand studies carried out between 1994 and 1998, it is appropriate to note two other areas of research relevant to this study.

### 2.5.2.1 Climate and Climatic Change

In the mid 1990's there was considerable interest in the impact that climatic change might have on the ability of the water industry to plan for the future. A number of organisations have considered the issue. The Met Office (1995) noted that a major source of uncertainty was the lack of understanding of the weather processes with Marsh (1995) further observing that the recent clustering of droughts raises doubts about the ability of historic data to provide a suitable

*(Figure 2.12)*

*Summary score sheet : UKWIR Headroom Project (1998)*

(Figure 2.13)

Score to planning allowance : Headroom conversion chart

(UKWIR, 1998)

basis for water management strategies. The IWSA (1995) also questioned any geographic consequences caused by climatic variation, a point also brought out by Marsh (1995), noting that the ratio of rainfall between Fort William and Kew Gardens was currently 4.25, compared to around 3.25 during the previous century.

The relationship between climate and demand has received little attention by the water industry although Carnell (1985) derived a relationship for South Staffordshire Water as shown in Figure 2.14.

UKWIR (1996) also compiled a climate versus water use model using non-linear relationships, derived using a neutral network approach. UKWIR, in the same report, offered a working assumption that climate over the period 1966 to 1995 represented a consistent block of climate which was unlikely to change over the next 10 years. Making this assumption allows the likelihood of future summer severity to be defined in terms of the last 30 years. This would infer a measure of acceptance for some sort of climatic clustering, lasting upwards of 40 years.

Some of the most interesting observations were reported by Burroughs (1996) who proposed that over the past two hundred years there has been a clear swing of rainfall distribution from summer to winter amounting to 1.9 mm per decade. This trend has clear implications for water resource planning, in particular whether drought reliability needs to be sustained by increasing storage. Graphs of the rainfall phenomenon reported by Burroughs (1996) are reproduced as Figure 2.14.

This research accepts the presumption for climate change and the degree of climate change uncertainty is discussed further in Chapters 4 and 5.

#### 2.5.2.2 Surface Water Yield Assessment

Much has been written of surface water yield assessment, particularly by the NRA and EA in recent years (NRA, 1995). Original techniques, prevailing over many decades, concentrated on simple mass balance methods, moving to the use of Markov Chains with the advent of computers. Mass balance techniques are perhaps the simplest to apply. Here the river inflow sequence is represented as a cumulative graph plot such that the gradient of the line gives the long term maximum abstraction and the variability of the line gives the size of reservoir required to achieve it.

*(Figure 2.14)*

*Nomogram demonstrating the relationship between weather variables and water demand for South Staffordshire Water (Carnell, 1985)*

(Figure 2.15)

Change in summer and winter rainfall 1765 to 1995 for England and Wales

(After Burroughs, 1996)

A Markov chain is a slightly more complex technique involving the multiplication of matrices. The Markov process begins by constructing a matrix of probabilities of a reservoir changing storage from one level to another over a specified time period (usually one year). If the matrix is multiplied by itself several times it will generally reach a steady state such that the original storage becomes irrelevant. This steady state matrix effectively describes the long term behaviour of the reservoir. For further reading see Moran (1959).

By 1995, behavioural analysis, simulating the behaviour of the water resource system itself, was favoured. The method allows reliable yield to be calculated for any return period, or design drought. Thus a statistical distribution can be formed which describes a level of service.

### 2.5.3 The National Rivers Authority and the Office of Water Services - 1989

Following the bill to privatise the water industry, the Water Industry Act of 1989 set down the functions of the two new regulators of the industry; the National Rivers Authority (NRA; the environmental regulator), which started operations on 1 September, 1989, and the Office of Water Services (OFWAT; the economic regulator), which began on 1 August, 1989. The NRA's functions, although tailored by the 1995 Environment Act, remain essentially as at creation i.e.

> *"... to manage water resources to achieve the proper balance between the needs of the environment and those of abstractors and other users ...".*

More recently the EA (1997) has adapted its corporate objectives to include a requirement to develop a better informed public, building on section 188 of the 1991 Water Resources Act to *"collate and report actual and prospective demands and resources"*. This drive for transparency, both from the NRA/EA and from OFWAT, has been instrumental to the need to develop more robust techniques for asserting the balance between supply and demand.

OFWAT was created under the same legislation as the NRA and its original function, tailored by section 2 of the 1991 Water Industry Act, is

> *"... to protect customers, promote efficiency and to facilitate competition".*

### 2.5.4 The Summer of 1995

With the benefit of hindsight the summer of 1995 was a key point in the evolution of water resources planning, as it exposed apparent shortfall within the water industry, both in terms of level of service but also an insufficient understanding of the optimal balance between supply and demand. This latter point was to emerge from the forthcoming House of Commons enquiry into the water industry and the subsequent Agenda for Action.

To demonstrate the severity of the summer and its consequences it is of value to note the experience of one of the water authorities worst affected, Yorkshire Water.

The warmest year on record stretching back over 300 years has been 1995 (although 1997 was very similar but not as extreme). The severity of the event exposed the degree of uncertainty facing the industry as noted by Lloyd and Stevens (1997) of Yorkshire Water, who observed that *"... there was little understanding of stated risks..."*. As a measure of this lack of understanding, and not intending to be critical, Yorkshire Water applied for a total of 36 drought orders in 1995/6 all of which were subsequently granted, in an attempt to restore water stocks. The extent of supply failure to customers as a result of both resource shortfall and of transfer mains capacity was extensive and, by September 1996, Yorkshire Water had invested in 28 additional groundwater sites and the laying of 240,000 metres of underground mains.

For further reading on the 1995 drought see Hassan (1998).

### 2.5.5 House of Commons Enquiry 1996

As a direct, and expected, consequence of the summer of 1995 failure in standards, the Government, through the DoE (now DETR), commissioned a House of Commons enquiry. The enquiry took place in June 1996 and invited submissions from the industry, its three Regulators (the Drinking Water Inspectorate, OFWAT and the EA) and a number of other consultees from industry, commerce and environmental groups.

Coincident with the House of Commons Enquiry was the publication of the Agenda for Action report in October 1996.

### 2.5.6 Agenda for Action 1996 and Subsequent Events

The Agenda for Action (1996) made a series of recommendations for the water companies and for each of the Regulators. These recommendations are presented for reference as Table A2 within Appendix III.

Notable within the recommendations to water companies, and consistent with this research, are the suggestions to: improve estimates of yield, better understand the use of water, improve the measurement of leakage and to better understand climate change. It was clear that the extent of uncertainty within the industry was cause for considerable concern.

Agenda for Action (1996) also identified that the Government intended to modify the legal and regulatory frameworks to ensure that the recommendations placed upon the water companies and Regulators might be more readily achieved. The first stage of framework re-development was the publication of the Deputy Prime Minister's 10 point plan on 19th May 1997. The 10 point plan is presented as Table A3 of Appendix AIII for reference but note should be taken of point 4, directing against supply expansion, and of point 8, which encourages water companies, by the use of financial penalties, to ensure proper provision of their supply-demand balance. This latter requirement, in particular, pushes the industry towards more robust resource planning.

By January 1999 the Government's position on the issue of the supply-demand balance reached a milestone with the issue of ministerial guidance to the EA and OFWAT (DETR, 1999) which advises, in particular, the need to make appropriate allowance for uncertainty. Several abstracts from this guidance report are cited in Section 1.2.

## 2.6 RESOURCE PLANNING IN THE USA

The United States water industry is uniquely structured with more than 60,000 suppliers, of which 43,000 serve between 25 and 500 persons each (Shelstad and Hanson, 1986). Despite this localisation there is considerable literature on resource planning demand forecasting methods, in particular, which are not dissimilar to those in the UK. Prasifka (1988) produced a manual of water supply planning which includes a detailed summary of demand forecasting in the USA and contains a number of extracts which are pertinent to the scoping of uncertainty.

Prasifka begins by setting down causes of demand forecasting uncertainty as repeated in Table 2.2:-

*(Table 2.2)*
*Factors that influence urban water demand*
*(Prasifka,1988)*

Prasifka (1988) noted that fine tuning of per capita forecasts may be overshadowed by uncertainties in population projection in areas with high growth. This reinforces the point that investment risk is most acute when demand growth is low, because rapid growth makes excess capacity useful and that knowing how to deal with, as well as how to reduce, uncertainty is essential in such circumstances.

Prasifka considers the supply demand balance in much the same way as the traditional UK planners have done, although goes on to discuss the use of alternative futures to which probabilities can be assigned. Prasifka suggests that alternative futures might be derived using contingency trees. This approach is discussed in Chapter 3.

Within this section on historical background and in the context of improved methods of dealing with uncertainty, it is appropriate to reproduce in Table 2.3 the evolving US demand forecasting techniques (Dekay, 1985) covering the period 1940-1984. There is a strong correlation between the evolution within the US and that experienced in the UK.

*(Table 2.3)*

*Evolution of demand forecasting techniques and data bases for the Seattle Water Department, 1940-1984 (Dekay , 1985)*

Dekay (1985) also makes interesting commentary concerning the relationship between the need for forecasting accuracy and the forecast horizon, taking the view that the uncertainty is so severe that understanding the uncertainty and being able to respond to different scenarios is more important than trying to fine tune the central forecast. While Dekay makes a good point, adopting this principle may encourage poor forecasts hidden within wide scenarios. Hence, if forecasting resources are limited, then it is sensible to strike a balance between a reasonable central forecast and a reasonable set of estimates for uncertainty.

Weber (1993) offers particularly useful advice on how to deal with demand side uncertainty, postulating that the key is to separately forecast components likely to grow differently from the homogenous mass. Weber also proposes that it is more efficient to specify uncertainty within a forecast than to persist with fine tuning the forecast. Although this may well be true in the majority of instances Weber should perhaps have qualified this observation by noting that the cost of fine tuning when applied to forecasts used for resource planning may turn out to be good value for money, depending on the cost of fine tuning. By example, capital development in the UK in the 1990's was anecdotally £500,000 for each megalitre per day of supply-demand imbalance.

## 2.7 PLANNING MARGINS AND RISK ANALYSIS IN OTHER SECTORS

It is of no real surprise that the sophistication of forecasting techniques is directly related to the value of the product market, whether social, environmental or in direct financial terms. In this respect it serves as an interesting comparison to examine the forecasting methods and general approach taken in other sectors. The degree of sophistication has, as expected, increased over the decades as computer speeds and capabilities have increased.

### 2.7.1 Energy Forecasting

As with predictions of future water demand there is evidence that energy predictions have been driven by external pressures. In the early to mid 1960's forecasts were supply focused (Department of Energy, 1978), driven by government policy and expectation for energy producing industries; coal, gas, electricity etc. The energy crisis in the early 70's demonstrated the importance of economic influence on demand and changing techniques began to evolve, this time giving more consideration to energy demand. Scenario analysis was a feature of the methodology used by the Department of Energy (1978) but the analyst points out that:-

> *"the model variables are not intended to have statistical significance in terms of probability distribution .... but to represent the different effect of discrete decisions .... in respect of certain alternative courses of action..."*

Optimal solutions based on scenarios therefore did not seek to estimate the most likely supply-demand balance but rather to suggest that many of the factors influencing the forecasts were controllable and in this respect were not random events. An optimal solution from amongst the wide range of alternative scenarios was based on lowest cost.

The use of planning margins in energy forecasting seems to have taken a secondary role to that of macro-economic analysis although security of supply is superficially allowed for when considering the availability of energy from power generation stations.

### 2.7.2 Inflexible Technologies - Nuclear Power

To demonstrate that uncertainty is not unique to water resources planning the following extract, taken from a paper by Collingridge (1984), shows the inextricable linkage between uncertainty, prudence, politics and planning inertia typical of rapid growth; long time horizons, and weak forecasting techniques. The analogy with reservoir schemes is obvious. The difference between water and power, of course, is that power has various source types where water has only one. The uncertainty is therefore likely to be higher in defining when and how to provide for energy need.

> *"The 1955 programme was greatly expanded in March 1957. There were many reasons behind this. The energy shortage was still perceived as a threat and a larger nuclear programme would help to reduce coal demand still further. There was a belief that larger Magnox reactors would produce cheaper electricity, but building large plant necessitated a larger programme in order to iron out the lumps in investment.*
>
> *"Forecasts were, however, seen to be seriously wrong before the programme was even half finished. The impending energy shortage soon evaporated. As early as 1959 there were coal stocks of 40 million tons. Only four years after the original White Paper, there was a world glut of oil and its price began to fall steadily. Electricity demand in the UK grew much more slowly than had been forecast.*
>
> *"The White Paper of 1960 recognised that there was no longer a case for nuclear power on grounds of fuel supply. By then, however, six stations of total capacity 2.7 GW were under construction, and two more had been approved. The justification given in the 1960 White Paper for continuing with the programme was that some time in the not too distant future, perhaps in 1970, Britain would need a third primary fuel."*

Collingridge (1984) then goes on to offer commentary on the lessons of the period:

> *"The hard lesson is that foreseeing what needs to be forecast to justify investment in nuclear power over the required time span is impossible to do with sufficient certainty.*
>
> *"The lessons here may concern forecasting, or the technology itself. Could these errors have been avoided if investment had been made to improve forecasting methods, or should people have looked with greater suspicion on technology which demanded that forecasts of this sort be made ? Long-term forecasts of energy supply and demand are notoriously inaccurate because of the great speed at which perceptions of fundamental problems can change ."*

The lessons for the water industry parallel this view. A sensible approach to minimising risk is to combine a reduction in forecasting uncertainty with a portfolio approach to resource development.

## 2.8 SUMMARY OF CHAPTER AND OBSERVATIONS

In the early days, resource planning uncertainties were dealt with by over-design such that errors would eventually be taken up through growth and rapid linear growth until 1976 made the need for sophisticated techniques seem pointless. In addition, water was seen as cheap and environmental costs considered insignificant. Uncertainties were arbitrary involving additions to demand or reductions to yield and no allowance was made for storage. The planning process created its own inertia, causing over-planning, over-design and scheme commitment.

Major reservoir development in the 1970's and 1980's was a significant trigger for change in forecasting techniques and the emphasis on health and hygiene became a secondary issue, particularly following water industry privatisation. In these circumstances growth in water use was seen as less and less essential, eventually becoming undesirable.

By the 1980's scenarios began to be used to represent uncertainty but invariably without comment on their likelihood. By 1999 there still remains no satisfactory method of predicting industrial demand.

Many writers recognise the need to understand and recognise uncertainty although few have attempted to quantify it. Through UKWIR, the 1990's saw a general move towards representing the supply-demand balance in terms of customer standards of service.

# CHAPTER THREE - DEALING WITH UNCERTAINTY AND RISK

## 3.1 INTRODUCTION

The main objective of this research is to offer a usable approach to evaluating uncertainties, or risks, in the calculation of water resources and water demands such that the 'difference' between them can be calculated. Evaluating uncertainty will involve combining together events and likelihoods, not all independent, in a way which provides a usable result. Chapter 3 considers how to develop such a result analytically. Chapter 4 scopes individual uncertainties and Chapter 5 assigns quantitative measures to the uncertainties derived in Chapter 4.

Chapter 3 is not meant to be a detailed or robust mathematical study but rather to give an insight to the reader, without recourse to mathematical literature, sufficient to provide continuity. For more advanced reading on simulation and risk analysis, see Morgan and Henrion (1990) and Tocher (1963). Chapter 3 focuses, inevitably, on areas of mathematics considered by the Author during development of the research.

There is a prior belief at the outset of this research that computer simulation is the only practicable way to handle complex uncertainty and that discussion consequently follows a path towards this conclusion. The desire to avoid complex mathematics also directs discussion towards simulation techniques. Before going too far, however, it is appropriate to reiterate that the complexity of risk analysis should be consistent with fitness for purpose. It is neither sensible nor cost effective to undertake an extensive risk analysis if the user wishes only to explore options for internal use rather than to promote, for example, a new resource development.

The chapter culminates with a review of prescribed simulation software as an 'off the shelf' aid in the evaluation of any problem with inherent uncertainty.

## 3.2 THE MATHEMATICS OF UNCERTAINTY AND RISK

The section provides a brief appreciation of how uncertainty propagates from a mathematical perspective. The analytical example is extracted from Herrington (1987).

Consider a simple two-component aggregate, $Y = X + Z$. Let confidence limits for some future year be given, by judgement, as $X_f = X \pm x$ and $Z_f = Z \pm z$, and assume $x > z$. It can be shown that the distributions of the possible values of $X_1$ and $Z_1$ reveal component limits of $Y_1 = (X + Z) \pm (x + z)$ and, given a perfect correlation between $X_1$ and $Z_1$, $Y_1 = (X + Z) \pm (x - z)$. The confidence limits of $Y = X + Z$ can then be shown to be based on the 'root mean square' of the component limits of $X$ and $Y$ (as Pythagoras). This principle extends such that confidence limits propagate with the root of the combined square of components as each new component or variable is introduced. The root mean square relationship also means that it is erroneous to simply add uncertainties together. This observation lies at the core of this research and reinforces the view that the planning techniques described in Chapter 2, which involved the crude addition of planning allowances, resulted in over-design.

The propagation of uncertainty becomes more complex when the ranges described in the two-component case are replaced by probability distributions as shown in Figure 3.1; such that specific points across each range can be assigned likelihoods. Within Figure 3.1 there are two input distributions $x_1$ and $x_2$, and the response function, or output distribution, is given by $y = f(x_1, x_2)$. In effect the response function, $y$, propagates from infinite sampling of $x_1$ and $x_2$ from their density functions.

## 3.3 METHODS OF DEALING WITH UNCERTAINTY AND RISK

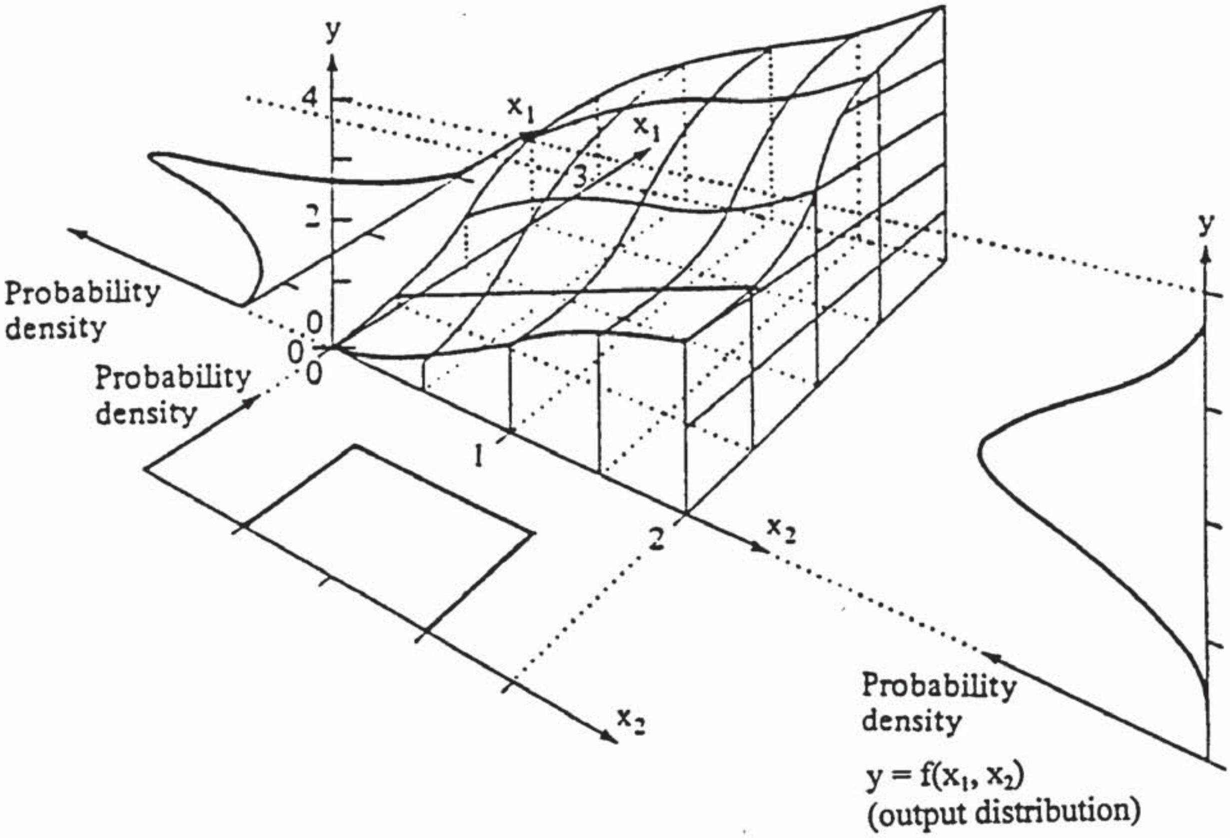
Section 3.3 considers some of the prevailing techniques for dealing with uncertainty and risk.

There is often confusion over the difference between uncertainty and risk, and methods tend to be referred to generically as risk analysis. However, since risk is the product of severity and likelihood, it is a straightforward matter to apply risk analysis methods where only uncertainty needs to be considered simply by fixing the event severities as equal.

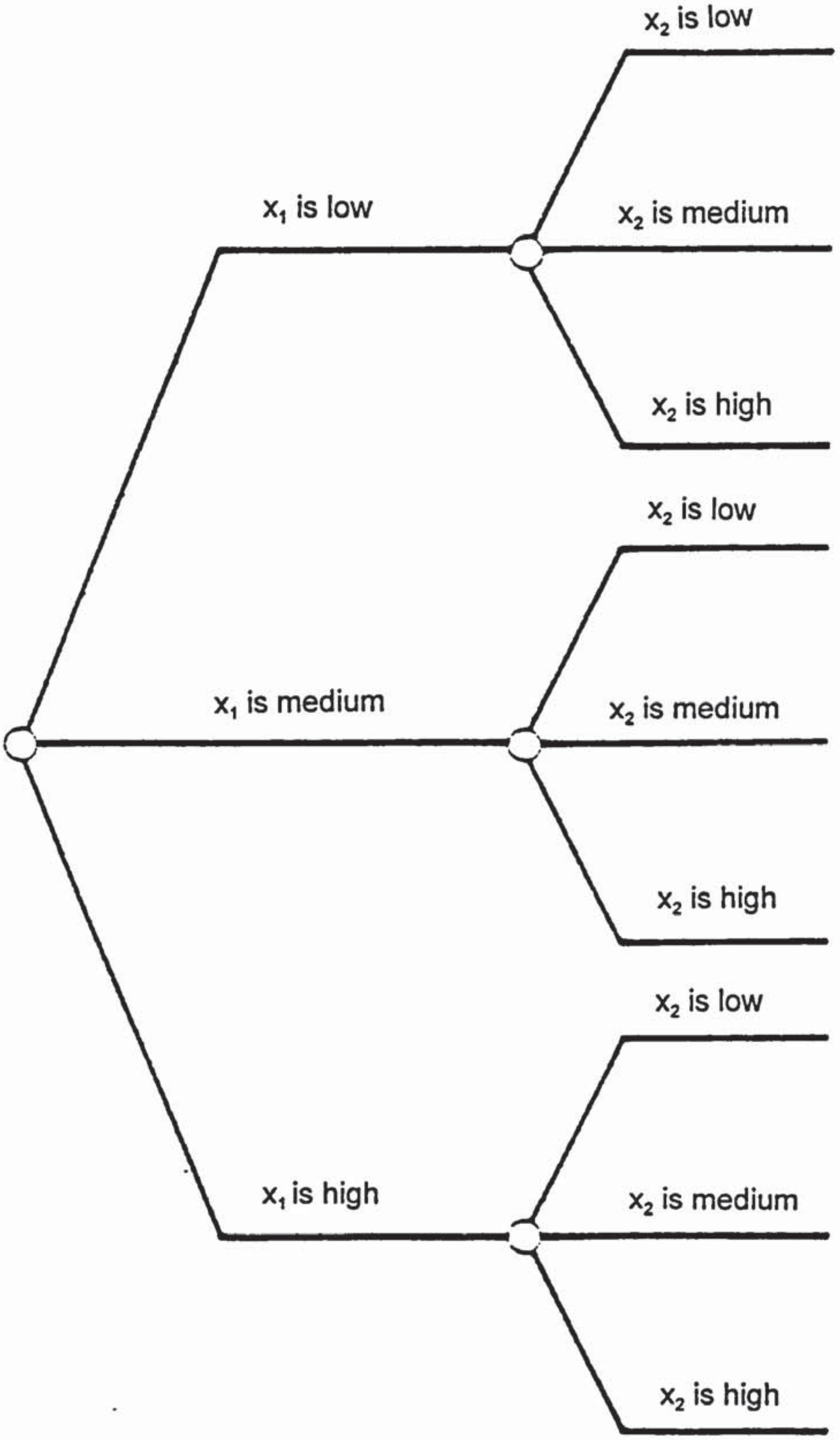
The techniques described in this section will range from the simple to the complex, with fitness for purpose as a primary driver. Description is superficial but appropriate references are provided for further reading.

### 3.3.1 Scenarios and Probability Trees

From Section 3.2, and particularly Figure 3.1, it is evident that, for anything other than the simplest of models, attempting to combine uncertainty using a mathematical approach would be highly complex. However, discrete scenarios (alternative possible outcomes) can be presented and analysed, very simply, in discrete form using a scenario tree. An example with two inputs at three levels is shown in Figure 3.2. For further reading see Kvanli *et al* (1989).



*(Figure 3.1)*
*An example of the propagation of continuous probability distributions through a normal distribution over x1, and a uniform distribution x2.*
*(after Morgan and Henrion, 1999)*



*(Figure 3.2)*
*Example of a scenario tree which uses three levels*

It is easy to see that the scenario tree in Figure 3.2 is geometrically complex, i.e. for two inputs at three levels there are nine branches ($3^2$) and likewise for ten uncertain inputs at three levels there are 59,049 branches ($3^{10}$). Computational effort therefore becomes excessive very quickly.

The UKWIR (1996) study into water sufficiency advocates use of a probability tree methodology across a wide variety of examples, highlighting its mathematical simplicity as well as its geometrical complexity.

Scenario analysis also allows for simple evaluation of a finite number of alternatives, including both consequence and likelihood. For example, suppose that two outcomes are possible from a game of poker; either win an average of £10 with a likelihood of 0.3, or lose an average of £5 with a likelihood of 0.7. The average return is then (0.3 x £10) - (0.7 x £5) = £0.50 loss for each game.

### 3.3.2 Simulation and Linear Complexity

In practice there is a severe constraint on the usefulness of scenario analysis because of having to consider all scenario branches individually. Simulation, by contrast, overcomes the problem of complexity by sampling from scenarios, often with infinite possible outcomes. Infinite outcomes are possible whenever one or more of the input variables has a continuous distribution.

Simulation approximates the mathematical solution, converging towards it as the number of samples taken, or iterations, is increased. Simulation is highly efficient in that accurate results can be obtained by considering only a small fraction of the potential combination of input scenarios. Perhaps more importantly, simulation produces a distribution for the output variable without any thought for the mathematics needed to combine the inputs precisely.

Section 3.3.1 noted how probability trees can be used to describe and analyse scenarios but noted that the analysis required solving a geometrically complex problem. A two variable problem with two scenarios contains four branches and, an 'n' variable problem with 'm' scenarios contains $m^n$ branches. The tree problem therefore becomes unmanageable with only moderate levels of complexity.

By contrast, simulation has linear complexity. For example, suppose that an output or response is a function of a number of uncertain input variables. Each uncertain variable is represented by a probability distribution which takes the place of the scenarios. A random number generator then samples from the first distribution and then moves on to the second. Once the final variable has been sampled the output is described and is then stored to form the output distribution. The process repeats until acceptable accuracy is achieved. This process is shown as a schematic in Figure 3.3.

The most obvious and notable feature of Figure 3.3 is that the process is linear. In other words doubling the number of variables doubles the length of the process. This is referred to as linear complexity and makes simulation workable. However, the greater the number of variables and the greater the spread, or uncertainty, assigned to each one, the greater the number of iterations required to achieve convergence to a desired level of accuracy. Convergence can be speeded up through the use of variance reduction techniques (Tocher, 1963).

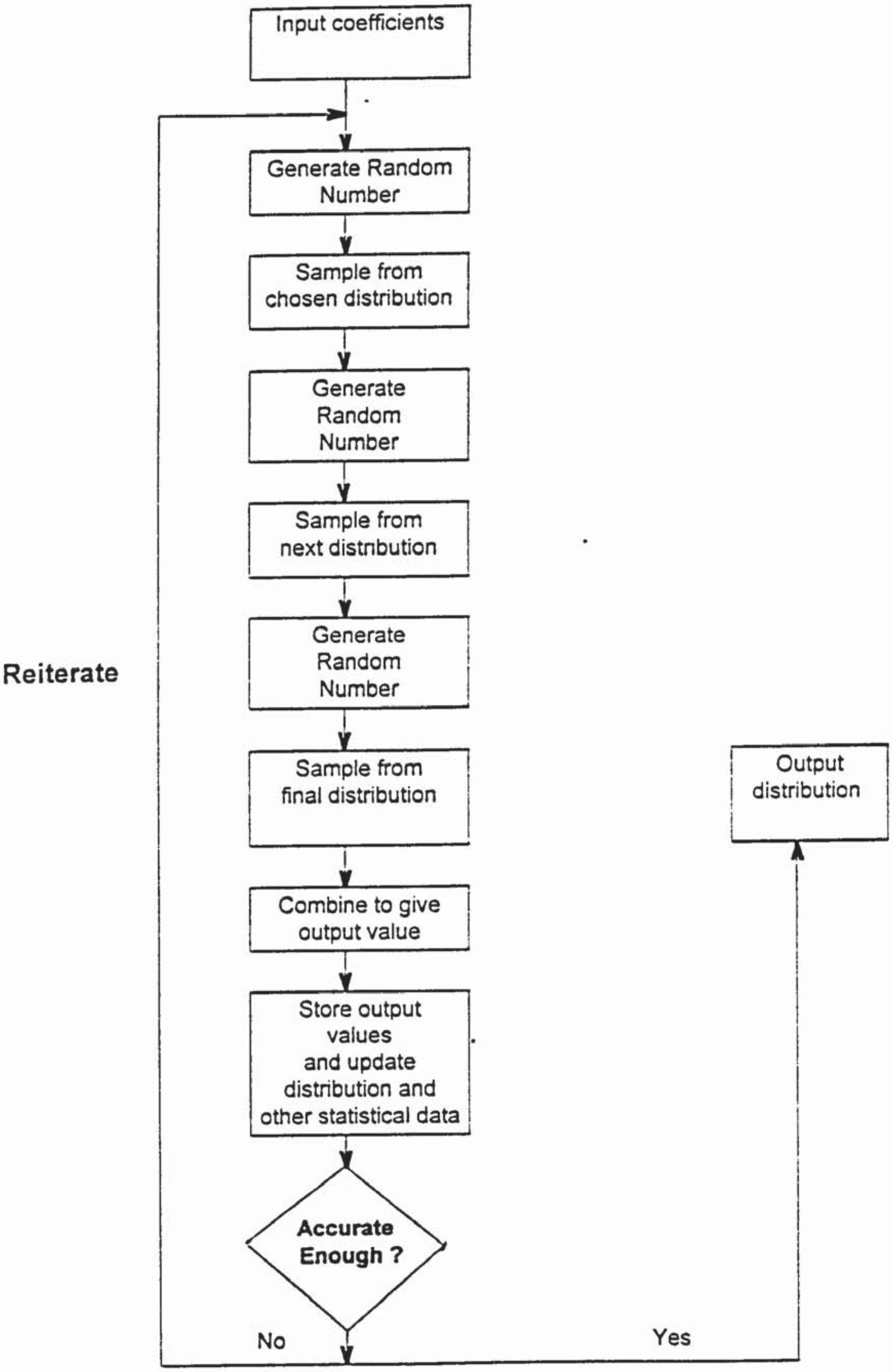
## 3.4 SAMPLING

Every simulation model will contain probability distributions describing the uncertainty surrounding the input variables. To combine these distributions mathematically, as previously discussed, is exceptionally complex but simulation simplifies the mathematics by moving from one distribution to the next, taking a sample at each stage. If enough samples are taken from each distribution then the output distribution will approach true mathematical form. The greater the number of iterations the better the result, although clearly following the law of diminishing returns.

The number of samples needed to reach a given standard of approximation to the true output varies with different sampling techniques. Hence certain sampling methods are more efficient than others.

### 3.4.1 Monte Carlo Sampling

Monte Carlo Sampling is sampling in its simplest form and derives from World War II when simulation was used to predict the risks associated with developing the atomic bomb.



*(Figure 3.3)*
*Linear combination of input scenarios to form an output distribution by simulation*

With enough iterations Monte Carlo will eventually approximate the shape of the distribution but with only a few iterations the tendency will be to produce samples which cluster around the expected value of the distribution. Thus the values within the tails of distributions may not be sampled. The more non-uniform and/or skewed the distribution, the worse this problem becomes. For further reading on Monte Carlo sampling see Palisade Corporation (1995).

### 3.4.2 Latin Hypercube Sampling

The problem of clustering with Monte Carlo sampling discussed in 3.4.1 can be overcome by forcing samples to be taken across the full range of the distribution. This forced sampling method is called Latin Hypercube sampling. The samples will no longer be strictly random but they will achieve the shape of the distribution much faster.

With complex models and long tail distributions the efficiency gain from Latin Hypercube sampling can be very substantial, particularly in terms of program run times.

For further reading on Latin Hypercube Sampling see Palisade Corporation (1995).

### 3.4.3 Types of Probability Distribution

Some of the more common probability distributions, including their application, are listed in Table 3.1. Quantifying uncertainty using expert judgement, which will be frequently applied within Chapter 5, tends to favour the application of a triangular distribution.

| **Distribution** | **Application** |
|---|---|
| Exponential | i) Time between events |
| | ii) Lifetimes |
| Gamma, Pearson | Time to construct or complete a task |
| Normal | i) Population characteristics |
| | ii) The sum of other quantities or distribution of averages (due to the central limit theorem) |
| Poisson | Number of events which occur in a given time |
| Student ("t") | A normal distribution with unknown population variance |
| Truncated Normal | A normal distribution with limits on the highest and lowest value |
| Triangular | Rough modelling where data is absent.<br>Distribution is based on a minimum likely, maximum likely and an expected value |
| Uniform | Quantities that vary uniformly between two values |
| Discrete | Where the independent variable is not continuous in terms of probability i.e. a histogram/barchart. |

*(Table 3.1)*
*Common probability distributions with applications*

These distributions, particularly the Normal, Triangular and Discrete distributions, form the core of the analysis in Chapters 5 and 6.

## 3.5 MODELLING IN PRACTICE

This chapter asserts that simulation is the most practical technique for handling complex problems involving uncertainty. The next stage, therefore, is to determine how to go about it in practice. The supply-demand problem, although not analytically sophisticated, is large in terms of the number of variables and the volume of data and, although a model could be custom written, the value of this research would not be enhanced by doing so. Given also that a number of prescribed software packages for risk analysis by simulation already exist then use of these packages was considered the sensible way forward.

### 3.5.1 '@Risk', 'Predict!', and other prescribed software packages

No doubt there are numerous software packages for dealing with risk analysis and some will clearly be better than others. Although it is not the intention here to carry out a software critique, it is appropriate to review and to seek out packages which are both relatively inexpensive and fit for purpose.

To say that risk analysis packages are in common usage would be misleading. There will be industries where risk is sufficiently important that they customise their own software. There will be other firms who do not analyse risk in any systematic form. The water industry typically does not use risk analysis as a design tool, but it is also true to say that a significant number of water companies have bought risk analysis packages following the UKWIR project on Outage Allowances (1995) which required them to be used.

Off-the-shelf packages tend to be applications which either bolt on to or incorporate spreadsheets. They also appear to be American imports with adopted UK suppliers who offer courses on their use and application. These courses often cost as much as the software. The two, more common, packages appear to be '@ Risk' developed by Palisade of New York and 'Predict !' distributed by The Risk Analysis Company, Oxford, UK.

### 3.5.2 A Review of '@ Risk'

In 1995 a version of '@ Risk' which included sister packages for viewing and fitting probability distributions cost around £600. The package bolts on to a Lotus 123 or Excel spreadsheet and has, as its basic function, the provision to replace spreadsheet cell entries by probability distributions. The programme then simulates by sampling from input distributions and stores these scenarios as an output distribution. The output distribution can then be viewed and analysed.

'@ Risk' realistically needs a Pentium processor with 8 Mb of RAM and, by example, attains convergence of a 10 input variable problem with 10,000 iterations in 170 seconds.

Spreadsheet cell entries can be cross-referenced, hence variable dependency can be included in the model.

### 3.5.3 A Review of 'Predict!'

'Predict!' cost £1200 in 1996, uses its own spreadsheet, and incorporates the same basic functions and model building approach as '@ Risk'.

For comparison on speed the 10 variable, 10,000 iteration problem using the same sampling method, took 31 seconds, more than 5 x faster than '@ Risk'.

'Predict!' refers to each iteration as a 'slice' and to a full simulation as a 'tier'. Once an operator has become used to these new terms they are actually quite helpful, particularly since slices can be referenced between tiers. This would allow, for example, a groundwater scenario in one year to be referenced to the groundwater condition in previous years. Each tier is then a year's simulation of the supply-demand balance.

On balance, given that '@Risk' is half the cost of 'Predict!' and is considered sufficient for this research, then '@Risk' will be the adopted software.

## 3.6 SETTING UP MODELS

Setting up models in spreadsheet form is straightforward. In essence the problem is described first as if uncertainty were absent and then with the 'uncertain' entries replaced by a probability distribution. Probability distributions can either be derived separately or directly using an '@Risk' optional extra called 'Bestfit'. 'Bestfit' checks the data against a database of distributions using a standard chi-squared test to optimise the fit.

When it is necessary to combine uncertainties, expressed as distributions, the computer will generate a random number, sample from the first distribution in the model, generate another random number, sample from the next distribution and so on. Once a value has been calculated for the output a single iteration has been completed and a second iteration will begin. After all iterations are complete, say 100, then 100 values of the output describe its distribution. The greater the number of iterations the smoother this distribution will become, hence closer to the true mathematical solution.

Chapter 5 describes model development in detail.

### 3.6.1 Fitting Probability Distributions

Plots of observed experimental or historic data can be presented in the form of a histogram. As more data becomes available, the histogram, in many cases, will begin to approximate one of the common forms of probability distribution. The dilemma facing the analyst is whether to stick with the histogram as the representation of uncertainty or whether to adopt a pure statistical form. Certainly in cases where the shape of the underlying distribution is less than obvious there may be a strong case for accepting the histogram as a discrete distribution. Distributions for the supply-demand problem will be derived within Chapter 5.

In classical statistics the analyst will choose a population distribution and test the hypothesis that the data fits the distribution at a given level of confidence. Various techniques are available for doing this, although the Chi-Squared test is used most commonly. These techniques are well described within Freund and Walpole (1980).

## 3.7 SIGNIFICANCE OF INPUTS TO OUTPUTS

There is a point in model development where adding additional terms, providing they are of decreasing significance, is not worthwhile. In traditional modelling, adding terms decreases the model residual and an analysis of variance will demonstrate the significance of a new term.

Regardless of statistical significance, however, it may be that the gain in accuracy is of lesser value than the cost of additional data acquisition and modelling.

Suppose, however, that the left hand side of an equation contains significant uncertainty and cannot be assessed accurately. This is the case with an evaluation of resource needs. The left hand side, resource shortfall, (or supply-demand balance) is evaluated by including more and more supply and demand terms to the right-hand side in an attempt to reduce omissions to an efficient minimum. Unfortunately the size of omitted terms will not be known precisely because all possible sources of uncertainty will not be represented in the model. In this respect a simulation, by default, has to assume that the model is always fully described.

Clearly if the inputs change or additional inputs are included then the output will change, which leaves the question of when the output has been sufficiently well described (given that it cannot be measured in the first place). Regrettably this can only be derived through judgement and experience.

The consequence of planning with unknown residuals tends to result in the inclusion of a contingency factor which sufficiently covers all possible unknowns. This is demonstrated quite clearly in Chapter 2, through the infamous '*factors of safety*' applied to 1960's demand forecasts. Other terms (UK Groundwater Forum, 1995) include assigning a '*precautionary principle*'.

The significance of input and output is measured in terms of variable correlations.

## 3.8 NUMBER OF REQUIRED ITERATIONS

The number of iterations to reach a good approximation will depend on the sampling technique, the severity and length of the tails of the distribution and on what 'a good approximation' actually means. The process of converging towards a good approximation occurs when the inputs begin to approximate sampling distributions. The output distribution then begins to stabilise, although typically much more slowly.

Both the '@ Risk' and 'Predict' packages allows convergence, or stability, to be monitored during simulation by measuring incremental movements in the percentiles to the distribution, the mean and the standard deviation. A target convergence figure is entered by the analyst.

As expected, increasing the severity of the convergence requirements increases the required number of iterations. Convergence is discussed further in Chapter 6.

## 3.9 SUMMARY OF CHAPTER AND OBSERVATIONS

This Chapter provides a brief foundation to handling uncertainty, particularly using simulation methods. The techniques and discussion are very specific to this research and somewhat superficial. Nevertheless, a number of additional texts are referenced for further reading if required.

Prescribed software packages are appraised with particular focus on sampling methods, correlation between events and convergence to a satisfactory accuracy of output. The software appraisal concludes in favour of using '@Risk'. This preview of the software sets the scene for Chapters 5 and 6, where analysis takes place in detail.

Prior to the analysis in Chapters 5 and 6 it is first necessary to scope the input distributions, or uncertainties, which might be considered for inclusion within the analysis. This is the purpose of Chapter 4.

# CHAPTER FOUR - SOURCES OF UNCERTAINTY

## 4.1 INTRODUCTION TO CHAPTER

Chapter 4 considers sources of uncertainty prevalent when calculating the balance between water supply and water demand. Note firstly, however, that this research is concerned with the imbalance, if any, between water resources and *unrestricted* water demand. This represents an important distinction with many resource planning methodologies which incorporate demand management techniques within their forecasts. Within this study, demand management techniques; such as pressure control, metering, sophisticated tariffs and flow controllers, are all considered to be solutions to a supply-demand imbalance. In this way a cleaner and clearer view of the future is obtained from which demand management options can be compared and appraised against classical resource development solutions, without prejudicial prior judgement of the most preferable solution.

Solutions to the supply-demand balance, by themselves, represents a new package of uncertainties. Chapter 8 considers this aspect of resource planning in more detail.

The chapter begins by setting out the author's view of what is meant by uncertainty within this research, going on to review the various dimensions of uncertainty. These dimensions include supply side and demand side uncertainties, physical errors and financial 'allowances', subjective and objective errors and partial and pure uncertainties. These dimensions, although overlapping considerably, will be used to scope and set down sources of uncertainty prior to discussion and evaluation.

Each source of uncertainty is described with thoughts on how it might be expressed and measured, focusing on historic evidence; direct prediction, cause and effect, and on how it might be dealt with.

Furthermore, each sub-section of Chapter 4 considers a single source of uncertainty and begins with its definition. Discussion then focuses on influences and existing research, concluding with how the available information, a combination of historic data, cause and effect assumptions and expert judgement, might be combined in a quantitative way. The assessment of risk is summarised within Table 4.9 for the supply side of the resource balance and Table 4.16 for the demand side.

Having set down the sources of uncertainty, Chapter 5 develops inputs to the risk analysis model by seeking to quantify the uncertainties involved.

## 4.2 CLASSIFYING UNCERTAINTY

Chapter 4 provides a scoping study of sources of uncertainty within the supply-demand balance. As such it draws upon research, individual experience and upon the issues raised by the various UKWIR studies referenced and, in particular, UKWIR (1998). Section 4.2 focuses the scoping study by first classifying sources of uncertainty across various dimensions as described in Section 4.2.2.

### 4.2.1 What is meant by Uncertainty?

There are numerous definitions of uncertainty but, in searching for one appropriate to this research, the WordNet Lexical Database (1997) defines a particularly good fit. This source of reference defines uncertainty as *'the state of being unsure of something'*. Likewise, this research is concerned primarily with the allocation of risk to supply-demand factors of which the water resource planner cannot be sure.

### 4.2.2 Dimensions of Uncertainty

The most obvious way of presenting sources of uncertainty would be simply to draw up a list. However, this procedure is much enhanced if different dimensions can be assigned to the uncertainty in a way which focuses the mind across different perspectives. Different categories of uncertainty are considered in Sections 4.2.2.1 through 4.2.2.5. The four categories considered are:-

i) resource planning uncertainty,
ii) partial and pure uncertainty,
iii) physical and financial uncertainty,
iv) subjective and objective uncertainty.

The scoping study is presented within a series of four tables, concluding with a summary table, Table 4.5, in Section 4.2.3. Each entry within the tables of uncertainties is cross referenced to a section within 4.3, 4.4, 4.5 or 4.6 in which the source of uncertainty is described in more detail.

The single requirement for including a source of uncertainty is that it must lie outside of the reasonable control of the water company. It is not appropriate, for example, for a water company to seek a planning allowance simply because it feels unable (or unwilling) to achieve its leakage targets. The materiality of the source of uncertainty is discussed in Chapters 5 and 6.

#### 4.2.2.1 Resource Planning Categories

Within the resource planning category, uncertainties will be defined as either on the supply side or on the demand side of the supply-demand balance. Examples on the supply side include those due to vulnerable sources, declining yields and to variation in climate change, and on the demand side include those due to demand precision, demand forecasting and variation in climate change.

The relationship between uncertainty in demand and uncertainty in supply is shown in Figure 4.1 (taken from UKWIR, 1998). The ranges "A" and "T" in Figure 4.1 describe Available and Target headroom, where available headroom is a subtraction of demand from supply and target headroom is the Company's minimum acceptable figure. Target headroom therefore occurs immediately prior to triggering the next increment in additional supply.

Sources of uncertainty within resource planning categories, expressed in terms of current and future influences are shown within Table 4.1. This table is derived from the author's own experience and is not exhaustive.

(Figure 4.1)
Graph showing the relationship between supply and demand uncertainty
(after UKWIR, 1998)

| | Sources of Uncertainty | | | |
|---|---|---|---|---|
| **Dimension of Uncertainty** | **Now** | **Future** | **Trend/Remarks on Source of Uncertainty** | **Cross Reference Section** |
| **Supply** | | | | |
| Groundwater Yield | Climate variability | | | 4.3.8 |
| | Has climate change already happened ? | Climate change | Impact of climate change is expected to worsen with time | 4.3.9 |
| | Outages (planned) | Outages (planned) | Depends on relative investment on maintenance and on levels of service. More emphasis on critical sites. | 4.3.6 |
| | Outages (unplanned) | Outages (unplanned) | See planned outages. | 4.3.7 |
| | Treatment process losses | Treatment process losses | Economics of recovery should cause reduction on site but general deterioration in water quality may cause increase in losses. | 4.3.13 |
| | Imminent clawback in resource by EA. | Future clawback in resource by EA. | Depends on Government policy on environmental capital and on who should pay. | 4.3.4 |
| | | Sustainability of abstraction (very long-term issue in some aquifers) | Difficult to define the meaning of sustainability in some aquifers. | 4.3.5 |
| | Inconsistent methods for assessing yields | Inconsistent methods for assessing yields | Should get better | 4.3.3 |
| | Historic yield data suspect ? | Historic yield data suspect ? | Should get better | 4.3.3 |
| | Is length of yield record adequate ? | Is length of yield record adequate ? | Should get better | 4.3.3 |
| | | Gradual pollution of source | Evidence needed | 4.3.2 |
| | | Other local sources influencing ability to abstract | | 4.3.5 |

*(Table 4.1)*
*Sources of uncertainty in resource planning categories*

Continued ......

|  | Sources of Uncertainty |  |  |  |
|---|---|---|---|---|
| **Dimension of Uncertainty** | **Now** | **Future** | **Trend/Remarks on Source of Uncertainty** | **Cross Reference Section** |
|  | Source meter error | Future source meter error | Metering Technology | 4.3.10 |
| **Supply**<br>Surface Water Yield | Inconsistent methods of calculating yields | Inconsistent methods of calculating yields | Should get better | 4.3.3 |
|  | Past hydrological sequence length may be inadequate | Past hydrological sequence length may be inadequate | Will get better in time | 4.3.3 |
|  | Current impact of climate change | Future impact of climate change | May increase or decrease yield, depending on geographical region | 4.3.9 |
|  |  | Risk of reduced licences due to environmental needs such as a change in compensation flows | Uncertainty should reduce with time | 4.3.4 |
|  |  | WQ standards increasing | Depends on political climate and on extent of technological change and ability to treat pollutants cost effectively | 4.3.2 |
|  | Outages at Treatment Works (planned) | Outages at Treatment Works (planned) | Depends on investment -vs- maintenance and on new technologies | 4.3.6 |
|  | Outages at Treatment Works (unplanned) | Outages at Treatment Works (unplanned) | Depends on investment -vs- maintenance and on new technologies | 4.3.7 |
|  | Variation in climate | Variation in climate | A function of river support | 4.3.8 |
| **Supply**<br>**Other Issues**<br>Bulk supplies from other Water Undertakers | Current certainty of bulks;<br>Water pressure uncertainty<br>WQ uncertainty<br>Uncertainty of commercial arrangements | Politics of bulk transfers<br>Long run marginal cost pricing | Bulk supplies received likely to reduce in future. May vary locally depending on policies, politics, pricing and practical alternatives | Excluded because example has negligible bulk transfers. |

*(Table 4.1)*
*Sources of uncertainty in resource planning categories*

Continued ......

|  | Sources of Uncertainty |  |  |  |
|---|---|---|---|---|
| **Dimension of Uncertainty** | **Now** | **Future** | **Trend/Remarks on Source of Uncertainty** | **Cross Reference Section** |
| Bankside Storage | Current policy with regard to allowing bankside storage to fall to cater for resource deficit during peak periods | Change in policy | Depends on licence flexibility to recover levels and on levels of service pressures -vs- resource development pressures.<br>Shared risk is likely to mean increased use of bankside storage | Excluded because example is for average day rather than peak periods. |
| Service reservoir storage | How much storage is included for peak day/week drawdown ? | How much storage should be included for peak day/week drawdown | Depends on source flexibility and extent of zone risk, multiple source inputs, etc.<br>Reservoirs which are fed by more than one source should be allowed to fall to a lower level. | Excluded because example is for average day rather than peak periods. |
| **<u>Demand</u>**<br>**<u>Measured</u>**<br>- Industrial | Meter under-registration | New metering technologies.<br>Better calibration of meters | Uncertainty should reduce | 4.5.10 |
|  | How often are customer meters read ? | Future meter reading policy | Pressures to read more:<br>Customers want to be better informed.<br>Uncertainty should reduce | Excluded. Not considered material. |
|  | Backlog of "consumption" against customers "in charge" | Future backlog | Should get proportionately better as more customers become metered | Excluded. Not considered material in the longer term. |
|  | Accuracy of estimating current measured demand | Forecasting future use is poor, may get better.<br>Tendency to over estimate. | Should reduce uncertainty | 4.5.3<br>4.5.7.2 |

*(Table 4.1)*
*Sources of uncertainty in resource planning categories*

Continued ......

|  | Sources of Uncertainty |  |  |  |
|---|---|---|---|---|
| Dimension of Uncertainty | Now | Future | Trend/Remarks on Source of Uncertainty | Cross Reference Section |
| **Demand Measured**<br>- Industrial cont. | Short term - prospective new development are risky and confuse forecasts | Method needs to take account of prospective demand. | Function of organisational size. Potentially an extreme event | 4.8 |
| **Demand Measured**<br>- Domestic | How often are meters read ? | Future policy for household metering ? | Use is likely to increase with economics of metering and with political pressure | 4.5.7.1 |
|  | Meter under-registration | New technologies | Uncertainty should reduce | 4.5.10 |
| **Demand Measured**<br>- Bulks given (exported) | Commercial arrangement | Policy - Is the export an alternative to new resources ? | Regulatory Influence | 4.3.14 |
| **Demand Unmeasured**<br>Household per capita | How well is unmeasured use understood ? | Better techniques for evaluation are likely. | Uncertainty will reduce with better techniques and as measured domestic use increases. | 4.5.3 |
|  | Politics for low leakage | Politics for low leakage likely to increase | Leakage levels likely to be forced down to political levels | 4.9 |
|  | Parity pressures | Parity pressures | Uncertainty reduces due to improved accuracy overall | Excluded. Complexity is beyond scope of research. |
|  | Climatic variability | Climate change and climate variability |  | 4.5.8<br>4.5.9 |
|  | Normalisation of base year not well understood | Normalisation techniques may improve | Base year uncertainty should reduce | 4.5.3 |
| Population/House-holds | OPCS/billing records | OPCS/Council forecasting skills | Low degree of uncertainty | 4.5.5 |

*(Table 4.1)*
*Sources of uncertainty in resource planning categories*

Continued ......

| | **Sources of Uncertainty** | | | |
|---|---|---|---|---|
| **Dimension of Uncertainty** | **Now** | **Future** | **Trend/Remarks on Source of Uncertainty** | **Cross Reference Section** |
| **Each component of per capita** | | | | |
| Baths | Measurement problems | Stable, but baths are likely to be used less often with growth in showers/power showers | Surveys will improve accuracy of measurement and prediction | 4.5.5 |
| Showers | Measurement problems | Power showers - frequency assuming climate change | See baths | 4.5.5 |
| Garden Watering | Survey bias due to stigma of garden watering | Sales rate Forecasting | See baths | 4.5.5 |
| | Uncertain ownership rates | Policy certainty Sprinkler metering | Uncertainty will reduce over time | 4.5.5 |
| Drinking Use | Measurement problems | Should get slightly higher with climate change | Probably an insignificant component | 4.5.5 |
| Waste Disposal | Measurement problems | Is it a "standard of living" product ? | See baths | 4.5.5 |
| Dishwashers/ Washing Machines | Measurement problems | Future technology | See baths | 4.5.5 |
| Toilets | Measurement problems | Hippo Bags<br>Dual flush | Function of water efficiency pressure. A "solution" | 4.5.5 |
| Cooking | Measurement problems | New technologies Microwaves, etc. | Reducing volume used | 4.5.5 |
| Hygiene | Measurement problems | Tending to increase with social behaviour, also increasing due to climate change | Unlikely to vary significantly | 4.5.5 |
| Leakage | Uncertainty of measurement. Politics. See also per capita issues. | Increased regulation, politicals and improved measurement | Uncertainty will reduce with regulation and as overall level of leakage falls | 4.9 |

*(Table 4.1)*
*Sources of uncertainty within resource planning categories*

### 4.2.2.2 Partial and Pure Uncertainty

This second category considers the concept of partial and pure uncertainty. Pure uncertainty deals with areas where lack of precision, forecasting assumption, or random variation is involved, but where the expected value is zero. Partial uncertainty has a non-zero expected value, such as climate change uncertainty where some degree of change is expected but it is not clear how much.

| | **Sources of Uncertainty** | | | |
|---|---|---|---|---|
| **Dimension of Uncertainty** | **Now** | **Future** | **Trend/Remarks** | **Cross Reference Section** |
| **Partial** | Reconciliation of top down and bottom up calculation of components of demand | As "now" | Should improve with time | 4.5.3 |
| | All climate variability effects | As "now" | A function of climate change | 4.3.8<br>4.3.9 |
| | Outages - planned/ unplanned | Future outages - planned/unplanned | See resource categories | 4.3.6<br>4.3.7 |
| | Permanent losses<br>- sustainability<br>- other yield losses<br>- uneconomic sources | Future clawback in licences | Timing is driven potentially in terms of available funding. | 4.3.4<br>4.3.5 |
| | | Prospective future developments | Potentially an extreme event | 4.8 |
| | Meter error | Future meter error | Better technologies. Uncertainty should reduce | 4.3.10<br>4.5.10 |
| | Current climate change effects | Future climate change effects | Unknown | 4.3.9 |
| | Current process losses | Future process losses | Depends on new technologies. Should reduce with time | 4.3.13 |
| **Pure** | Measuring current demand components | Forecasting components of demand | Uncertainty should reduce with time | 4.5.4 |

*(Table 4.2)*
*Sources of partial and pure uncertainty*

#### 4.2.2.3 Physical and Financial Uncertainty

This third category considers those uncertainties where the availability and economics of funding impact on the supply-demand balance. At the introduction to this chapter, it was made clear that this analysis will deal only with unrestricted supply and demand, as such no presumptions will be made regarding new resource options or demand management. Likewise, no prior view will be taken of source availability on the basis of economic viability. Nevertheless, future water quality deterioration/pollution represents a real uncertainty which is likely to render certain sources uneconomic. This may result in a material reduction in supply and cannot be overlooked.

The concept of physical uncertainty is provided simply to give a balance or symmetry to financial uncertainty. It might as easily be termed non-financial uncertainty.

| | **Sources of Uncertainty** | | | |
|---|---|---|---|---|
| **Dimension of Uncertainty** | **Now** | **Future** | **Trend/Remarks** | **Cross Reference Section** |
| **Physical** | Where "money" is not an influence | As "now" | Unknown | Various |
| | All pure uncertainties | As "now" | Should reduce with time | Various |
| | Third party influences | As "now" | Politically driven, trend unknown | Various |
| | Climatic variation | As "now" | Function of climate change | 4.3.8 |
| | | Climate change | Possibly greater impacts | 4.3.9 |
| | | Contingencies - e.g. allowance for risky new developments | A function of organisational size | 4.8 |

*(Table 4.3)*
*Physical and financial sources of uncertainty*

Continued ......

| | Sources of Uncertainty | | | |
|---|---|---|---|---|
| Dimension of Uncertainty | Now | Future | Trend/Remarks | Cross Reference Section |
| **Financial** | Uneconomical source use | Uneconomical source use | A function of demand management politics | Various |
| | Treatment losses - no washwater recovery | As "now" | Should reduce with time | 4.3.13 |
| | Capacity constraints | Future capacity constraints | Stationary | 4.4.2 |
| | Level of outages | Future level of outages | See resource planning categories | Various |
| | External influences such as the macro-economic environment | As "now" | Unknown | Likely to influence industrial water use. Uncertainty is therefore considered as part of demand components. |

*(Table 4.3)*
*Physical and financial sources of uncertainty*

### 4.2.2.4 Subjective and Objective Uncertainty

The final category or dimension of uncertainty is referred to as subjective or objective. As with the first three categories, this new category once again changes the focus of thought in the hope that any uncertainties previously omitted might be revealed.

Subjective uncertainties are considered to be those which are somewhat more speculative.

|  | Sources of Uncertainty |  |  |  |
|---|---|---|---|---|
| **Dimension of Uncertainty** | **Now** | **Future** | **Trend/Remarks** | **Cross Reference Section** |
| **Largely Subjective** |  | Future source loss due to WQ | Unknown | 4.3.1<br>4.3.2 |
|  |  | Future regulation | Unknown | Considered to be beyond the scope of this research |
|  |  | Future tariffs | Likely to reduce demands | Considered to be beyond the scope of this research |
|  | Whether forecast base should be changed | As "now" | Likely to reduce with time | 4.5.4 |
| **Largely Objective** | Meter under-registration | As "now" | Likely to reduce with time | 4.3.10<br>4.5.10 |
|  | Outages - planned, unplanned | Future outages | See resource planning categories | Various |
|  | Current tariffs |  |  | Considered to be beyond the scope of this research |
|  |  | Change in yield due to climate change | Yield likely to reduce in most areas | 4.3.9 |
|  | Treatment losses | Future treatment losses | See resource planning categories | Various |
|  |  | Future bulk supplies | Politically and financially driven | 4.3.14 |

*(Table 4.4)*
*Subjective and objective sources of uncertainty*

### 4.2.3 Summarised Uncertainty Table

Table 4.5 summarises the scoping exercise carried out in Sections 4.2.2.1 through 4.2.2.4. There is inevitably a significant degree of overlap across the four different dimensions, hence each dimension lists only areas of uncertainty omitted from other dimensions.

| Dimension of Uncertainty | (Measurement) Now | (Predictive) Future |
|---|---|---|
| **Supply and Demand** (Resource Planning Categories) | • Bulks received<br>• Variability of climate<br>• Outages<br>• Normalising skills<br>• Assessing unmeasured demand<br>• Yield analysis<br>• Meter reading frequency | • Environmental issues<br>• Climate change<br>• Deteriorating water quality<br>• Forecasting skills<br>• Pollution of sources |
| **Partial and Pure** | • Current climate change<br>• Process losses<br>• Measuring current demand<br>• Meter under-registration<br>• Reconciliation item | • Prospective future developments<br>• Future outages |
| **Physical and Financial** | • Current economic source use | • Future economic source use |
| **Subjective and Objective** | • Whether forecast base year should be changed | • Future tariffs<br>• Future policies<br>• Future regulation |

*(Table 4.5)*
*Uncertainty table showing*
*principal sources of uncertainty from scoping study*

## 4.3 SUPPLY SIDE UNCERTAINTY

This section describes influences, causes and effects, and advises on quantification of supply side uncertainties following the scoping exercise in 4.2.2. A summary table of the key influences on risk assessment is presented, for supply-side uncertainty, as Table 4.9.

One assumption mistakenly made when assessing a supply-demand balance is that existing supply will remain available over the planning horizon. Clearly, however, there are a number of substantial and significant reasons why it may not; including decline due to pollution, clawback, sustainability and climate. (Although climate might also result in a gain in yield in some areas). Each of the causes will be discussed in turn, with particular emphasis on climate change.

Future loss of yield, shown under the heading of 'other planning allowances' in Figure 4.2, is arguably the most uncertain element of the supply-demand calculation and requires a careful balance to be struck between the Precautionary Principle (discussed in 4.3.9.2 from an environmental perspective) and a non-rigorous approach to over-provision of resources along the lines discussed in Chapter 2. Striking the right balance requires acquisition of meaningful evidence, an early dialogue with regulators and a pragmatic conclusion. With climate change, for example, the water industry was discouraged from making any allowance for its possible effects until such time as the *"balance of evidence"* was sufficient to support it. This position should also hold for other causes of yield loss, such as that resulting from irreversible and untreatable pollution, but tempered with the Precautionary Principle which takes due account of consequences even where sufficient evidence is not available. Reference should also be made to section 4.8 which discusses how to deal with extreme events.

### 4.3.1 Sudden Pollution

By definition, a pollution incident may result in a temporary or permanent loss of output. A loss of output of less than 12 months duration is defined by UKWIR (1995) to be an outage rather than a reduction in deployable yield. Outages are discussed further in 4.3.6 and 4.3.7. "Sudden" in this context is taken to mean circumstances preventing reasonable prediction of the timing of the event.

Predicting long term loss of source output due to a sudden pollution incident involves contingency planning at its most obvious. Those familiar with financial budgeting will know that if a specific need for expenditure cannot be justified in advance then funding is unlikely. The same is true here. Nevertheless contingencies often materialise and loss of source yield does happen. Many examples can be directly correlated via the local authority planning process when an industrial development has either slipped through the net of the aquifer protection policy, administered by the Environment Agency, or conditions imposed on the developer not followed. Examples would include oil spillage, solvent discharge or other pollutant released within the short-term zone of influence surrounding a groundwater source. In the majority of circumstances the polluter is either unaware of the event or wishes to avoid prosecution, thus preventing a realistic chance of clean up. On routine testing the water company would observe an early trace of the pollutant and cease public water supply use. However, clean up of groundwater is rarely successful leaving treatment or blending as the only options, the cost of which are often prohibitive, resulting in the permanent loss of the source. Even if treatment is practicable the source may be unavailable for several years.

Permanent source loss of river sources is unlikely since rapid flow rates disperse even the most concentrated substance in only a few days. Of course, if the pollutant entering a surface reservoir is severe enough to prevent adequate dilution then draindown and refill may be the only alternative. This could easily take in excess of 12 months.

(Figure 4.2)
Terms used in the definitions of the output of an active source or group of active sources
(UKWIR, 1995)

A final entry here must include bacteriological contamination where no trend could have been observed and where a single incident would require treatment. The most obvious example is cryptosporidia, a potentially life threatening virus for which microfiltration is the recognised treatment in groundwaters. The cost of treatment, together with the high energy consumption involved in the process, may render continued use of the source impractical. Certainly the short term use of the source is unlikely.

If the worst happens and a sudden pollution incident occurs which has already affected the water quality, the resource planner will need to conclude whether the loss is temporary or permanent. In most cases within groundwater, source loss is almost inevitable, with only the traditional pumping to waste systems offering any sort of long term hope. Much research has been done in this field, Harmon (1997), but achieving acceptable water quality can be a long term if not a fruitless endeavour.

Having concluded that a source is likely to be polluted in the longer term the resource planner will need to decide if treatment is an economic option. This process, known as appraisal of the supply-demand balance, requires comparison, using a marginal cost approach, of the costs of alternative resource development, additional metering or additional leakage reduction. This is discussed in 4.9 under the heading of legitimacy of planning allowances.

### 4.3.2 Gradual Pollution

Most incidents of permanent source pollution occur in groundwater and most involve a gradual process. They are also invariably a direct result of social behaviour, such as that impacting on agricultural practice and chemical processes. Exceptions to this include saline intrusion and other geochemical ingress.

Thirty years ago treatment of groundwater sources was the exception rather than the norm. This has changed dramatically since.

In many cases sources can be blended, or mixed, together to prevent parameter exceedance but there is clearly a limit to how much of this can be done. Blending is analogous to linking sources in series, effectively in the same way as a set of Christmas tree lights, such that a single source failure has a domino effect. The mathematics of combining sources can also become unworkable where, for example, the output from one blend is used to blend another combination of outputs.

Inevitably, therefore, treatment will be required to some extent and it is then that the question of economics is raised. Is it justifiable to invest in treatment? Is it practical or cost effective to invest in a replacement resource or, conversely, seek a demand management solution?

This research is not concerned with finding solutions to a supply - demand imbalance. However, the initial derivation of the supply - demand equation may begin by making an assumption, for example, that all sources which are expected to become nitrate polluted are removed from deployable yield. Treatment of the source, and its financial justification, will therefore become a development option alongside options for other resource development.

An extract from the NRA's Water Resources Plan (1991) illustrates the importance of the issue as a source of both concern and uncertainty.

> *"Blending is now frequently required and some sources are likely to be abandoned, requiring new resources to be developed to compensate. Other sources will be provided with denitrification plants; one such plant is already in operation at Little Hay in Staffordshire. The long term solution is to change land use in critical areas, which is now a requirement of the EC Nitrate Directive which the NRA will be responsible for implementing.*
>
> *"The availability of water resources in urban areas is significantly restricted by long established industrial contamination, particularly affecting groundwater. This is most marked in the Birmingham area where the water resource potential of the groundwater is limited by quality problems, and where the best the NRA can hope to achieve is to prevent further quality deterioration."*

## 4.3.3 Uncertainty of Yield Assessment

Section 4.3.3 considers uncertainty in the assessment of source yield; firstly with respect to groundwater then, secondly, surface water.

### 4.3.3.1 Groundwater Yield Uncertainty

UKWIR ($1995_c$) developed an Industry methodology for calculating groundwater yield in the light of the need to reassess yields in time for the third Periodic Review. The method recommended is described in 2.5.1.1 and remains widely regarded as a pragmatic and user-friendly technique. However, the method generally describes the limiting factor at the source station, e.g. pump inlet or booster capacity, rather than the volume of water which might be available in the longer term. It is this latter description which the EA call '"sustainability".

From the industry's perspective sustainability might only become an issue after decades or even centuries of over-abstraction. There is, therefore, a natural tendency to take a more pragmatic view of source yield as described by UKWIR ($1995_c$).

Groundwater yield in the short term is a function of recent rainfall and rate of abstraction, i.e. if recent months have been wet, then yield will be likely to remain high for some time; depending on the lag between rainfall and aquifer recovery. In the medium term the average yield is a function of critical period (e.g. a single summer), the aquifer starting position and of how much contingent aquifer storage is available. This method of calculation is described by Twort *et al* (1985) and illustrated in Table 4.6.

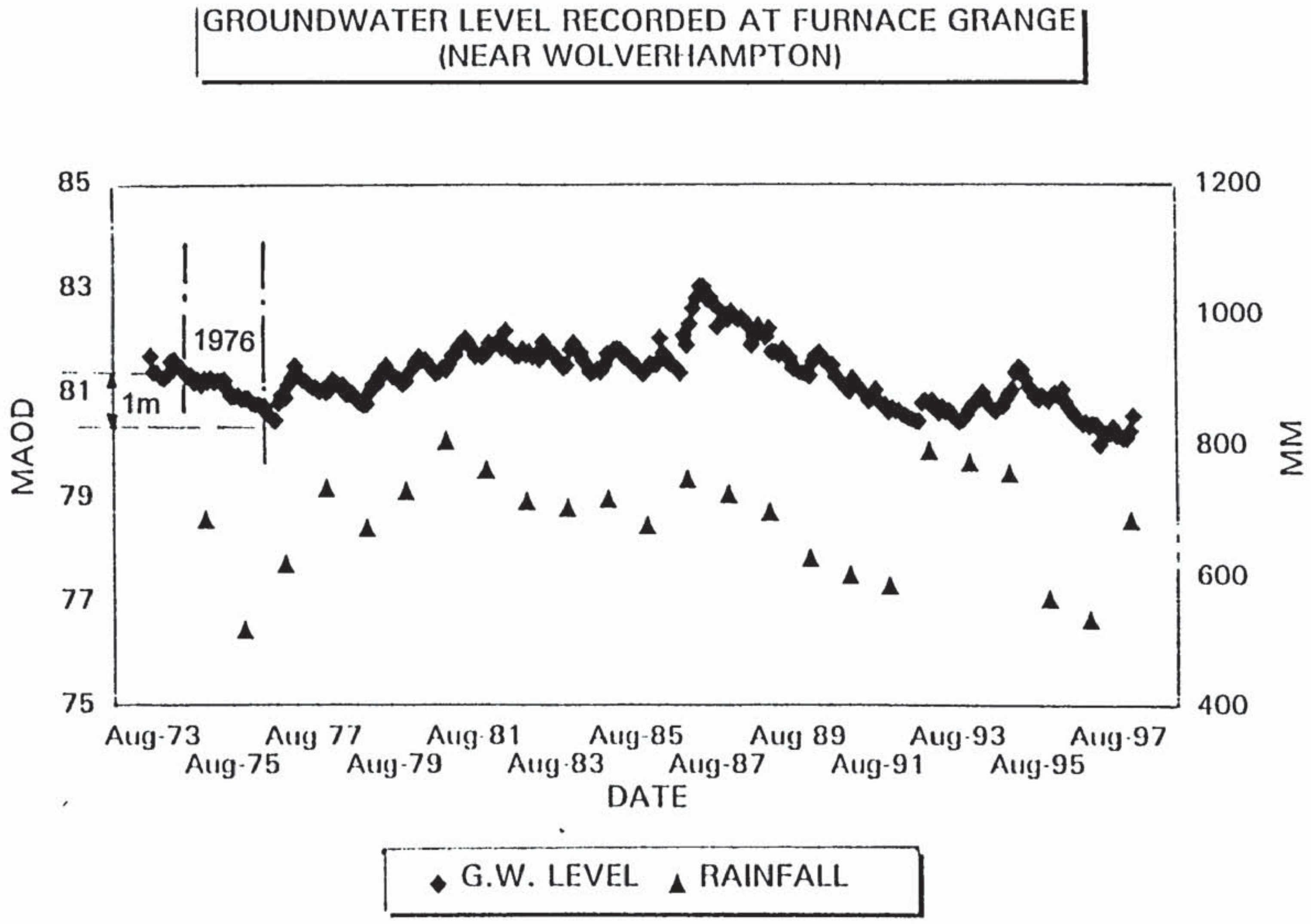
| Length of Critical Period | Inflow | Storage above Baseline Aquifer Level | Contingent storage (available during a drought) | Maximum Average Abstraction Potential over Critical Period |
|---|---|---|---|---|
| 100 days | 0 | 1000 | 3000 | 4000/100<br>= 40 Ml/d |

*(Table 4.6)*
*Calculation of groundwater yield for a single summer*
*(extracted from Twort et al, 1985)*

The current 'surplus' storage above the contingent point can be calculated by multiplying the aquifer surface area by the depth of wetted area above the contingent point and then by the storage co-efficient. Alternatively, local hydrographs can give a pragmatic view of aquifer yield, as well as information on the lag between rainfall and recovery.

From a water resource planning perspective the level in the aquifer as at to-day is probably irrelevant since the horizon calculations are likely to extend perhaps 25 years into the future. However, the level of surplus storage in an aquifer is a legitimate source of uncertainty and, providing the aquifer is not being mined, can arguably be taken from historical records as shown in Figure 4.3.

If, for example, 1976 is considered to have been effectively dry, then Figure 4.3 shows a one metre decline in groundwater level for a local abstraction of 5 Ml/d. This suggests a usable



*(Figure 4.3)*

*Graph of groundwater level and rainfall for a Midlands catchment* storage during a one year critical period of 365 x 5 = 1,825 Ml for each metre depth of aquifer. It is to state the obvious to note that the aquifer shown in Figure 4.3 is highly resilient to changes in rainfall in the medium term.

In many aquifers, notably sandstones, the volume available is almost independent of rainfall, even over decades, because of the very substantial storage properties of the aquifer. Uncertainty of yield is, therefore, associated much more with clawback by the Environment Agency, sustainability, aquifer mining and other localised influences. These are discussed in Sections 4.3.4 and 4.3.5.

The assessment of risk for error within yield analysis is described in Table 4.9.

#### 4.3.3.2 Surface Water Yield Uncertainty

The reliability calculation for surface water yield is described by the EA ($1997_a$) and follows the principles of behavioural analysis, where a catchment is modelled and reliability is stated in terms of frequency of failure at a particular yield. There are inherent uncertainties within this technique.

Assessing uncertainty due to data length and sufficiency is almost meaningless since the degree to which historic behaviour maps long term behaviour, even in the absence of climate change, is unknown. Conventional wisdom requires that the worst drought in recent record should be included within the data, otherwise the yield may be over-stated. In the twentieth century, the worst droughts, with little to choose between them, have been 1934, 1976, 1995 and 1996. Where river records exclude data of worst drought severity, then simulation techniques must be applied (EA, $1997_a$).

The effect of climate change on streamflows is described in 4.3.9.5 in terms of percentage variations in monthly flow. These variations can be applied to catchment models to derive the likely effects of climate change. In addition, there are four separate national climate change models which have equal weight of validity amongst experts. This, by definition, offers a range of uncertainty against the impact of climate change itself.

Chapter 5 will consider the practical case of climate change uncertainty on surface water yield.

Assessing other sources of uncertainty, particularly those associated with the practical application of catchment operating rules and catchment measurement are beyond the scope of this research.

### 4.3.4 Environment Agency Clawback

Clawback is a generic term frequently used by regulators to represent an asset or provision retrieved from a water company.

From an Environment Agency perspective, clawback is a return of abstraction back to the environment. It most typically applies in groundwater units designated as over-abstracted by the Agency, but where licences were granted under the transfer provisions contained within the Water Resources Act (1963). The most recent water resources legislation, the Water Industry Act (1991), provides a mechanism for the Environment Agency to revoke licences where it deems a reduction or revocation to be in the interests of the environment. However, this provision requires compensation to be paid to the affected company to ensure that alternative resources can be developed at no net cost.

The compensation clause is rarely applied, firstly because the Agency has no independent source of funding and secondly, if they were to increase abstraction licences to fund the compensation, then the water company, through its abstraction licence charges, will eventually fund some, or all, of its own compensation. On the face of it, therefore, the uncertainty surrounding use of clawback is small under the arrangements in place in 1998.

However, during AMP2 the water industry's second price review, the Agency were encouraged, through the DoE, to develop an appraisal of environmental costs and benefits associated with a company's resource development. Officially, the Agency prepared a list of environmentally sensitive areas which would benefit from investment by water companies and, at the national level, the DoE agreed that, if the benefits outweighed the costs, then the company would be funded by OFWAT to carry out the investment. The reality of this process, however, is that a company would be most willing to debate investing in the environment only if it had a forthcoming resource development programme, i.e. a reason to negotiate with the Agency. Periodic reviews tend to be trigger points for these developments.

As the industry moves towards AMP3 (April 1999 to March 2004) and then to AMP4, due allowance will need to be made within water resource development plans for the possible impact of future clawback.

## 4.3.5 Sustainability

The reliable yield of a source is typically described in terms of a return period, or the resource availability during a drought year. In the case of groundwater, this reliable yield is defined as the amount available during the worst historic drought on record; probably 1976. However, the reliability of the source may well be affected by more than the variation in climate, particularly over the longer term. These reasons include:-

i) climate change,
ii) insufficient re-charge, for example where the aquifer is being 'mined',
iii) local increased abstraction at other sources reducing water levels,
iv) increased head loss through the borehole wall or lining tubes causing lower pumping water levels,
v) an increased tendency to pump sand or other deposits out of the borehole.

Climate change is considered in Section 4.3.9, thus discussion will begin with aquifer mining.

### 4.3.5.1 Aquifer Mining

Aquifer mining is broadly what many resource planners consider to be 'non-sustainability'. Mining, as with any product removed from the ground, implies a permanent removal which depletes stocks. This is no different for water. In cases where abstraction exceeds the recharge, then the source is considered to be mined. A typical long term example of probable mining is shown in Figure 4.4.

In chalk and other low storage aquifers the impact of mining is observed very quickly and account will be taken immediately. However, in sandstone aquifers, high levels of storage may allow the abstractor to carry on 'over-abstracting' for perhaps 50 years or more before action is necessary. Even then it may only be necessary for the abstractor to relocate the pump inlet at a lower depth in the borehole to continue pumping at excessive rates. In the Midlands, for example, the triassic sandstones are typically 200 metres deep, yet the aquifer itself moves by only a few metres due to variations in recharge. A hydrograph near to Lichfield in Staffordshire was shown as Figure 4.3 and demonstrates this point.

In certain parts of the world it is commonplace to sink a borehole knowing that it will only last a finite period of time. In Jakarta, Indonesia, for example, controlled groundwater mining has been ongoing since 1950, where abstraction from deep wells is around 53 Ml/d, compared with direct recharge of only 15 Ml/d (Jakarta Department of Water Resources, 1997). As a result, groundwater levels are falling at between 1 and 3 metres each year. While, in the longer term, abstraction will need to reduce, it is not certain when this time will come. Certainly, there will be a future decline in yield which will need planning for and it may be appropriate to apply likelihoods across a time axis as shown in Figure 4.5.

#### 4.3.5.2 Local Influences

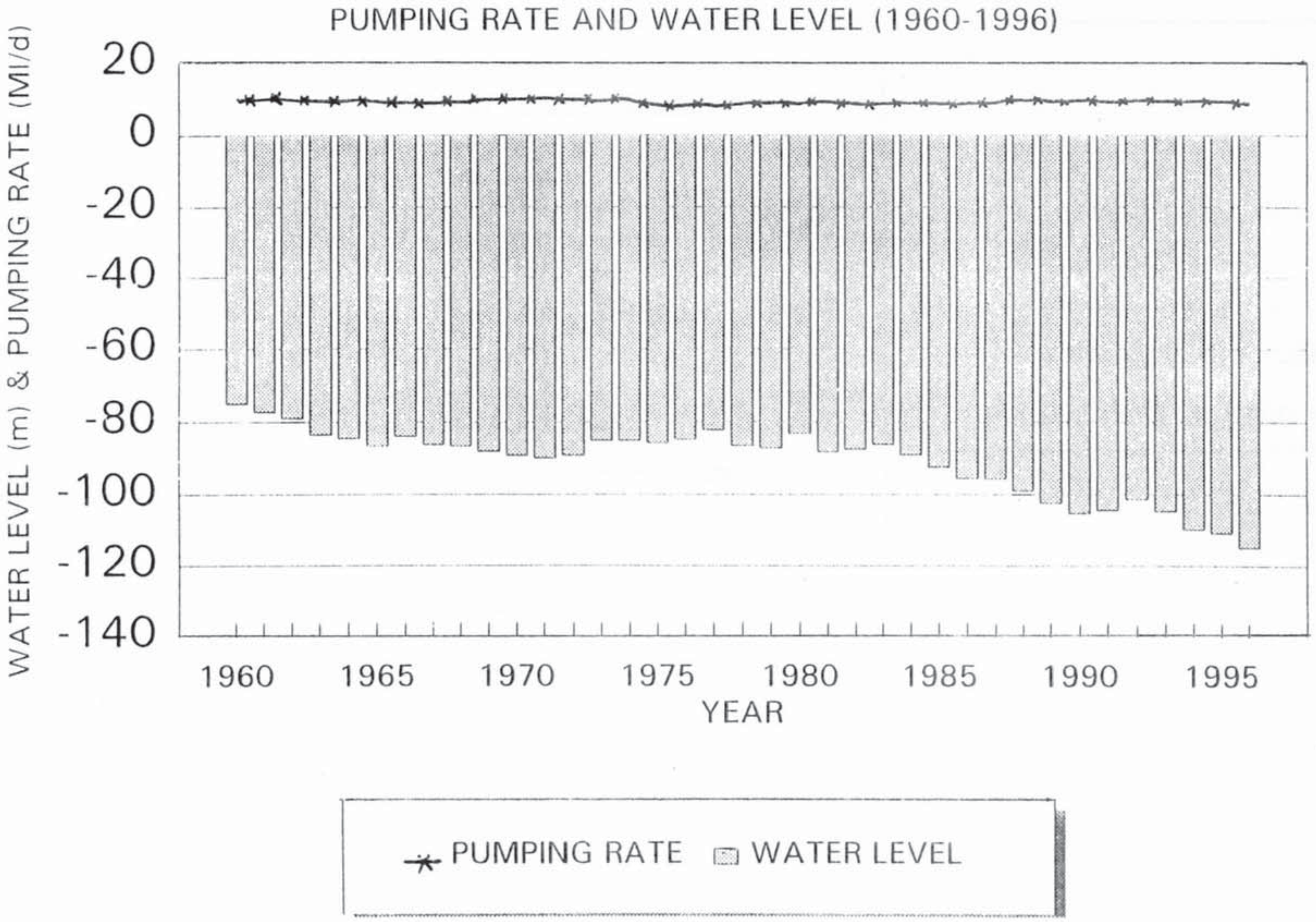
The next reason cited as causing a reduction in sustainable yield is that due to localised increase in abstraction by others. This situation is shown in Figure 4.6.

In most cases the result of localised pumping is no more than to cause a small decrease in water level. This requires only that the pump works a little harder to sustain the same output. The situation becomes critical when there is insufficient head of water through which to drive the desired output Q, resulting in a loss of output if suction to the pump inlet is to be maintained.

Depending upon the depth of the aquifer it is, of course, a legitimate solution to drill the borehole deeper, although this can sometimes result in a detrimental change in water quality.

#### 4.3.5.3 Borehole Head Loss

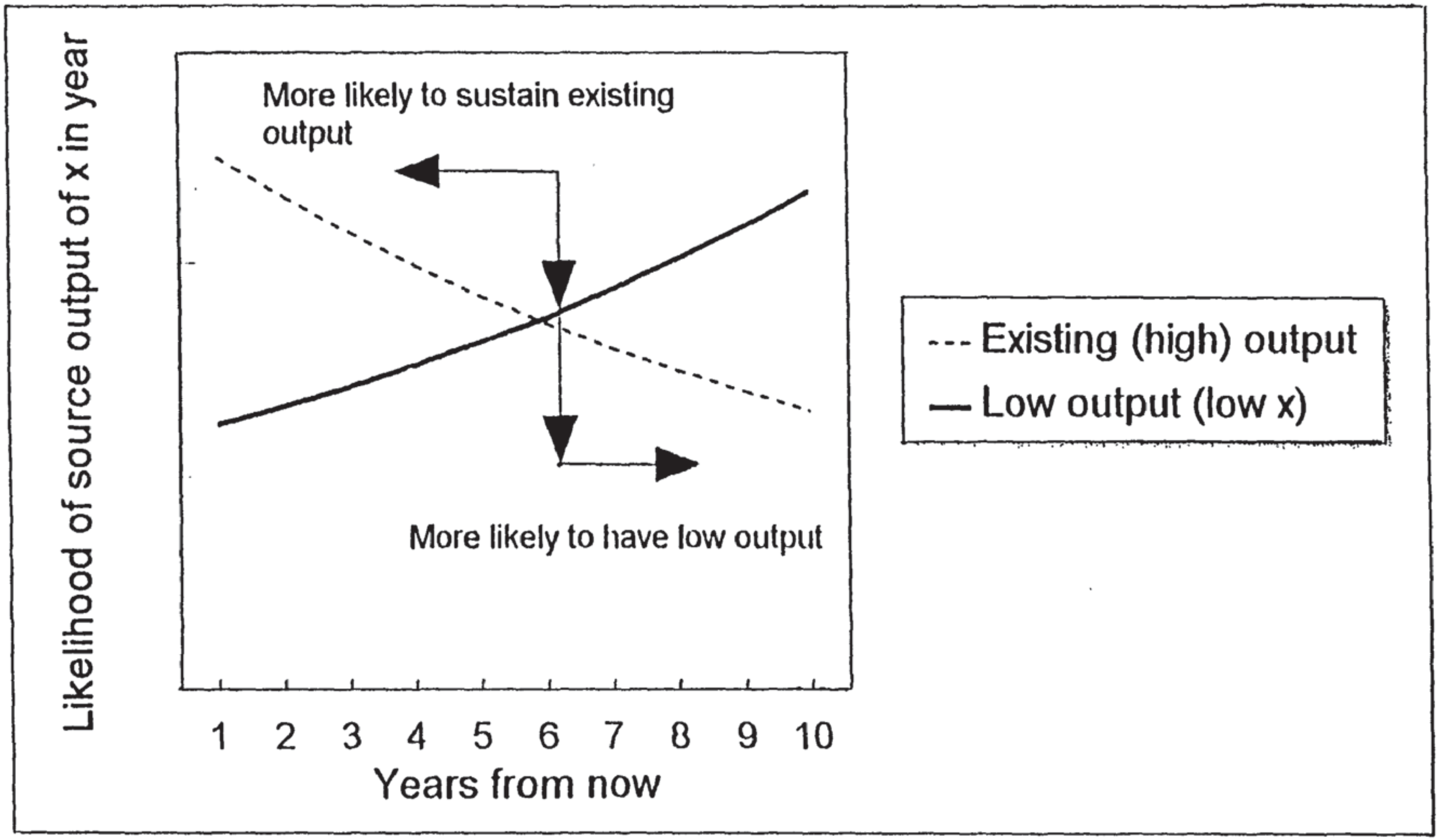
A borehole, whether naturally constructed in rock or with its own screening system, is essentially a filter which allows the passage of water. Over a period of time this filter can become blocked with various chemical deposits and effectively increase the hydraulic gradient required for the same volume of water to be taken from the hole. In the majority of cases, this will simply require an increase in pump output and a consequent impact in energy costs. Alternatively, various well development techniques are available (Hamill & Bell, 1986). However, if there is no realistic alternative, then as with the effect of well interference, it may be necessary to downrate the yield of the source.



*(Figure 4.4)*

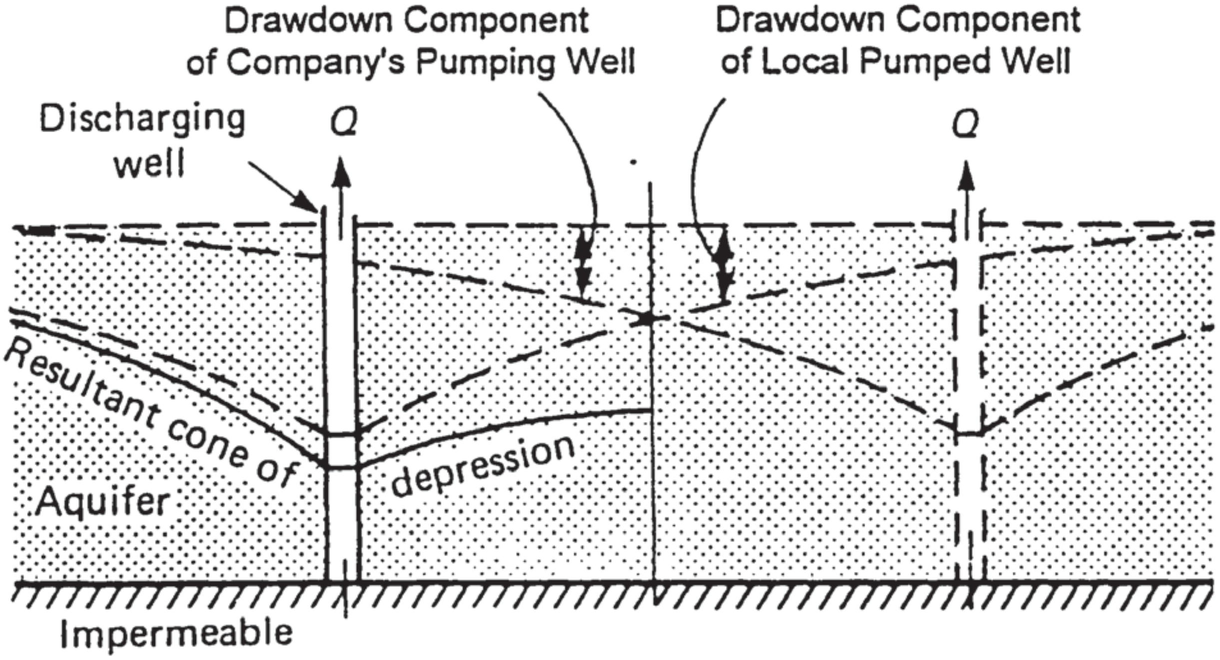
*Abstraction amd pumped water level showing evidence of groundwater mining 1960 to 1995*

*(example only - no source of reference)*



*(Figure 4.5)*

*Likelihood of future resource from a mined aquifer*



*(Figure 4.6)*
*Impact of localised pumping on water levels and sustainability*

#### 4.3.5.4 Increase in Sand Pumping

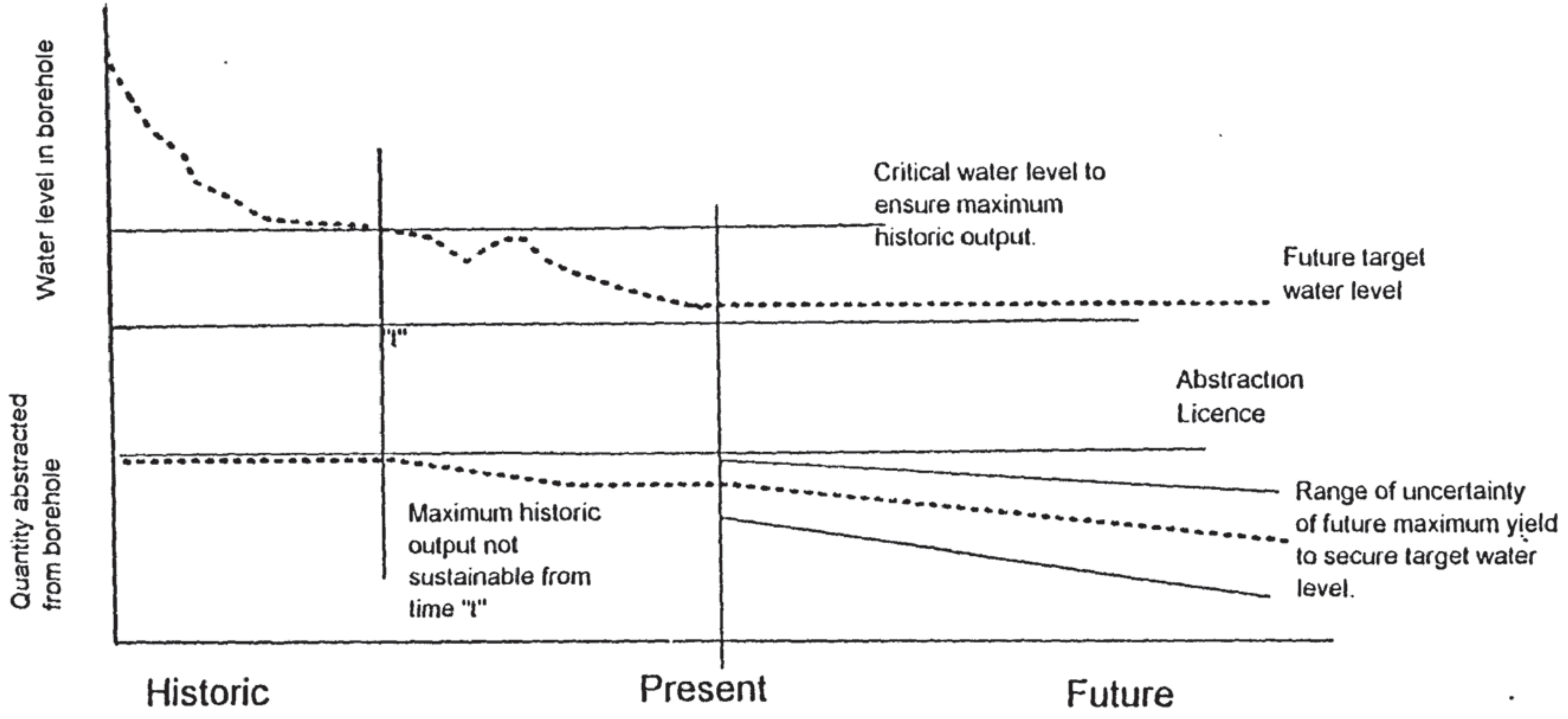
As the velocity of water entering the well through the side of the well wall increases, the scouring effect within the strata is increased. Eventually, in a sandstone aquifer, the inflow will reach a velocity where sand is carried into the borehole itself. Sometimes this can have a positive effect in that fissures created through sand pumping offer a more direct route for water to enter the well. However, in other cases the presence of sand in any appreciable quantity is likely to require that the output from the source is reduced to prevent either sand entering the distribution system, sand damaging the pumping plant, or sand damaging the well itself, causing well collapse. In a borehole which is prone to the ingress of sand, the borehole itself begins to fill with sand over a number of years. This has the effect of partially reducing the ability of water to enter the well and, thus, increase inflow velocity. This has a spiralling effect which makes the sand problem even worse. From time to time, therefore, it is either necessary to remove the sand from the well or take a view that the yield needs to be downrated in the light of the long term future of the source.

#### 4.3.5.5 Source Deterioration

The uncertainty assigned to issues of sustainability due to source deterioration can often be considered in the light of individual source histories. A source troubled with a history of manganese deposition, for example, will gradually clog up with a black slime and become less productive with time, although at a reducing rate of decline. A decision to attempt to unclog the source is likely to be avoided or delayed because of risk to the source due to the remedial "surgery" . In addition, the yield decline, from a supply perspective, is irrelevant until the licenced abstraction is itself compromised. This is shown in Figure 4.7.

### 4.3.6 Outages (planned)

UKWIR/EA (1997) define an outage to be a '*temporary loss of deployable output*'. Likewise, deployable output is the output available for supply; constrained by licence and the works capacity. From an accounting perspective, given that a company's supply-demand balance is typically reviewed annually, then an outage which has a duration longer than 12 months is no longer classified as such and is taken to be a "permanent" loss of deployable outage. Restoring the source into supply is then dealt with in the same way as a new resource development. These definitions are accepted within the context of this research.



(Figure 4.7)
*Decline in source yield due to source deterioration over time*

Outages, or removal of a water source from supply, fall into two groups; planned and unplanned. The distinction is obvious: a planned outage is a voluntary removal from supply, typically in the interests of major refurbishment, whereas an unplanned outage tends to be the result of an unpredictable failure of a critical component at the source.

In practice, making due allowance for outages is blurred because of administrative reality. Planning outages is a continuous process such that precise definition of a future outage programme is unlikely. More sensibly, therefore, a planned outage is taken to be any removal of a source from supply in circumstances where the Supply Manager had a reasonable choice on timing.

Causes of planned outages include:-

i) installation of new treatment plant,
ii) installation of new pumping plant,
iii) modifications to a distribution network into which the source feeds,
iv) major building modifications,
v) extended periods of pumping to waste in advance of returning a source to supply because of poor raw water quality.

A typical planned outage programme is shown in Figure 4.8.

The extent to which planned outages impact on a company's supply-demand balance will depend on that company's critical planning period. It is taken as read, for example, that a Supply Manager would not plan to have sources out of supply during periods of peak demand. Hence, any company with a peak week or peak day critical period for design is unlikely to suffer as a result of planned outages.

For a company where average resource availability is a problem, typically caused by insufficient source flexibility and inadequate licenced abstraction, then planned outages can cause an overall source loss. The key issue is one of retrievability.

Suppose, for example, a company has a stock of resources as follows:-

| | | Average | Peak Output | Average Licence |
|---|---|---|---|---|
| Groundwater | : | 200 Ml/d | 200 Ml/d | 200 Ml/d |
| Surface Water | : | 150 Ml/d | 300 Ml/d | 150 Ml/d |
| **Total** | | **350 Ml/d** | **500 Ml/d** | **350 Ml/d** |

Such a company has a heavy reliance of groundwater which, in many areas of the UK, is inflexible to changes in output. Suppose then that the company has to meet an average annual demand of 340 Ml/d, from the total licence of 350 Ml/d, and cater for a planned groundwater outage of 45 Ml/d for four months (an average of 15 Ml/d). The inflexibility of the groundwater sources to retrieve outages, i.e. they have no material peak potential, means that the groundwater yield is reduced by 15 Ml/d to 185 Ml/d.

Having supplied 340 Ml/d will, therefore, have forced the surface water source to exceed its licence, i.e. 340 - 185 = 155; greater than the licence of 150 Ml/d.

Assessing the risk of planned outages will be described in Table 4.9.

### 4.3.7 Outages (unplanned)

UKWIR (1995) defines an unplanned outage to be '*an outage caused by an unforeseen or unavoidable legitimate outage event affecting any part of the sourceworks and which occurs with sufficient regularity that the probability of occurrence and severity of effect may be predicted from previous events or perceived risk*'. At first sight this definition appears unnecessarily lengthy, but the underlying intention of the latter half of the definition is to specifically exclude extreme events. Extreme events are considered to be outside of the scope of long term resource planning, instead more an issue involving crisis management. Extreme events are discussed in Section 4.8.

UKWIR (1994) describe and limit unplanned outages to those due to:-

i) pollution of source (retrievable within one year),
ii) turbidity (temporary treatment constraint),
iii) nitrate (seasonal nitrate load),
iv) algae (temporary treatment constraint),
v) power failure,

Aston University

Illustration removed for copyright restrictions

(Figure 4.8)
Planned outage programme
(courtesy of South Staffordshire Water Plc)

vi) system failure (mechanical failure of station or distribution system into which the station feeds).

One area which is not covered by the above list is where a planned outage extends beyond its planned period. If this extension turns into a critical demand period then, for all practical purposes, it becomes an unplanned outage.

An example of the spread of unplanned outages across general headings of water quality, power, plant and 'other causes', is shown in Figure 4.9.

Note that an unplanned outage is only registered as a source loss when mitigation measures also fail. There are numerous examples of events where parts of a process can fail without short term detriment, such as:-

i) failure of a river intake, providing bankside storage is available,
ii) failure of a power supply, providing auto-start generators are installed,
iii) failure of a trunk main due to bursting, providing re-routing or duplication is available.

### 4.3.8 Climatic Variation and Persistence

The effect of climate on resource yield takes two forms; that due to climate variation and that due to climate change. The term 'climatic persistence' is applied by those who consider climate change to be as yet unproven.

Climate variation within the context of this research refers to the period over which a variation in climate has a material impact on the yield of the source. For example, a dry year in a resilient sandstone aquifer may be immaterial. Conversely, a dry month for an under-sized single season impounding reservoir may be very significant. Providing that there is sufficient historical yield information covering an adequate range of climates, then the impact of climate variation can be described statistically. This, of course, assumes independence between climatic periods and the absence of historic climate change.

### 4.3.9 Climate Change

Climate change is arguably the most important source of uncertainty when calculating the balance between water supply and water demand. The subject area is a relatively new one, remembering that in 1994 the OFWAT-imposed assumption for resource planning within the

*(Figure 4.9)*
*Lost water production - first 12 weeks of 1996 (unplanned events)*
*(courtesy of South Staffordshire Water PLC)*

second Periodic Review, AMP2, were that *'no allowance would be made for the effects of climate change'* (OFWAT, 1993). As much as anything else, this statement highlighted the extent of uncertainty surrounding the subject. Much of this uncertainty remains, but perceivable evidence in 1995 and 1996, coupled with increased customer intolerance to demand restrictions, made it essential to make due allowance for climate change within the third Periodic Review, beginning in 1999.

Note that this section of the research deals with the uncertainty of climate change and not the effects of climate variability or climatic persistence, except where climate variability itself is influenced by climate change. Assessing risk due to climate variation will be discussed within Table 4.9.

#### 4.3.9.1 Introduction

This section of the research discusses the effects of climate change on the supply side of water resource planning. At the time of writing, the extent of research on the supply side was growing rapidly, although research on the demand side was weak.

#### 4.3.9.2 Uncertainty, the Precautionary Principle and Public Reaction

Hanson (1995) discusses the Precautionary Principle as an argument for making due allowance for uncertainty. It is not, of course, a justification for over-planning, but a philosophy which requires that the consequence of ignoring uncertainty is given full consideration.

The Precautionary Principle (Hanson, 1995) contains six basic concepts, the first of which comes under the heading of 'preventative anticipation', or a willingness to take action in advance of scientific proof. Thus, the Precautionary Principle is the driving force behind the Water Industry's intention to make due allowance for climate change within the next Periodic Review in 1999. In essence, the potential impact of climate change is too significant to ignore, given the increased intolerance to hosepipe bans and the rapid rise in garden watering.

The hot summers and dry winters of 1990, 1995 and 1996 will have left a real impression of severe climate in the mind of the customer. As the IWSA (1995) noted at the Congress of Madrid *'living through a crisis often allows the public to be convinced that certain projects are justified, as well as agreement to bear the cost'.*

In addition, water resource schemes can take years, sometimes decades, to commission. If the *'balance of evidence'* now points to climate change, it would be foolhardy to look back at a UK climate in years to come wishing that due allowance had been made. This attitude does not mean premature or unnecessary investment, but rather that consideration of climate change is made at the planning stage and that the planning of resources (or demand reduction) proceeds with due speed, but also with caution.

#### 4.3.9.3 Causes of Climate Change

The causes of climate change are substantially beyond the scope of this research and, at the time of writing, are somewhat less than proven. There is, nevertheless, considerable research into the subject, in particular by the Hadley Centre (1995) and the Department of the Environment (1996).

#### 4.3.9.4 Evidence and Predictions of Climate Change - Myth or Reality ?

Before discussing the uncertainty surrounding climate change, it is appropriate to note that there is a body of opinion which discards the current thoughts regarding climate change as little more than hot air.

The Australian Viewpoint Lobby (1997), for example, proposes a view that predicting catastrophe is a highly productive and profitable area for research. They further propose that climate is cyclical and that the current phase began 15,000 years ago.

From the perspective within this research it is not so much whether human influence is causing the change, although clearly this helps with its prediction, but that climate is apparently changing in a manner which is uncertain.

#### 4.3.9.5 Uncertainty of Climate Change on Surface Water Yield

In the face of uncertainty of yield assessment, required as part of the third Periodic Review, UKWIR and the Environment Agency commissioned research into the effects of climate change on river flows and groundwater yields (UKWIR/EA, $1997_b$).

The method derived by UKWIR/EA ($1997_b$) converts changes in rainfall, temperature and potential evapotranspiration into estimates of river run-off changes on a monthly basis. These run-off changes are presented as indices which can be applied easily to existing yield assessment models allowing different yields to be produced for each of the various climate change scenarios tested.

The UKWIR/EA (1997$_b$) research proposes four models which predict changes in river/stream flows as shown in Table 4.7.

*(Table 4.7)*
*Percentage change in streamflow for the Midlands region by 2020*
*for various climate change models*
*(extracted from UKWIR/EA, 1997$_b$)*

The range of uncertainty in Table 4.7 is extensive. The month of May, for example, has an assigned range of streamflow changes of - 2%, from the HADCM1 model, to + 25% for the GS1t model. UKWIR/EA (1997$_b$) provide no evidence to suggest which of the models is more accurate.

#### 4.3.9.6 Uncertainty of Climate Change on Groundwater Yield

As with surface water yield, it is possible to apply the run-off factors, shown in Table 4.7 to groundwater catchment models. However, in more robust aquifers, those with high storage such as Triassic sandstones, the prevailing wisdom suggests that changes in abstraction potential are unlikely over the period to 2020.

#### 4.3.9.7 Reducing Climate Change Uncertainty

Despite investing hundreds of millions of pounds in climate change, it seems that the only definitive comment to come out of Climate Research is that *'the balance of evidence suggests a discernible human influence on climate'* (Hadleigh Centre, 1995).

Nevertheless, meteorologists will argue that there is one issue remaining which, when resolved, will significantly improve understanding of the impact and timing of climate change. This will involve a study of clouds.

As far as climate is concerned, there are generally two types of clouds; those which cool the climate and those which warm it up. Clouds which reflect sunlight promote cooling and others, which trap infra-red radiation, promote warming. The proportion of clouds is, therefore, critical. If temperatures rise then the composition of clouds may change, but it is not known if these changes will attenuate or amplify the temperature rise.

It is not clear how much investment would be needed to address the "clouds" issue or, as importantly, how much uncertainty would be reduced as a result. There is little doubt, however, that the cost to the Water Industry of planning for uncertainties of climate change will be very considerable and that substantial investment to reduce this uncertainty could well be justified.

### 4.3.10 Source Meter Error

In assessing the uncertainties within the supply-demand balance, it is usually taken as read that the volume of water abstracted can itself be considered as certain. Regrettably, however, the error inherent within source meters is arguably the most uncertain factor of all. Twort (1985), for example, observes that source output errors of +/- 40% are not unknown.

Within this research the error surrounding source meters is considered as a supply-side uncertainty, since it puts in doubt the actual volume of water available for use. However, it could equally well be included as a demand side uncertainty because if the volume of water entering a system is unknown, then the demand for water, which has to balance the supply, is invalidated.

Bocock (1996) notes that errors in source meters have been the subject of research by Cranfield University for many years and that errors of +/- 5% are widespread. The problem, however, is complicated because the methods used to calibrate meters are themselves subject to errors of +/- 10%.

### 4.3.11 Trends in Supply Side Losses and Uncertainties

Factors which will influence whether supply side losses and uncertainties increase or decrease in the medium to long term include:-

i) whether the age of the company's borehole stock is increasing,

ii) whether the borehole stock has a tendency towards clogging or siltation,

iii) whether output from the sources remains sustainable over the medium to long term in terms of aquifer recharge,

iv) whether environmental pressures are likely to change the balance of economics in favour of the environment and, thus, increase the likelihood of future groundwater clawback,

v) whether there is a predominance towards additional or new groundwater abstractions in the vicinity of a company's sources,

vi) whether the effects of climate change increase in significance,

vii) whether improved techniques for the calculation of both groundwater and surface water yield reveal that yield is, in fact, less than previously thought,

viii) whether policies for maintenance, treatment and blending impact on outage frequency, magnitude and duration.

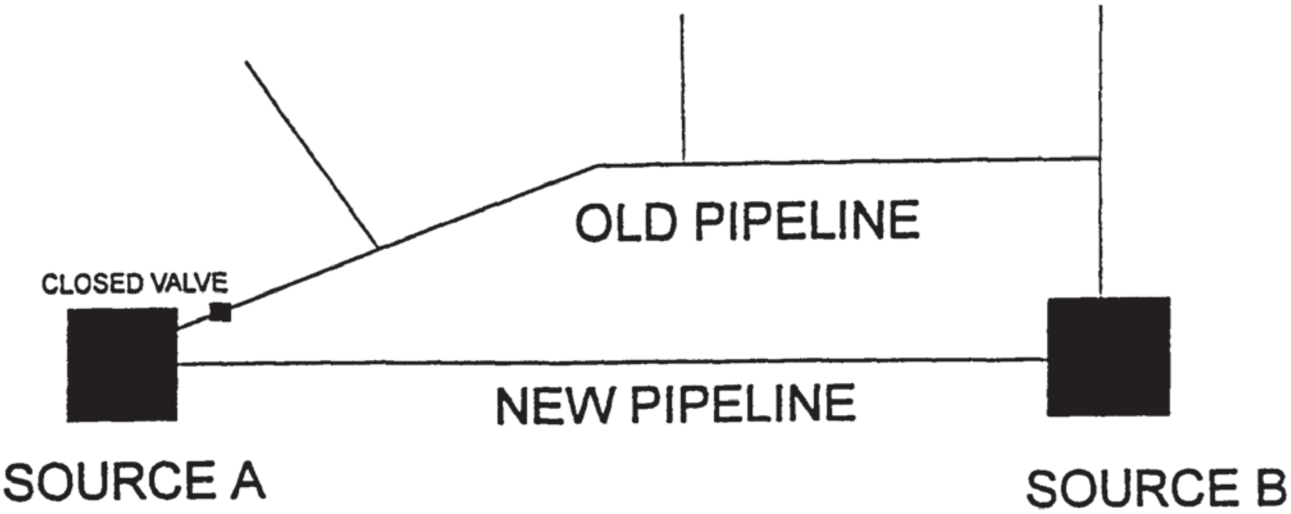
### 4.3.12 The Consequence of Blending Water Sources Together to Ensure Water Quality Compliance

Sections 4.3.6 and 4.3.7 consider the issue of outage allowances, loss of source output which cannot be recovered, whether planned or unplanned. The typical assumption for a source outage is that the source is taken out of supply for a period of time and that its inability to supply over this period represents a reduction from deployable yield. In the majority of cases this calculation is quite straightforward.

However, as part of the economic optimisation of water quality compliance, it is sometimes possible to link sources together as described in Section 4.3.2. This linking together, or blending, usually involves laying a dedicated pipeline so that the output from one source mixes with another such that the final water quality is compliant. This is shown for a simple two source case in Figure 4.10.

Note that the criteria for blending is not that one source of water needs to be compliant, only that the combined water is compliant. For example a source with an excess chloride level but low nitrate might be satisfactorily mixed with a source high in nitrate but low in chlorides.

On occasion sources may be linked in groups of more than two, as the example in Figure 4.11 shows.



*(Figure 4.10)*

*Simple example of a two source blending arrangement*

It is easy to see, however, that the distribution system described in Figure 4.11 relies on the flow arrows remaining in the directions shown as well as the requirement for supplies to be isolated along certain sections of pipeline. Any customers normally supplied from point Q on the map, for example, would have to be isolated at this point and supplied back from point R.

The specific implication for water resource planning is that the economics of whether to treat a source or to blend it may well have overlooked the fact that where sources are mixed together then outage at one source may have a knock-on effect which forces an outage at another. In the system shown in Figure 4.11, for example, an outage at the major nitrate treatment works, shown as source D, will force outages at sources C and E, together with a partial outage from A.

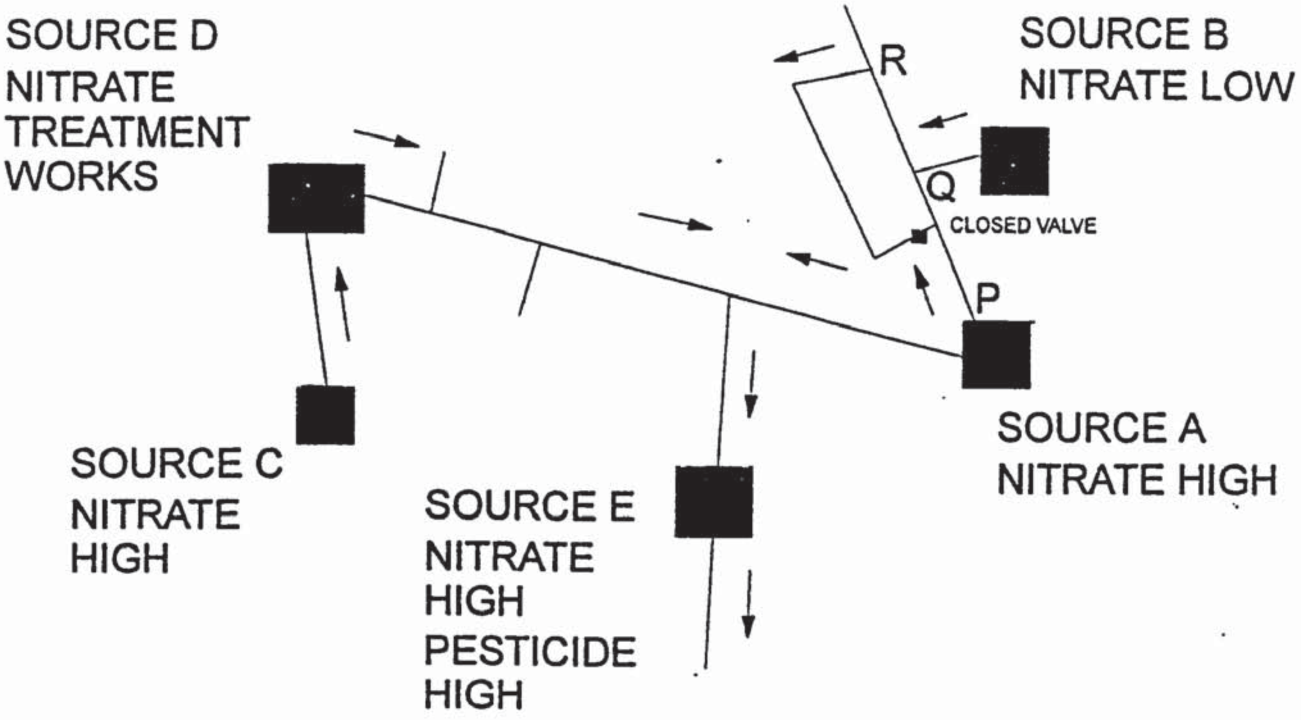
Rules for operating the network shown in Figure 4.11, under blending constraints, are as shown in Table 4.8.

| **Outage at source reference** | **Implications for source reference** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| A | OUT | IN | IN | IN | IN |
| B | PART OUT | OUT | IN | IN | IN |
| C | IN | IN | OUT | IN | IN |
| D | PART OUT | IN | OUT | OUT | OUT |
| E | IN | IN | IN | IN | OUT |

*(Table 4.8)*
*Implications of consequential outages*
*at sources in Figure 4.11*

### 4.3.13 Water Treatment Losses

Most, if not all, water treatment processes have some measure of water loss, either as a result of backwashing or as a result of effluent discharge. In some cases, it makes economic sense to introduce washwater recovery such that any water lost is returned to the entrance to the works, but this is not always cost effective. These losses, which can be as high as 3% for a nitrate removal plant and 10% for a conventional surface water treatment process without washwater



*(Figure 4.11)*

*Complex example of nitrate blending*

recovery, can add up a significant loss of resource. Treatment losses are typically accounted for by making a deduction from resource stock before calculating deployable yield.

### 4.3.14 Bulk Supplies

A bulk supply is a source of water either imported from a neighbouring supplier or exported to a supplier. They represent a considerable source of uncertainty because the supplies are rarely covered by legal agreements. Most typically, they are cross -boundary points where, providing sufficient water pressure exists, water will move to or from adjoining companies.

### 4.3.15 Summary of Key Influences for Risk Assessment of Supply Side Uncertainties

Sections 4.3.1 through 4.3.14 discuss 14 areas of uncertainty on the supply side of the supply-demand equation. Within Chapter 5 an analysis will be undertaken, where possible, to assign likelihoods to these uncertainties. To do so will require an understanding of the key influences impacting on the extent and magnitude of these uncertainties.

Key influences on the supply side of the equation are presented as Table 4.9.

| Source of Uncertainties | Key Influences on the Assessment of Risk |
|---|---|
| **Sudden Pollution** | Assessing the risk of sudden pollution is unlikely to be scientific and may require an expert. This judgement will consider:-<br>i) the history of water pollution in the region,<br>ii) whether recent changes have taken place, such as within the local authority planning liaison process, a water company's aquifer protection policy or a company's emergency clean-up procedure,<br>iii) how robust the company's sources are to pollution - e.g. are oil tanks and transformers bunded,<br>iv) are sewers local to the source high pressure rated and/or double-sleeved,<br>v) are appropriate pollutant interceptor drains in place and are car parking areas impermeable. |

*(Table 4.9)*

*Key influences on the assessment of risk for supply side uncertainties*

Continued ......

PAGE

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| Source of Uncertainties | Key Influences on the Assessment of Risk |
|---|---|
| **Surface Water Yield Uncertainty (cont'd)** | vii)the effect of climate variability and climate change on current and future yield. |
| **Environment Agency Clawback and Sustainability** | The key issues which will determine an individual company's clawback level are:-<br>i) the extent of designated low flow rivers in the area,<br>ii) the extent of theoretically over-abstracted groundwater units,<br>iii) whether the company intends to promote a water resource development programme over the periodic review period,<br>iv) the cost of the Environment Agency's proposals relative to the size of the water company as a business,<br>v) whether the DoE, via OFWAT, is likely to allow funding of the schemes, or whether the company will be asked by the Agency to fund the schemes regardless of funding,<br>vi) the extent to which the water company understands the Agency's intentions at a regional level,<br>vii) the extent to which past clawback has already solved regional problems,<br>viii) the extent to which past clawback will decrease over time, unless the value of environmental capital changes.<br>Assessing risk in these circumstances will require a combination of fact, expert judgement and dialogue.<br>Assessing the loss of source due to sustainability will draw on an extensive review of source history, particularly trends in draw-down and yield. The intentions of the EA on matters of clawback may also indicate a problem of sustainability. |
| **Outages (planned)** | Predicting future planned outages represents the classical forecasting skill of attempting to optimise art and science. The analyst will have a database of historic outages, but each period of outage will have its own unique problems. To extrapolate on such a basis assumes that the future is simply an extension of the past and, clearly, life is rarely so simple.<br>A company's Investment Programme will typically cover a five year period and should contain sufficient information for a reasoned medium term analysis. |

*(Table 4.9)*

*Key influences on the assessment of risk for supply side uncertainties*

Continued ......

| Source of Uncertainties | Key Influences on the Assessment of Risk |
|---|---|
| **Outages (planned) (cont'd)** | Over the longer term, complex techniques may become less valuable (DeKay, 1985) and simple scenarios, based on possible future and assigned likelihoods, may be sensible. The analyst might also take account of a company's plant replacement policy and its accounting practices for appraisal and writing down of assets. |
| **Outages (unplanned)** | As with planned outages, it would be naive to assume that the future is a mirror of the past, although it is likely that observed events will give guidance on future expectation.<br>In making an assessment of future risk the analyst will need to use the present day as a springboard, giving due consideration to:-<br>i) the seasonality of unplanned outages and how this impacts on the critical design period,<br>ii) whether any category of unplanned outage is demonstrating a trend - if so why?<br>iii) if trend is absent, can the events be described statistically?<br>iv) will new technologies make failures more, or less, likely?<br>v) will new processes make failures less likely?<br>In addition the analyst should not pre-judge whether it is sensible to reduce unplanned outages by enhancing forms of mitigation. Reducing outages is a legitimate policy option when compared to new resource development and demand management. As such, it represents a solution to the supply-demand balance rather than an assumption within it. |
| **Climatic Variation and Persistence (Source Yield)** | Various techniques are available for relating source yield to return interval or risk (EA, $1997_a$), including behavioural analysis, mass balance techniques and Markov chains (Carnell, 1980). The majority of techniques consider surface water yield rather than groundwater yield. In defining a reliable yield for an impounded reservoir system, for example, it is usual to provide operating rules, a reservoir capacity, a range of dead and contingent storage, together with an acceptable failure frequency. |
| **Climate Change** | Risk is assessed by considering the effects on surface water yield of each of the four climate change models described by UKWIR/EA ($1997_b$). Each model is considered equally likely.<br>The effect of climate change on groundwater yield (in sandstone) is considered not to be material. |

*(Table 4.9)*

*Key influences on the assessment of risk for supply side uncertainties*

Continued ......

| Source of Uncertainties | Key Influences on the Assessment of Risk |
|---|---|
| **Source Meter Error** | Assuming that meter error can be calculated then there are two distinct scenarios:-<br>i) that, on balance, there is no overall bias - i.e. the meters are considered equally likely to over-estimate as they are to under-estimate,<br>ii) that, following a meter audit, there is a demonstrable bias which suggests that water available for use is either being over-estimated or under-estimated.<br>Considering the first scenario it is relatively straightforward to assign a distribution of error to source input. However, for each sample from the distribution, there is a required reconciliation between supply and demand given that the supply side of the balance will have changed.<br>For the second scenario, if a meter audit shows a net over- or under-estimation of water availability, then this will require adjustment for bias at the outset. Uncertainties can then be based on the approach described in the first scenario. |
| **Trends in Supply Side Losses** | Risk assessment of trend should consider the table of influences listed in section 4.3.11. |
| **The Consequences of Blending Water Sources Together to Ensure Water Quality Compliance** | Attempting to determine the consequences of outages due to blending cannot be done by simple reference to the past. This is because blending schemes are relatively recent in the history of most companies and outage histories will not capture consequential source loss.<br>One option is to derive rules for each source outage and then apply these rules retrospectively to historic outage events. These consequential outages can then be added to the database at the corresponding point. |
| **Water Treatment Losses** | The uncertainty element of water treatment losses is not considered significant. |
| **Bulk Supplies** | From a resource planning perspective, a bulk supply is only uncertain if it is imported. Any exported bulk is likely to be assumed exported with certainty, since export is entirely controllable.<br>The degree to which the imported bulk supply is uncertain will depend on: |

*(Table 4.9)*
*Key influences on the assessment of risk for supply side uncertainties*

Continued ......

| Source of Uncertainties | Key Influences on the Assessment of Risk |
|---|---|
| **Bulk Supplies (cont'd)** | i) the reliability of the donor's supplier in terms of pressure, quality and continuity,<br>ii) the degree of resource surplus in the resource zone at the point of receipt,<br>iii) the strength of any contractual relationship between the two companies,<br>iv) the personal relationship between the local supply management team of the two companies.<br>For most companies, the materiality of a bulk supply is low. This is inevitable, given the isolated development of individual companies but, most importantly, that water is a heavy product, not easily transported over large distances. |

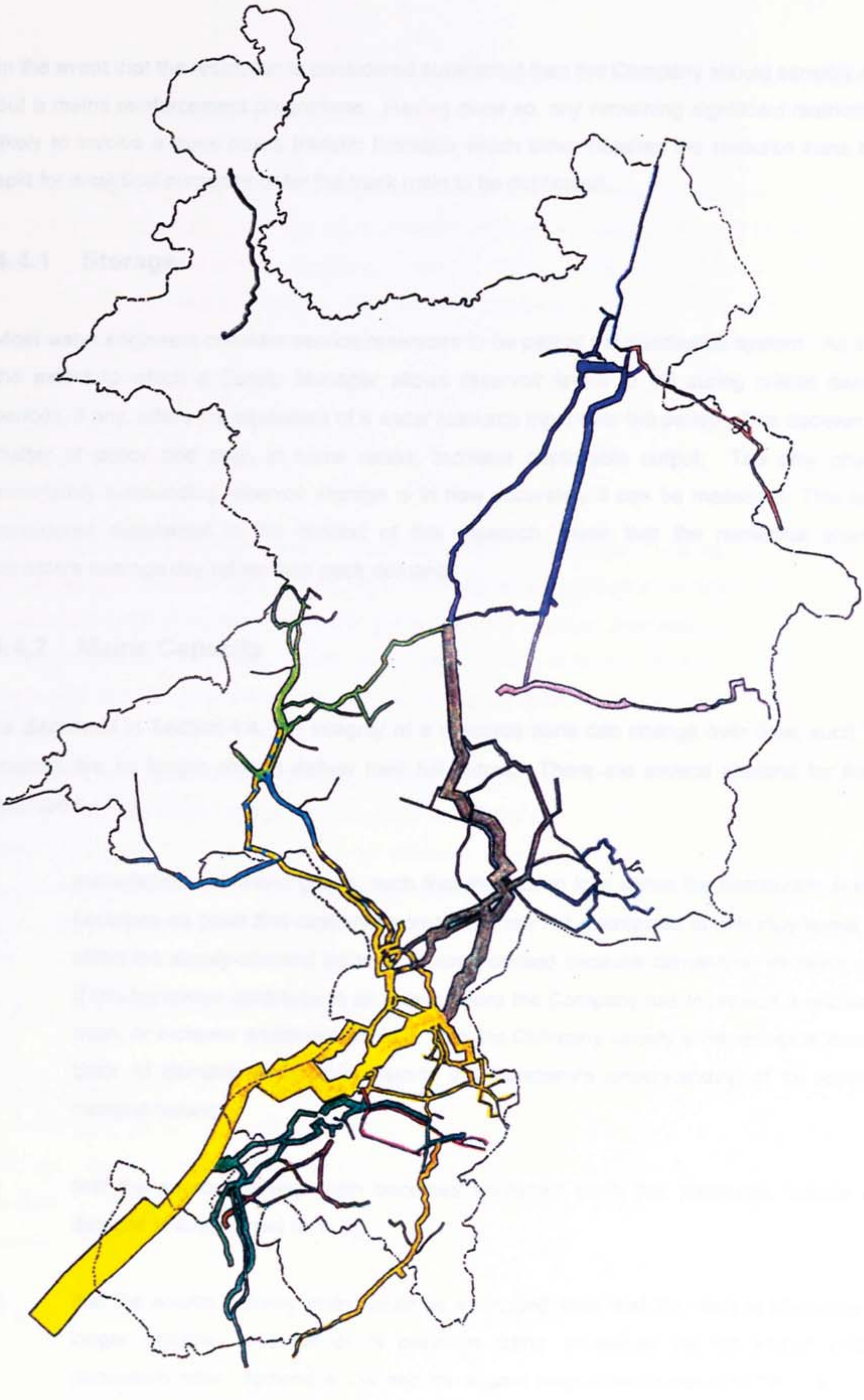
*(Table 4.9)*
*Key influences on the assessment of risk for supply side uncertainties discussed in Section 4.3*

## 4.4 SYSTEM CONSTRAINT UNCERTAINTY

UKWIR (1995) define a resource zone to be a region within which each customer receives the same level of service. It should, therefore, be possible to transfer water, without restriction, from any one point within the zone to any other point.

The practice, however, is never quite as simple as the theory and mains capacity, as demand rises, will invariably limit the extent to which water resources can be fully used. Taken literally, this would fragment the single resource zone into perhaps hundreds of smaller zones required unrealistic analysis to conclude the supply-demand balance in each case. A sensible approach is necessary. An example of mains capacity is shown visually in Figure 4.12, courtesy of the South Staffordshire Water Company.

Section 4.4.2 describes the principal reasons behind capacity limitation, included here for completeness. Trying to deal with the problem from an analytical perspective requires commonsense. At any point in time a proportion of customers will receive inadequate water pressure, hence sub-standard flow of water. Restriction is, therefore, always prevalent to some degree.



*(Figure 4.12)*
*Visual presentation demonstrating mains capacity*
*by thickness of connecting line*

In the event that the restriction is considered substantial then the Company should sensibly carry out a mains reinforcement programme. Having done so, any remaining significant restriction is likely to involve a trunk mains transfer limitation which either requires the resource zone to be split for analytical purposes or for the trunk main to be duplicated.

### 4.4.1 Storage

Most water engineers consider service reservoirs to be part of the distribution system. As such, the extent to which a Supply Manager allows reservoir levels to fall during critical demand periods, if any, offers the equivalent of a water resource input over the period. This decision is a matter of policy and may, in some cases, increase deployable output. The only obvious uncertainty surrounding reservoir storage is in how accurately it can be measured. This is not considered substantial in the context of this research, given that the numerical example considers average day rather than peak demand.

### 4.4.2 Mains Capacity

As discussed in Section 4.4, the integrity of a resource zone can change over time, such that sources are no longer able to deliver their full output. There are several reasons for mains restriction:-

i) instantaneous demand grows, such that the friction loss within the distribution system becomes so great that customers pressures are not maintained at previous levels. In effect the supply-demand balance is compromised because demand is not being met. If this behaviour continues to an extent where the Company has to replace a section of main, or increase pressures within it, then the Company usually experiences a 'bounce back' of demand which also distorts the Company's understanding of its supply - demand balance,

ii) that the source delivery main becomes encrusted such that pressures reduce and demand is suppressed as in (i),

iii) that the source delivery main becomes encrusted such that the main is physically no longer capable, by virtue of its pressure rating, to deliver the full source output, particularly when demand is low and the source output has to travel further. In effect this behaviour reduces the source output and effectively creates a fragmented resource zone, which by definition means the creation of a new resource zone. The decision to reinforce the mains system will usually be taken on economic grounds, reuniting the fragmented zones on commissioning.

Attempts to predict sources which might be affected by mains capacity limitation at some stage over the planning over, say 25 years, is considered totally impractical. A small to medium sized water company, for example, supplying around 1 million people, would have a mains network around 6,000,000 metres in length. Despite the complexity of this issue it is considerd to have significance, particularly when calculating potential demands during peak periods. Further research is recommended.

### 4.4.3 Pressure Variation

The relationship between pressure and flow within a distribution network is such that flow increases with increase in pressure. It is obvious, therefore, that a company with high mains pressure is likely to supply more water per person, on average, than one with lower pressures. This fact of life explains why purists often argue that the true demand for water can never be known because 'supply', a function of pressure, is geographically and diurnally variable.

It is taken as read that water demand is uncertain given changes in water pressure, pressure management schemes, mains reinforcement, re-zoning and so on. These practices are either slow or evolving or, in the case of pressure management, represent a solution to a supply-demand imbalance. Calculating the extent of pressure-demand variation is considered too complex for inclusion within this research.

## 4.5 DEMAND SIDE UNCERTAINTY

There is little doubt that much of the uncertainty within the supply-demand balance lies on the demand side; particularly with the rapid growth in garden watering and with expected climate change. Demand side uncertainty is most sensibly broken down into current uncertainties and forecast uncertainties and then into the various components of demand. The issues involved in cataloguing the uncertainties are presented in Section 4.2.2.1.

This section of the research begins with analysing current or 'time zero', uncertainties and how these might be dealt with. This is referred to as the initial water balance. Future uncertainty is then discussed with particular emphasis on:-

i) baseline uncertainty and normalisation,
ii) forecasting techniques, suitability and expert systems,
iii) trends in uncertainty,
iv) historic evidence of improved techniques,
v) climate change.

### 4.5.1 Components of Water Demand

UKWIR (1995$_a$) have produced a concise representation of the components of water demand, as reproduced in Figure 4.13. A company is required to make a number of forecasts as suggested in Figure 4.13. These are:-

i) a forecast of abstraction; which includes process losses, water given to other water companies, water used by a company's own customers less water received from other companies. Process losses are typically deducted from the supply side of the equation and, for many companies, the import and export of water is only of minor consideration. The use of water by a company's own customers is called distribution input,

ii) forecasts of distribution input are broken down into water delivered and water loss in distribution (leakage),

iii) water delivered is dominantly the volume of water for which bills are sent out (hence used for income projection), but a small volume is taken unbilled; either illegally (which is almost impossible to estimate), by a company itself for washing out mains, etc., and other legal unbilled use such as that used by the Fire Service,

iv) water delivered billed is broken down into customer leakage and customer use.

This section will consider the calculation and prediction of all components of distribution input from the perspective of how to appraise the extent of uncertainty within the assessments.

The largest component of consumption for most companies is unmeasured household use which itself can be broken down into components due to the household (such as washing machines, sprinklers, etc.) and those due to the occupants (such as baths and toilet use). Best practice (UKWIR, 1997$_a$) recommends that unmeasured household use is described as the sum of (household components x frequency of use x volume per use) + (occupant components x

Illustration removed for copyright restrictions

*(Figure 4.13)*
*Components of water use from abstraction to billing*
*(taken from UKWIR, 1995)*

frequency of use x volume per use). Household use is typically converted to a per person or per capita figure and then multiplied by a population figure to give an aggregate amount.

Measured industrial use can be broken down by sector as an aid to forecasting, such as use by breweries, chemical companies, agriculture and so on.

Additional sources of uncertainty on the demand side include that due to meter under-registration, discussed in Section 4.5.10.

### 4.5.2 Demand Forecasting Methodologies

Herrington (1987) suggests that forecasting methods can be classified as:-

i) judgement,
ii) surveys,
iii) extrapolation,
iv) analysis (cause and effect).

Lo (1993) offers an alternative classification based on suitability of application, where an expert system is used to decide the most appropriate technique. Lo suggests that forecasting method suitability is closely linked to the product life cycle. For example, a product at the early stages of development will have a different cause-effect relationship than a product in decline.

Lo (1993) proposes an expert system for choosing a forecasting method which draws on:-

i) the decision required,
ii) the information needed,
iii) the availability of data,
iv) the relevance of the data,
v) the historic data pattern,
vi) the market structure.

The expert system inputs different techniques into the evaluation which are then assessed for suitability and likely performance.

The Harvard Business Review (1986) provides an exceptionally comprehensive breakdown of forecasting techniques, shown in Figure 4.14. The techniques are described across two

*(Figure 4.14)*
*Breakdown of forecasting techniques*
*(Harvard Business Review)*

dimensions, forecasting type and then in terms of available time, skills, data and output needs. The strengths of the technique, appropriate to each condition along the Y axis, are shown yellow. The weaknesses are shown in grey.

As with Herrington (1987) the Harvard Business Review (1986) describes four classifications:-

i) judgement,
ii) counting,
iii) time series,
iv) cause and effect.

The 'counting' classification corresponds directly with the Herrington classification of surveys. Likewise, the time series classification corresponds with extrapolation.

### i) Judgement based forecasts

Herrington (1987) notes that judgement methods are unlikely to be of value if they are used as a cheap alternative to quantitative methods. Nevertheless, judgement, or professional deduction, may be the best, or the only, approach which may be taken in many cases. Even where considerable data is available it would be naive to rely wholly on quantitative techniques without a top down judgmental assessment.

Arguably the most well known judgement technique is the consensus method, involving between two and four rounds of peer group pressure where those with outlying views at the end of each round are asked to reconsider. This is commonly called the *Delphic* method. Other methods involve converting judgement into a quantitative form, such as the probability wheel (Morgan and Henrion, 1990).

### ii) Surveys/Counting Methods

With surveys, customers are asked about their view of a particular event or of the future. This is different to pure judgement forecasts in that the questioning is directed typically at large numbers of people and where an average or most common view is extracted.

Unbiased questioning is notoriously difficult to control. Likewise there is a general inability among those questioned to describe views in quantitative or specific terms.

### iii) Extrapolation/Time Series

Essentially, extrapolation is the generic term for direct prediction of the future using only data from the past. There is no review of cause and effect; simply an acceptance that the future is an extension of the past. The main assumption is that the patterns and inertia present within historic data will propagate future demands in a predictable way. It is to state the obvious to say that this assumption is dangerous.

Extrapolation techniques range from the simple to the esoteric and can be found described in detail in Abraham and Ledolter (1983).

### iv) Analysis (cause and effect)

Cause and effect models require considerable data and analysis to develop. They also require the relationship between cause and effect to be stable and that all effects predicted from a cause lie within the range of the original model. Providing these conditions are satisfied, then these models can be both accurate and revealing. However, finding sufficient data to derive models with sufficient variables and a high degree of statistical significance is often impractical. Choice of variables is also a key part of successful cause and effect model building. It is clearly the case that just because variables appear to be related mathematically is not sufficient reason to assume a cause and effect relationship.

A listing of forecasting methods across the four classifications (Harvard Business Review, 1986), is as follows:-

### Judgement Methods

i) naive extrapolation,
ii) sales force composition,
iii) jury of executive opinion,
iv) scenario methods,
v) delphi technique,
vi) historical analogy.

**Counting Methods**

i) market testing,
ii) consumer market survey,
iii) industrial market survey .

**Time Series**

i) moving averages,
ii). exponential smoothing,
iii) adaptive filtering,
iv) time series extrapolation,
v) time series decomposition,
vi) box-Jenkins.

**Cause and Effect Methods**

i) correlation methods,
ii) regression models,
iii) leading indicators,
iv) econometric models,
v). input-output models.

UKWIR/EA (1997$_a$) compiled a best practice manual for the forecasting of water demand components and it is appropriate to repeat these findings in Table 4.10. The table notes the trade off between cost and accuracy. Accuracy figures are taken to be applicable to year on year forecasts.

## 4.5.3 Uncertainty Within Current Demand

In most fields of demand forecasting the analyst will be able to start with a fixed point. The current value of each component, such as expenditure by Government Department or insurance claims by age group, will be known with reasonable accuracy. This, regrettably, is not the case for water demand because:-

i) much of the demand is not measured,

(Table 4.10)
Major components of demand forecast (information extracted from UKWIR/EA,1997.)
Table shows precision and accuracy of forecasting techniques

ii) that which is measured is usually under-registering partly because of the nature of meters not to respond to low flows.

There is, therefore, significant uncertainty evident within the components of demand even before the forecasting process begins. This uncertainty is often referred to as the initial water balance. The relative precision, or uncertainty, for the different components of the initial water balance, depending on the choice of calculation method, is shown in Table 4.11.

*(Table 4.11)*

*Major components of initial water balance (UKWIR, 1997$_a$)*

For reference, the RB column, reliability band, described accuracy as:-

A : +/- 1%
B : +/- 5%
C : +/- 10%
D : +/- 25%

These accuracies will be taken to represent the upper and lower 95% confidence limits for demand components within Chapter 5. See also Table 4.16 on assessing demand side risk.

### 4.5.4 Baseline Uncertainty and Normalisation

Perhaps the first problem a forecaster comes up against is in trying to decide the starting value for a forecast. During an annual review of a demand forecast the analyst will ask whether the forecast is still on track and whether any of the underlying assumptions have changed since the last revision. A number of scenarios are possible:-

i) the outturn values are as expected but circumstances suggest that the outturn values should have been different, concluding that forecast assumptions have changed,

ii) the outturn values are not as expected but there are untypical reasons why, concluding that forecast assumptions have not changed,

iii) the outturn values are not as expected and forecast assumptions have changed, concluding that the outturn values are consistent with new assumptions,

iv) the outturn values are as expected and forecast assumptions have not changed.

Scenarios (ii) and (iv) above require no action to be taken. Scenario (iii) requires a revised forecast starting from the new outturn values and scenario (i) requires *'normalisation'* of the outturn value in order to determine the revised starting position. These actions are summarised in Table 4.12.

| Outturn Value | Forecast Assumptions | |
|---|---|---|
| | Unchanged | Changes |
| As expected | No action needed | Outturn should have changed, hence, determine what the value should have been. (Normalisation required.) |
| Not as expected | Determine explanatory factors. Either take no action or change forecast assumptions. | New forecast from outturn value. |

*(Table 4.12)*
*Actions required following periodic assessment of outturn demand -vs- forecast demand*

Dealing with the problem of adjusting an outturn value with hindsight is called normalisation and might typically involve trying to adjust water demand for abnormal climatic influence. In practice this adjustment tends not to be applied to outturn values with the intention of reassigning a new base year. Here the water industry tends to use the most recent 'normal' year as the base year with the years 1990, 1993 and 1997 considered to be more 'normal' than hot years such as 1995.

Retrospective adjustment to demand from the point of view of deciding if a forecast should be changed tends, as with the majority of forecasting techniques, to be an ill defined blend of art and science. The analyst will first compile a list of explanatory factors, taking care to remember that even the most 'normal' of years has its own unusual events. A list of explanatory factors, each of which will influence peak, drought and average demand conditions differently might look as follows:

i) severe frost and thaw periods causing high levels of latent leakage and potentially causing peak demands. Leakage is likely to be the main influence upon peak demands in areas with a less variable domestic demand component, such as non-holiday regions and areas with a high industrial base,

ii) a politically or financially driven purge on leakage rates which lowers overall demand below that expected. Examples might include:

  a) adoption of a free supply pipe repair service,

  b) a redefinition of leakage targets,particularly if these are mandatory,

  c) a refusal by the industry regulator, OFWAT, to accept the contents of a company's Water Efficiency Plan.

iii) a change in metering policy, such as the introduction of sprinkler metering or more widespread domestic metering,

iv) introduction of a new tariff structure for metered customers,

v) adoption of a more aggressive policy towards the promotion of the efficient use of water,

vi) a significant loss, or gain, of industrial consumption due to prevailing economic conditions or to competition within the water industry; such as inset agreements or common carriage,

vii) critically, and most importantly, summer climate impacting on either peak demand, due to exceptional hot weather over short periods or drought demand, due to low rainfall and high temperatures over long periods.

Once the analyst has established the reasons why outturn demand had been different to that expected a decision needs to be taken on whether the reasons are sufficient to require a change in the forecast line. Interestingly, the outturn forecast may have been very close to that expected for all the wrong reasons. Nevertheless this should still require a change in the forecast. For example, suppose the effects of causes (i) through (vii) were analysed as shown in Table 4.13.

| **Cause** | **Effect** | | **Permanent** | **Temporary** | **Remarks** |
|---|---|---|---|---|---|
| | + | - | | | |
| Severe Leakage | 2 Ml/d | - | - | 2 Ml/d | |
| Leakage Purge | 0 Ml/d | - | - | - | |
| Metering Policy | - | 5 Ml/d | - 5 Ml/d | - | Expected to be more widespread in future years. Impact to rise to 10 Ml/d by 2020. |
| New Tariffs | 0 Ml/d | - | - | - | - |
| WEP | 0 Ml/d | - | - | - | - |
| Economy/ Competition | - | 2 Ml/d | - 2 Ml/d | - | - |
| Climatic Variation in Year | 8 Ml/d | - | - | 8 Ml/d | - |
| TOTAL | 10 Ml/d | 7 Ml/d | -7 Ml/d | 10 Ml/d | Significant permanent change |
| NET | 3 Ml/d | - | - | 3 Ml/d | |

*(Table 4.13)*
*Summary normalisation table for outturn peak demand*

The normalisation summary in Table 4.13 shows that the permanent downward changes in demand have been largely hidden by severe leakage and severe climate. If the permanent change is considered material then a change in the forecast should be made; moving from a baseline which is the outturn demand net of any temporary effects. This is shown within Figure 4.15.

Triggers for materiality will vary between companies and will be closely linked to the criticality of a company's supply demand balance. Triggers will be based on permanent changes in future assumptions rather than temporary ones.

Assuming that the baseline can be determined then component forecasting of water demand, discussed and described in Chapter 2, involves predicting each individual component of demand starting at a base year. The base year will only move forward if outturn values legitimately deviate from expectations in the light of changed circumstances which require a change in forecasting assumptions. Material change is a matter of judgement and the trigger is likely to be a percentage change in outturn, after normalisation, when compared with the forecast.

This approach is, in itself, straightforward. However, the components of demand are often not physically measured. Rather, they will be given allocated values based, for example, on the results of surveys or samples. Hence the starting position, their magnitude at the base year, is uncertain. Purists may argue that the best forecasts are independent of the past. However, in practice, history invariably plays a part.

The uncertainty within the calculation of current demand is discussed in detail in Section 4.5.3.

### 4.5.5 Unmeasured Demand

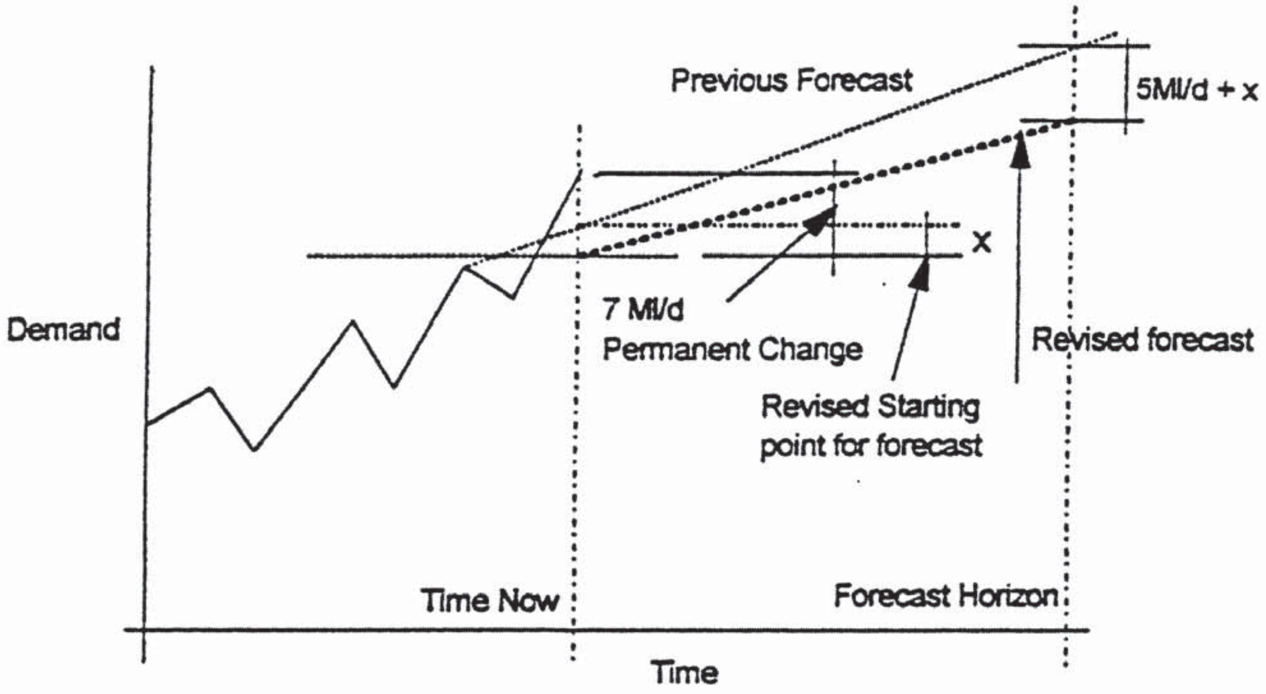
There are three major components of unmeasured demand:-

i) unmeasured domestic demand,

ii) unmeasured non-domestic demand,

iii) unaccounted for water, including leakage.

By far the largest of the three components is unmeasured domestic; at least for those water companies who do not have a widespread domestic metering programme.



*(Figure 4.15)*

*Baseline and forecast revisions*

#### 4.5.5.1 Unmeasured Domestic Demand

Unmeasured domestic demand is traditionally described in terms of 'per capita' (PCC) or per person, which is then multiplied by population to give a volume supplied. Forecasts are likewise calculated by multiplying forecast population change, obtained from the Office of Population, Census and Surveys (OPCS) and/or Local Councils, by a forecast of per capita change. The accuracy of population forecasts for the Midland counties has been exceptional in recent years, requiring less than a 0.5% adjustment each decade. In the context of this research, this uncertainty is considered insignificant and will not be taken forward to Chapter 5. In circumstances where population change is substantial then consideration will be essential. Further consideration here is believed to be beyond the scope of the research.

Per capita can be divided into that due to the household generally and that due to the occupant. UKWIR/EA (1997$_a$) describe the two groups as:-

**Population Related :**

Bath
Shower/Power Shower
WC
Personal Washing

**Household Related :**

Washing Machine
Dishwasher
Manual Dishwashing
Hosepipe Use
Sprinkler Use
Car Washing

Within each sub-component the ownership rate, frequency of use and volume per use is assessed and combined. For household related use the combined volume is then divided by household occupancy to give an equivalent per capita and added to the per capita for population related components.

Forecasts for each component of unmeasured use are made by applying assumptions to future ownership and frequency of use. Volume per use only varies as the appliance varies, such as the introduction of dual flush toilet systems. Assumptions will consider:-

i) the product life cycle,

ii) current national/local policies,

iii) climate change,

iv) change in garden size/number of houses with gardens,

v) trends by appliance manufacturers towards water efficient appliances.

Assessing risk within the growth in unmeasured domestic demand is discussed within Table 4.16.

#### 4.5.5.2 Unmeasured Non-Domestic Demand

The category of unmeasured non-domestic water use comprises old and well established water users who do not fall within the category for mandatory metering. Typically, these fall into categories of minor non-domestic use such as churches, banks, lock up garages, small businesses, libraries and other civic properties, etc. It is fair to say that the use of water within this category is not well understood. Analysis of water consumption for unmeasured non-domestic demand tends to be based on the consumption of new properties in these categories for whom measured information is available. Typically, this component of demand represents between 2% and 4% of total demand, but in terms of its measurement and prediction, it has a high level of uncertainty, perhaps within the range of -50% to +100% around a central estimate. Uncertainty within this category can be reduced very simply by installing meters on these properties, such that the customer is being measured, but is not being asked to pay by volume. Long term prediction of the component is likely to be a function of a company's metering policy, rather than based on any view whether there will be more banks or libraries in the future than there are now.

#### 4.5.5.3 Unaccounted for Water

UKWIR/EA (1997a) conclude, quite rightly, that the leakage element of unaccounted for water should not be considered as a component of demand, although, clearly, some assumption needs to be made about future values in order to compile an overall forecast.

From 1998 individual company leakage rates in the Water Industry, as a minimum, have been set as mandatory. Failure to achieve these targets will result in severe financial penalties.

Over the longer term leakage rates should follow a profile consistent with a company's economic level of leakage, i.e. a company in an area with few available water resources and growing water demand is likely to favour leakage reduction and metering. That company's economic level of leakage is, therefore, likely to be low.

In advance of a demand forecast, a company will not be able to calculate an economic level of leakage. It is the imbalance between supply and demand which determines this. The practice, therefore, is to have a forecast on mandatory leakage targets, then determine the supply-demand balance. The economic level of leakage (ELL) can then be determined and reinserted into the forecast. This, of course, then changes the supply-demand position and, hence, the leakage target.

The assessment of risk is discussed within Table 4.16.

Other components of water not delivered to the customers include water taken illegally, that used by a company for operational purposes, and that taken legally, but not billed for (such as fire fighting). These components tend not to change with time and are not subject to wide uncertainty in the context of other components within the supply-demand balance. An initial assessment of their magnitude is usually made based on reasoned assumption, such as the number of times a mains flushing operation occurred last year and for how long each was running to waste on average. Forecasting then assumes a constant value over time.

Over the longer term it is likely that pressures to reduce uncertainty, or headroom, will increase. Existing assumptions regarding the smaller components of demand are inevitably increasing the uncertainty surrounding the larger components, hence, in due course, may require a review of their accuracy.

### 4.5.6 Targets and Expectations

Within the prediction of any future goal or event there is both a target to aspire towards and an expectation. The latter reflects a more realistic approach. A first division football team, for example, will almost certainly have premiership football next season as its target but a position in the top quartile of the existing division may be the unspoken expectation. Indeed, often the target is used as a motivator to talk up an organisation in an attempt to exceed expectations.

Within the supply-demand balance the most commonly heard of target is that for leakage levels, where companies are encouraged to achieve lower and lower levels, almost without regard to the economic optimum. There are those, however, that believe that these targets, particularly those giving the long term position, are not realistic and will not be achieved given timescales and the financial resources available to the industry.

At the first industry seminar, in July 1997, of the UKWIR Headroom project a delegate asked if the issue of a company's inability or failure to meet targets represented a justifiable planning margin when calculating a future supply-demand balance. At face value the question seems legitimate in that if the target is genuinely too severe then there will certainly be an under provision of planning allowances.

However, taking the alternative perspective, it is difficult to see how either the Environment Agency or OFWAT could condone an allowance for water resources which implicitly accepts that the targets may not be achieved. OFWAT, in particular, would be agreeing funding for achieving leakage targets in addition to funding for not achieving the targets. While it is easy to understand the logic of seeking to include this uncertainty it has to be seen as a business risk that if a company has agreed to unrealistic targets then it is the company who will have to face the consequences. No allowance for this potential source of uncertainty will be allowed for within this research.

### 4.5.7 Measured Demand and Impact of Metering

Chapter 1 notes that this research considers uncertainty surrounding unrestricted growth in demand. In other words, there is no presumption that demand will be managed or restricted in preference to developing new water resources. The assumption, therefore, is that demand management is considered to be a solution to a supply-demand imbalance and will follow an iterative procedure in practice.

Nevertheless, a forecast of unrestricted demand should always project the effects of current policies in so far as they represent commitment within the supply-demand balance, rather than any alternative within it.

There are two key issues within measured demand:-

i) what policy does a company have towards metering of domestic customers,

ii) what methods can realistically be applied to forecasting the future use of water by industrial customers.

#### 4.5.7.1 Measured Domestic

A company will meter a domestic customer for four reasons:-

i) because the customer has requested a meter under a meter option scheme,

ii) because a company has determined to meter domestic customers in a widespread way,

iii) because a company has introduced selective metering; e.g. sprinkler users are required to be metered,

iv) because all new houses are metered in the absence of an alternative method of charging. Rateable Values will not be allowed to be used after 1st April 2000 under the 1991 Water Industry Act.

Each of the four causes of domestic metering requires separate consideration for forecasting purposes. Each assessment will need to take a view on expected future policy.

Once a forecast of measured domestic use has been made, the analyst will need to make due allowance for the effects of 'switching'. Switching is the effect caused by currently unmeasured households moving to the measured category. The degree to which this occurs and the impact it will have is less than obvious and requires consideration of:-

i) the cost of a meter to the customer,

ii) the volume of water the unmeasured customer currently uses and will use when measured., i.e. the savings incentive in the future from switching,

iii) the relative volumetric rate, referred to as parity (see definitions section in Appendix III).

As at December 1998, the Government had stated its wish to see all customers given the option of a free meter. This is not, as yet, legislation. If this proposal becomes law, then the switching effects of customers moving from unmeasured to measured will be substantial.

#### 4.5.7.2 Measured Non-Domestic

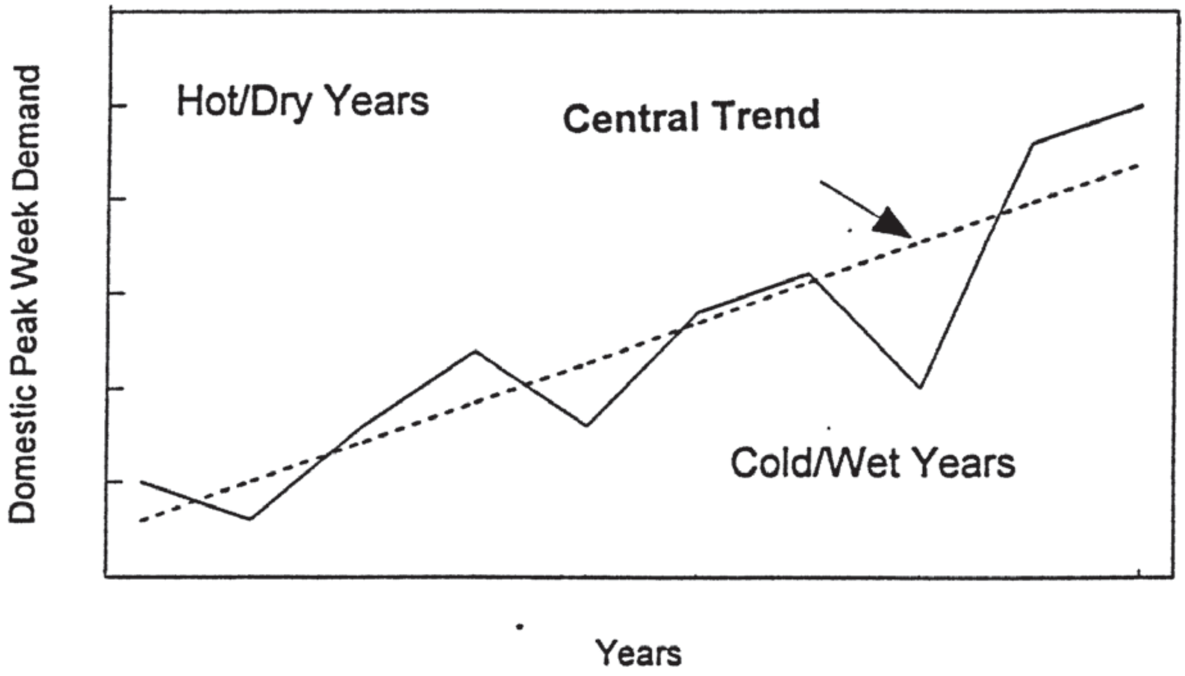
There are various techniques for forecasting measured non-household demand for water (UKWIR, 1997, and Thakray & Archibald, 1981), including trend analysis, cause-effect models and so on. Experience suggests low reliabiity for any of these techniques but that overall accuracy can be improved by making top-down assumptions about major customers and specific industrial categories.

### 4.5.8 Climatic Effect on Demand

Whether climate change is a fact of life or not, it is always true that climate varies year on year. There is also evidence to suggest that climate behaves in cycles where several cold years or several hot years occur in clusters. The impact of climate on water demand within the supply area of South Staffordshire Water has been examined by Carnell (1985) and is described in section 2.5.2. Research has also been undertaken by Herrington (1995) and Smith (1989). To set a likelihood distribution on demand for water due to variation in climate it is theoretically necessary to set a likelihood on various weather parameters; in effect simulating the weather. As a practical approach, however, this may not be realistic.

As an alternative approach it is possible to assume that, regardless of climatic cycle, domestic demand for water varies about its mean value with a constant standard deviation, even if the mean value is itself not constant. Under these circumstances variation in historic domestic demand acts as a surrogate for variation in the future. This relationship is presented as Figure 4.16.

The impact of climate variation on demand is a fundamental part of evaluating the supply - demand balance, both in the short and long term. In addition to this variation, customers experience the effects of climatic persistence which, in the short term , may be significant.



*(Figure 4.16)*

*The effect of climate variation on domestic demand*

Figure 4.16 shows a drought index, a factor describing weather severity, plotted for 103 years for Massachusetts, New England, USA (USA Today, 1997)). Visually the drought index appears to demonstrate persistence and a run test of randomness shows only 34 sequences in 103 years, confirming persistence at the 99% significance level. The expected number of runs in 103 years is 49. It may, therefore, be possible to improve an assessment of future summer climate using conditional probabilities. This dependency will, however, weaken rapidly with time and only be of value for resource planning in the medium term, perhaps three or four years ahead. This is one area which might benefit from additional research.

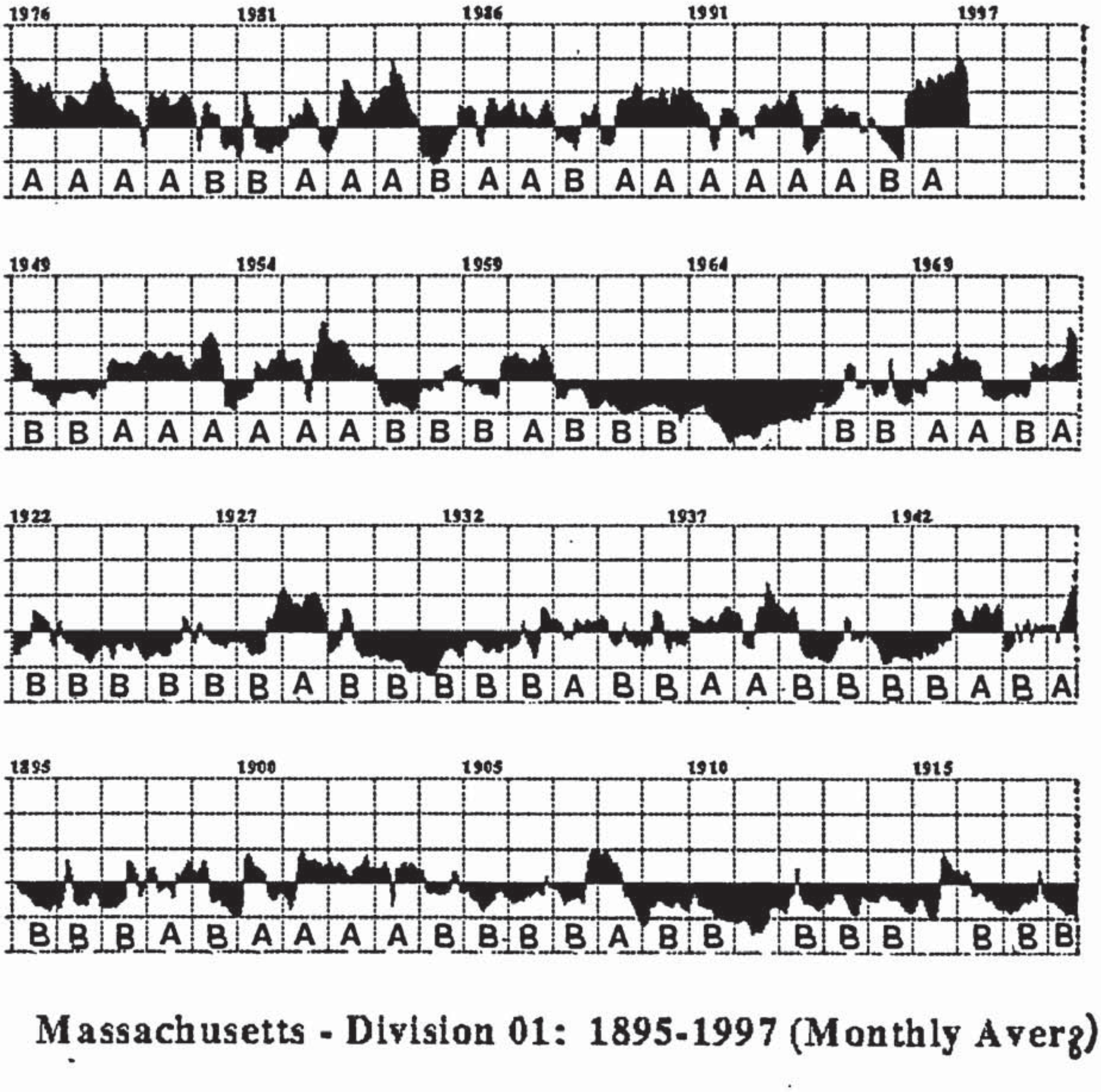
Assessing uncertainty due to variation in cimate is discussed within Table 4.17.

### 4.5.9 Climate Change Effect on Demand

The most notable research into the impact of climate on demand is due to Herrington (1995). The approach taken by Herrington is based on first assessing the relationship between climate and demand and assuming this relationship holds true for changes in climate. This is then overlaid with a number of pragmatic assumptions. Summary statistics taken from the study suggest that average demand will rise by 4% by 2021 due to climate change, and that peak week demand will rise by more than 6%.

In order to understand the reasoning and magnitude of the impact of climate change on demand, it would be ideal to consider which of the components of water demand are influenced by climate, to what extent and what relative weighting they will have in the future. In practice, much of this would be judgmental since component response to climate at the micro level is unknown to any useful extent. Chapter 5 considers this issue further.

A more practical alternative is to first consider the impact of climate on aggregate demand, derive a unit relationship, forecast future climate and, hence, predict future demand. In Herrington (1995) research suggests, for the Cambridge area, that at 1°C increase in the average daily maximum temperature is associated with an increase in the system peak ratio (increase in peak demand over average demand) of 0.01. Profiling a climate pattern, based on this relationship, would allow the impact on average demand to be determined and also allow future peaks to be evaluated given predictions for temperature change. Separate relationships, however, would clearly need to be established for individual companies/resource zones for the calculation to be meaningful.



*(Figure 4.17)*
*Palmer hydrological drought index for Massachusetts, USA*
*for period 1895 - 1997*
*(Key: A = years greater than standard index*
*B = years less than standard index)*

In Herrington (1995) the relationship between water supply and climate was established for the Thames Water area, deriving a different relationship for each month of the summer. A climate change scenario of +1.05°C (by 2020) and +2.10°C (by 2050) with soil moisture deficit +10% to +50% by 2020 and +20% to +100% by 2050, was superimposed on the supply-climate relationships to derive increases in demand. The climate scenario also assumes increases in the number of daylight hours of between 0 and 0.5 hours per day by 2020 and 0 and 1 hours per day for 2050. Assigning likelihoods to the climate change scenarios allows a range of impacts to be determined which Herrington (1995) refers to as minimum, likely and maximum responses.

Herrington (1995) also offers a judgmental approach to the impact of climate change on demand by prescribing assumptions to how each micro component of demand might be affected. The analysis suggest that, for average demand, only showering and garden use would be substantially affected. The effects assumed appear reasonable, but arbitrary. A possible relationship between reduced toilet use due to dehydration is also discussed.

The Herrington study also suggests that appliance ownership is seen to increase as a result of climate change.

Assessing climate change uncertainty is discussed in Section 4.5.14 and Table 4.16.

### 4.5.10 Demand Side Meter Error

UKWIR/EA ($1997_a$) suggests that current and predicted demand side meter error should be given substantial attention on the basis of insignificance within the supply-demand balance.

However, studies carried out in America (Prasifka, 1988) show a dramatic relationship between under-registration and age, repeated as Table 4.14.

*(Table 4.14)*
*Under-registration of meters due to age*
*(from Prasifka, 1988)*

Assessing the risk of demand side meter error is discussed within Table 4.16 in Section 4.5.14.

### 4.5.11 Time Lags within Resource Development

Many water resource managers will argue that the single largest source of uncertainty within a company's water resource development programme is that caused by variables within the planning and construction process which are not easily predictable. With a groundwater development, for example, it may be that the Environment Agency requires pumping tests of a longer duration than that envisaged or it may be that the geology encountered is unsuitable and alternatives need to be explored. Whilst it is easy to see the logic of this argument, from a Regulators perspective any allowance for such uncertainty would be to the benefit of those companies who have an inferior planning process. Clearly, it will always be the case that some resource development schemes, or even some demand management schemes, are more or less certain than others. It is always likely to remain a business risk that a company needs to take due account of these uncertainties within its planning process such that the work is started in good time and that contingency planning is put in place. In this way, unforeseen circumstances can be dealt with in an efficient manner when they arise. Section 2.4.6 discussed the development of this arguable source of uncertainty.

### 4.5.12 Trend in Demand Uncertainty

A forecast of water demand is a combination of expectation, probably an amalgam of knowledge and assumption, and extrapolation. The latter assumes an inertia of historic influence which is driving the demand forward.

For a short range forecast the expectation element is likely to dominate over extrapolation but this domination quickly reverses as the length of the horizon increases. In essence, the analyst's view of the very long-term is likely to be without substance. DeKay (1985), for example, considers that for forecasts of long horizons, refinements in technique become less valuable and that time is better spent analysing plausible scenarios, based only on a projection of the past and a combination of policy assumptions.

During the first few years of a forecast, the analyst can take a view, based on the likelihood attached to the assumptions, on how uncertain a forecast is. This analysis, for example, might involve computing a number of different scenarios and looking at the range of outcomes. Once extrapolation takes over, as the horizon gets longer, then judgement becomes less meaningful.

### 4.5.13 Are Forecasting Methods Improving?

Part of the assessment of future uncertainty requires an appreciation of whether uncertainty itself is reducing. Will future forecasts be more certain than those of the past? Intuitively, looking at the development of forecasting tools from their very crude beginnings, then improvement might be expected. Identifying and measuring improvement, however, is highly complex.

Chapter 2 demonstrates that for a very long period in the water industry, water demand grew at a constant rate, year on year. An analyst making a 10 year demand forecast in 1960 would probably have got it more or less right, but for all the wrong reasons. The analyst probably had little understanding of the underlying causes of growth, instead relying on historic behaviour patterns. By contrast an analyst forecasting water demand in 1985, using contemporary component techniques, stood a high chance of getting the forecast wrong because of the excessive instability within the components. In particular, manufacturing industries were in decline but with elements of domestic demand, such as hosepipe use, growing very rapidly.

Performance within a forecast is therefore not just about technique. Issues of stability and luck will pay an equally important part. Perhaps even more important will be the influence of prevailing political pressure on the forecasts. Following water industry privatisation, for example, pressure on water companies to achieve low levels of leakage increased dramatically.

Having concluded that forecasting performance is not readily measured in terms of technique then a comparison of past performance may not be particularly revealing. However, Table 4.15 compares, for the South Staffordshire Water Company, forecasts produced over the last 20 years, by principal component. The table compares five-year-ahead forecasts with 10-year-ahead forecasts for each base year. The comparison statistic is chi-square, reflecting the square of errors between observed and expected values.

| Principal Component of Water Demand | | | | | | |
|---|---|---|---|---|---|---|
| **Forecast Base Year** | **Trade Use** | | **Domestic Use** | | **Total Use** | |
| | 5 yrs ahead | 10 yrs ahead | 5 yrs ahead | 10 yrs ahead | 5 yrs ahead | 10 yrs ahead |
| **1978** | 15 | 79 | 10 | 46 | 0.7 | 0.2 |
| **1981** | 8 | 62 | 2 | 13 | 0.4 | 0.4 |
| **1984** | 1.7 | 7.1 | 13 | 11 | 6.5 | 3 |
| **1991** | 12 | - | 0.3 | - | 3 | - |
| **Average Performance** | 8 | 49 | 8 | 23 | 2.5 | 1.2 |

*(Table 4.15)*
*Forecasting performance as measured by chi-squared*

Despite the lack of method for separating out the underlying causes behind forecasting performance, there are still several interesting observations to be made from the analysis. Many of the observations will apply across the water industry.

i) five-year ahead forecasts, as expected, perform better than 10 year ahead forecasts,

ii) forecasting of total demand outperformed the principal components because the over-estimate of domestic growth in demand counteracted under-estimation of trade growth. This might therefore be described simply as luck, although there is an alternative opinion that analysts attempt to compensate for severe variation in one component by introducing a counter-variation in another, i.e. they take an intuitive top-down approach. This confirms the view that forecasting is more of an art than a science,

iii) long-term forecasts appear to be improving. This is a combination of recent demand stability and also a reluctance by Regulators to accept contingencies, or unrealistically high forecasts, submitted as part of the resource development process,

iv) looking to the future of forecasting methods intuitively, they should improve but how quickly and to what extent is unknown. Clearly the lessons of the past reveal little except perhaps that a long-range forecast carried out now or in the future might be expected to outturn with a 'chi-square' lower than in the past. This of course assumes, as does the central theme of this research, that the demand forecast is unrestricted, i.e. not subject to demand management.

### 4.5.14 Summary of Key Influences for Risk Assessment of Demand Side Uncertainties

Sections 4.5.1 through 4.5.13 discuss areas of uncertainty on the demand side of the supply-demand side equation. Within Chapter 5 likelihoods, where possible, will be assigned to these uncertainties.

Key influences on the demand side of the equation are presented as Table 4.16.

| Source of Uncertainties | Key Influence on the Assessment of Risk |
|---|---|
| **Sections 4.5.1 through 4.5.3: Uncertainty within current demand**<br>Continued ...... | The overall degree of uncertainty within the calculation of demand can be determined (UKWIR, $1997_a$) using the method of maximum likelihood, described in Section 2.5.1.2, which compares a bottom up addition of estimated demand components with the top down estimate (the volume of water put into the distribution system). The difference between the two figures is referred to as the reconciliation item which represents the extent of error and which should reduce over time.<br>The reconciliation item will reduce as a result of:-<br>i) a greater understanding of night-time water use and the relationship between pressure and leakage as pressure changes between night and day,<br>ii) a greater understanding of meter error and/or improved meter accuracy,<br>iii) a greater proportion of measured domestic customers,<br>iv) a greater proportion of measured non-domestic customers,<br>v) improved techniques for measuring domestic unmeasured use (UKWIR, $1997_a$). |

*(Table 4.16)*
*Key influences on the assessment of risk for demand side uncertainties discussed in Section 4.5*

Continued ......

| Source of Uncertainties | Key Influence on the Assessment of Risk |
|---|---|
| **Sections 4.5.1 through 4.5.3: Uncertainty within current demand** | The components and relative precision within the water balance, according to the method of calculation, are described in UKWIR, $1997_a$ and repeated in Table 4.11. Table 4.11 provides guidance on assigning uncertainties within the initial water balance. |
| **Domestic unmeasured demand: Section 4.5.5.1** | Arguably, the most appropriate way of assigning uncertainty to the growth in domestic per capita is to re-do the forecast under various scenarios, some of which may be considered equally likely and other less so. A weighted average can then be obtained for each time horizon, together with a distribution of per capita which surrounds it. Such scenarios tend to be based on rational argument rather than extrapolation. A simpler view can be obtained by applying the percentage accuracy figures listed in Table 4.10 (UKWIR, $1997_a$). Section 5.4.3.6 considers both approaches.<br>Other principal uncertainties within the calculation of domestic unmeasured forecasts are the rate of population growth and the change in household occupancy. The former of these is generally considered to be highly stable but, in any event, beyond the scope of most water companies to predict. The latter is more complicated and can be highly variable, depending on:-<br>i) economic development,<br>ii) motorway infrastructures,<br>iii) climate change regionally,<br>iv) availability of water regionally,<br>v) age profile, particularly widows/widowers,<br>vi) propensity for living alone.<br>Predicting household density is usually carried out by researching Government publications of regional social trends. Placing uncertainties on these statistics is considered to be beyond the scope of this research. |

*(Table 4.16)*
*Key influences on the assessment of risk for*
*demand side uncertainties discussed in Section 4.5*

Continued ......

| Source of Uncertainties | Key Influence on the Assessment of Risk |
|---|---|
| **Unaccounted-for water** | In practice, there will always be a risk of a company not achieving a leakage target. Reasons for this will include:-<br>i) the effect of a severe winter,<br>ii) incorrect assessment of leakage economics linked with inadequate funding,<br>iii) a company choosing to accept a penalty for non-achievement in the face of more pressing priorities.<br>Although, in theory, it might be possible to assign risks to leakage targets, it is considered highly unlikely that a regulator would either support it or allow funding. This dilemma is discussed further in 4.5.6.<br>The question of legitimacy of planning allowances is considered further in 4.9. |
| **Measured domestic: Section 4.5.7.1** | Assessing the risk within forecasts of domestic measured demand is made by reference to table 4.10. |
| **Measured non-domestic: Section 4.5.7.2** | Assessing the risk within forecasts of non-domestic measured demand is made by reference to table 4.10. |
| **Climate effect on demand: Section 4.5.8**<br>Continued ...... | Arguably the most robust way of assessing uncertainty due to variation in climate is to establish the relationship between different components of supply and demand and climate and then to derive a climate related probability distribution. Given a distribution which can then be applied at the component level of the supply-demand balance allows future variability to be predicted.<br>It is perhaps the most obvious statement within water resources planning that variations in weather cause variations in water use. These variations are most acute during peak periods and are usually, but not always, associated with hot weather. Variations are also not constrained to customer demand.<br>Yorkshire Water (1997) make the following observation regarding the effect of weather on leakage levels:- |

*(Table 4.16)*
*Key influences on the assessment of risk for demand side uncertainties discussed in Section 4.5*

Continued ......

| Source of Uncertainties | Key Influence on the Assessment of Risk |
|---|---|
| **Climate effect on demand: Section 4.5.8** | *"There is no doubt that weather conditions can influence leakage levels - an extreme example being the massive rise in leakage following the severe freeze/thaw in Yorkshire at Christmas 1995/New Year 1996. It is believed that severe droughts, through their impact on ground movement, can also increase burst rates and hence leakage levels, though the evidence for the magnitude of this effect is less clear".*<br>Looking at the impact of weather on customer demand it is most valuable to consider the demand components which are most affected by weather. There are two fundamental approaches. The first is to look historically at how domestic demand has varied against a long-term trend, such as that shown in Figure 4.16, or secondly to consider cause and effect and to project the cause, and thus the effect, forward in time.<br>Applying cause and effect has the advantage that trend can be projected forward in a logical manner. Attempting to project trend from Figure 4.16, for example, requires that the standard deviation of the observed values is re-calculated along the timeline. There is unlikely to be sufficient data to do this in a meaningful way. In addition, to do so assumes that the future is a simple extension of the past and, in so doing, ignores climate change or any other external influences on demand.<br>A simple cause and effect model is presented in Table 4.17 in which the domestic demand is broken down into components which vary differently with climate. |
| **Climate change effect on demand: Section 4.5.9** | In Herrington (1995) a level of uncertainty over the relationship between demand and climate is put as +/- 10%. However, the major uncertainty surrounds the prediction of climate change itself. UKWIR/EA (1997) researched the variability of climate change models and, on the assumption that, *a priori*, no scenario is more likely than another, then a distribution of monthly climate variables, or scenarios, can be established.<br>Predicted changes are extracted from the UKWIR/EA ($1997_b$) report and shown in Tables 4.18 and 4.19.<br>The variation between models is clearly substantial and represents a significant source of uncertainty within the supply-demand balance.<br>An example of the predicted impacts of climate change, from Herrington (1995), is shown in Table 4.20 for an average change of 1.1°C. This relationship will be referred to again within Chapter 5. |

*(Table 4.16)*
*Key influences on the assessment of risk for demand side uncertainties discussed in Section 4.5*

Continued ......

| Source of Uncertainties | Key Influence on the Assessment of Risk |
|---|---|
| **Demand Side Meter Error (4.5.10)** | The uncertainty of meter error is partial, as defined in 4.2, since there is a genuine bias towards under-registration. As at February 1998 there are numerous known and anecdotal studies being undertaken by individual water companies, the majority of which will not be published for commercial reasons. Table 4.14, extracted from Prasifka (1988) gives some guidance on assigning uncertainty. This issue is considerd further in Chapter 5. |

*(Table 4.16)*
*Key influences on the assessment of risk for demand side uncertainties discussed in Section 4.5*

| | **Base Year Calculation** | | |
|---|---|---|---|
| **Component of Demand** | **Current per capita** | **Peak Week Variation with Climate (Standard Deviation** | **Peak Week Per Capita (+ 2 standard deviations)** |
| Garden Watering | 10 l/p/d | 30 l/p/d | 70 l/p/d |
| Other | 140 l/p/d | 10 l/p/d | 160 l/p/d |
| | | Total | 230 l/p/d |
| | **Horizon Calculation** | | |
| **Component of Demand** | **Horizon per capita** | **Peak Week Variation with Climate (Standard Deviation** | **Peak Week Per Capita** |
| Garden Watering | 30 l/p/d | 90 l/p/d | 210 l/p/d |
| Other | 150 l/p/d | 11 l/p/d | 172 l/p/d |
| | | Total | 382 l/p/d |

*(Table 4.17)*
*Intuitive analysis of the impact of climate on peak week domestic demand*

|  | Month |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Model** | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** | **Annual** |
| HADCM1 | 1 | 0.6 | 0.8 | 0.5 | 0.9 | 0.8 | 0.8 | 1 | 1.1 | 0.8 | 0.6 | 0.9 | 0.8 |
| GG1m | 0.6 | 0.9 | 0.7 | 0.8 | 0.9 | 0.6 | 1.1 | 0.8 | 0.9 | 1 | 1.3 | 1 | 0.9 |
| GS1m | 0.7 | 0.7 | 0.5 | 0.5 | 0.5 | 0.4 | 0.6 | 0.7 | 0.6 | 0.7 | 0.7 | 0.5 | 0.6 |
| GS1t | 0.7 | 1 | 0.1 | 0.6 | 1.1 | 0.5 | 1.1 | 2 | 0.8 | 1 | 1.2 | 0.4 | 0.9 |

*(Table 4.18)*
*Predicted change in Midlands region temperature by month,*
*for various models, for the year 2020*
*(table shows °C change from 1997)*

|  | Month |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Model** | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** | **Annual** |
| HADCM1 | 9 | 6 | 8 | - 6 | 2 | 2 | 4 | - 9 | - 4 | 7 | 17 | 3 | 4 |
| GG1m | 1 | 8 | 2 | 7 | 4 | - 3 | - 8 | 3 | 3 | 7 | 7 | 6 | 3 |
| GS1m | 5 | 1 | 4 | 4 | 4 | 0 | - 3 | - 2 | - 1 | 3 | 3 | 2 | 2 |
| GS1t | 3 | - 6 | - 4 | 10 | 17 | - 11 | - 22 | - 9 | 0 | 16 | - 4 | 4 | 0 |

*(Table 4.19)*
*Predicted change in Midlands region rainfall by month,*
*for various models, for the year 2020*
*(table shows % change from 1997)*

*(Table 4.20)*
*Domestic demand components for non-Metropolitan South & East England*
*in 1991 and 2021 incorporating climate change*
*(figures are in litres per person per day)*
*(from Herrington, 1995)*

## 4.6 FINANCIAL UNCERTAINTY

Water resource planners and supply managers will argue that they should not be asked to make full use of water resources on the basis that the marginal cost of sources at very high levels of output can exceed the cost of new resource development or demand management.

From a political perspective a Regulator may find it hard to accept the argument that a company has water available, but refuses to use it on the grounds of economics. Nevertheless, at least in theory, the argument for optimum use of sources, either on the basis of long run marginal cost carries the same weight as any argument for leakage reduction, pressure management, or any other solution to the supply-demand equation.

It will remain for individual companies to argue with their own Regulators whether the provision of headroom to meet source optimisation is justifiable or not. Clearly, each case will need to be considered on its merits.

## 4.7 DIFFERENT TIME PERIODS AND CRITICALITY

Water resource planning traditionally considers water sufficiency over the long term. To most planners, this means having enough water in a dry year to meet the demands in that year, taking due account of other uncertainties.

However, particularly since accelerated domestic growth began in the 1970's, it has become more widespread for water resources to become strained over much shorter time periods. A company with groundwater dominance, for example, and little surface water stock, may find that the critical time for water resource is a two week period in July.

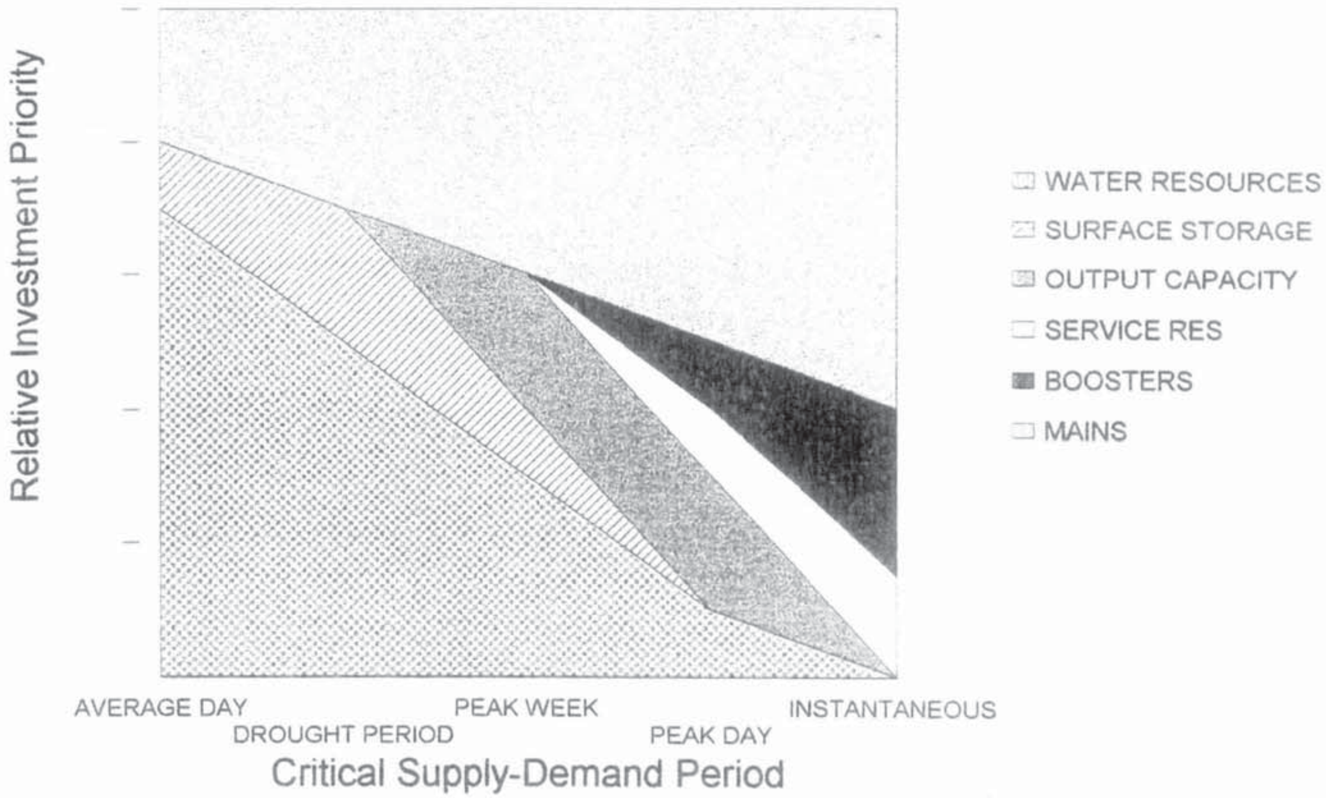
For companies with substantial surface water stocks, then water resources are likely to be adequate, although treatment works capacity may not. As the time period gets smaller, the extent to which water resource need drives investment reduces and the extent of distribution investment increases. At the extreme, instantaneous demand only requires sufficient mains capacity. The relationship, derived indicatively and based on experience, is demonstrated in Figure 4.18.

This research is concerned with calculating the imbalance between supply and demand and focuses on the traditional calculation, involving consideration of resource availability. It is evident, however, that the degree of uncertainty surrounding the supply and demand component will change significantly as the critical supply period changes. Clearly, climate change uncertainty will be more acute to consideration of peak week than average day, for example.

Providing that uncertainties are reconsidered in the light of changes in the supply-demand period, then this research is applicable across the range of critical periods. The UKWIR (1998) Headroom project specifically excludes consideration of any period shorter than one year.

## 4.8 DEALING WITH EXTREME EVENTS

Risk analysis, by definition, is concerned with quantifying risk, expressed as the aggregate product of consequence and likelihood. However, it may not be appropriate to consider events of highly significant consequence yet low likelihood in the same way as traditional risk analysis.



*(Figure 4.18)*
*Relationship between investment driver and critical supply-demand period*

In Chapter 2, Shrewsbury Water Corporation argued for a substantial planning margin "Just in case" of a new factory developing within their supply area. It is easy to understand their concern and there is very likely an inverse relationship between planning risk and increasing organisational size. However, there must be a point where the planning margin or contingency required to cater for the risk becomes so large as to be meaningless. For example, a 5 Ml/d water company would be foolish to add 5 Ml/d to their resource plans on the basis of a 50 Ml/d potential customer with a 10% likelihood. The figures become pointless. If the customer does not materialise, which is very likely, then the Company will have incurred massive proportionate costs and if the customer does seek a supply the company cannot meet their needs anyway without several years lead time and firm investment proposals.

Clearly neither of the two extremes shown is acceptable and the answer lies in optimum mitigation of risk, accepting that the Water Company has no control over the event and that the usual form of planning and risk are of little value. A form of crisis management is, therefore, required.

In crisis management the proposed new development, if it happens in the absence of pre-planning, would be considered in the same category as a *disaster.*

Latham (1987) describes a disaster in terms of:-

> *"Any event, happening with or without warning,........ which, because of its scale, cannot be dealt with ..... as part of day to day activity".*

This definition seems appropriate to the plight of the Water Company, directing the planner towards the natural course of crisis management.

Crisis management requires consideration of effects, rather than causes, emphasising mitigation and recovery systems. In the case of the water company example these will include:-

i) drawing up a rationing plan for existing customers,

ii) negotiating a phased development scheme with new major customer,

iii) importing supplies from neighbouring water companies at high cost. Lay additional mains as necessary,

iv) developing higher cost, but fast and low risk resource development schemes,

v) negotiating an investment plan with regulatory to cover crisis recovery.

It would be cost prohibitive for a company to design for every conceivable event and it is therefore recommended that no allowance should be made for crisis conditions within the supply-demand balance. The remaining question, however, is of when an incident becomes a crisis. In addressing the question, the analyst will appraise the trade off between the cost of planning the event as if it were an incident, set against the consequence of ignoring the event within the planning process, providing mitigation instead.

## 4.9 LEGITIMACY OF PLANNING ALLOWANCES

There are numerous uncertainties, inherent within the supply-demand balance, which a water company will need to make allowance for. As discussed in Section 4.2 these uncertainties will vary in type, but might be described, from a regulators perspective, as those which are reasonably within the control of a water company and those which are not. For example, the variation of climate on an annual basis is clearly something uncontrollable whereas the accuracy of demand prediction or yield assessment is, in part, within the control of the water company.

The UKWIR (1998) project looking at Headroom defines any uncertainty which is within the reasonable control of a water company is not legitimate for water resources planning. A less absolute view is that many uncertainties will, to some degree, be partly controllable. As such, they have the potential to be reduced. Any reduction in uncertainty will, by definition, reduce the supply-demand imbalance and thus has a water resource benefit which might be expressed in cost terms. However, reductions in uncertainty will also have a cost : companies who wish to improve their demand forecast accuracy will need to invest in component studies and new techniques.

Essentially, therefore, reducing uncertainty is no different to reducing leakage or increasing water resource provision in so far as they all reduce a supply- demand imbalance. All solutions have a cost and all have a benefit and any solution to a resource imbalance is likely to involve a basket of alternatives. Reducing uncertainty is perhaps the first option which should be considered.

Both OFWAT and the EA are unlikely to support claims for resource development where it appears that best practice techniques have not been used and that, as a result, uncertainty is greater. From a company's perspective they may consider resource development a cheaper option than technique improvement; particularly so with small companies for whom research is proportionately expensive. In theory an appraisal of options on financial grounds is perfectly reasonable. In practice, rules of best practice and controllability will apply. The best strategy for the company wishing to avoid best practice may be to fund the cheaper option of resource development outside of the charging mechanism.

## 4.10 THE CONSEQUENCES OF BEING WRONG

Over-estimating a future supply-demand imbalance will have the result of seeking excessive funding. This, in turn, is likely to force excessive investment in demand management and artificially suggest a lower economic level of leakage. The consequences will, therefore, be both inefficient and ineffective.

Given also that periodic price reviews have a significant top down perspective by OFWAT, such that the relationship between strength of argument and amount of funding is weak, then declaring a need to invest in the supply-demand balance is very likely to require a reduced investment elsewhere. There may, therefore, be a level of service consequence elsewhere within the business.

Under-estimating a supply-demand imbalance may be even more serious, particularly for those companies who have accepted Condition "Q" within their licences. Condition "Q" is a UK guaranteed standard which requires companies to pay domestic customers £10 per day (as at December 1998) for each day they are subject to restricted domestic availability during a drought. The company's liability is limited to payments not exceeding the customer's bill. In such circumstances it is easy to imagine that an event involving widespread demand restrictions could easily wipe out a company's entire operating profit.

For the resource planner, the issue is fairly straight-forward. The company has a declared level of service, perhaps a hosepipe ban with a likelihood of 1%, or once in a 100 years. The planner can design a sufficient supply-demand balance to meet such an event.

For the company's Chief Executive the issue is a different one. Science may dictate that the level of service is sufficient but the threat of Condition "Q" may force the company to seek to maximise headroom beyond the level of service threshold into an unquantifiable comfort zone. Defining this zone is beyond the scope of this research.

## 4.11 CHANGE IN UNCERTAINTIES WITH TIME

Section 4.2 catalogues sources of uncertainty considered within this research and makes comment on the differences between current and future uncertainties.

On balance, the analyst might expect uncertainty to grow over time, since the future is unknowable and the distant future even more so. There are, however, areas where uncertainty might be expected to reduce. Reasons for such reduction will include:-

i) improved methods of calculation,

ii) increasing length of data,

iii) increasing reliability of data,

iv) improved technologies, e.g. meter accuracy, process losses,

v) improved cause-effect models for forecasting.

On the other side of the equation, uncertainty is likely to increase as a result of climate change; legislation and water quality changes. UKWIR (1998) suggest that uncertainty increases with time.

## 4.12 SUMMARY OF CHAPTER

Chapter 4 is a core chapter of this research, considering sources of uncertainty across the supply-demand balance. Sources of uncertainty were derived across a number of categories as a means of exploring alternative perspectives and optimising coverage. This aspect of the research represents a substantial original contribution. For each source of uncertainty, ideas are discussed with regard to key influences on risk assessment. Risk assessment influence is summarised within Sections 4.3.15 and 4.5.14 (Tables 4.9 and 4.16).

For the sources of uncertainty where quantification is practicable, and where they are within the scope of this research, then they are taken forward to Chapter 5. Chapter 5 develops the numerical engine and model, moving on to results in Chapter 6.

# CHAPTER FIVE - MODEL CONSTRUCTION

## 5.1 INTRODUCTION TO CHAPTER

Chapter 5 develops the numerical engine for the research based on the @Risk software package discussed in Chapter 3. The risk analysis package requires that each source of uncertainty, or risk, is input as a statistical distribution in spreadsheet format. For example, a company may consider that its population supplied in the year 2015 will have a central estimate of 1 million with a standard deviation of 10,000 following a normal distribution. This would be shown, using the @Risk notation, as: @<<Risk>> NORMAL (1000000, 10000).

The principal purpose of Chapter 5 is to quantify these uncertainties, for the hypothetical case of Company A, and to construct the supply-demand balance model in preparation for a numerical example within Chapter 6. Section 5.7 describes the form of the simulation model, including discussion of model accuracy and of how to test the significance of individual sources of uncertainty.

As a guide to the reader Chapter 5 is structured with a large central core of analysis in Sections 5.3 and 5.4 where uncertainties, firstly on the supply side and secondly the demand side of the equation, are quantified. Uncertainties calculated within Sections 5.3 and 5.4 are summarised in Section 5.6.

### 5.1.1 The Demands and Resources for Company A

Before assigning uncertainties to the supply-demand balance for Company A, it is appropriate to briefly set the background of demands and resources around which uncertainties will be based. These statistics are shown within Table 5.1.

| | **Statistics** | **Remarks** |
|---|---|---|
| Winter population | 1.3 million | |
| Total demand | 362.5 Ml/d | (Average day) |
| Water Resources | | |
| (Groundwater) | 185 Ml/d | 30 separate sources |
| (Direct river) | 171 Ml/d | Supported by river regulation |
| (Impounded) | 55 - 80 Ml/d | Single season reservoir, variable with climate |

*(Table 5.1)*
*General supply-demand statistics for Company A*

## 5.2 ASSIGNING VALUES TO UNCERTAINTIES

Chapter 4 describes the catalogue of uncertainties which might be considered within the supply-demand equation. It also provides guidance on risk assessment, with techniques ranging from those involving substantial data to those requiring pure expert panel judgement. Chapter 5 considers, in the same order, each of the sources of uncertainty identified in Chapter 4 and seeks to assign a quantitative distribution. The data used is anonymous and referred to as assigned to Company A.

### 5.2.1 Direct Techniques

For many of the uncertainties described in Chapter 4 there will be a combination of factual and numerical information on which to base an assessment of future uncertainty. In some cases the data alone may be sufficient to describe the uncertainty, but in others a measure of assumption may be needed. In all cases the analyst is predicting future risk, hence, in the absence of assumption or judgement, is implicitly accepting that the future is a naive extrapolation of the past.

Forecasting techniques, presented on the basis of fitness for purpose, are tabled within Section 4.5.2.

### 5.2.2 Expert Panels

In the real world questions of uncertainty are often dealt with using factors of safety, a pot for luck, a 'preferred solution' and so on. History suggests that these contingencies, in part because they are not well understood, adopt a precautionary principle. Indeed the consequences of being wrong may make such behaviour both understandable and essential. For example the UK Groundwater Forum (1995) noted that:

> *"The precautionary principle is routinely applied due to the large gaps in knowledge, and the lack of robust and standard guidelines for key determinations, such as for reliable yield".*

The need to move away from arbitrary planning allowances is discussed in Chapters 1 and 2, and this research focuses on how to combine measures of uncertainty and risk in a meaningful way. This may, on occasion, be for events which have limited, if any, historic evidence of occurrence. Morgan and Henrion (1990) define analysing such a problem as:

> *"the evaluation, ordering and structuring of incomplete knowledge so as to allow decisions to be made with as complete an understanding as possible of the current state and limitations of knowledge".*

This is the role of the expert panel.

By definition the future is unknowable. Thus, to some extent, the data the analyst has available will be less than perfect. In some cases, where the environment is stable in the short term, such as the number of calories used per person per day, then the past may be a reasonable predictor. Likewise, if the reason for the change is well understood, such as population change, then mathematical models offer a sensible way forward. In these circumstances the uncertainty element within the prediction tends to be described either in terms of historic variability against a model or by scenario analysis in which model parameters are varied on the basis of changes in assumptions. Scenario or "what if ?" analysis requires a measure of judgement or experience and is clearly only of value when carried out by an expert.

In other circumstances there may be a great deal of data available, such as ownership of dishwashers, but where sales are moving quickly. In such circumstances historic extrapolation alone would be inadvisable. Here, the role of the expert becomes more important in terms of attempting to describe alternative future environments, the impact of the environment on the dependent variable, and the degree of likelihood assigned to each scenario.

A similar situation arises where the environment is stable, but where there is very little data to describe the source of uncertainty. An example might involve predicting loss of source water as a result of pollution where there is little or no evidence of historic events. Here, again the role of the expert is critical.

The expert panel, or "Jury of Executive Opinion" (Harvard Business Review, 1986), meets to convert qualitative views into a quantitative prediction which usually includes a measure of uncertainty. Techniques are based either on scenario analysis, described in Chapter 3, or the Delphi method (Dalkey and Helmes, 1963), which involves achieving consensus by convergence of expert opinion. If only one expert is available then the analyst is likely to be confronted with a natural bias which the Delphi technique tends to overcome but which, for a single expert, requires careful handling. Dealing with natural bias is mentioned in Section 5.2.3.

The use of expert panels is not a substitute for data collection. It is, however, an essential supplement in many cases. Equally, the value of expert judgement should not be understated. The Harvard Business Review (1986), list the benefits of an executive jury, *inter alia*, as:-

i) providing quick, cost effective in-house forecasts,

ii) providing a technique where the jury can easily accommodate change if they meet frequently enough,

iii) providing a wide range of experiences to allow changes to be accommodated accurately,

iv) allowing subjectivity to be converted into objective and quantitative distributions.

Many of the assessments within this research have involved the use of an expert panel. This has involved a five person group of:-

i) the Supply Director; responsible for all aspects of water supply, treatment and resource planning,

ii) the Supply Manager; responsible for the operation of all sources and treatment works,

iii) the Resources Manager; responsible for source maintenance, demand forecasting and water resource planning,

iv) the Site Performance Manager; responsible for source integrity, maintenance and outages,

v) the Water Quality Manager; responsible for water quality compliance and the prediction of future water quality.

### 5.2.3 Dealing with Natural Bias

Bias can accrue in circumstances where there is only a single expert; essentially a panel of one.

Quantifying subjective judgement requires consideration of an analyst's own judgement or that of an expert. Much of risk analysis falls into this category. However, this requires that expectations should not be distorted either as a result of bias or poor questioning. Bias might either be the direct result of long term experience, the result of a single experience, or, more likely, the result of an inability to express likelihood of events in a quantitative way.

It is clearly not the job of the analyst to persuade the expert that his view is biased. However, there are a number of well researched protocols for improving the chance of acquiring a reasoned and more balanced response. Spetzler and Staél von Holstein (1975) cited in Morgan and Henrion (1990), offer a number of methods.

It has not been considered necessary to use a procedure for bias within this research. This, of course, assumes that the view of the author, where this prevails, is unbiased. Nevertheless, it is the development of method which is key to this research, rather than a correct numerical outcome.

## 5.3 UNCERTAINTY CALCULATIONS - SUPPLY SIDE

This section considers sources of uncertainty on the supply side of the equation described in Chapter 4 such that they can be described in a quantitative way. A summary of techniques and approaches used is presented in Section 5.6.

### 5.3.1 Loss of Source Yield

Chapter 4 describes loss of source yield within four categories; due to sudden pollution, due to gradual deterioration in water quality, due to clawback by the Environment Agency or due to non-sustainable abstraction. Each of these is considered in turn.

Assessing the risk of sudden pollution requires the expert panel to consider the extent to which sources are vulnerable. Adequacy of aquifer protection will be a key consideration. For Company A the following information is relevant:-

i) there has been a total loss of resource of 7.5 Ml/d spanning 25 years as a result of sudden pollution, an average of 0.3 Ml/d per year, as a result of industrial development,

ii) the company has a nationally recognised aquifer protection policy,

iii) all sewers which cross within 100 metres of groundwater sources are double sleeved and pressure tested,

iv) the company has a sound clean up procedure in the event of spillage

v) the company has a designated officer who ensures the integrity of septic tanks in the vicinity of sources as well as the sufficiency of on-site bunds and oil interceptors.

vi) there are two audits of substantial length, that extend from one of the company's groundwater sites, which are essentially uncontrolled and present a genuine pollution risk. The total volume of water at risk is 9.5 Ml/d. There have been a number of incidents, but non serious, and the risk of loss of each of these two sources; one of 5 Ml/d and the other 4.5 Ml/d, is put at no more than 1 in 50 on an annual basis.

There is very little science that can be applied to these risks, although they do not appear to be substantial. In aggregate, the panel consider the risk to be:-

i) a loss of 0.3 Ml/d each year due to industrial development,

ii) a risk of independent loss of source of 4.5 Ml/d and 5 Ml/d each year with a likelihood of 0.02 (1 year in 50). With time, the risk of source retention will reduce, using the relationship:-

$p(\text{loss of source}) = 1 - (0.98)^n$ where $n$ is the number of years from now

The next area of risk to be considered is that due to gradual loss of source water due to deterioration of water quality. This risk is realised when the cost of treatment exceeds the cost of new development.

In general, a well managed company will monitor trends in water quality and will also have aquifer models which allow for future prediction. Although these models are by no means certain, it is usually the timing of quality exceedance which is suspect, rather than whether the exceedance will actually occur.

The decision for source abandonment on economic grounds is rarely taken in haste and always in consultation with the Drinking Water Inspectorate (DWI), OFWAT and the Environment Agency. Circumstances under which abandonment might be considered are as follows:-

i) where failure of multiple parameters is predicted within a few years of each other. For example, nitrate treatment would require Ion Exchange and Pesticide treatment would require Granular Activated Carbon and, perhaps, Ozone. All of these processes are highly capital intensive and Ion Exchange has very high operating costs,

ii) where a source is at risk of contamination from a single parameter with either improved or highly complex treatment. Examples would include treatment for oocysts, such as Cryptosporidium, which are unaffected by chlorination and require micro-filtration with, in some instances, pre-ozonation.

The question of whether the economics of source abandonment can be justified is outside the scope of this research. However, having concluded in favour of abandonment, the uncertainty will be in the timing of the abandonment. This is shown in Figure 5.1.

In Figure 5.1, scenarios 1 and 3 assume different aquifer parameters and scenario 2 assumes a change in agricultural practice. Each scenario would be assigned a likelihood, probably based on expert judgement surrounding the assumptions.

For Company A likelihoods are assigned as shown in Table 5.2.

| Source | Output | Likelihood of Loss in Year (time slice) | | | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2010 | 2015 |
| A | 5 Ml/d | 0.10 | 0.80 | 0.10 | 0.00 |
| B | 10 Ml/d | 0.00 | 0.50 | 0.50 | 0.00 |
| C | 3 Ml/d | 0.30 | 0.10 | 0.10 | 0.50 |

*(Table 5.2)*
*Table of source loss likelihoods in each of four time periods for three groundwater sources*

As each year goes by, then the likelihood of source loss increases until source loss is certain under the summation of all scenarios. This summation is shown in Table 5.3.

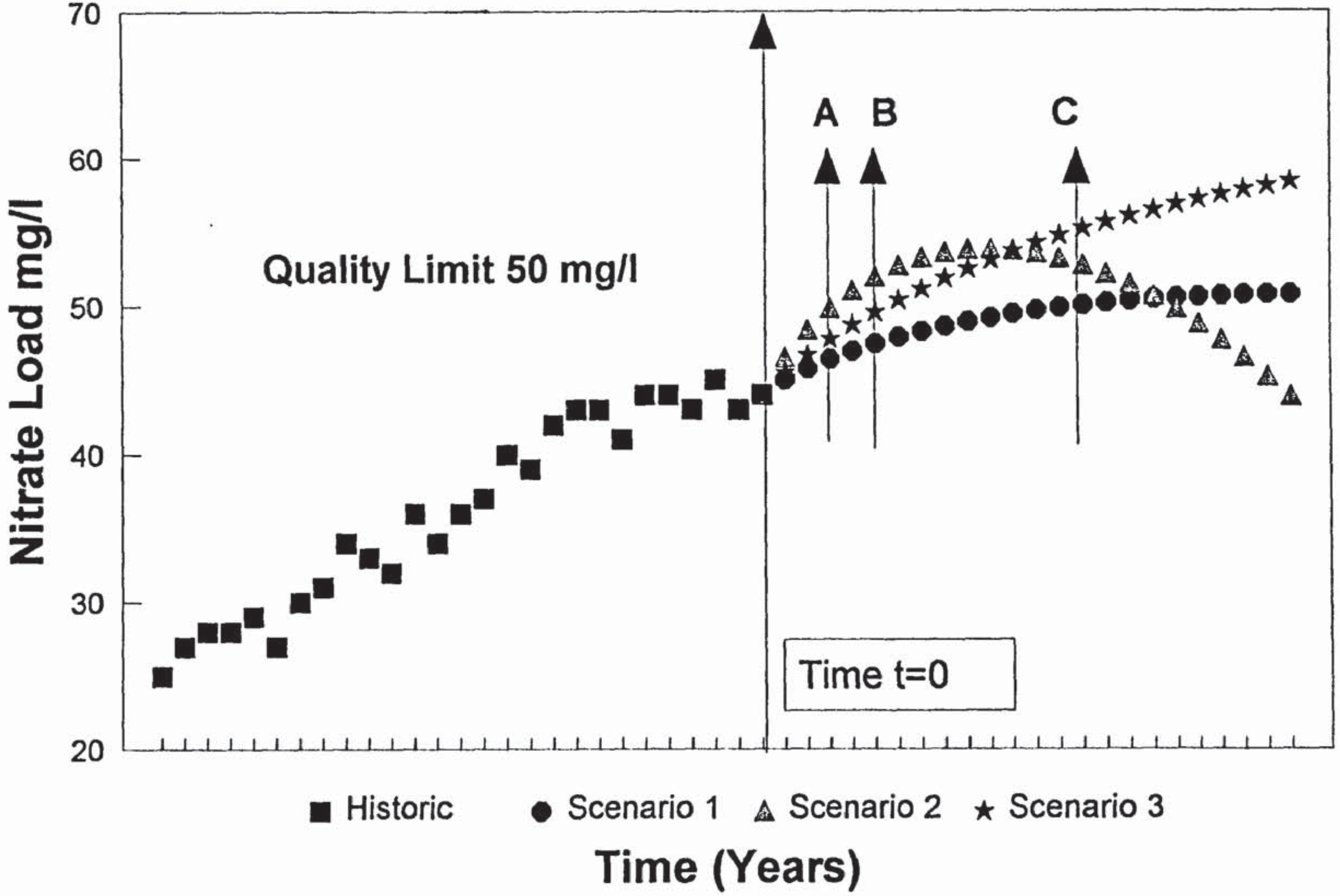
| Source | Output | Likelihood of Source Loss up to and Including Year | | | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2010 | 2015 |
| A | 5 Ml/d | 0.10 | 0.90 | 1.00 | 1.00 |
| B | 10 Ml/d | 0.00 | 0.50 | 1.00 | 1.00 |
| C | 3 Ml/d | 0.30 | 0.40 | 0.50 | 1.00 |

*(Table 5.3)*
*Table of likelihood of source loss up to and including a particular year*

Given the cumulative risk of loss in a particular year, then the volume of water at risk can be represented as a binomial with a single sample, i.e. either the source is lost or it is not. For example, the volume of water at risk in year 2005 within Table 5.3 is given by:-

Volume at risk =

5 Ml/d x (Binomial (1, 0.9))
+ 10 Ml/d x (Binomial (1, 0.5))
+ 3 Ml/d x (Binomial (1, 0.4))



*(Figure 5.1)*

*Uncertainty of source abandonment timing due to nitrate exceedence*

Significant correspondence on clawback exists between the EA and Company A such that loss of yield due to clawback is known with a high degree of certainty to be 2 Ml/d in 2005 and 4 Ml/d in 2010. Loss of yield due to sustainability is taken to be zero over the period to 2020.

## 5.3.2 Planned Outages

For short term prediction it may be sufficient to assume that a company's planned outage programme occurs in practice and that predicting at least two years ahead should be reasonably accurate. As the time horizon increases, influences on planned outages change. The emphasis on investment requiring source outage is a function of a company's policy towards plant maintenance and will change over time.

There are a number of individual components involved in predicting future plant outage:-

i) the extent to which a company's planned programme is adhered to,

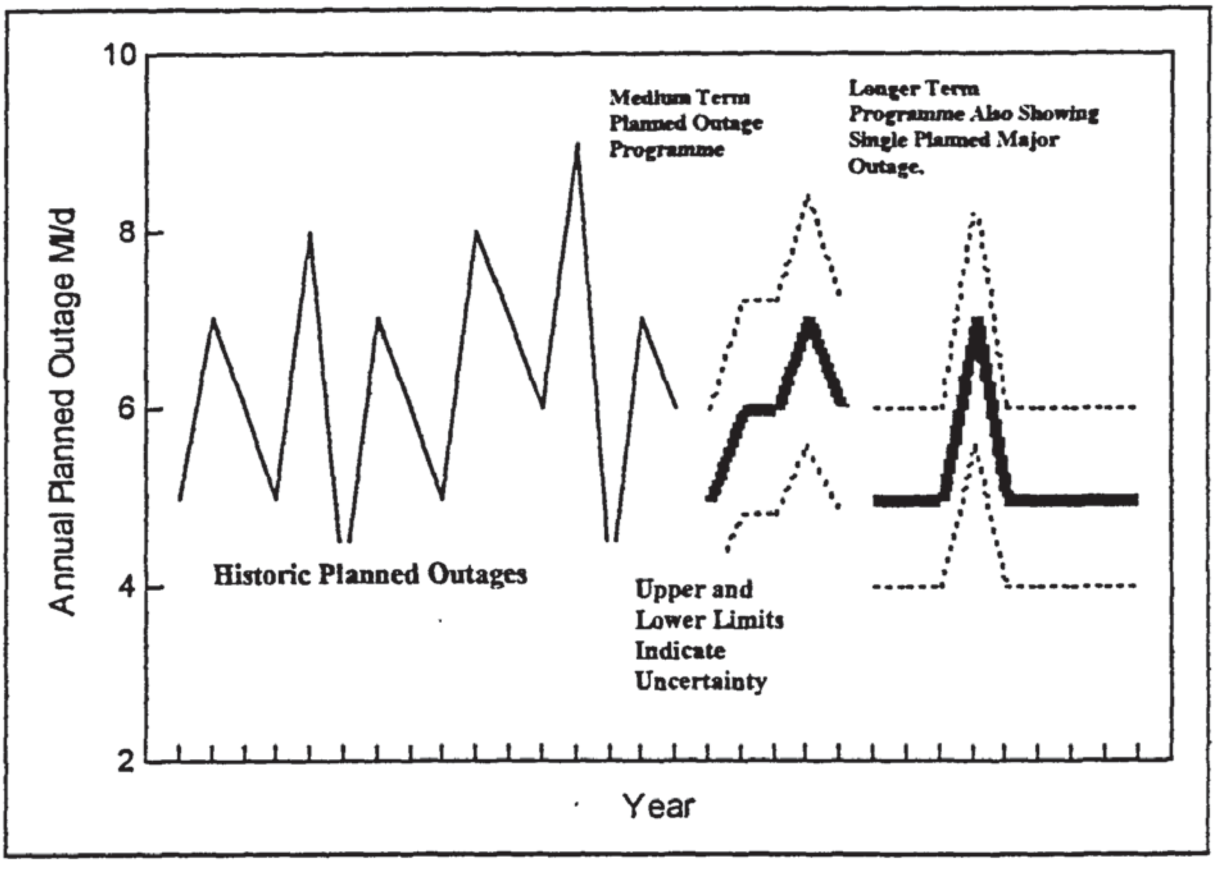
ii) the number of sources which will need to be taken out of supply for major refurbishment as part of a company's medium term investment programme,

iii) the number of sources to be taken out of supply because of potential future long term exceedance of water quality parameters requiring the installation of new processes (assuming continued use of the source remains economic).

The relative importance of the influences varies with time as shown in Table 5.4 and Figure 5.2.

| **Years From Now** | **Influences on Planned Outage Certainty** | | | |
|---|---|---|---|---|
| | **Adhering to Known Programmes** | **Part of Medium Term Programme** | **Long Term Water Quality** | **Unknown Influences** |
| 1 | High | High | Low | Low |
| 2 | Medium | High | Low | Low |
| 5 | Low | Medium | Low | Medium |
| 25 | None | Low | High | High |

*(Table 5.4)*
*Influences on planned outage certainty over time*



*(Figure 5.2)*

*Influences on planned outage uncertainty with time*

Before proceeding further with the calculation of planned outage, it is important to make the distinction between events which are retrievable and those which are not. This distinction is discussed in 4.3.6., noting that outages become irrelevant over long time periods providing that the source has surplus capacity to recover the short term loss of resource.

It is also assumed within this analysis that planned outages do not feature as part of a peak period calculation since a well managed company would not design a works programme to extend into a critical period. In this respect, any planned event which extends into a critical period due to error or extended timescales is designated as an unplanned outage.

A review of historical planned outages for Company A provides a distribution for average day source loss as shown in Table 5.5.

| Year | Planned Outage Ml/d (average) | Year | Planned Outage Ml/d (average) |
|---|---|---|---|
| 1988 | 6.10 | 1993 | 4.10 |
| 1989 | 4.20 | 1994 | 7.20 |
| 1990 | 4.50 | 1995 | 4.80 |
| 1991 | 6.30 | 1996 | 8.3 (5.8) |
| 1992 | 2.90 | 1997 | 9.0 (6.6) |

*(Table 5.5)*
*Average day loss of source water due to planned outages*
*(figures in brackets exclude unusual events)*

A visual examination of Table 5.5 suggests the absence of trend, although 1996 and 1997 have seen significant activity on water quality compliance which is unlikely to be repeated. Describing a more random sequence requires that unusual events are removed. The figure for 1996 is thus reduced to 5.8 Ml/d and the figure for 1997 to 6.6 Ml/d to give a more typical base for planned outages.

Over the medium term, a review of the Capital Programme for Company A identifies planned outages for the next five years as Table 5.6.

| Year | Planned Outage Ml/d (average day) |
|---|---|
| 1999/00 | 5.70 |
| 2000/01 | 9.10 |
| 2001/02 | 4.30 |
| 2002/03 | 7.50 |
| 2003/04 | 4.40 |

*(Table 5.6)*
*Planned outages for Company A over the medium term horizon*

Internal discussion with Company A's engineers suggests that each outage is certain in that it needs to be done. Timescales, however, can never be quite so certain, although, for financial planning, a lag in investment can invariably be offset by bringing forward alternative projects. Assuming that Company A's Programme can be managed effectively, then annual outages will fall into a range based on possible movements between each year. Again, internal discussion with the expert panel suggests that a 25% annual movement of the original Programme is the largest to be expected.

The range of planned outages is, therefore, calculated as in Table 5.7.

| Year | (A) Maximum Brought Forward Ml/d | (B) To be Done in Year Ml/d | (C) Maximum Carry Forward Ml/d | (D) Range Ml/d |
|---|---|---|---|---|
| 1998/99 | - | 6.50 | 1.60 | - |
| 1999/00 | 1.60 | 5.70 | 1.90 | 3.8 - 7.3 |
| 2000/01 | 1.90 | 9.10 | 2.30 | 6.8 - 11.0 |
| 2001/02 | 2.30 | 4.30 | 1.10 | 3.2 - 6.6 |
| 2002/03 | 1.10 | 7.50 | 1.90 | 5.6 - 8.6 |
| 2003/04 | 1.90 | 4.40 | 1.10 | 3.3 - 6.3 |

*(Table 5.7)*
*Range of planned outage each year over the medium term*

Statistically, the range of values in column (D) of Table 5.7 will be taken to represent the upper and lower limits of a triangular distribution.

Looking to the long term values for planned outages, then the following points are notable:-

i) Company A is predicting a major new treatment works in 2010 which will involve a nine month outage of a 6 Ml/d source; an average outage of 4.5 Ml/d,

ii) Company A has an existing policy of seeking to match asset investment to current cost depreciation, i.e. such that asset condition and serviceability is sustainable over the longer term. As such, it is reasonable to assume that the baseload, and distribution, of normalised historic outages will continue into the longer term,

iii) Company A considers that the likelihood of unknown events in the longer term is not sufficient to justify extending the upper and lower limits of uncertainty which surround the baseload of planned outages,

iv) The same principle of year on year movement discussed under the medium term horizon will continue into the longer term.

Using standard statistical techniques the best fit statistical distribution for the 10 data points in Table 5.5, adjusted for 1996 and 1997, is a triangular distribution with parameters 2.51, 4.43, 9.39; representing the mean and upper/lower limits. This distribution will be taken to represent the long term trend for planned outages.

### 5.3.3 Unplanned Outages

Unplanned outages are subject to a higher degree of uncertainty than planned outages, both in cause and effect. This degree of uncertainty requires that any attempt at prediction should first involve causal analysis of the components of unplanned outage.

It is not the prime purpose of this research to carry out exhaustive data analysis. However, to allow demonstration of approach and reach a meaningful solution to the supply-demand balance, it has been necessary to compile a database of unplanned outage events for Company A. A twelve month extract from the database is presented as Appendix II to this research.

The database notes the magnitude and duration of each event and considers whether mitigation, i.e. whether the source loss is recoverable, is applicable. The outages are also grouped by cause code.

This chapter considers assigning values to uncertainties for average day rather than peak demand. In practice, it is necessary to consider and satisfy all critical periods.

However, for the average day analysis, distributions for each of the cause codes described in Appendix II can be derived with results as in Table 5.8. Note that "N" within Table 5.8 refers to a normal distribution.

| Cause Code | Description | Distribution |
|---|---|---|
| ECO | Tariff management | N (0.55, 0.15) |
| UME | Electrical/mechanical failure | N (0.13, 0.02) |
| UBL | Due to blended sources | N (0.02, 0.005) |
| UPO | Pollution | Negligible |
| USP | Water Quality less than 1 day | Negligible |
| UWQ | Water Quality more than 1 day | N (1.42, 0.65) |
| UPF | Power failure | N (0.20, 0.04) |

*(Table 5.8)*
*Historic distributions for unplanned outage by cause code*

One of the cause codes, 'ECO', described as an optional outage, is discussed in Section 4.9 in terms of whether a regulator would consider such an outage to be legitimate for water resource planning purposes. It is clearly up to individual companies to argue their own case, but for the analysis of Company A it will be considered legitimate.

Making future prediction of unplanned outages based on a simple view of the past can be misleading. However, taking a causal view, policy observations derived by expert opinions are applied to each cause as follows:-

i) tariff management is a function of source optimisation skill and the degree of resource surplus. Resource surplus, or available headroom, should be stable over the long term, although optimisation skills should improve. The number of optional source outages (code 'ECO') for Company A has increased significantly in recent years, although this shows signs of slowing down. The distribution is assumed to increase to 150% of its current level by 2002 and to remain stable thereafter,

ii) unplanned outages due to electrical/mechanical failure are a function of maintenance and replacement policy. This policy is expected to remain unchanged,

iii) the policy of blending is expected to be eliminated in the longer term. By 2020 all Company A sources are expected to be treated. The distribution for UBL is, therefore, expected to decrease, on a straight-line basis, to zero by 2020,

iv) there is no apparent evidence or view which suggests how unplanned pollution incidents may change in the future. The distribution for UPO will be assumed unchanged. Likewise, for both water quality spikes and short term water quality outages.

In the light of the above commentary, Table 5.8 can be revised to offer predictive distributions by cause code. The results of the revision are shown in Table 5.9.

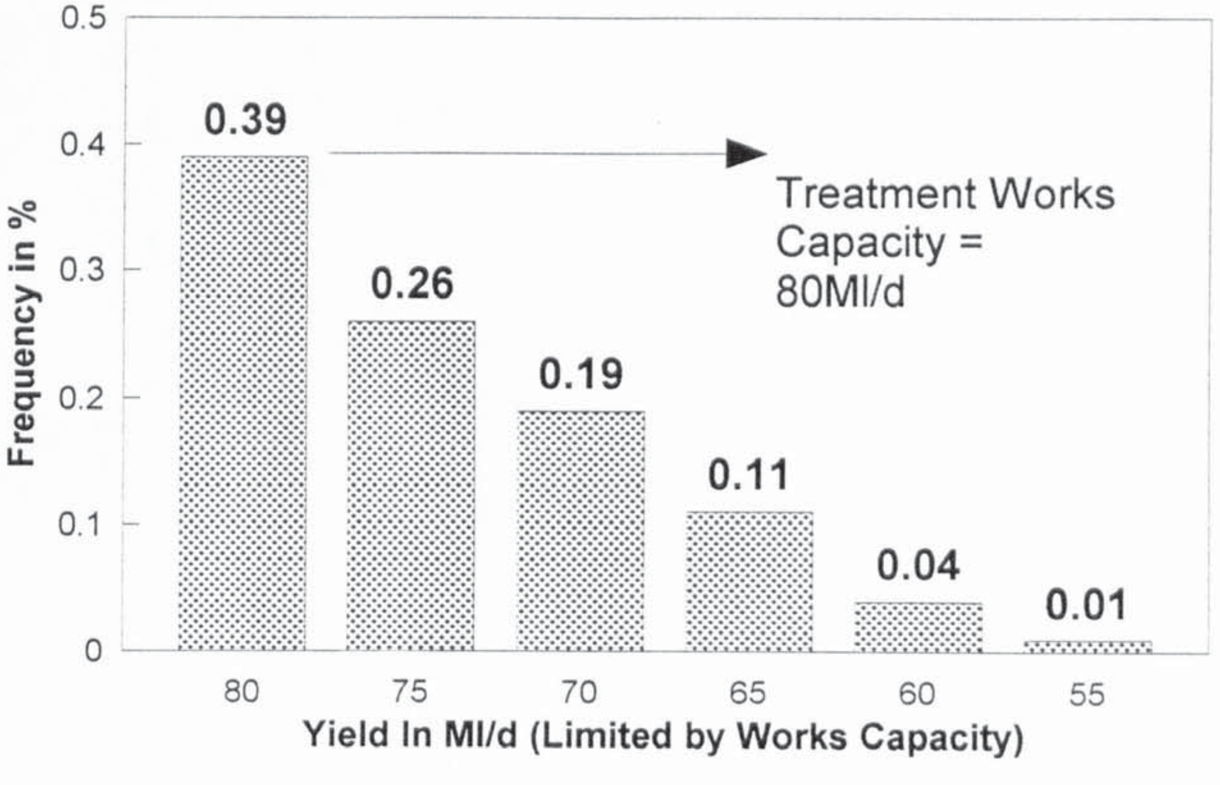
| Code | Description | Distribution/Year |
|---|---|---|
| ECO | Tariff management | N (0.87, 0.22) by 2002 |
| UME | Electrical/mechanical failure | N (0.13, 0.02) |
| UBL | Due to blended sources | Zero by 2020 |
| UPO | Pollution | Negligible |
| USP | Water Quality less than 1 day | Negligible |
| UWQ | Water Quality more than 1 day | N (1.42, 0.65) |
| UPF | Power failure | N (0.20, 0.04) |

*(Table 5.9)*
*Predictive distributions for unplanned outage by cause code*

### 5.3.4 Due to Climatic Variation on Average Resource

Company A has three principle sources of water: groundwater, direct river abstraction and impounded abstraction. The uncertainty of groundwater is discussed in 4.3.3.1 and notes the high degree of resilience of sandstone aquifers to changes in climate. Furthermore, the direct river abstraction is supported by various river regulation options which ensure minimal, if any, variation in yield due to variation in climate.

Variation in climate, however, has a significant impact on the yield of the impounded reservoir system. The reservoir for Company A is relatively small for its catchment and is susceptible to rapid drawdown and even faster refilling. In dry years the yield of the reservoir is low compared to average years, reaching a historic minimum of 54.5 Ml/d.



*(Figure 5.3)*
*Historically observed yield of Company A*
*Impounding reservoir under Standard Operating Rules*

For all practical purposes the yield of the impounding reservoir is limited by the size of the treatment works, currently 80 Ml/d. A review of the potential yield of the reservoir, under standard operating rules, for a 25 year period of record, suggests a distribution shown in Figure 5.3.

For analytical use, the distribution will remain discrete at @<<Risk>>Discrete(80, 75, 70, 65, 60, 55, .39, .36, .19, .11, .04, .01), noting, however, that the distribution is weather related and that dependency between demand and yield is likely. Section 5.4.8 considers this dependency further.

### 5.3.5 Due to Climatic Change on Average Resource

Section 4.3 describes the resilience of groundwater sources in Triassic sandstones to the effects of variation in climate. For the purpose of this research the resilience of the aquifers in Company A's supply area will also be assumed to apply to climate change and no allowance will be made for uncertainty. Furthermore, any attempt to describe the impact of climate change on average groundwater yield is almost certain to overlap with the Environment Agency's requirement for clawback. Since, clearly, it is the reduced groundwater availability which is, of itself, driving the need for clawback.

In terms of surface water yield, Company A has a single impounded reservoir system which, when applying a level of service of "no historic restrictions" gives a base yield of 54.5 Ml/d. Applying the four different climate change models to the catchment then gives yield results as shown in Table 5.10.

| Scenario/National Model Applied | Yield (Ml/d) | % Change from Base Yield |
|---|---|---|
| Base Yield | 54 | - |
| HADCM1 | 55 | + 1 |
| GG1m | 63 | + 17 |
| GS1m | 57 | + 5 |
| GS1t | 53 | - 3 |

*(Table 5.10)*
*Yield of impounded reservoir system for Company A;*
*with and without climate change models applied*

Table 5.10 suggests, therefcre, that three of the four climate change models predict an increase in yield for the resource system.

Given that each of the climate change models listed in Table 5.10 is equally likely, then yield will depend on the model selected. The impact of climate change on yield for various likelihoods has been considered by reference to a number of assumptions:-

i) the statistical distribution of yield changes due to climate change. Since the distribution is discrete, it is sufficient to vary the likelihoods for each point yield,

ii) that the GG1M model, which suggests that climate will become much wetter, is likely to impact more on the higher point yields than the lower ones,

iii) that the GS1T model, which suggests that climate will become drier, is likely to impact more on the lower point yields than the higher ones,

iv) the maximum point yield of 80 Ml/d is unchanged, since it represents the limit of treatment capacity.

The impact of the different climate change models on the distribution of yields shown in Figure 5.3 is shown in Table 5.11. Each of these models is assumed to be equally likely and will be considered as such in the spreadsheet model.

| **Model** | **Point Yield (Ml/d) and Likelihood** | | | | | | **Remarks** |
|---|---|---|---|---|---|---|---|
| | **55** | **60** | **65** | **70** | **75** | **80** | |
| **Base** | **0.01** | **0.04** | **0.11** | **0.19** | **0.26** | **0.39** | |
| HADCIM1 | 0.00 | 0.04 | 0.11 | 0.19 | 0.26 | 0.39 | + 1% on base yield |
| GG1M | 0.00 | 0.00 | 0.04 | 0.21 | 0.29 | 0.46 | + 17% on base yield |
| GS1M | 0.00 | 0.02 | 0.10 | 0.20 | 0.27 | 0.41 | + 5% on base yield |
| GS1T | 0.02 | 0.06 | 0.11 | 0.19 | 0.25 | 0.37 | - 3% on base yield |

*(Table 5.11)*
*Assumed distribution of impounding reservoir yields using different climate change models*

Company A also has a direct river intake system where reliability is assured using various supported systems, including direct groundwater discharge. This river resource has a yield of 171 Ml/d, limited by abstraction licence. Materially, uncertainty is not considered to apply to this resource.

### 5.3.6 Due to Source Meter Error

Company A has carried out in-situ testing of a sample of its source meters to give an indication of each meters ability to provide an accurate measurement of water passing through it.

Hypothetical results are shown in table 5.12.

| Source | Flow Difference (-ve means that source meter is under-registering) |
|---|---|
| A | - 1.6% |
| B | - 12.8% |
| C | 4.8% |
| D | 0.5% |
| E | - 5.4% |
| F | - 16.7% |
| G | - 10.0 |
| H | - 4.0% |
| J | 0.3% |
| K | - 8.6% |
| L | - 3.0% |

*(Table 5.12)*
*Source meter error when compared to an ultrasonic calibration meter*

In Table 5.12, eight of the 11 readings demonstrate an under-registration. If this is representative, then, on average, Company A is under-recording the volume of water going into supply which means that one or more of the demand components is higher than expected. This result will clearly also affect the forecasting of these components.

From Table 5.12 it can be shown that the distribution of the mean value of the source errors is given, via the central limit theorem (Freud and Walpole, 1980) by N (- 5.9%, 1.8%).

Making due allowance for source metering error requires assumptions to be made about how the other demand components are affected. Section 5.4.5 considers demand side meter error and, hence, how the relative impact on measured use can be inferred. Overall adjustment of components will follow the Maximum Likelihood Estimation (MLE) approach discussed in Section 2.5.1.2.

For each MLE calculation at the base year of a forecast, a sample will be taken from the source error distribution which will be applied to the normalised distribution input and either added or subtracted to the reconciliation item. This aspect is discussed in more detail in 5.7.7.

### 5.3.7 Uncertainty of Yield - Groundwater

As discussed in Chapter 4, uncertainty of groundwater yield can fall into a number of distinct areas:-

i) uncertainty due to climate change,

ii) uncertainty due to assessment method,

iii) uncertainty due to sustainability of resource and aquifer mining,

iv) uncertainty due to clawback of resource by the Environment Agency.

Uncertainty due to climate change is discussed in Section 5.3.5 and issues of sustainability and clawback are considered in Section 5.3.1. This section considers only the uncertainty within the assessment method.

The only practical assessment method in common use is that developed by UKWIR ($1995_c$). Regrettably, however, although the method is known to be subject to uncertainty, the UKWIR study gives no guidance on accuracy. There is an anecdotal view among Resource Managers, however, that the technique is perhaps accurate to within +/- 10%. Clearly, this is highly subjective and further research is required. A triangular distribution, defined simply by reference to a minimum value, an expected value and a maximum value, will be assigned to the uncertainty.

### 5.3.8 Uncertainty of Surface Water Yield due to Data Sufficiency

In the absence of climate uncertainty (considered in Section 5.3.4 and 5.3.5) there are still reasons why the calculation of surface water yield might be uncertain. These are described in Section 4.3.3.2.

Most notable, perhaps, of the causes of yield uncertainty is the accuracy and sufficiency of the length of river flow record upon which to model behaviour. Clearly, a 100 year record which covers all modern day droughts and floods will be more valuable than a much shorter period of record, assuming all other things equal.

Section 4.3.3.2 proposes that a data set is likely to be sufficient for analysis if it contains the 1934, 1976, 1995 and 1996 flow sequences, considered to be the worst four droughts this century. For Company A the impounded reservoir system has a flow record spanning 1920 to 1998 and is considered sufficient. However, whether a drought of sufficient severity occurred this century to make behavioural analysis itself meaningful is beyond the scope of this research.

The reliable yield of the reservoir system for Company A is considered in Sections 5.3.4 and 5.3.5.

## 5.4 UNCERTAINTY CALCULATIONS - DEMAND SIDE

This section considers sources of uncertainty on the demand side of the equation. As with supply side uncertainties a summary of techniques and approaches is presented in Section 5.6.

### 5.4.1 Normalising Baseline Demand

Section 5.5.4 describes the difficulty the analyst faces if an outturn demand or outturn assumption varies from that predicted. This might be classed as one or more of the following:-

i) the variation is within an acceptable range of variation and the starting year for the forecast need not be reconsidered,
ii) the variation is as expected, but the analyst knows that assumptions have changed,
iii) the variation is not as expected, but assumptions have not changed,
iv) the variation is not as expected and assumptions have changed.

For Company A in 1998 the outturn demand was lower than expected, but the severity of climate was exceptionally mild. In a typical year a higher demand would have expected.

The first stage of normalising baseline demand is to estimate what might have been expected in a more typical climate. Unfortunately, however, the UKWIR best practice in demand forecasting (UKWIR, $1997_c$) offers little guidance on how to do so.

One very simple approach, although fraught with pitfalls, is to consider the main components of demand in terms of their relationship with climate and to trend these relationships historically. Consider, for example, that only domestic demand is climate sensitive and that by removing non-domestic demand from historic data reveals a historic trend as shown in Figure 5.4 for Company A.

Figure 5.4 shows that a simple trend line drawn through the data points, ignoring the effects of the 1975/6 drought, might be used to suggest a more normal demand for 1998. This approach is workable, but has a number of significant dangers as follows:-

i) that the cause of the variation in outturn domestic demand is not due to climate (for example, a downturn in demand might be expected if a company offers free water meters),

ii) that there is insufficient data to get a reasonable spread of climates upon which to base a meaningful central estimate,

iii) the effects of trend can easily distort the measurement of climatic variation. It is clear, for example, that the main component of domestic demand which is climate sensitive is garden watering. This is the fastest growing element of domestic demand and there is a danger that genuinely high domestic demand can be wrongly assumed to be the result of abnormally severe climate,

iv) the data ignores climatic persistence and climate change.

More rigorous approaches to normalisation would involve either the separation of domestic demand into its more climatically sensitive components or a more scientific look at the climate itself. This is discussed in Chapter 2.

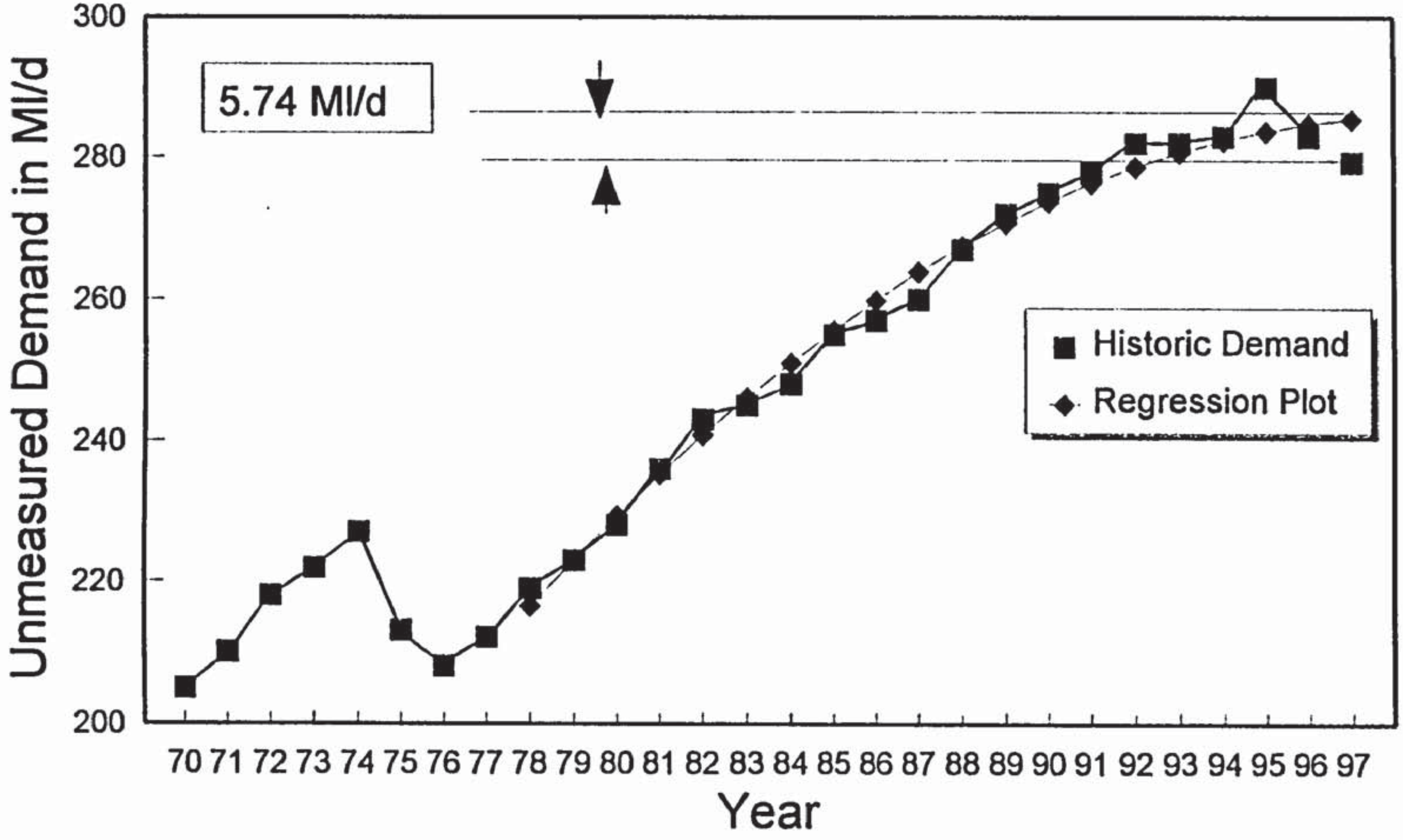
A review of the dangers of using the simplified approach to normalisation, in the case of Company A, suggests that these dangers may not be material, because:-

i) Company A does not have a free meter programme,

ii) the transition from unmeasured to measured domestic use has been slow and gradual,

iii) the most recent years on record have seen a widespread of climates.

Given these mitigations, but still noting that the situation is far from perfect, then the normalised average demand for Company A is taken directly from the regression line in Figure 5.4 as equivalent to 5.74 Ml/d greater than the outturn demand. 5.74 Ml/d is equivalent to the difference between the projected demand for 1997 based on historic projection and the outturn



(Figure 5.4)
*A presentation showing the effect of annual variation in domestic demand - assumed to be due to climate*

demand in what turned out to be a cooler than expected year. This figure is taken forward to the spreadsheet in Section 5.7.7.

### 5.4.2 Uncertainty in the Baseline Demand Components

Section 4.5.3 describes the need for an initial water balance given that the addition of estimated and measured demand components rarely, if ever, equates to the volume of water put into supply. UKWIR ($1997_c$) recommend that this uncertainty is addressed using the method of maximum likelihood (MLE). This approach is described in Section 2.5.1.2.

In the case of Company A a two-stage MLE is necessary because of the need to normalise outturn demand in the base year, for both untypical demand and source meter error, as a springboard for future forecasts.

The first stage MLE distributes the difference between the individually summated components of demand and the total water into supply, referred to as the reconciliation item, in proportion to component uncertainties. An example calculation is shown in Table 5.13. The reconciliation item to be distributed is 18.22 Ml/d; i.e. the individual components of calculated demand are less than the distribution input figure by 18.22 Ml/d. The reconciliation item in the example is a combination of the sum of the individual components and the bias of source meter of - 5.9% (under-registration), derived within Section 5.3.6. The under-registration is equivalent to 22.54 Ml/d, with the unbiased reconciiation item calculated to be -4.32 Ml/d. Within the simulation programme the source meter error distribution will be re-sampled at each iteration, effectively changing the baseline positions at each iteration.

The key assumptions within Table 5.13 are that unmeasured use and distribution losses are the most uncertain components. Within unmeasured use itself, garden watering is considered to be least certain, in particular because of the difficulty within behaviour surveys of obtaining a true response.

| Demand Component | Estimate Ml/d for 1998 | 95% Variation | Range | % of Total | Adjust | Revised Estimate |
|---|---|---|---|---|---|---|
| Measured Household | 6.02 | ± 0% | 0.00 | 0.00 | 0.00 | 6.02 |
| Measured Non-Household | 72.82 | ± 0% | 0.00 | 0.00 | 0.00 | 72.82 |
| Unmeasured Non-Household | 11.30 | ±10% | 1.30 | 3.04 | 0.55 | 11.85 |
| **Unmeasured Household** | - | - | - | - | - | - |
| Washing Machine | 26.63 | ± 5% | 1.33 | 3.58 | 0.65 | 27.28 |
| Dishwasher | 3.93 | ± 5% | 0.20 | 0.53 | 0.10 | 4.03 |
| Manual Dishwashing | 10.35 | ± 5% | 0.52 | 1.39 | 0.25 | 10.60 |
| Hosepipe | 3.06 | ± 50% | 1.53 | 4.11 | 0.75 | 3.81 |
| Sprinkler | 1.09 | ± 50% | 0.55 | 1.47 | 0.27 | 1.36 |
| Car Washing | 3.07 | ± 30% | 0.92 | 2.48 | 0.45 | 3.52 |
| Bath | 39.29 | ± 5% | 1.96 | 5.28 | 0.96 | 40.25 |
| Shower | 16.93 | ± 5% | 0.85 | 2.28 | 0.41 | 17.34 |
| Power Shower | 4.35 | ± 5% | 0.22 | 0.58 | 0.11 | 4.46 |
| WC - High Volume | 31.81 | ± 5% | 1.59 | 4.28 | 0.78 | 35.29 |
| WC - Dual Flush | 7.07 | ± 5% | 0.35 | 0.95 | 0.17 | 7.24 |
| Other | 44.18 | ± 15% | 6.63 | 17.82 | 3.25 | 47.43 |
| Other - Unmeasured Components | 6.10 | ± 25% | 1.53 | 4.10 | 0.75 | 6.85 |
| Distribution Losses | 71.59 | ± 25% | 17.90 | 48.12 | 8.77 | 80.36 |
| Distribution Input | 377.81 |  | 0.00 | 0.00 | 0.00 | 377.81 |
| Total of Components | 359.59 |  | 37.19 | 100.00 | 18.22 |  |
| Reconciliation Item | 18.22 |  |  |  |  |  |

*(Table 5.13)*
*Maximum Likelihood Estimation : Stage I - Baseline Uncertainty*

Stage 2 of the reconciliation by MLE distributes the difference between the outturn demand and the normalised demand assessed in Section 5.4.1 to those components considered to be climatically sensitive, in particular garden use. Table 5.14 shows the result:-

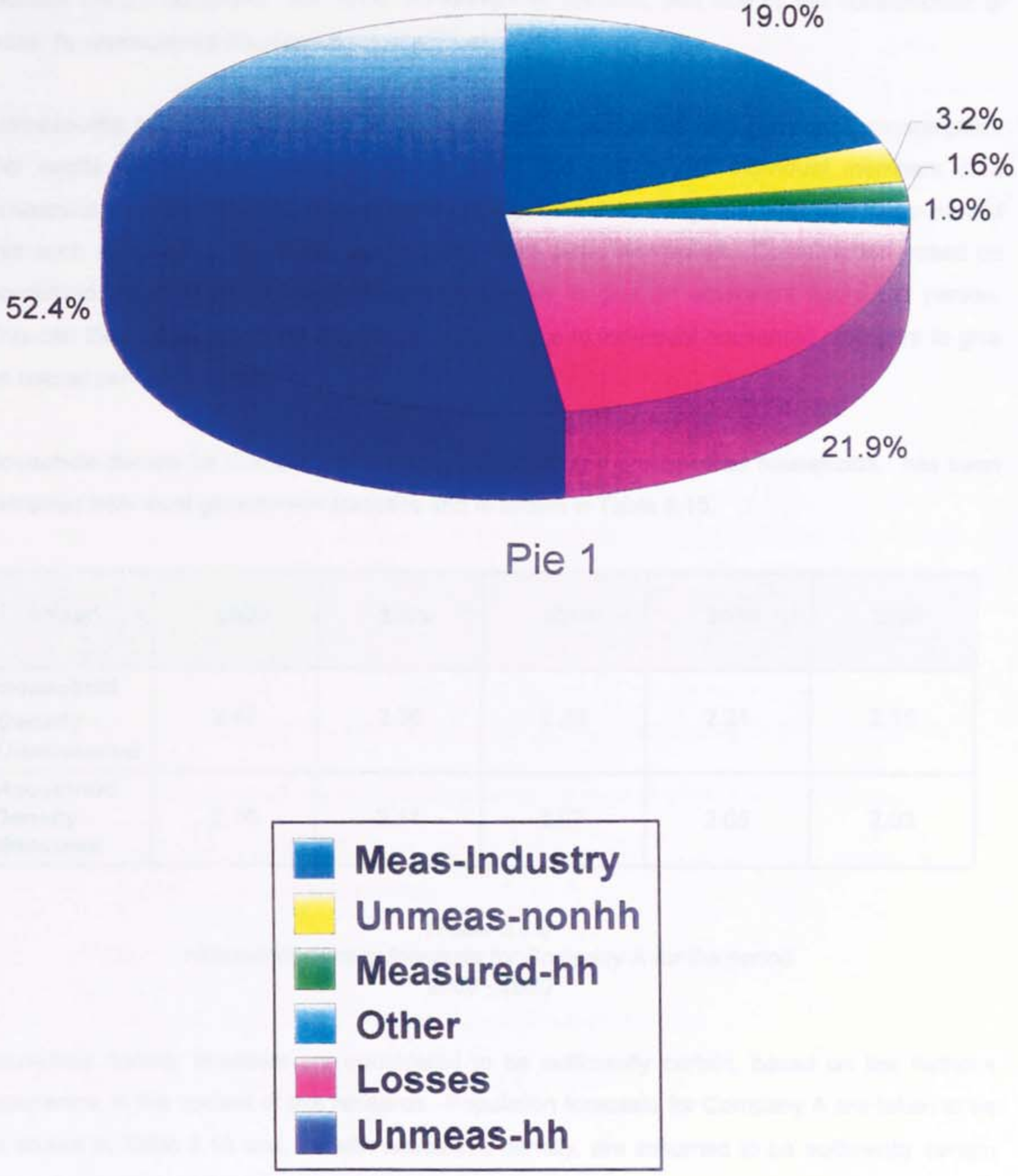
| Demand Component | Estimate Ml/d for 1998 | 95% Variation | Range | % of Total | Adjust | Revised Estimate |
|---|---|---|---|---|---|---|
| Measured Household | 6.02 | ± 0% | 0.00 | 0.00 | 0.00 | 6.02 |
| Measured Non-Household | 72.82 | ± 0% | 0.00 | 0.00 | 0.00 | 72.82 |
| Unmeasured Non-Household | 11.85 | ± 0% | 0.00 | 0.00 | 0.00 | 11.85 |
| **Unmeasured Household** | - | - | - | - | - | - |
| Washing Machine | 27.28 | ± 0% | 0.00 | 0.00 | 0.00 | 27.28 |
| Dishwasher | 4.03 | ± 0% | 0.00 | 0.00 | 0.00 | 4.03 |
| Manual Dishwashing | 10.60 | ± 0% | 0.00 | 0.00 | 0.00 | 10.60 |
| Hosepipe | 3.81 | ± 100% | 3.81 | 18.45 | 1.06 | 4.87 |
| Sprinkler | 1.36 | ± 100% | 1.36 | 6.57 | 0.38 | 1.73 |
| Car Washing | 3.52 | ± 25% | 0.88 | 4.26 | 0.24 | 3.77 |
| Bath | 40.25 | ± 5% | 2.01 | 9.75 | 0.56 | 40.81 |
| Shower | 17.34 | ± 10% | 1.73 | 8.40 | 0.48 | 17.83 |
| Power Shower | 4.46 | ± 10% | 0.45 | 2.16 | 0.12 | 4.58 |
| WC - High Volume | 32.59 | ± 0% | 0.00 | 0.00 | 0.00 | 32.59 |
| WC - Dual Flush | 7.24 | ± 0% | 0.00 | 0.00 | 0.00 | 7.24 |
| Other - Unmeasured Components | 47.43 | ± 5% | 2.37 | 11.49 | 0.66 | 48.09 |
| Other | 6.85 | 0% | 0.00 | 0.00 | 0.00 | 6.85 |
| Distribution Losses | 80.36 | ± 10% | 8.04 | 38.92 | 2.23 | 82.59 |
| Distribution Input | 377.81 | 0% | 0.00 | 0.00 | 0.00 | 383.55 |
| Reconciliation Item | 5.74 |  | 20.65 | 100.00 | 5.74 |  |
| Normalised Distribution | 383.55 |  |  |  |  |  |

*(Table 5.14)*
*Maximum Likelihood Estimation : Stage II - Normalisation*

### 5.4.3 Demand Forecast Components

This section considers one of the major sources of uncertainty within the supply-demand equation, that resulting from the forecasting of future demand.

The section is divided into six sub-sections, each of which deals with a sub-component of demand. The relative size of these components is shown in Figure 5.5.



*(Figure 5.5)*
*Pie chart showing major components of demand for Company A*
*(Nonhh = non-household, hh = household)*

### 5.4.3.1 Unmeasured Household Demand

Section 5.4.3.1 considers the major component of demand; that due to the consumption of water by unmeasured households.

Unmeasured household consumption is the product of population and per capita consumption. Per capita consumption is further broken down into that due to individual members of a household such as toilet use, bathing and other personal washing, and that due to household use such as washing machines, car washing, hose pipes and so on. Consumption based on household use is then divided by household density to give an equivalent figure per person. This can then be added to the per capita which is due to individual household members to give an overall per capita figure.

Household density for Company A, for both measured and unmeasured households, has been extracted from local government statistics and is shown in Table 5.15.

| **Year** | **2000** | **2005** | **2010** | **2015** | **2020** |
|---|---|---|---|---|---|
| **Household Density - Unmeasured** | 2.47 | 2.36 | 2.28 | 2.21 | 2.15 |
| **Household Density - Measured** | 2.16 | 2.11 | 2.07 | 2.05 | 2.03 |

*(Table 5.15)*
*Household density forecasts for Company A for the period 2000 - 2020*

Household density forecasts are considered to be sufficiently certain, based on the Author's experience, in the context of this research. Population forecasts for Company A are taken to be as shown in Table 5.16 and, as with household density, are assumed to be sufficiently certain that a distribution around the central estimate is not required.

| Year | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| **Unmeasured Population 000's** | 1230 | 1218 | 1200 | 1190 | 1189 |
| **Measured Population 000's** | 59 | 74 | 94 | 105 | 116 |
| **Total Population 000's** | 1289 | 1292 | 1294 | 1295 | 1295 |

*(Table 5.16)*
*Measured and unmeasured domestic population forecasts for Company A for the period 2000 - 2020*

The methodology for predicting unmeasured household demand for Company A is based on UKWIR ($1997_a$) and is shown within Tables 5.17 and 5.18. The method is known as microcomponent analysis.

Key assumptions made within the analysis are:

i) power showers will become more popular, gradually replacing traditional showers,

ii) dual flush systems will again show preference against traditional flush toilets,

iii) dishwasher ownership will effectively double between 2000 and 2020, causing a reduction in manual dishwashing,

iv) hosepipe and sprinkler ownership will increase, but not rapidly,

v) the number of cars per household will continue to increase.

The accuracy of the forecasts is considered in 5.4.3.6.

**SPREADSHEET OF POPULATION RELATED USE OF WATER**

| | 1992 | 1994 | 1996 | 1998 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|---|---|---|
| **BATH** | | | | | | | | | |
| Ownership % | 98 | 98 | 98 | 99 | 99 | 100 | 100 | 100 | 100 |
| Frequency/day | 0.416 | 0.416 | 0.416 | 0.416 | 0.416 | 0.416 | 0.416 | 0.416 | 0.416 |
| Vol/Use litres | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| Total l/p/d | 32.58 | 32.58 | 32.58 | 32.92 | 32.92 | 33.25 | 33.25 | 33.25 | 33.25 |
| % CHG ON PREV YR | | | | | 0 | 1.01 | 0 | 0 | 0 |
| **SHOWER** | | | | | | | | | |
| Ownership % | 68 | 68 | 69 | 70 | 68 | 65 | 62 | 55 | 50 |
| Frequency/day | 0.685 | 0.685 | 0.685 | 0.685 | 0.685 | 0.685 | 0.685 | 0.685 | 0.685 |
| Vol/Use litres | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Total l/p/d | 13.97 | 13.97 | 14.17 | 14.38 | 13.97 | 13.35 | 12.74 | 11.3 | 10.27 |
| % CHG ON PREV YR | | | | | -2.86 | -4.41 | -4.62 | -11.3 | -9.09 |
| **POWER SHOWER** | | | | | | | | | |
| Ownership % | 5 | 6 | 8 | 9 | 11 | 14 | 18 | 27 | 35 |
| Frequency/day | 0.684 | 0.684 | 0.684 | 0.684 | 0.684 | 0.684 | 0.684 | 0.684 | 0.684 |
| Vol/Use litres | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Total l/p/d | 2.052 | 2.462 | 3.283 | 3.694 | 4.514 | 5.746 | 7.387 | 11.08 | 14.36 |
| % CHG ON PREV YR | | | | | 22.22 | 27.27 | 28.57 | 50 | 29.63 |
| **WC-HIGH VOL** | | | | | | | | | |
| Ownership % | 75 | 75 | 75 | 75 | 75 | 73 | 71 | 69 | 67 |
| Frequency/day | 3.894 | 3.894 | 3.894 | 3.894 | 3.894 | 3.894 | 3.894 | 3.894 | 3.894 |
| Vol/Use litres | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Total l/p/d | 26.28 | 26.28 | 26.28 | 26.28 | 26.28 | 25.58 | 24.88 | 24.18 | 23.48 |
| % CHG ON PREV YR | | | | | 0 | -2.67 | -2.74 | -2.82 | -2.9 |
| **WC-DUAL FLUSH** | | | | | | | | | |
| Ownership % | 25 | 25 | 25 | 25 | 25 | 27 | 29 | 31 | 33 |
| Frequency/day | 3.89 | 3.89 | 3.89 | 3.89 | 3.89 | 3.89 | 3.89 | 3.89 | 3.89 |
| Vol/Use litres | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Total l/p/d | 5.835 | 5.835 | 5.835 | 5.835 | 5.835 | 6.302 | 6.769 | 7.235 | 7.702 |
| % CHG ON PREV YR | | | | | 0 | 8 | 7.407 | 6.897 | 6.452 |
| **OTHER PERS WASHG** | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| **UNEXPLAINED PCC** | 22 | 24 | 25 | 24.78 | 28 | 28 | 28 | 28 | 28 |
| **POP RELATED** | 80.72 | 81.13 | 82.16 | 83.11 | 83.52 | 84.23 | 85.02 | 87.04 | 89.07 |
| **CONSUMPTION L/P/D** | 155.3 | 159 | 161.9 | 164.1 | 168.2 | 171.2 | 173.8 | 177.7 | 181.1 |

**Legend:**

pcc = per capita consumption

l/p/d = litres per person per day

*(Table 5.17)*
*Company A : population-related consumption of water*
*- unmeasured households*

## SPREADSHEET OF HOUSEHOLD RELATED WATER USE

| | 1992 | 1994 | 1996 | 1998 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|---|---|---|
| **WASHING MC** | | | | | | | | | |
| Ownership % | 90 | 91 | 91 | 92 | 92 | 93 | 93 | 94 | 95 |
| Frequency/wk | 4.405 | 4.405 | 4.405 | 4.405 | 4.405 | 4.405 | 4.405 | 4.405 | 4.405 |
| Vol/Use litres | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 |
| Total l/hh/wk | 376.6 | 380.8 | 380.8 | 385 | 385 | 389.2 | 389.2 | 393.4 | 397.6 |
| % CHG ON PREV YR | | | | | 0 | 1.087 | 0 | 1.075 | 1.064 |
| **DISHWASHER** | | | | | | | | | |
| Ownership % | 20 | 22 | 24 | 27 | 30 | 34 | 39 | 44 | 47 |
| Frequency/wk | 5.55 | 5.55 | 5.55 | 5.55 | 5.55 | 5.55 | 5.55 | 5.55 | 5.55 |
| Vol/Use litres | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 38 |
| Total l/hh/wk | 42.18 | 46.4 | 50.62 | 56.94 | 63.27 | 71.71 | 82.25 | 92.8 | 99.12 |
| % CHG ON PREV YR | | | | | 11.11 | 13.33 | 14.71 | 12.82 | 6.818 |
| **MAN DISHWASH** | | | | | | | | | |
| Ownership % | 80 | 78 | 76 | 73 | 70 | 66 | 62 | 58 | 53 |
| Frequency/wk | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 |
| Vol/Use litres | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Total l/hh/wk | 164 | 159.9 | 155.8 | 149.7 | 143.5 | 135.3 | 127.1 | 118.9 | 108.7 |
| % CHG ON PREV YR | | | | | -4.11 | -5.71 | -6.06 | -6.45 | -8.62 |
| **HOSEPIPE** | | | | | | | | | |
| Ownership % | 48 | 50 | 52 | 54 | 56 | 56 | 56 | 56 | 56 |
| Frequency/wk | 0.637 | 0.637 | 0.637 | 0.637 | 0.637 | 0.637 | 0.637 | 0.637 | 0.637 |
| Vol/Use litres | 199.7 | 199.7 | 199.7 | 199.7 | 199.7 | 199.7 | 199.7 | 199.7 | 199.7 |
| Total l/hh/wk | 61.06 | 63.6 | 66.15 | 68.69 | 71.24 | 71.24 | 71.24 | 71.24 | 71.24 |
| % CHG ON PREV YR | | | | | 3.704 | 0 | 0 | 0 | 0 |
| **SPRINKLER** | | | | | | | | | |
| Ownership % | 4 | 6 | 8 | 12 | 10 | 10 | 10 | 10 | 10 |
| Frequency/wk | 0.317 | 0.317 | 0.317 | 0.317 | 0.317 | 0.317 | 0.317 | 0.317 | 0.317 |
| Vol/Use litres | 600 | 642.9 | 642.9 | 642.9 | 642.9 | 642.9 | 642.9 | 642.9 | 642.9 |
| Total l/hh/wk | 7.608 | 12.23 | 16.3 | 24.46 | 20.38 | 20.38 | 20.38 | 20.38 | 20.38 |
| % CHG ON PREV YR | | | | | -16.7 | 0 | 0 | 0 | 0 |
| **CAR WASHG** | | | | | | | | | |
| Ownership per house | 1.08 | 1.1 | 1.12 | 1.14 | 1.16 | 1.19 | 1.2 | 1.2 | 1.2 |
| Frequency/wk | 0.467 | 0.467 | 0.467 | 0.467 | 0.467 | 0.467 | 0.467 | 0.467 | 0.467 |
| Vol/Use litres | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Total l/hh/wk | 50.44 | 51.37 | 52.3 | 53.24 | 54.17 | 55.57 | 56.04 | 56.04 | 56.04 |
| % CHG ON PREV YR | | | | | 1.754 | 2.586 | 0.84 | 0 | 0 |
| **TOTAL L/HH/WK** | 701.9 | 714.3 | 722 | 738 | 737.6 | 743.4 | 746.2 | 752.7 | 753 |
| | | | | | | | | | |
| **HH DENSITY** | 2.6 | 2.56 | 2.53 | 2.5 | 2.47 | 2.36 | 2.28 | 2.21 | 2.15 |
| | | | | | | | | | |
| | | | | | | | | | |
| **PCC L/P/D** | 38.57 | 39.86 | 40.77 | 42.17 | 42.66 | 45 | 46.75 | 48.66 | 50.03 |

*(Table 5.18)*
*Company A : household-related consumption of water*
*- unmeasured households*

#### 5.4.3.2 Measured Household Demand

Measured household demand is the product of measured population and measured per capita. The key area of uncertainty is measured population as shown in Table 5.16, which is based on assumptions regarding metering policy; price of meters, numbers of new houses, charging policies and so on. These assumptions have widespread uncertainty but have a second order effect in that a reduction in the number of measured houses will result in a corresponding increase in the number of unmeasured houses. The effect is therefore only material where there is a significant difference between measured and unmeasured per capita; effectively the saving in water use due to metering. The household density forecast for measured houses for Company A is shown in Table 5.15.

A simple example of materiality can be demonstrated by supposing that the take up of meters is subject to a 10% error by 2020. It can be shown that this is equivalent to a population of 11,600. The impact on demand as a result would be:

$$11{,}600 \times (181 \text{ l/p/d} - 163 \text{ l/p/d}) = 0.2 \text{ Ml/d}$$

where 181 l/p/d is the unmeasured per capita for 2020
and 163 l/p/d is the measured per capita for 2020 (assuming a 10% saving due to metering)

For a potential impact of 0.2 Ml/d the increase in programming complexity is considered too great to warrant inclusion of this source of uncertainty within this research. Further research into this issue is recommended.

The difficulty with forecasting measured household use is the lack of any real history. Before 1990 very few houses in Company A's area of supply were metered.

One approach is to use the same methodology for unmeasured households but to tailor assumptions for discretionary water use, such as garden watering. Forecasts using this approach are shown in Tables 519 and 5.20. There is very limited trend information upon which to base the forecasts and considerable engineering judgement has been used. This low level of accuracy is reflected in Table 5.25.

**SPREADSHEET OF HOUSEHOLD RELATED WATER USE**
**MEASURED HOUSEHOLDS**

| | 1996 | 1998 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|---|
| **WASHING MC** | | | | | | | |
| Ownership % | 90 | 92 | 95 | 95 | 95 | 95 | 95 |
| Frequency/wk | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Vol/Use litres | 95 | 95 | 95 | 95 | 95 | 95 | 95 |
| Total l/hh/wk | 384.8 | 393.3 | 406.1 | 406.1 | 406.1 | 406.1 | 406.1 |
| % CHG ON PREV YR | | | 3.261 | 0 | 0 | 0 | 0 |
| **DISHWASHER** | | | | | | | |
| Ownership % | 30 | 35 | 40 | 45 | 45 | 50 | 50 |
| Frequency/wk | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 |
| Vol/Use litres | 38 | 38 | 38 | 38 | 38 | 38 | 38 |
| Total l/hh/wk | 74.1 | 86.45 | 98.8 | 111.2 | 111.2 | 123.5 | 123.5 |
| % CHG ON PREV YR | | | 14.29 | 12.5 | 0 | 11.11 | 0 |
| **MAN DISHWASH** | | | | | | | |
| Ownership % | 60 | 55 | 50 | 45 | 45 | 40 | 40 |
| Frequency/wk | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Vol/Use litres | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Total l/hh/wk | 120 | 110 | 100 | 90 | 90 | 80 | 80 |
| % CHG ON PREV YR | | | -9.09 | -10 | 0 | -11.1 | 0 |
| **HOSEPIPE** | | | | | | | |
| Ownership % | 35 | 37 | 40 | 40 | 40 | 40 | 40 |
| Frequency/wk | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Vol/Use litres | 199.7 | 199.7 | 199.7 | 199.7 | 199.7 | 199.7 | 199.7 |
| Total l/hh/wk | 34.95 | 36.94 | 39.94 | 39.94 | 39.94 | 39.94 | 39.94 |
| % CHG ON PREV YR | | | 8.108 | 0 | 0 | 0 | 0 |
| **SPRINKLER** | | | | | | | |
| Ownership % | 8 | 12 | 10 | 10 | 10 | 10 | 10 |
| Frequency/wk | 0.317 | 0.317 | 0.317 | 0.317 | 0.317 | 0.317 | 0.317 |
| Vol/Use litres | 642.9 | 642.9 | 642.9 | 642.9 | 642.9 | 642.9 | 642.9 |
| Total l/hh/wk | 16.3 | 24.46 | 20.38 | 20.38 | 20.38 | 20.38 | 20.38 |
| % CHG ON PREV YR | | | -16.7 | 0 | 0 | 0 | 0 |
| **CAR WASHG** | | | | | | | |
| Ownership per house | 0.9 | 1 | 1.12 | 1.13 | 1.14 | 1.15 | 1.15 |
| Frequency/wk | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Vol/Use litres | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Total l/hh/wk | 36 | 40 | 44.8 | 45.2 | 45.6 | 46 | 46 |
| % CHG ON PREV YR | | | 12 | 0.893 | 0.885 | 0.877 | 0 |
| **TOTAL L/HH/WK** | 666.1 | 691.2 | 710 | 712.8 | 713.2 | 715.9 | 715.9 |
| | | | | | | | |
| **HH DENSITY** | 2.2 | 2.17 | 2.16 | 2.11 | 2.07 | 2.05 | 2.03 |
| | | | | | | | |
| | | | | | | | |
| **PCC L/P/D** | 43.25 | 45.5 | 46.96 | 48.26 | 49.22 | 49.89 | 50.38 |

*(Table 5.19)*
*Company A : household-related consumption of water*
*- measured households*

## SPREADSHEET OF POPULATION RELATED USE OF WATER MEASURED HOUSEHOLDS

| | 1996 | 1998 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|---|
| **BATH** | | | | | | | |
| Ownership % | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Frequency/day | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 |
| Vol/Use litres | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| Total l/p/d | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 |
| % CHG ON PREV YR | | | 0 | 0 | 0 | 0 | 0 |
| **SHOWER** | | | | | | | |
| Ownership % | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| Frequency/day | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Vol/Use litres | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Total l/p/d | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| % CHG ON PREV YR | | | 0 | 0 | 0 | 0 | 0 |
| **POWER SHOWER** | | | | | | | |
| Ownership % | 15 | 15 | 20 | 20 | 20 | 20 | 20 |
| Frequency/day | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Vol/Use litres | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Total l/p/d | 5.4 | 5.4 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 |
| % CHG ON PREV YR | | | 33.33 | 0 | 0 | 0 | 0 |
| **WC-HIGH VOL** | | | | | | | |
| Ownership % | 65 | 65 | 65 | 65 | 60 | 60 | 60 |
| Frequency/day | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 |
| Vol/Use litres | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Total l/p/d | 22.82 | 22.82 | 22.82 | 22.82 | 21.06 | 21.06 | 21.06 |
| % CHG ON PREV YR | | | 0 | 0 | -7.69 | 0 | 0 |
| **WC-DUAL FLUSH** | | | | | | | |
| Ownership % | 35 | 35 | 35 | 35 | 40 | 40 | 40 |
| Frequency/day | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 |
| Vol/Use litres | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Total l/p/d | 8.19 | 8.19 | 8.19 | 8.19 | 9.36 | 9.36 | 9.36 |
| % CHG ON PREV YR | | | 0 | 0 | 14.29 | 0 | 0 |
| **OTHER PERS WASHG** | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| **UNEXPLAINED PCC** | 20 | 23 | 23 | 23 | 23 | 23 | 23 |
| **POP RELATED** | 66.01 | 66.01 | 67.81 | 67.81 | 67.22 | 67.22 | 67.22 |
| **CONSUMPTION L/P/D** | 141.3 | 146.5 | 149.8 | 151.1 | 151.4 | 152.1 | 152.6 |

*(Table 5.20)*
*Company A : population-related consumption of water*
*- measured households*

#### 5.4.3.3 Measured Non-Household Demand

Trend plots of measured non-household demand for industrial sectors within Company A is shown in Figure 5.6 and a forecast table presented as Table 5.21. The year on year error is considered in Section 5.4.3.6.

The forecast of measured non-household demand is based on an extrapolation of industrial categories (not shown) but which is added into the forecast in Table 5.21.

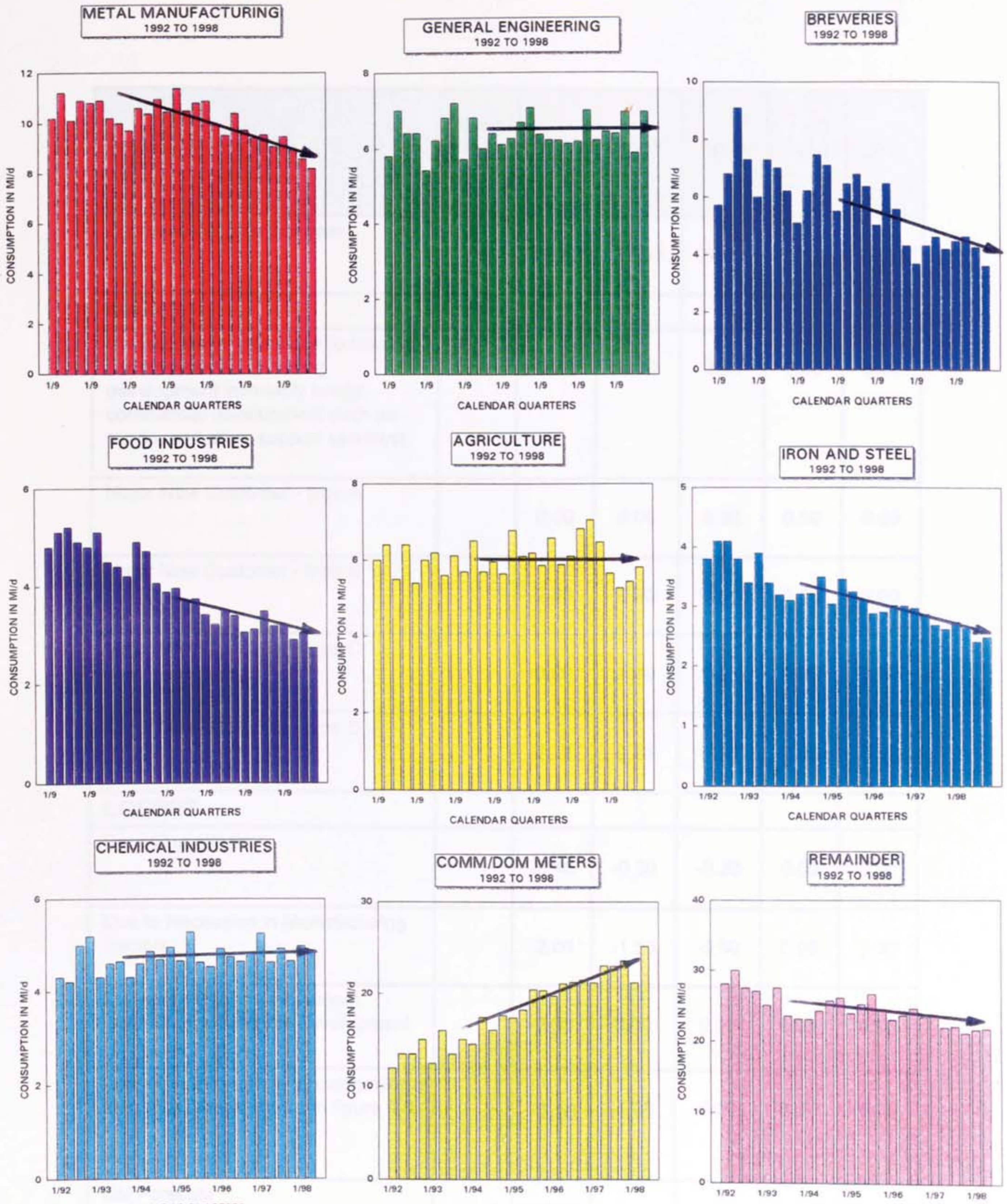
Outside of trends within industrial categories, there are a number of entries in Table 5.21 for major new customers. These entries are based on the type of customer and assessed using local planning studies.

#### 5.4.3.4 Other Demand Components

Components of genuine demand not covered by the three main uses described in 5.4.3.1, 5.4.3.2 and 5.4.3.3 are that due to unmeasured non-household use (such as banks, churches, libraries, etc.) and that collectively termed miscellaneous use (such as that used by fire authorities, that which is used illegally and that used by water companies themselves during operational works). These components are generally quite small.

For unmeasured non-household use the adopted method for forecasting follows UKWIR (1997$_a$) where use in an unmeasured non-household sector is forecast by reference to measured properties in the same sector, as shown in Table 5.22 for Company A. This average use is then assumed to be constant over time and the forecast based on a projection of property numbers. This is shown in Table 5.23.

The only notable assumption within the forecast for Company A is an expected reduction in the numbers of community properties, particularly banks and building societies, at the rate of 2% per five years for the first 10 years; 1% per five years thereafter.



(Figure 5.6)
*Trends in measured non-household use by sector for the years 1992 to 1998 for Company A*

| FORECAST PERIOD | Base Year 1998 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|
| Baseloads at previous year | | 72.82 | 70.81 | 70.11 | 70.01 | 70.81 |
| **GAINS** | | | | | | |
| Consequential effect due to Housing Developments. (Housing development invariably brings commercial development such as shops, and other support services). | | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Major New Customer - type A | | 0.00 | 0.00 | 0.30 | 0.50 | 0.50 |
| Major New Customer - type B | | 2.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| Major New Customer - type C | | 0.00 | 1.80 | 0.00 | 0.00 | 0.00 |
| Major New Customer - type D | | 2.39 | 0.00 | 0.00 | 0.00 | 0.00 |
| **LOSSES** | | | | | | |
| Recycling effects | | -0.40 | -0.30 | -0.20 | 0.00 | 0.00 |
| Due to Recession in Manufacturing Sectors | | -2.00 | -1.50 | -0.50 | 0.00 | 0.00 |
| Breweries Sector - movement towards own borehole development | | -2.50 | 0.00 | 0.00 | 0.00 | 0.00 |
| Impact due to trends in categories of industrial use as shown in figure 5.6. | | -2.00 | -1.00 | 0.00 | 0.00 | 0.00 |
| Net Forecast | 72.82 (Actual) | 70.81 | 70.11 | 70.01 | 70.81 | 71.61 |

*(Table 5.21)*
*Measured non-household demand forecasts for Company A for the period 2000 to 2020*

| Sector | Total Use in Measured Sector Ml/d | Number of Measured Properties in Sector | Average Use in Litres/Property per Day |
|---|---|---|---|
| Farms | 2.14 | 1712 | 1250 |
| Community properties | 3.92 | 10453 | 375 |
| Other properties | 1.32 | 6226 | 212 |

*(Table 5.22)*
*The use per property for measured non-domestic properties for Company A*

| Year | 1998 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|
| Forecast of total number of unmeasured non-domestic properties | 23975 | 23862 | 23638 | 23418 | 23311 | 23205 |
| Community properties | 11307 | 11194 | 10970 | 10750 | 10643 | 10537 |
| Farms | 4744 | 4744 | 4744 | 4744 | 4744 | 4744 |
| Others | 7924 | 7924 | 7924 | 7924 | 7924 | 7924 |
| Farms Ml/d (@ 1250 l/prop/d) | 5.93 | 5.93 | 5.93 | 5.93 | 5.93 | 5.93 |
| Community properties Ml/d (@ 375 l/prop/d) | 4.24 | 4.20 | 4.11 | 4.03 | 3.99 | 3.95 |
| Others Ml/d (@ 212 l/prop/d) | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 |
| Total Ml/d | 11.85 | 11.81 | 11.72 | 11.64 | 11.60 | 11.56 |

*(Table 5.23)*
*Forecast of unmeasured non-domestic use for Company A based on property numbers*

Miscellaneous use, including that used for firefighting at 2.0 Ml/d, for mains flushing and other operational uses at 2.5 Ml/d, illegal use at 0.5 Ml/d and other uses at 1.85 Ml/d, is assumed to remain constant at 6.85 Ml/d throughout the forecast period.

#### 5.4.3.5 Total Leakage

In theory, the level of total leakage should be that which is economically achievable. In practice the level of leakage is likely to be that set by OFWAT as a mandatory target.

As such, it would be inappropriate to set a range of uncertainty for the figure since this would suggest that the target is not achievable. By definition a mandatory target must be achieved.

The profile for total leakage, for Company A, is shown in Table 5.24. Note that for 2005 onwards the economic level of leakage is used as the expected mandatory target.

| **Total Leakage in Ml/d** | **Year** | | | | | |
|---|---|---|---|---|---|---|
| | 1998 | 2000 | 2005 | 2010 | 2015 | 2020 |
| | 82.59 | 80.0 | 77.0 | 75.0 | 75.0 | 75.0 |

*(Table 5.24)*
*Total leakage for Company A*
*Actual value in base year (1998) and targets for the period 2000 to 2020*

#### 5.4.3.6 Forecast Uncertainty

Scenario analysis is the most obvious technique for considering the spread of future demand forecasts, although this can be time-consuming.

As a simpler alternative to scenario analysis, Table 4.10 of Section 4.5.3 describes accuracy levels for each of the principle components of demand (after UKWIR, $1997_c$). Accuracy is described in terms of percentage variation likely to accrue year on year.

Forecast accuracy is a measure of how much a forecast might vary as a result of lack of knowledge about the future. The degree of accuracy will depend on the forecasting tool used and will compound with other variables acting on the central forecast.

Based on a central forecast for Company A, then accuracy levels can be applied assuming that each accuracy band is the equivalent of a typical 2 standard deviation from the central figure.

Demand forecast uncertainty can, therefore, be described as in Table 5.25, applying the appropriate accuracies from Section 4.5.2 to the principal forecast components. However, extrapolating these errors over long time horizons produces unrealistically large compounded errors, suggesting that considerably more research is required in this area. A somewhat subjective alternative view of the longer term is also shown in Table 5.25, reflecting the need for realism but that this is a major area where the water industry lacks understanding.

The largest component of demand, unmeasured domestic, is shown with a long term accuracy of +/- 0.5% year. Running the simulation programme shown in Table 5.32 with accuracies of +/- 0% and +/- 0.5% shows that the net effect of this assumption causes an increase in demand, at the 5% level, of between 3 and 4 Ml/d. This is equivalent to an increase per capita of between 3 and 4 l/person/day.

As a means of comparison with assumed annual forecast errors, a worst case scenario of unmeasured domestic demand, varying the assumptions embedded within Tables 5.16 and 5.17, increases components for the year 2020 as follows:

| | | pcc change |
|---|---|---|
| Power showers: | ownership from 35% to 45% | + 4.1 l/p/d |
| Dual flush: | ownership from 33% to 27% | - 1.4 l/p/d |
| High vol. flush: | ownership from 67% to 73% | + 2.1 l/p/d |
| | | + 4.8 l/p/d |

This scenario is consistent with the assumption of +/- 0.5% within the worksheet in Section 5.7.7 and it is therefore considered reasonable to adopt the long term forecast rates contained within Table 5.25.

The performance of demand forecasting techniques is referred to in 4.5.13, but it is important to note that the long term performance of demand forecasting in the water industry seems to have been more to do with luck than judgement. This was particularly so between 1945 and 1975 until a visible tail-off in demand occurred for the first time during the 1970's recession. This relationship is shown more fully, for the South Staffordshire Water Company, in Figure 2.1.

| Component of Forecast | Description of Forecast Method | Accuracy Medium Term per year | Accuracy Long Term per year |
|---|---|---|---|
| Unmeasured Household (all components) | Micro-components | +/- 1% | +/- 0.5% |
| Measured Household | New housing starts and micro-components | +/- 5% | +/- 1% |
| Measured Non-Household | Top-down judgement and economic indicators | +/- 5% | +/- 2% |
| Unaccounted for Water | Mandatory target | 0.00 | 0.00 |
| Unmeasured Non-Domestic | Analogy with measured sectors | +/- 25% | +/- 2% |
| Other uses | Judgement | +/- 25% | +/- 2% |

*(Table 5.25)*
*Forecasting components for Company A*

#### 5.4.3.7 Summary of Central Demand Forecasts

The central forecast, arising from the analysis within Sections 5.4, for each principal component of demand for the period 1998 to 2020 is shown in Table 5.26. The table is essentially the complete summary of demand forecasts for Company A in the absence of uncertainty. This forecast represents the traditional approach to resource planning for the demand side of the equation. It forms the central estimate around which uncertainty is considered.

| COMPONENT | 1998 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|
| POPULATION-MEASURED | 41110.00 | 59000.00 | 74000.00 | 94000.00 | 105000.00 | 116000.00 |
| MEASURED PER CAPITA | 146.50 | 149.80 | 151.10 | 151.40 | 152.10 | 152.60 |
| **Measured Domestic** | **6.02** | **8.84** | **11.18** | **14.23** | **15.97** | **17.70** |
| UNMEASURED DOMESTIC | | | | | | |
| POPULATION-UNMEASURED | 1240.00 | 1230.00 | 1218.00 | 1200.00 | 1190.00 | 1189.00 |
| Washing Machines | 22.00 | 22.27 | 23.56 | 24.39 | 25.43 | 26.42 |
| Dishwashers | 3.25 | 3.66 | 4.34 | 5.15 | 6.00 | 6.59 |
| Manual Dishwashers | 8.55 | 8.30 | 8.19 | 7.96 | 7.69 | 7.22 |
| Hosepipes | 3.93 | 4.12 | 4.31 | 4.46 | 4.61 | 4.73 |
| Sprinklers | 1.40 | 1.18 | 1.23 | 1.28 | 1.32 | 1.35 |
| Car Washing | 3.04 | 3.13 | 3.36 | 3.51 | 3.62 | 3.72 |
| Bath | 32.92 | 33.25 | 33.25 | 33.25 | 33.25 | 33.25 |
| Shower | 14.38 | 13.97 | 13.35 | 12.74 | 11.30 | 10.27 |
| Power Showers | 3.69 | 4.51 | 5.75 | 7.39 | 11.08 | 14.36 |
| WC - High Volume | 26.28 | 26.28 | 25.58 | 24.88 | 24.18 | 23.48 |
| WC - Dual Flush | 5.83 | 5.83 | 6.30 | 6.77 | 7.23 | 7.70 |
| Other | 38.78 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 |
| TOTAL - PER CAPITA | 164.05 | 168.50 | 171.23 | 173.79 | 177.70 | 181.10 |
| TOTAL - UNMEASURED DOMESTIC | **203.42** | **207.25** | **208.56** | **208.54** | **211.46** | **215.33** |
| Measured Non-Domestic | **72.82** | **70.81** | **70.11** | **70.01** | **70.81** | **71.61** |
| Unmeasured Non-Domestic | **11.85** | **11.81** | **11.72** | **11.64** | **11.60** | **11.56** |
| Miscellaneous Use | **6.85** | **6.85** | **6.85** | **6.85** | **6.85** | **6.85** |
| Total Losses | **82.59** | **80.00** | **77.00** | **75.00** | **75.00** | **75.00** |
| TOTAL DEMAND | **383.55** | **385.56** | **385.42** | **386.27** | **391.69** | **398.05** |

NOTE : Figures for 1998 are post normalisation and post MLE adjustment for central source meter bias of 5.9% (see table 5.13)

*(Table 5.26)*

*Summary of central demand forecasts for Company A for the period 2000 to 2020*

### 5.4.4 Effect of Climate on Average Demand

Outside of climate change, the demand for water varies year on year due to variation of climate. Climate can impact on demand either as a result of a very dry summer, causing an increase in garden use or due to a severe winter which causes an increase in mains leakage.

History has shown that the impact of a dry summer is by far the most significant influence on demand. Section 4.5.8 considers the impact of climate on demand and notes that it is first necessary to understand the relationship between climate and water demand and to then set a likelihood distribution on climate itself in order to sensibly determine the distribution for demand itself. Very little research has been done in this area, other than Herrington (1995), Smith (1989) and Carnell (1985).

For Company A the relationship between climate and demand is not well understood as tends to be the case for most of the water industry. As a simple surrogate, therefore, it will be assumed that only the domestic component of demand is influenced by climate and that, when an outturn demand has been higher than forecast, that this has been due to hot weather and, conversely, when the outturn demand has been lower than expected, that this has been due to mild weather.

This relationship is shown indicatively as Figure 4.21. For Company A this relationship is shown in Figure 5.4, where the regression line is the surrogate and is compared to the outturn demand to identify untypical events.

Accepting the 'health warning' which goes with this approach, as described in Section 4.5.8, then Figure 5.4 suggests a normal distribution for climatic variation on unmeasured demand, which has a mean of zero and a standard deviation of 2.7 Ml/d. For simplicity, this figure will be converted to be constant percentage over the period 2000 to 2020. For 1998 2.7 Ml/d is equivalent to 1.33% of domestic demand.

### 5.4.5 Effect of Climate Change on Average Demand

The effect of climate change on average demand is derived by reference to work carried out by Herrington (1995). Table 5.27 is extracted in part from Herrington (1995). The end three columns assuming that there is a straight line relationship between the consumption increase due to a 1.1° C rise in temperature assumed by Herrington and the smaller rises of 0.6, 0.8 and 0.9°C suggested by UKWIR/EA (1997$_b$) and discussed in Section 4.5.10. The end columns therefore represent the spread of uncertainty due to climate change. These percentage ranges are converted to per capitas in Table 5.28. All demand components excluded from the table are assumed not to be influenced by climate change.

| Component | Household or Population | 2021 No climate change PCC in l/h/d | 2021 with 1.1 degree of warming PCC in l/h/d | % difference in PCC per 1 degree warming | Range of differences in % PCC with warmings of | | |
|---|---|---|---|---|---|---|---|
| | | | | | 0.6. Deg | 0.8 Deg | 0.9 Deg |
| Showering | Population | 24.00 | 26.80 | 11.67 | 7.00 | 9.33 | 10.50 |
| Lawn Sprinkling | Household | 8.70 | 11.75 | 35.06 | 21.03 | 28.05 | 31.55 |
| Other Garden Use | Household | 7.20 | 8.55 | 18.75 | 11.25 | 15.00 | 16.88 |

*(Table 5.27)*

*Table showing impact of % changes in average day per capita consumption (pcc) for varying climate change models (based on Herrington, 1995).*

| COMPONENT/YEAR | Forecast Unmeasured Per Capita litres/person/day | Range of % Differences in per capita with warmings of (based on Herrington,1995) | | | Per Capita Additions under various degrees of warming | | |
|---|---|---|---|---|---|---|---|
| | | 0.6degC | 0.8degC | 1.1degC | 0.6degC | 0.8degC | 1.1degC |
| **2005** | | | | | | | |
| Shower | 13.35 | 1.75 | 2.3325 | 2.625 | 0.23 | 0.31 | 0.35 |
| Power Shower | 5.75 | 1.75 | 2.3325 | 2.625 | 0.10 | 0.13 | 0.15 |
| Lawn Sprinkling | 1.23 | 5.2575 | 7.0125 | 7.8875 | 0.06 | 0.09 | 0.10 |
| Other Garden Use | 4.31 | 2.8125 | 3.75 | 4.22 | 0.12 | 0.16 | 0.18 |
| **TOTAL INCREASE** | | | | | 0.52 | 0.69 | 0.78 |
| **2010** | | | | | | | |
| Shower | 12.74 | 3.5 | 4.665 | 5.25 | 0.45 | 0.59 | 0.67 |
| Power Shower | 7.39 | 3.5 | 4.665 | 5.25 | 0.26 | 0.34 | 0.39 |
| Lawn Sprinkling | 1.28 | 10.515 | 14.025 | 15.775 | 0.13 | 0.18 | 0.20 |
| Other Garden Use | 4.46 | 5.625 | 7.5 | 8.44 | 0.25 | 0.33 | 0.38 |
| **TOTAL INCREASE** | | | | | 1.09 | 1.45 | 1.64 |
| **2015** | | | | | | | |
| Shower | 11.3 | 5.25 | 6.9975 | 7.875 | 0.59 | 0.79 | 0.89 |
| Power Shower | 11.08 | 5.25 | 6.9975 | 7.875 | 0.58 | 0.78 | 0.87 |
| Lawn Sprinkling | 1.32 | 15.7725 | 21.0375 | 23.6625 | 0.21 | 0.28 | 0.31 |
| Other Garden Use | 4.61 | 8.4375 | 11.25 | 12.66 | 0.39 | 0.52 | 0.58 |
| **TOTAL INCREASE** | | | | | 1.77 | 2.36 | 2.66 |
| **2020** | | | | | | | |
| Shower | 10.27 | 7 | 9.33 | 10.5 | 0.72 | 0.96 | 1.08 |
| Power Shower | 14.36 | 7 | 9.33 | 10.5 | 1.01 | 1.34 | 1.51 |
| Lawn Sprinkling | 1.35 | 21.03 | 28.05 | 31.55 | 0.28 | 0.38 | 0.43 |
| Other Garden Use | 4.73 | 11.25 | 15 | 16.88 | 0.53 | 0.71 | 0.80 |
| **TOTAL INCREASE** | | | | | 2.54 | 3.39 | 3.81 |

*Notes:*

The figures for per capita are extracted from table 5.17 and 5.18
*The figures for the impact of warming are extracted from table 5 27.*
Climate change effects are assumed to be linear between 2000 and 2020. For example, one quarter of the effect is assumed for each five-year block.

*(Table 5.28)*
*Impact of different climate change models on per capita consumption in the year 2020*

### 5.4.6 Demand Side Meter Error

There is little doubt that meters slowly begin to under-register flow under the effects of age as discussed in Section 4.5.10. The key issue is whether this under-registration is material in the case of Company A in terms of the potential effect on the supply-demand balance.

As with the assessment of domestic measured property numbers discussed in Section 5.4.3.2 any adjustment in the measured demand components will have a second order effect on unmeasured demand since, clearly, the volume of water being pumped does not change.

For Company A the profile of meters and age of meters for measured domestic customers is broadly as shown in Table 5.29.

| | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| Number of meters (000's) | 27 | 35 | 45 | 51 | 57 |
| Average age in years (approximate) | 5 | 4.8 | 4.6 | 5 | 5.4 |

*(Table 5.29)*
*Age profile for measured domestic meters*

Prasifka (1988) suggests an under-registration profile for meters which translate to that shown in Table 5.30 for Company A. Statistics within Table 5.30 have been extracted largely from Table 5.26.

Table 5.30 shows that a level of under-registration (taken from Prasifka, 1988) of 5% translates into an increase in allocated unmeasured domestic demand of between 0.2% and 0.4%. This is equivalent to a movement in domestic unmeasured per capita of between 0.3 and 0.7 litres per day; a figure not considered material, particularly since it has a second order effect and the volume of water pumped does not change.

| Year | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| Number of meters (000's) | 27 | 35 | 45 | 51 | 57 |
| Average age in years | 5 | 4.8 | 4.6 | 5 | 5.4 |
| Household density (from table 5.15) | 2.16 | 2.11 | 2.07 | 2.05 | 2.03 |
| Per capita (from table 5.26) litres per person per day | 149.8 | 151.1 | 151.4 | 152.1 | 152.6 |
| Total demand in Ml/d | 8.84 | 11.18 | 14.23 | 15.97 | 17.70 |
| % under-registration (from section 4.5.10) | 5% | 5% | 5% | 5% | 5% |
| Reduction in measured domestic demand (as reduction in measured) in Ml/d | 0.44 | 0.56 | 0.71 | 0.79 | 0.88 |
| Increase in unmeasured demand in Ml/d | 0.44 | 0.56 | 0.71 | 0.79 | 0.8 |
| Unmeasured demand in Ml/d | 207.25 | 208.56 | 208.54 | 211.46 | 215.33 |
| % increase in unmeasured demand | 0.2% | 0.3% | 0.3% | 0.4% | 0.4% |

*(Table 5.30)*
*Impact of measured domestic under-registration on unmeasured demand*

For measured non-domestic demand the pareto principle applies, in that 20% of the meters account for 80% of demand. In addition, the large meters are subject to more frequent replacement and are often cross-calibrated with the customers' own meters. As with measured domestic demand, the second-order effect of this uncertainty is not considered material to this research.

### 5.4.7 The Relationship Between Uncertainty and Organisational Size

Section 2.3.2 discusses the relationship between planning margin and organisational size, citing the case of the Shrewsbury Planning Application as evidence. In addition, Section 4.8 considers how an analyst should deal with extreme events.

The rationale for relating uncertainty and organisational size is substantially a portfolio issue, where risks can be spread either over time, purpose or relative size. Where size is the problem, as was the case in Section 2.3.2, then the risk is greater for a small organisation than a large one. For the smaller organisation there is some point at which the risk becomes extreme and the problem moves away from planning allowance in the traditional sense to a matter of contingency or crisis management. There is clearly a grey area, however, as suggested in Figure 5.7.

For Company A, there are no risks at the crisis end of the scale which require consideration and the company is considered sufficiently large not to have to make specific adjustment to its headroom requirement because of its organisational size. The question of organisational size is considered further in Section 9.8 under opportunities for further research.

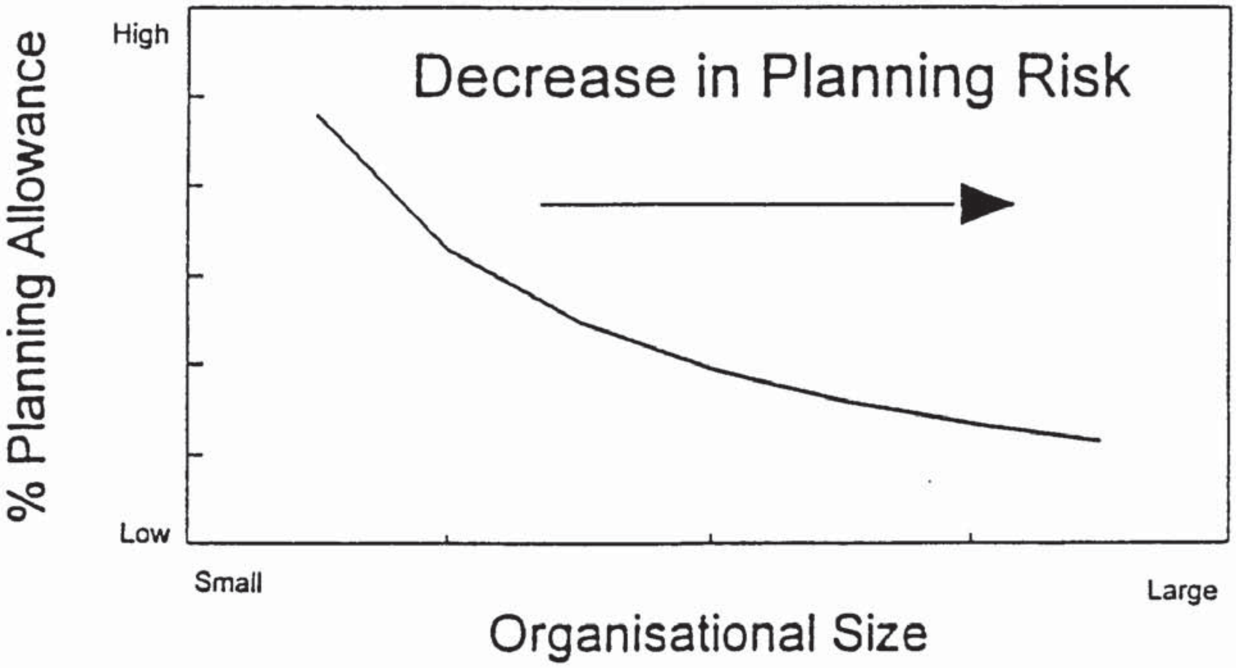
### 5.4.8 Dependent Uncertainties

The general principle of simulation sampling is that each source of uncertainty is represented by a statistical distribution and at each interation a sample is taken from each distribution and combined to form an overall uncertainty. Successive iterations produce a distribution of combined uncertainties which describe the solution to the problem across a range of probabilities. However, the result will be severely distorted if any of the uncertainties are related to each other. Consider, for example, that the computer samples a demand forecast consistent with a hot climate but then samples a source yield consistent with a wet climate. The sampled events are not compatible.

More importantly, because hot years invariably produce high demands and low resource yields, then ignoring this dependency gives an overall answer which understates the severity of the supply demand imbalance.

The @Risk software allows independent events to be correlated within the sampling procedure while still allowing uncertainty surrounding each event. The technique requires that one event is designated as independent, and can therefore be sampled first. The second, or subsequent events, are then described in terms of the strength of the relationship between them, or correlation, together with the uncertainty of the event.

Note that it is also possible using @Risk to correlate multiple input variables, which might be necessary in the event that several reservoirs, for example, demonstrate inter-dependency. In these circumstances @Risk provides a facility to enter a correlation matrix between designated dependent variables. Effectively this allows sampling of these variables to be governed by the correlation coefficients.



*(Figure 5.7)*

*The postulated relationship between planning margin and organisational size*

In the case of surface water yield for an impounding reservoir, for example, the relationship between the yield of the reservoir in a particular year and the domestic demand in that year can be shown visually as in Figure 5.8. The data is hypothetical and assigned to Company A for the period 1956 to 1990.

Suppose the domestic demand ratio (the ratio of a year's average demand compared to the long term trend) could be described by a normal distribution with mean 1.00 and standard deviation of approximately 0.013 then the independent variable "domestic demand" ratio is shown as:-

domestic demand ratio (log) : A1 @ << Risk >> Indepc ("Demand")
+ @ << Risk >> Normal (1.00, 0.013)

The dependent variable, source yield, has an independent distribution which can be described in discrete form as Ml/d, together with a correlation of moderate strength (-0.54) linking it with domestic demand. Note that the correlation applies only to source yields which are below the capacity of the works.

The source yield can thus be shown as:-

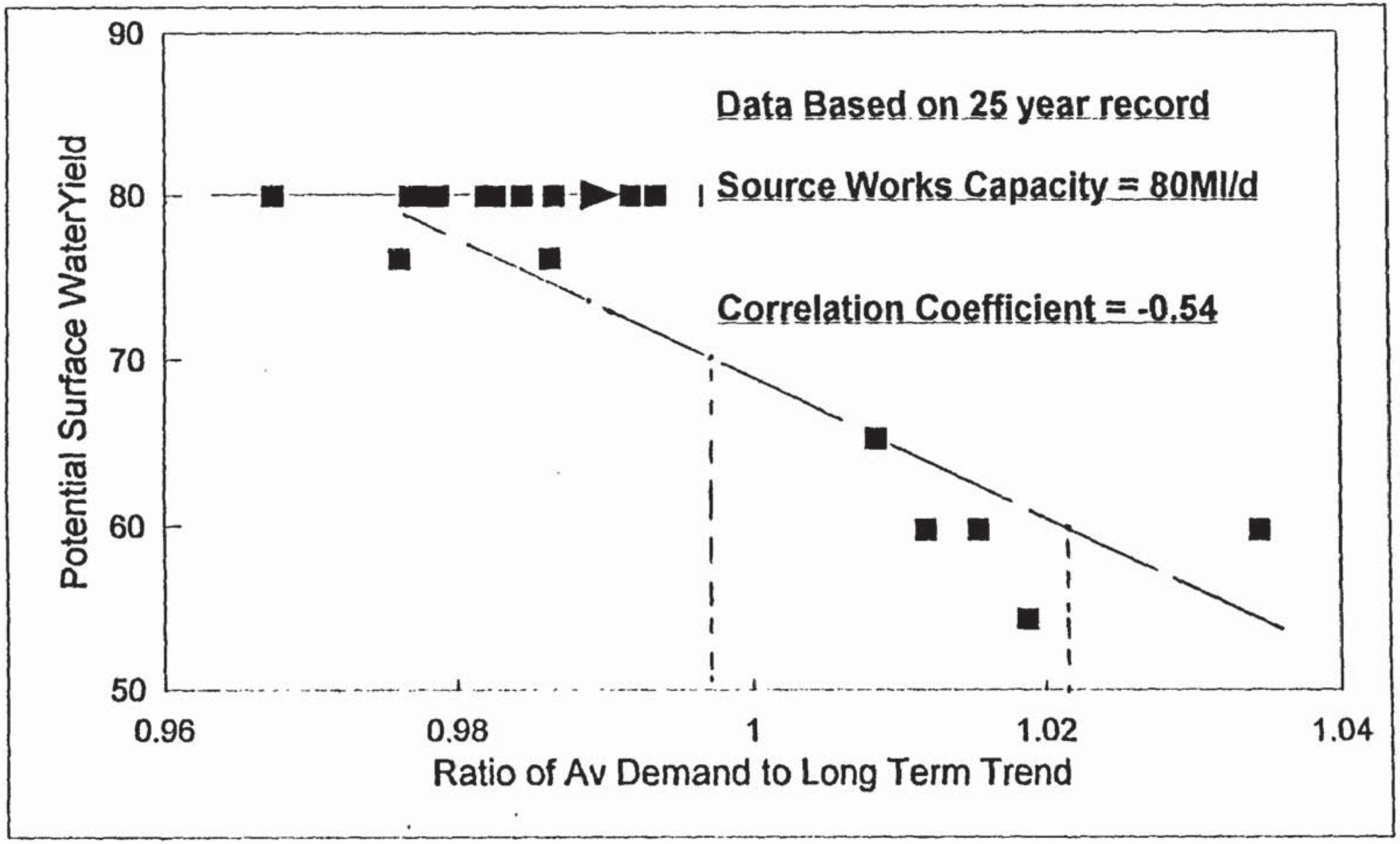
Source yield : A2 @ << Risk >> depc ("Demand", -0.54)
+ @ << Risk >> (Distribution of Source Yield)

The 'A1' and 'A2' terms are simply spreadsheet cell references and the term "Demand" is a link term so that the computer knows that there is dependency between them.

Alternatively, Figure 5.8 suggests a reduction in yield of 4.1 Ml/d for an increase in the domestic demand ratio of 0.01, but that this reduction only occurs in practice with demand ratios greater than 1. Dependency is then included by comparing the simulated demand ratio due to climate variation with the central demand forecast and making a deduction in yield if the ratio is greater than 1. This is a more straightforward approach and has been adopted in Section 5.7.7.

**Other Sources of Interdependence**

For Company A there is very little correlation between groundwater/major river yield and climatic severity and there are no other clear sources of interdependence.



*(Figure 5.8)*

*Independent variable*

*Relationship between domestic demand ratio and impounded source yield*

## 5.5 RANKING UNCERTAINTIES

Common sense dictates that it may be both impractical and unnecessary to attempt to include all uncertainties within a supply-demand analysis.

To optimise research, analysis, spreadsheet formulation and computing effort it may be appropriate to include only those sources of uncertainty which are considered to have a material effect on the result. Chapter 6 ranks the uncertainties included, initially, within the model described in 5.7.7.

### 5.5.1 Proposed Uncertainties to be used within the Analysis

Assessing the point at which the additions of a variable offer no material improvement is clearly a function of the value of improved accuracy. This will vary from one organisation to the next, but Chapter 1 indicates a saving benefit within the range £500,000 to £1,000,000 for a 1 Ml/d resource would be reasonable. This suggests that uncertainties should be included down to very small levels of significance.

Many of the uncertainties discussed within this research have a positive mean value and to exclude these would generate errors of omission discussed in 5.7.5. To exclude these would also introduce bias. The analysis in Chapter 6 will include all uncertainties discussed in this research except where there is considered to be a non-material second order effect, (such as with demand side metering and measured household number discussed in 5.4.3.2), or where classifying the uncertainty is outside the scope of the research.

## 5.6 SUMMARY OF DATA INPUTS AND DISTRIBUTIONS

Sections 5.3 and 5.4 consider how the various sources of uncertainty can be assigned a quantitative value for the analysis. The values and distributions will form the inputs to the risk model in 5.7.7 and for convenience and ease of spreadsheet construction are summarised within this section. Uncertainties are split between the supply side and the demand side uncertainties.

Section 5.6 begins by summarising the techniques used, within Sections 5.3 and 5.4 in Table 5.31.

| Source of Uncertainty | Technique |
|---|---|
| Loss of source yield | Historic projection<br>Cause and effect<br>Judgement |
| Planned outages | Historic projection<br>Known future plans<br>Historic uncertainty |
| Unplanned outages | Historic distributions of unplanned outages |
| The effect of climate variation on Resources | Historic distribution of resource yield limited by works capacity |
| The effect of climate change on Resources | Uncertainty within external research |
| Due to source meter error | In-house commissioned research |
| Uncertainty of groundwater yield | Anecdotal opinion of uncertainties |
| Uncertainty of surface water yield due to data sufficiency | Not considered uncertain |
| Uncertainty in Baseline demand components | Regression analysis and maximum likelihood estimation |
| Demand forecast uncertainty | UKWIR research, engineering judgement and scenario analysis |
| Leakage | Not considered uncertain |
| Effect of climate on average demand | Climate change scenarios and research by P Herrington |
| Demand side meter error | Not considered material |

*(Table 5.31)*
*Summary of uncertainties and techniques*

### 5.6.1 Supply Side Uncertainties

Section 5.6.1 summarises the supply side uncertainties calculated within Section 5.3.

i) Due to Industrial Development :

Loss of resource = *n* x 0.3 Ml/d - central estimate, no variability

ii) Due to Sudden Pollution of two sources at risk :

Loss of resource = 4.5 Ml/d x Binomial (1, (1 - $0.98^n$)) + 5 Ml/d x Binomial (1, (1 - $0.98^n$))

iii) Due to Timing of Gradual Source Loss :

The risk of gradual source loss is shown within Table 5.32.

| **Time Slice** | **Volume at Risk (Ml/d) (B = Binomial Distribution)** |
|---|---|
| 2000 | 5 Ml/d x (B (1, 0.1)) + 10 Ml/d x (B (1, 0)) + 3 Ml/d x (B (1, 0.3)) |
| 2005 | 5 Ml/d x (B (1, 0.9)) + 10 Ml/d x (B (1, 0.5)) + 3 Ml/d x (B (1, 0.4)) |
| 2010 | 5 Ml/d x (B (1, 1)) + 10 Ml/d x (B (1, 1)) + 3 Ml/d x (B (1, 0.5 ))<br>(= 15 Ml/d + 3 Ml/d (B (1, 05.)) |
| 2015 | 5 Ml/d x (B (1, 1)) + 10 Ml/d x (B (1, 1)) + 3 Ml/d x (B (1, 1 ))<br>(= 18 Ml/d) |

*(Table 5.32)*
*Source loss distribution up to and including a specific time slice*
*(values extracted from Table 5.3)*

iv) Due to Planned Outages

| **Year** | **Distribution** |
|---|---|
| 1999/00 | Triang (3.8, 5.05, 7.3) |
| 2000/01 | Triang (6.8, 8.9, 11) |
| 2001/02 | Triang ( 3.2, 4.9, 6.6) |
| 2002/03 | Triang (5.6, 7.1, 8.6) |
| 2003/04 | Triang (3.3, 4.8, 6.3) |

*(Table 5.33)*
*Distribution of planned outages over the medium term*
*(figures are in Ml/d)*
*(extracted from Table 5.7)*

| Year | Distribution |
|---|---|
| 2005 | Triang (2.51, 4.43, 9.39) |
| 2010 | Triang (2.51, 4.43, 9.39) + 4.5 |
| 2015 | Triang (2.51, 4.43, 9.39) |
| 2020 | Triang (2.51, 4.43, 9.39) |

*(Table 5.34)*
*Distribution of planned outages over the longer term*
*(figures are in Ml/d)*
*(extracted from Section 5.3.2)*

v) Unplanned Outages

The distribution for unplanned outages vary by cause of outage and also with time. The initial distributions, extracted from Table 5.8, are shown alongside the projected distributions, in Table 5.35. Distributions beyond 2005 are identical to those in 2005.

| Cause | 2000 | 2005 |
|---|---|---|
| | | |
| Due to economic source use | N(.55, .15) | N (.87, 2.2) |
| Due to electronic-mechanical failure | N (.13, .02) | N (.13, .02) |
| Due to blending problems | N (.02, .005) | Nil |
| Due to water quality | N (1.42, .65) | N (1.42, .65) |
| Due to power failure | N (.2, .04) | N (.2, .04) |

*(Table 5.35)*
*Unplanned outage distribution by cause and time slice*
*for Company A*

vi) Due to Climatic Variation on Average Resource

Direct river abstraction is considered certain within the context of this study. Likewise, the yield of groundwaters is considered exceptionally resilient to change in climate.

The yield of Company A's surface water impounded reservoir is highly variable with climate with a discrete distribution (as shown in Figure 5.3) of: Discrete (80, 75, 70, 65, 60, 55, .39, .36, .19, .11, .04, .01)

The distribution is shown as Figure 5.3.

vii) Due to Climatic Change on Average Resource

There are four climate change models proposed by UKWIR/EA ($1997_b$). These are considered equally likely.

Separate extrapolation has been carried out into the effects of each of the UKWIR/EA ($1997_b$) models on average yield and the interpretative effect of the yield changes across the range of point yields is shown in Table 5.11 for Company A.

viii) Due to Source Meter Error

Section 5.3.6 identifies that separate research for Company A gives a distribution for measurement error of Normal (-5.9%, 1.8%) average error of 5.9% under-registration with a standard deviation of 1.8%.

ix) Uncertainty of Yield - Groundwater

Section 5.3.7 suggests a triangular distribution of +/- 10% due to the calculation methods.

### 5.6.2 Demand Side Uncertainties

Other than the sequence of maximum likelihood estimations, carried out to distribute source meter error uncertainty and abnormal climate effects, demand side uncertainties are assigned to demand forecasts. These uncertainties are discussed in Section 5.4.3.6 and presented as Table 5.25.

In addition climate change scenarios derived in Section 5.4.5 are considered in terms of their impact on unmeasured domestic demand. Year on year additions to per capita range between 0.52 l/p/d and 3.81 l/p/d. Each of the three climate change models is assumed equally likely. Table 5.28 demonstrates the full effect of climate change.

## 5.7 MODEL AND MODEL FEATURES

A flow diagram of the simulation process is shown in its simplest form as Figure 5.9. The flow diagram shows the property of linear complexity, inherent within the simulation process. Linear complexity is discussed in Section 3.3.2.

As discussed in Chapter 3 the model uses the "@Risk" tool as a bolt on to a standard Lotus 1-2-3 spreadsheet. Each uncertainty is described as a statistical distribution, either as a continuous distribution if sufficient data or theory exists, or as a discrete distribution. Simple events with only two outcomes, i.e. they either happen or not, are described either using the binomial distribution with one sample taken or using a discrete distribution with two event alternatives.

### 5.7.1 General Model Form

The spreadsheet for the supply-demand risk simulation takes the form of a series of discrete simulations across a number of future time horizons, or slices. Uncertainties within the supply-demand equation are referred to as input variables and the balance between supply and demand is the output variable.

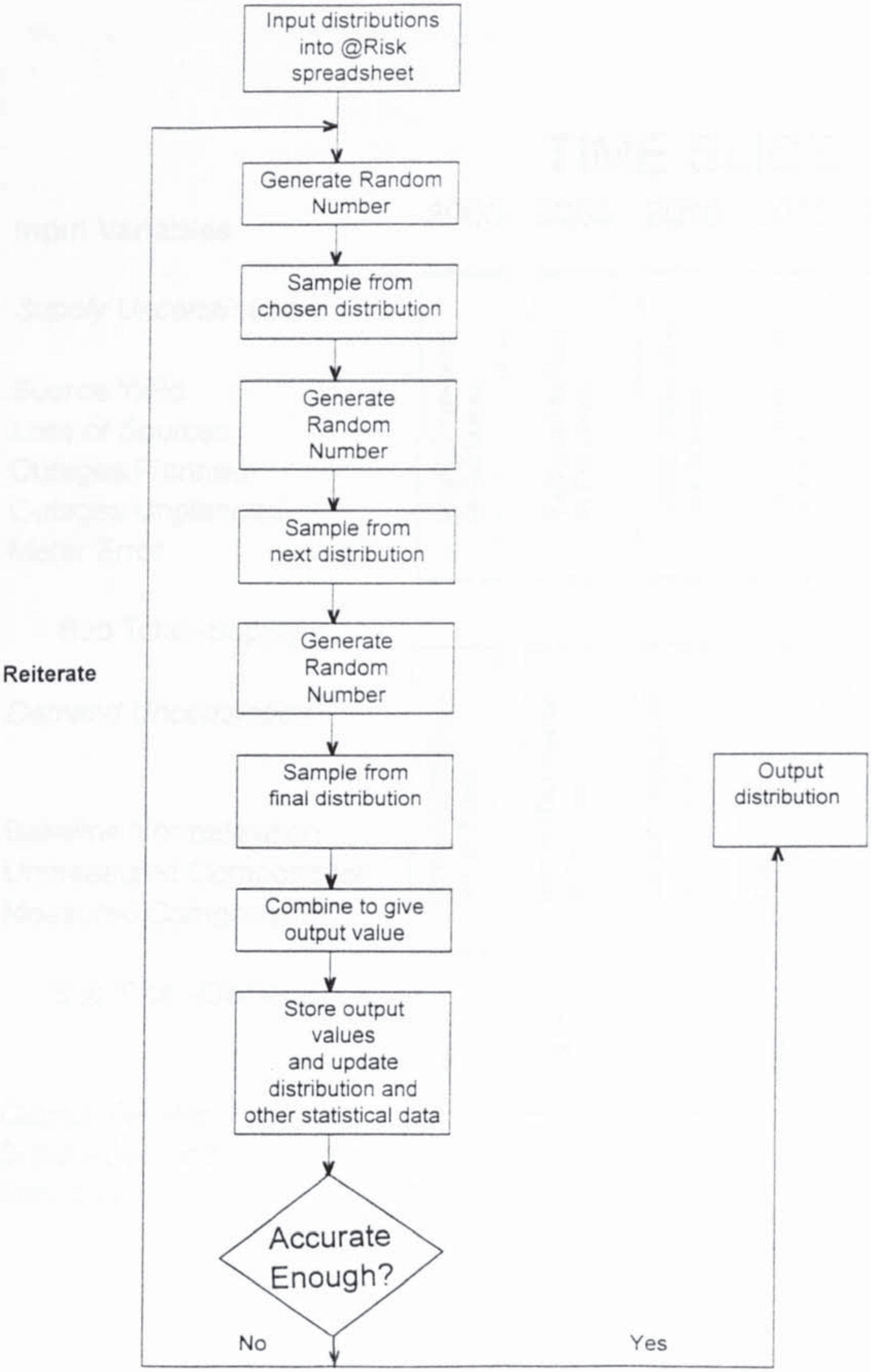
Visually, the spreadsheet will be constructed as shown in Figure 5.10.

### 5.7.2 Sensitivity Analysis

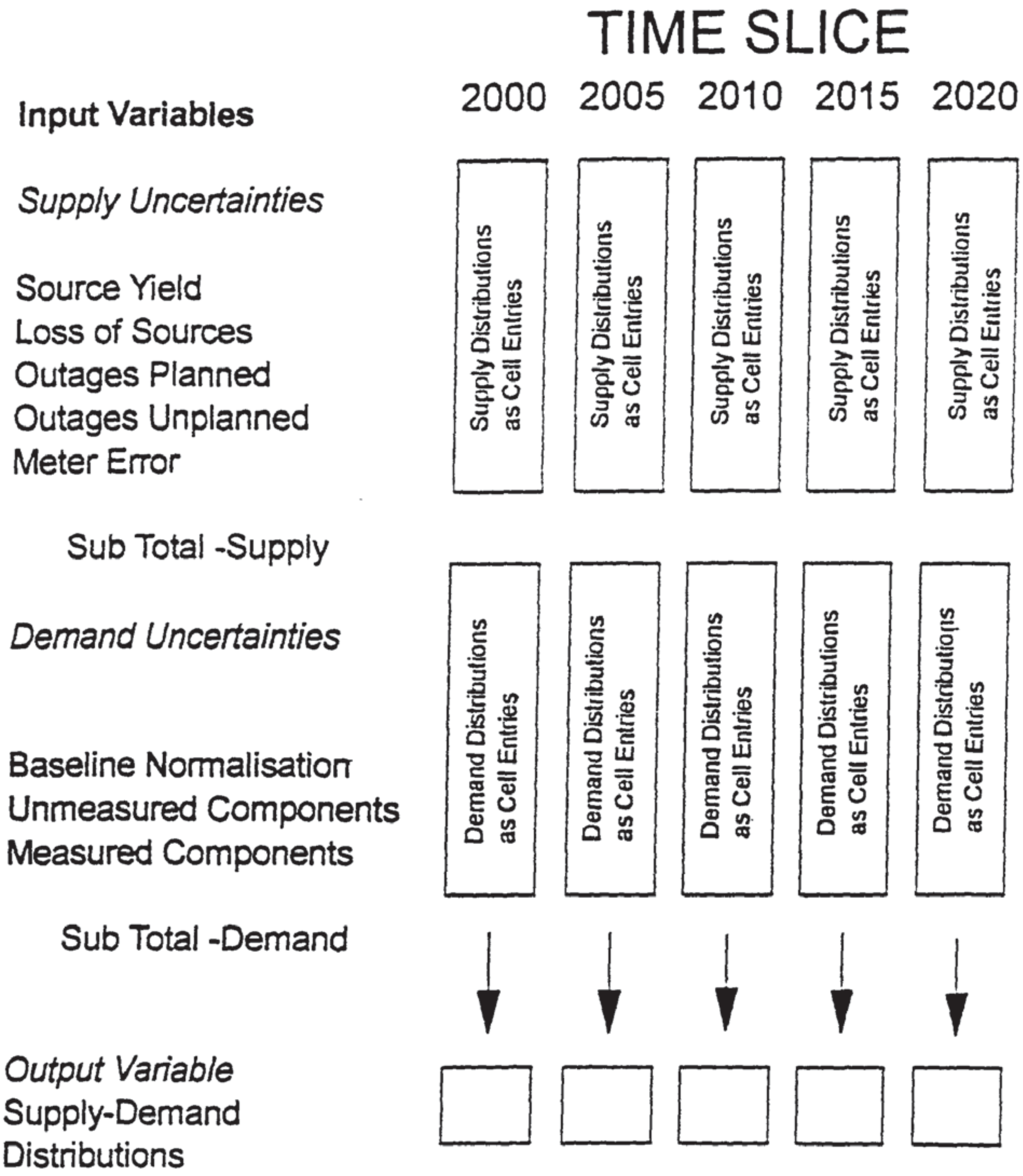
Chapter 4 identified sources of uncertainty to be taken forward to the quantification in Chapter 5. It may be an advantage, however, to reduce the number of uncertainties for various reasons; in particular:-

i) the larger the model, the greater the run time,

ii) a large number of relatively insignificant variables can distort the model relationship in terms of identifying which variables are most important. If the most critical uncertainties cannot be properly identified, then any future attempt to reduce uncertainty by improving accuracy may be misdirected.



*(Figure 5.9)*
*Risk analysis model for the supply-demand equation*
*Flow diagram of simulation process*



*(Figure 5.10)*
*General model form Risk Analysis spreadsheet model*
*for the supply-demand equation*

The '@Risk' software carries out Stepwise Regression (Palisade Corporation, 1995) on the relationship between the input variables and the output, highlighting which variables have the most significant effect. This process involves calculating the correlation co-efficient between each input and the output distribution; noting that the higher the correlation, the greater the significance.

The ranking of those uncertainties of considerable significance will guide Chapters 7 and 8 in the discussion of reducing uncertainty.

### 5.7.3 Scenario Analysis

Within @Risk, scenario analysis attempts to identify groups of uncertainties defining a particular output event. Examples might be:-

i) a resource surplus occurs when outages are low and yield is high,
ii) a resource deficit occurs when outages are high and yield is low.

For the supply-demand example explored within this research, these relationships are essentially obvious and will, therefore, not form part of the analysis within Chapter 6.

### 5.7.4 Convergence and Accuracy

Section 5.7.2 notes the benefit of reducing the number of uncertainties in avoiding unnecessary computer run times. Likewise, there is benefit in optimising the number of iterations.

Perhaps, even more important, the output distribution by itself gives no indication of how accurate it is. For example, whether the accuracy, essentially the distribution parameters, would change significantly if the number of iterations increased. Without such a measure of accuracy the analyst would start with an instinctive view of the number of iterations needed and then increase the number of iterations until the result shows no material change. Likewise, the number of iterations might be decreased until a material change is observed if the analyst starts the exercise with too many iterations. The key is to define the required level of accuracy of the output distribution.

For the example within this research, accuracy will be taken to be sufficient when the addition of 100 iterations changes the parameters of the output distribution by less than 2%. There is no obvious scientific reason for this choice, except that of experience. This suggests that an accuracy substantially better than 2% tends to produce excessive numbers of iterations and consequent run times.

The parameters of the output distribution to be monitored during convergence are:-

i) all 5% incremental percentiles (0% to 100%),

ii) mean,

iii) standard deviation.

### 5.7.5 Errors of Omission

In classical multiple regression it is the significance of the dependent variables which influence the accuracy of the response function. In this respect the addition of variables does not necessarily improve the accuracy of the model and indeed can have an adverse effect, particularly if multicolinearity occurs. The response function which describes the supply-demand balance, however, is, for the most part, the linear combination of additions or subtractions from the function, rather than the mathematical translation of factors which influence the supply-demand balance.

As such, any factor, particularly those with a non-zero mean, which are omitted from the analysis, will cause a corresponding omission error within the supply-demand balance. Section 1.1 notes that the benefit of a 1 Ml/d water resource lies within the range of £500,000 - £1,000,000 and that uncertainties therefore should be included down to very small levels of significance. However, strictly speaking, an error of omission within the model will mean that the design level of service is under-estimated rather than over-estimated. The cost of omission therefore is not one of over-investing in water resources but more one of providing a sub-standard level of service.

Section 5.4.1 recommends including all non-zero mean uncertainties within the analysis and also recommends including zero mean uncertainties which have an impact on the output variable of more than 0.1% demand. This recommendation has been carried forward to the spreadsheet in Section 5.7.7.

### 5.7.6 Time Slices for Analysis

Given that the development horizons for water resources planning are invariably medium to long term, then it is considered sufficient to analyse the supply-demand balance at five-year intervals. These intervals are referred to as time slices. Mid-time slice analysis will be confined to demand forecast calculations in order to capture the error within these forecasts on a year by year basis. The time slices are shown within Figure 5.10 as part of the general model form for the supply-demand spreadsheet.

### 5.7.7 Constructed Spreadsheet and Description of Model

Tables 5.37 through to 5.48 show in detail how the spreadsheet model is constructed. Within these tables, each of the numerical cell entries is replaced with the text/formula entry where there is one.

The overall form of the model is presented in Table 5.36 which shows the model divided into five time slices for the years 2000, 2005, 2010, 2015 and 2020. The worksheet itself is divided into two halves across a horizontal axis with the supply side inputs and losses in the upper part of the sheet and demand forecasts in the lower half. The worksheet begins by considering values during the base year, 1998; in particular the reconciliation of source meter error, any unusual climates during the year and any difference between the sum of individual components of demand when compared to distribution input.

The worksheet contains several particular features which will be described by reference to Tables 5.37 through 5.48 as follows:

i) reconciliation phase,
ii) demand forecasts for the year 1999 and 2000,
iii) time slice for the year 2000 which assumes the absence of climate change. Climate change on the supply side is assumed to be present for the first time in 2015. Climate change on the demand side is assumed for the first time in 2005,
iv) interim demand forecasts for the years 2001 to 2004,
v) repeat calculations for period 2005 to 2014,
vi) time slice calculation for the year 2015 which assumes the presence of climate, change for both water resources and water demand. For water resources the worksheet sample is from one of four climate change models.

**The reconciliation stage (table 5.37 and table 5.38)**

Table 5.37 shows the content of the worksheet in text form through columns A, B, C and D. The pre-normalised demands for 1998 are shown in cells D45 through to D62 using the ratios shown in cells B45 through B62. The first stage normalised demands are then calculated, as shown in cells E45 through E62 in Table 5.38. These cell entries are also copied into cells D66 through D82. This process is exactly as shown within Table 5.13.

Using the ratios shown in cells B66 through B83, the demands shown in cells D66 through D82 are then normalised for the effects of unusual climate in exactly the same way as that shown in Table 5.14. The final post-normalised demand is shown in cell C84 and the individual components in cells E68 through E82.

**Demand forecasts for 1999 and 2000 (table 5.39)**

Demand forecasts for the key components of demand are shown in summary form within Table 5.26. The rate of growth or decline within these demand forecasts has been converted within the worksheet into percentage changes on an annual basis. For the years 1999 and 2000 these annual changes are shown within cells G6 through G9. In addition the level of forecasting accuracy for these components of demand is described in Table 5.25. These accuracies have been transferred within the worksheet into cells D3 through D7 within Table 5.37.

The forecasts for the year 1999 are shown within cells G50 through G55 which show that the forecasts contain an element for forecasting uncertainty in addition to an element for growth. Likewise cells G58 through cells G62 build upon the 1999 forecasts to give forecasts for the year 2000. The forecasts for the year 2000 are then carried forward into cell H84 within Table 5.40.

**Time slice for the year 2000 (table 5.40)**

Cells H12 through H23 record uncertainties within supply side losses extracted from Sections 5.3.1, 5.3.2 and 5.3.3. Supply side inputs are shown in cells H28 through H31 noting in particular the discrete probability distribution for the yield of the Company A impounding reservoir as shown in Figure 5.3. The uncertainty surrounding the calculation of groundwater yield, discussed in Section 5.3.7 is recorded in cell H33.

The summation of supply side losses and supply side inputs is recorded in cell H40 which, when added to the demand in cell H84 and to an allowance for climate variation discussed in 5.4.4

gives an initial estimate for the supply-demand balance in cell H89. The overall supply-demand balance for the year 2000 is shown in cell H93.

### Demand Forecasts for 2001 - 2005 (see table 5.41)

This section of the spreadsheet is essentially identical to Table 5.39 which looks at demand forecasts for 1999 and 2000. Forecasting accuracies are shown in cell numbers J50 through J86.

### Time slice for the year 2005 (table 5.42)

Table 5.42 is very similar to Table 5.40 except that the supply side losses recorded within cells K12 through K23 have moved on five years in accordance with Section 5.5. Demand uncertainty due to climate change is included for the first time for this time slice. The impact of climate change on demand is described in Section 5.4.5. The overall supply-demand balance for the year 2005 is shown in cell K93.

### Demand forecasts for 2006 - 2010 (table 5.43)

Table 5.43 is essentially the same as Table 5.41 except that the demand forecast uncertainties described within cells M6 through M10 are different to those within Table 5.41.

### Time slice for the year 2010 (table 5.44)

The time slice for the year 2010 in Table 5.44 is essentially the same as Table 5.42 except that the supply side losses described in cells N12 through N23 have changed in accordance with Section 5.5 and the impact of climate change on demand has changed in accordance with Table 5.28.

### Demand forecast for year 2011 - 2015 (table 5.45)

Table 5.45 is essentially the same as Table 5.43 except that the demand forecast uncertainties described within cells P6 through P10 are different to those within Table 5.43.

**Time slice for the year 2015 (table 5.46)**

The time slice for the year 2015 in Table 5.46 is essentially the same as Table 5.44 except that the supply side losses described in cells Q12 through Q23 have changed in accordance with Section 5.5 and the impact of climate change on demand has changed in accordance with Table 5.28.

**Demand forecast for year 2016 - 2020 (table 5.47)**

Table 5.47 is essentially the same as Table 5.45 except that the demand forecast uncertainties described within cells S6 through S10 are different to those within Table 5.45.

**Time slice for the year 2020 (table 5.48)**

The time slice for the year 2020 in Table 5.48 is essentially the same as Table 5.46 except that the supply side losses described in cells T12 through T23 have changed in accordance with Section 5.5 and the impact of climate change on demand has changed in accordance with Table 5.28.

## 5.8 MODEL SNAPSHOT

Table 5.36 shows the constructed spreadsheet for the supply-demand analysis for Company A prior to simulation. The spreadsheet shows the starting numerical values and, as such, represents the average supply condition and the average demand condition. Figure 5.11 displays graphically the pre-simulation average supply and demand conditions. Figure 5.11 shows that, in the absence of uncertainty, Company A has sufficient resources to meet demand until the year 2019. Clearly it would be inappropriate to use this information other than for comparative purposes.

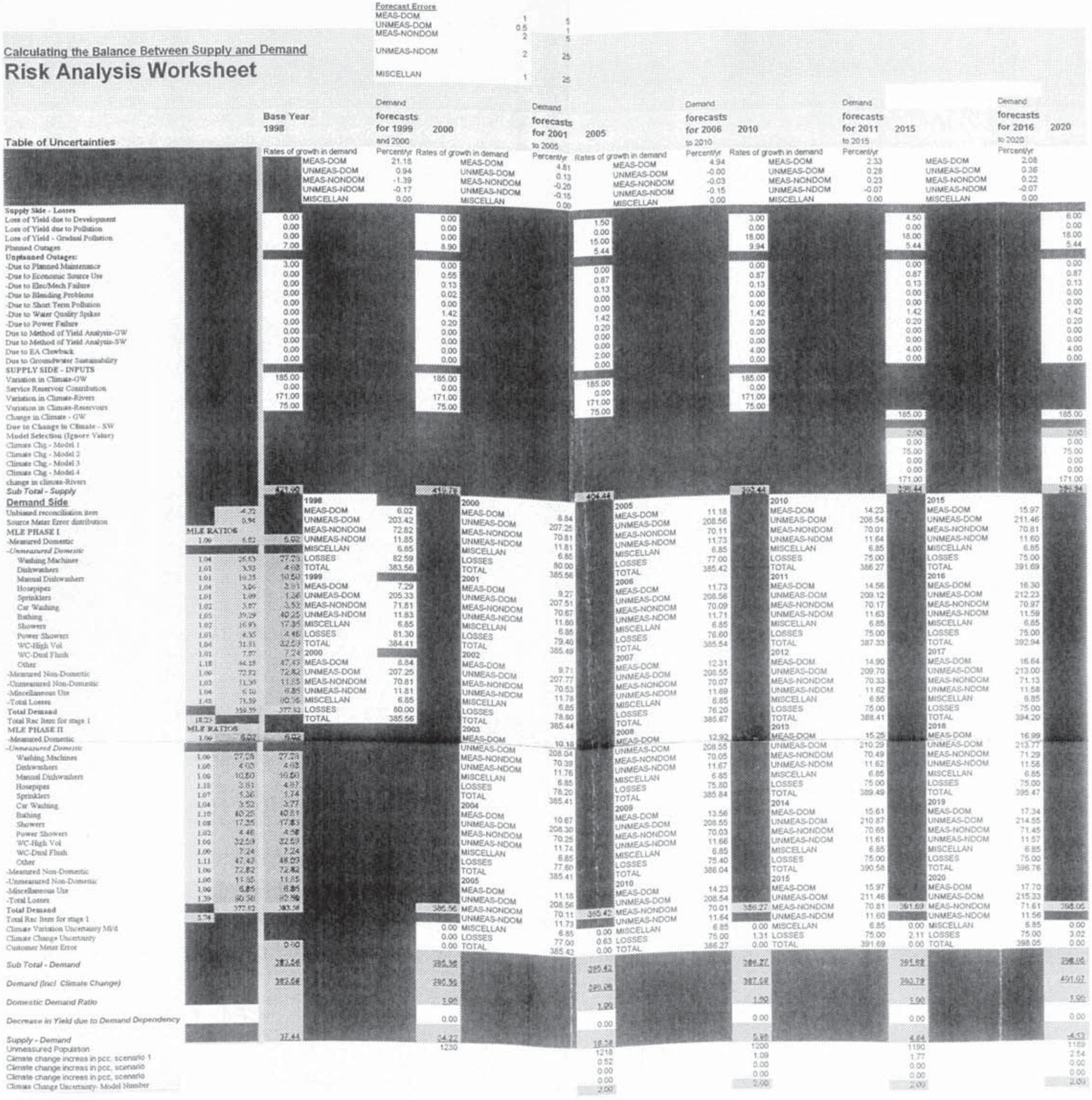
## 5.9 SUMMARY OF CHAPTER

A considerable part of Chapter 5 has been spent considering how the uncertainties described in Chapter 4 have been quantified. In some cases, the evidence has been robust but in others highly subjective. A summary of uncertainties and key techniques used is presented within Table 5.31.

Chapter 5 serves to demonstrate how the theory of uncertainty analysis converts into practice. Through the use of expert panels, available specific research carried out internally and externally by the Company, as well as the compendium of research carried out by UKWIR, it has been possible to develop and construct a spreadsheet model of the supply-demand balance. The spreadsheet model contains numeric fixed entries where uncertainties are absent and probability distributions where uncertainties are present. The chapter concludes by presenting a snapshot of the supply-demand balance prior to simulation. This snapshot, presented as Table 5.36, describes the average supply-demand condition for Company A.

The quantification of uncertainty within Chapter 5 shows that it is possible to apply various different thought processes across a wide range of uncertainties.

Chapter 6 will take the spreadsheet developed in Chapter 5 and apply simulation to the uncertainties within it.



## Calculating the Balance Between Supply and Demand

# Risk Analysis Worksheet

| Forecast Errors | | |
|---|---|---|
| MEAS-DOM | 1 | 5 |
| UNMEAS-DOM | 0.5 | 1 |
| MEAS-NONDOM | 2 | 5 |
| UNMEAS-NDOM | 2 | 25 |
| MISCELLAN | 1 | 25 |

| Rates of growth in demand | Demand forecasts for 1999 and 2000 Percent/yr | Demand forecasts for 2001 to 2005 Percent/yr | Demand forecasts for 2006 to 2010 Percent/yr | Demand forecasts for 2011 to 2015 Percent/yr | Demand forecasts for 2016 to 2020 Percent/yr |
|---|---|---|---|---|---|
| MEAS-DOM | 21.18 | 4.81 | 4.94 | 2.33 | 2.08 |
| UNMEAS-DOM | 0.94 | 0.13 | -0.00 | 0.28 | 0.36 |
| MEAS-NONDOM | -1.39 | -0.20 | -0.03 | 0.23 | 0.22 |
| UNMEAS-NDOM | -0.17 | -0.15 | -0.15 | -0.07 | -0.07 |
| MISCELLAN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| Table of Uncertainties | Base Year 1998 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|
| **Supply Side - Losses** | | | | | | |
| Loss of Yield due to Development | 0.00 | 0.00 | 1.50 | 3.00 | 4.50 | 6.00 |
| Loss of Yield due to Pollution | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Loss of Yield - Gradual Pollution | 0.00 | 0.00 | 15.00 | 18.00 | 18.00 | 18.00 |
| Planned Outages | 7.00 | 8.90 | 5.44 | 9.94 | 5.44 | 5.44 |
| **Unplanned Outages:** | | | | | | |
| -Due to Planned Maintenance | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -Due to Economic Source Use | 0.00 | 0.55 | 0.87 | 0.87 | 0.87 | 0.87 |
| -Due to Elec/Mech Failure | 0.00 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| -Due to Blending Problems | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| -Due to Short Term Pollution | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -Due to Water Quality Spikes | 0.00 | 1.42 | 1.42 | 1.42 | 1.42 | 1.42 |
| -Due to Power Failure | 0.00 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Due to Method of Yield Analysis-GW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Due to Method of Yield Analysis-SW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Due to EA Clawback | 0.00 | 0.00 | 2.00 | 4.00 | 4.00 | 4.00 |
| Due to Groundwater Sustainability | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **SUPPLY SIDE - INPUTS** | | | | | | |
| Variation in Climate-GW | 185.00 | 185.00 | 185.00 | 185.00 | | |
| Service Reservoir Contribution | 0.00 | 0.00 | 0.00 | 0.00 | | |
| Variation in Climate-Rivers | 171.00 | 171.00 | 171.00 | 171.00 | | |
| Variation in Climate-Reservoirs | 75.00 | 75.00 | 75.00 | 75.00 | | |
| Change in Climate - GW | | | | | 185.00 | 185.00 |
| Due to Change in Climate - SW | | | | | | |
| Model Selection (Ignore Value) | | | | | 2.00 | 2.00 |
| Climate Chg - Model 1 | | | | | 0.00 | 0.00 |
| Climate Chg - Model 2 | | | | | 75.00 | 75.00 |
| Climate Chg - Model 3 | | | | | 0.00 | 0.00 |
| Climate Chg - Model 4 | | | | | 0.00 | 0.00 |
| change in climate-Rivers | | | | | 171.00 | 171.00 |
| *Sub Total - Supply* | 421.00 | 419.78 | 404.44 | 393.44 | 398.44 | 396.94 |
| **Demand Side** | | | | | | |
| Total Demand | 383.56 | 385.56 | 385.42 | 386.27 | 391.69 | 398.05 |
| Climate Variation Uncertainty Ml/d | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Climate Change Uncertainty | | 0.00 | 0.63 | 1.31 | 2.11 | 3.02 |
| Customer Meter Error | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Sub Total - Demand* | 383.56 | 385.56 | 385.42 | 386.27 | 391.69 | 398.05 |
| *Demand (incl Climate Change)* | 383.56 | 395.56 | 386.06 | 387.48 | 393.79 | 401.07 |
| *Domestic Demand Ratio* | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| *Decrease in Yield due to Demand Dependency* | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Supply - Demand* | 37.44 | 24.22 | 18.38 | 5.96 | 4.64 | -4.13 |
| Unmeasured Population | | 1230 | 1218 | 1200 | 1190 | 1169 |
| Climate change increas in pcc, scenario 1 | | | 0.52 | 1.09 | 1.77 | 2.54 |
| Climate change increas in pcc, scenario | | | 0.00 | 0.00 | 0.00 | 0.00 |
| Climate change increas in pcc, scenario | | | 0.00 | 0.00 | 0.00 | 0.00 |
| Climate Change Uncertainty- Model Number | | | 2.00 | 2.00 | 2.00 | 2.00 |

| Demand Side | MLE RATIOS | | |
|---|---|---|---|
| Unbiased reconciliation item | | 4.32 | |
| Source Meter Error distribution | | 0.94 | |
| **MLE PHASE I** | | | |
| -Measured Domestic | 1.00 | 6.02 | 6.02 |
| *-Unmeasured Domestic* | | | |
| Washing Machines | 1.04 | 26.63 | 27.73 |
| Dishwashers | 1.01 | 3.93 | 4.02 |
| Manual Dishwashers | 1.01 | 10.35 | 10.50 |
| Hosepipes | 1.04 | 3.66 | 3.81 |
| Sprinklers | 1.01 | 1.09 | 1.26 |
| Car Washing | 1.02 | 3.87 | 3.52 |
| Bathing | 1.05 | 39.29 | 40.25 |
| Showers | 1.02 | 16.93 | 17.35 |
| Power Showers | 1.01 | 4.35 | 4.46 |
| WC-High Vol | 1.04 | 31.81 | 32.53 |
| WC-Dual Flush | 1.01 | 7.07 | 7.24 |
| Other | 1.18 | 44.15 | 47.43 |
| -Measured Non-Domestic | 1.00 | 72.82 | 72.82 |
| -Unmeasured Non-Domestic | 1.03 | 11.30 | 11.85 |
| -Miscellaneous Use | 1.04 | 6.10 | 6.85 |
| -Total Losses | 1.48 | 71.59 | 80.36 |
| Total Demand | | 359.39 | 377.82 |
| Total Rec Item for stage 1 | 18.23 | | |
| **MLE PHASE II** | | | |
| -Measured Domestic | 1.00 | 6.02 | 6.02 |
| *-Unmeasured Domestic* | | | |
| Washing Machines | 1.00 | 27.28 | 27.28 |
| Dishwashers | 1.00 | 4.03 | 4.03 |
| Manual Dishwashers | 1.00 | 10.50 | 10.50 |
| Hosepipes | 1.18 | 3.81 | 4.87 |
| Sprinklers | 1.07 | 1.36 | 1.74 |
| Car Washing | 1.04 | 3.52 | 3.77 |
| Bathing | 1.10 | 40.25 | 40.81 |
| Showers | 1.08 | 17.35 | 17.83 |
| Power Showers | 1.02 | 4.46 | 4.58 |
| WC-High Vol | 1.00 | 32.59 | 32.59 |
| WC-Dual Flush | 1.00 | 7.24 | 7.24 |
| Other | 1.11 | 47.43 | 48.03 |
| -Measured Non-Domestic | 1.00 | 72.82 | 72.82 |
| -Unmeasured Non-Domestic | 1.00 | 11.85 | 11.85 |
| -Miscellaneous Use | 1.00 | 6.85 | 6.85 |
| -Total Losses | 1.39 | 80.36 | 82.59 |
| Total Demand | | 377.82 | 383.56 |
| Total Rec Item for stage 1 | 3.74 | | |

| | MEAS-DOM | UNMEAS-DOM | MEAS-NONDOM | UNMEAS-NDOM | MISCELLAN | LOSSES | TOTAL |
|---|---|---|---|---|---|---|---|
| 1998 | 6.02 | 203.42 | 72.82 | 11.85 | 6.85 | 82.59 | 383.56 |
| 1999 | 7.29 | 205.33 | 71.81 | 11.83 | 6.85 | 81.30 | 384.41 |
| 2000 | 8.84 | 207.25 | 70.81 | 11.81 | 6.85 | 80.00 | 385.56 |
| 2000 | 8.84 | 207.25 | 70.81 | 11.81 | 6.85 | 80.00 | 385.56 |
| 2001 | 9.27 | 207.51 | 70.67 | 11.80 | 6.85 | 79.40 | 385.49 |
| 2002 | 9.71 | 207.77 | 70.53 | 11.78 | 6.85 | 78.80 | 385.44 |
| 2003 | 10.18 | 208.04 | 70.39 | 11.76 | 6.85 | 78.20 | 385.41 |
| 2004 | 10.67 | 208.30 | 70.25 | 11.74 | 6.85 | 77.60 | 385.41 |
| 2005 | 11.18 | 208.56 | 70.11 | 11.73 | 6.85 | 77.00 | 385.42 |
| 2005 | 11.18 | 208.56 | 70.11 | 11.73 | 6.85 | 77.00 | 385.42 |
| 2006 | 11.73 | 208.56 | 70.09 | 11.71 | 6.85 | 76.60 | 385.54 |
| 2007 | 12.31 | 208.55 | 70.07 | 11.69 | 6.85 | 76.20 | 385.67 |
| 2008 | 12.92 | 208.55 | 70.05 | 11.67 | 6.85 | 75.80 | 385.84 |
| 2009 | 13.56 | 208.55 | 70.03 | 11.66 | 6.85 | 75.40 | 386.04 |
| 2010 | 14.23 | 208.54 | 70.01 | 11.64 | 6.85 | 75.00 | 386.27 |
| 2010 | 14.23 | 208.54 | 70.01 | 11.64 | 6.85 | 75.00 | 386.27 |
| 2011 | 14.56 | 209.12 | 70.17 | 11.63 | 6.85 | 75.00 | 387.33 |
| 2012 | 14.90 | 209.70 | 70.33 | 11.62 | 6.85 | 75.00 | 388.41 |
| 2013 | 15.25 | 210.29 | 70.49 | 11.62 | 6.85 | 75.00 | 389.49 |
| 2014 | 15.61 | 210.87 | 70.65 | 11.61 | 6.85 | 75.00 | 390.58 |
| 2015 | 15.97 | 211.46 | 70.81 | 11.60 | 6.85 | 75.00 | 391.69 |
| 2015 | 15.97 | 211.46 | 70.81 | 11.60 | 6.85 | 75.00 | 391.69 |
| 2016 | 16.30 | 212.23 | 70.97 | 11.59 | 6.85 | 75.00 | 392.94 |
| 2017 | 16.64 | 213.00 | 71.13 | 11.58 | 6.85 | 75.00 | 394.20 |
| 2018 | 16.99 | 213.77 | 71.29 | 11.58 | 6.85 | 75.00 | 395.47 |
| 2019 | 17.34 | 214.55 | 71.45 | 11.57 | 6.85 | 75.00 | 396.76 |
| 2020 | 17.70 | 215.33 | 71.61 | 11.56 | 6.85 | 75.00 | 398.05 |

(Table 5.36)
Constructed spreadsheet for the supply-demand analysis for Company A

|  |  |  |  |
|---|---|---|---|
| 1 | **Risk Analysis Worksheet** |  |  |
| 2 |  | Forecast Errors |  |
| 3 |  | MEAS-DOM | 1 |
| 4 | **Table of Uncertainties** | UNMEAS-DOM | 0.5 |
| 5 |  | MEAS-NONDOM | 2 |
| 6 |  | UNMEAS-NDOM | 2 |
| 7 |  | MISCELLAN | 1 |
| 8 |  |  |  |
| 9 |  |  |  |
| 10 | **Supply Side - Losses** |  |  |
| 11 | Loss of Yield due to Development |  |  |
| 12 | Loss of Yield due to Pollution |  |  |
| 13 | Loss of Yield - Gradual Pollution |  |  |
| 14 | Planned Outages |  |  |
| 15 | **Unplanned Outages:** |  |  |
| 16 | -Due to Planned Maintenance |  |  |
| 17 | -Due to Economic Source Use |  |  |
| 18 | -Due to Elec/Mech Failure |  |  |
| 19 | -Due to Blending Problems |  |  |
| 20 | -Due to Short Term Pollution |  |  |
| 21 | -Due to Water Quality Spikes |  |  |
| 22 | -Due to Power Failure |  |  |
| 23 | Due to Method of Yield Analysis-GW |  |  |
| 24 | Due to Method of Yield Analysis-SW |  |  |
| 25 | Due to EA Clawback |  |  |
| 26 | Due to Groundwater Sustainability |  |  |
| 27 | **SUPPLY SIDE - INPUTS** |  |  |
| 28 | Variation in Climate-GW |  |  |
| 29 | Service Reservoir Contribution |  |  |
| 30 | Variation in Climate-Rivers |  |  |
| 31 | Variation in Climate-Reservoirs |  |  |
| 32 | Change in Climate - GW |  |  |
| 33 | **Due to Change in Climate - SW** |  |  |
| 34 | **Model Selection (Ignore Value)** |  |  |
| 35 | Climate Chg - Model 1 |  |  |
| 36 | Climate Chg - Model 2 |  |  |
| 37 | Climate Chg - Model 3 |  |  |
| 38 | Climate Chg - Model 4 |  |  |
| 39 | change in climate-Rivers |  |  |
| 40 | ***Sub Total - Supply*** |  |  |
| 41 | **Demand Side** |  |  |
| 42 | Unbiased reconciliation item |  | -4.32 |
| 43 | Source Meter Error distribution |  | @<<RISK>>NORMAL(0.941,0.018) |
| 44 | **MLE PHASE I** | **MLE RATIOS** |  |
| 45 | -Measured Domestic | 1 | 6.02 |
| 46 | *-Unmeasured Domestic* |  |  |
| 47 | Washing Machines | 1.0358 | 26.63 |
| 48 | Dishwashers | 1.0053 | 3.93 |
| 49 | Manual Dishwashers | 1.0139 | 10.35 |
| 50 | Hosepipes | 1.0411 | 3.06 |
| 51 | Sprinklers | 1.0147 | 1.09 |
| 52 | Car Washing | 1.0248 | 3.07 |
| 53 | Bathing | 1.0528 | 39.29 |
| 54 | Showers | 1.0228 | 16.93 |
| 55 | Power Showers | 1.0058 | 4.35 |
| 56 | WC-High Vol | 1.0428 | 31.81 |
| 57 | WC-Dual Flush | 1.0095 | 7.07 |
| 58 | Other | 1.1782 | 44.18 |
| 59 | -Measured Non-Domestic | 1 | 72.82 |
| 60 | -Unmeasured Non-Domestic | 1.0304 | 11.3 |
| 61 | -Miscellaneous Use | 1.041 | 6.1 |
| 62 | -Total Losses | 1.4812 | 71.59 |
| 63 | **Total Demand** |  | @SUM(C45..C62) |
| 64 | Total Rec Item for stage 1 | +C63/($C$43)-C63+$C$42 |  |
| 65 | **MLE PHASE II** | **MLE RATIOS** |  |
| 66 | -Measured Domestic | 1 | 6.02 |
| 67 | *-Unmeasured Domestic* |  |  |
| 68 | Washing Machines | 1 | 27.28 |
| 69 | Dishwashers | 1 | 4.03 |
| 70 | Manual Dishwashers | 1 | 10.60 |
| 71 | Hosepipes | 1.1845 | 3.81 |
| 72 | Sprinklers | 1.0657 | 1.36 |
| 73 | Car Washing | 1.0426 | 3.52 |
| 74 | Bathing | 1.0975 | 40.25 |
| 75 | Showers | 1.084 | 17.35 |
| 76 | Power Showers | 1.0216 | 4.46 |
| 77 | WC-High Vol | 1 | 32.59 |
| 78 | WC-Dual Flush | 1 | 7.24 |
| 79 | Other | 1.1149 | 47.43 |
| 80 | -Measured Non-Domestic | 1 | 72.82 |
| 81 | -Unmeasured Non-Domestic | 1 | 11.85 |
| 82 | -Miscellaneous Use | 1 | 6.85 |
| 83 | -Total Losses | 1.3892 | 80.36 |
| 84 | **Total Demand** |  | @SUM(C66..C83) |
| 85 | Total Rec Item for stage 1 | 5.74 |  |
| 86 | Climate Variation Uncertainty Ml/d |  |  |
| 87 | Climate Change Uncertainty |  |  |
| 88 | Customer Meter Error |  |  |
| 89 | ***Sub Total - Demand*** |  |  |
| 90 | ***Demand (Incl Climate Change)*** |  |  |
| 91 | ***Domestic Demand Ratio*** |  |  |
| 92 | ***Decrease in Yield due to Demand Dependency*** |  |  |
| 93 | ***Supply - Demand*** |  |  |
| 94 | Unmeasured Population |  |  |
| 95 | Climate change increas in pcc, scenario 1 |  |  |
| 96 | Climate change increas in pcc, scenario |  |  |
| 97 | Climate change increas in pcc, scenario |  |  |
| 98 | Climate Change Uncertainty- Model Number |  |  |

*(Table 5.37)*
*Constructed spreadsheet for the supply-demand balance for Company A*
*Columns through to D*
*Sheet 1 of 12*

| A | A | E | F |
|---|---|---|---|
| 1 | **Risk Analysis Worksheet** | | |
| 2 | | Base Year | |
| 3 | | 1998 | |
| 4 | **Table of Uncertainties** | | |
| 5 | | Rates of growth in demand | |
| 6 | | | |
| 7 | | | |
| 8 | | | MEAS-NONDOM |
| 9 | | | UNMEAS-NDOM |
| 10 | **Supply Side - Losses** | | MISCELLAN |
| 11 | Loss of Yield due to Development | 0 | |
| 12 | Loss of Yield due to Pollution | 0 | |
| 13 | Loss of Yield - Gradual Pollution | 0 | |
| 14 | Planned Outages | 7 | |
| 15 | **Unplanned Outages:** | | |
| 16 | -Due to Planned Maintenance | 3 | |
| 17 | -Due to Economic Source Use | 0 | |
| 18 | -Due to Elec/Mech Failure | 0 | |
| 19 | -Due to Blending Problems | 0 | |
| 20 | -Due to Short Term Pollution | 0 | |
| 21 | -Due to Water Quality Spikes | 0 | |
| 22 | -Due to Power Failure | 0 | |
| 23 | Due to Method of Yield Analysis-GW | 0 | |
| 24 | Due to Method of Yield Analysis-SW | 0 | |
| 25 | Due to EA Clawback | 0 | |
| 26 | Due to Groundwater Sustainability | 0 | |
| 27 | **SUPPLY SIDE - INPUTS** | | |
| 28 | Variation in Climate-GW | 185 | |
| 29 | Service Reservoir Contribution | 0 | |
| 30 | Variation in Climate-Rivers | 171 | |
| 31 | Variation in Climate-Reservoirs | @<<RISK>>DISCRETE(55,60,65,70,75,80,0.01,0.04,0.11,0.19,0.26,0.39) | |
| 32 | Change in Climate - GW | | |
| 33 | **Due to Change in Climate - SW** | | |
| 34 | **Model Selection (Ignore Value)** | | |
| 35 | Climate Chg - Model 1 | | |
| 36 | Climate Chg - Model 2 | | |
| 37 | Climate Chg - Model 3 | | |
| 38 | Climate Chg - Model 4 | | |
| 39 | change in climate-Rivers | | |
| 40 | ***Sub Total - Supply*** | -@SUM(E11..E26)+@SUM(E26..E38)-E34 | |
| 41 | Demand Side | | 1998 |
| 42 | Unbiased reconciliation item | | MEAS-DOM |
| 43 | Source Meter Error distribution | | UNMEAS-DOM |
| 44 | **MLE PHASE I** | | MEAS-NONDOM |
| 45 | -Measured Domestic | +C45+(B45-1)*$B$64 | UNMEAS-NDOM |
| 46 | *-Unmeasured Domestic* | | MISCELLAN |
| 47 | Washing Machines | +C47+(B47-1)*$B$64 | LOSSES |
| 48 | Dishwashers | +C48+(B48-1)*$B$64 | TOTAL |
| 49 | Manual Dishwashers | +C49+(B49-1)*$B$64 | 1999 |
| 50 | Hosepipes | +C50+(B50-1)*$B$64 | MEAS-DOM |
| 51 | Sprinklers | +C51+(B51-1)*$B$64 | UNMEAS-DOM |
| 52 | Car Washing | +C52+(B52-1)*$B$64 | MEAS-NONDOM |
| 53 | Bathing | +C53+(B53-1)*$B$64 | UNMEAS-NDOM |
| 54 | Showers | +C54+(B54-1)*$B$64 | MISCELLAN |
| 55 | Power Showers | +C55+(B55-1)*$B$64 | LOSSES |
| 56 | WC-High Vol | +C56+(B56-1)*$B$64 | TOTAL |
| 57 | WC-Dual Flush | +C57+(B57-1)*$B$64 | 2000 |
| 58 | Other | +C58+(B58-1)*$B$64 | MEAS-DOM |
| 59 | -Measured Non-Domestic | +C59+(B59-1)*$B$64 | UNMEAS-DOM |
| 60 | -Unmeasured Non-Domestic | +C60+(B60-1)*$B$64 | MEAS-NONDOM |
| 61 | -Miscellaneous Use | +C61+(B61-1)*$B$64 | UNMEAS-NDOM |
| 62 | -Total Losses | +C62+(B62-1)*$B$64 | MISCELLAN |
| 63 | **Total Demand** | @SUM(E45..E62) | LOSSES |
| 64 | Total Rec Item for stage 1 | | TOTAL |
| 65 | **MLE PHASE II** | | |
| 66 | -Measured Domestic | +C66+(B66-1)*$B$85 | |
| 67 | *-Unmeasured Domestic* | | |
| 68 | Washing Machines | +C68+(B68-1)*$B$85 | |
| 69 | Dishwashers | +C69+(B69-1)*$B$85 | |
| 70 | Manual Dishwashers | +C70+(B70-1)*$B$85 | |
| 71 | Hosepipes | +C71+(B71-1)*$B$85 | |
| 72 | Sprinklers | +C72+(B72-1)*$B$85 | |
| 73 | Car Washing | +C73+(B73-1)*$B$85 | |
| 74 | Bathing | +C74+(B74-1)*$B$85 | |
| 75 | Showers | +C75+(B75-1)*$B$85 | |
| 76 | Power Showers | +C76+(B76-1)*$B$85 | |
| 77 | WC-High Vol | +C77+(B77-1)*$B$85 | |
| 78 | WC-Dual Flush | +C78+(B78-1)*$B$85 | |
| 79 | Other | +C79+(B79-1)*$B$85 | |
| 80 | -Measured Non-Domestic | +C80+(B80-1)*$B$85 | |
| 81 | -Unmeasured Non-Domestic | +C81+(B81-1)*$B$85 | |
| 82 | -Miscellaneous Use | +C82+(B82-1)*$B$85 | |
| 83 | -Total Losses | +C83+(B83-1)*$B$85 | |
| 84 | **Total Demand** | @SUM(E66..E83) | |
| 85 | Total Rec Item for stage 1 | | |
| 86 | Climate Variation Uncertainty Ml/d | | |
| 87 | Climate Change Uncertainty | | |
| 88 | Customer Meter Error | 0 | |
| 89 | ***Sub Total - Demand*** | +E84 | |
| 90 | ***Demand (Incl Climate Change)*** | +E89+E87 | |
| 91 | ***Domestic Demand Ratio*** | | |
| 92 | ***Decrease in Yield due to Demand Dependency*** | | |
| 93 | ***Supply - Demand*** | +E40-E90 | |
| 94 | Unmeasured Population | | |
| 95 | Climate change increas in pcc, scenario 1 | | |
| 96 | Climate change increas in pcc, scenario | | |
| 97 | Climate change increas in pcc, scenario | | |
| 98 | Climate Change Uncertainty- Model Number | | |

*(Table 5.38)*

*Constructed spreadsheet for the supply-demand balance for Company A*

*Columns through to D*

*Sheet 2 of 12*

| A | A | G |
|---|---|---|
| 1 | **Risk Analysis Worksheet** | |
| 2 | | Dem fcasts |
| 3 | | for 1999 |
| 4 | **Table of Uncertainties** | and 2000 |
| 5 | | Percent/yr |
| 6 | | 21.179 |
| 7 | | 0.937 |
| 8 | | -1.389777 |
| 9 | | -0.1689 |
| 10 | **Supply Side - Losses** | 0 |
| 11 | Loss of Yield due to Development | |
| 12 | Loss of Yield due to Pollution | |
| 13 | Loss of Yield - Gradual Pollution | |
| 14 | Planned Outages | |
| 15 | **Unplanned Outages:** | |
| 16 | -Due to Planned Maintenance | |
| 17 | -Due to Economic Source Use | |
| 18 | -Due to Elec/Mech Failure | |
| 19 | -Due to Blending Problems | |
| 20 | -Due to Short Term Pollution | |
| 21 | -Due to Water Quality Spikes | |
| 22 | -Due to Power Failure | |
| 23 | Due to Method of Yield Analysis-GW | |
| 24 | Due to Method of Yield Analysis-SW | |
| 25 | Due to EA Clawback | |
| 26 | Due to Groundwater Sustainability | |
| 27 | **SUPPLY SIDE - INPUTS** | |
| 28 | Variation in Climate-GW | |
| 29 | Service Reservoir Contribution | |
| 30 | Variation in Climate-Rivers | |
| 31 | Variation in Climate-Reservoirs | |
| 32 | Change in Climate - GW | |
| 33 | **Due to Change in Climate - SW** | |
| 34 | **Model Selection (Ignore Value)** | |
| 35 | Climate Chg - Model 1 | |
| 36 | Climate Chg - Model 2 | |
| 37 | Climate Chg - Model 3 | |
| 38 | Climate Chg - Model 4 | |
| 39 | change in climate-Rivers | |
| 40 | ***Sub Total - Supply*** | |
| 41 | **Demand Side** | |
| 42 | Unbiased reconciliation item | +E66 |
| 43 | Source Meter Error distribution | (@SUM(E68..E79)) |
| 44 | **MLE PHASE I** | +E80 |
| 45 | -Measured Domestic | +E81 |
| 46 | -*Unmeasured Domestic* | +E82 |
| 47 | Washing Machines | +E83 |
| 48 | Dishwashers | @SUM(G42..G47) |
| 49 | Manual Dishwashers | |
| 50 | Hosepipes | (G42*(1+G6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 51 | Sprinklers | (G43*(1+G7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 52 | Car Washing | (G44*(1+G8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 53 | Bathing | (G45*(1+G9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 54 | Showers | (G46*(1+G10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 55 | Power Showers | 81.3 |
| 56 | WC-High Vol | @SUM(G50..G55) |
| 57 | WC-Dual Flush | |
| 58 | Other | (G50*(1+G6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 59 | -Measured Non-Domestic | (G51*(1+G7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 60 | -Unmeasured Non-Domestic | (G52*(1+G8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 61 | -Miscellaneous Use | (G53*(1+G9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 62 | -Total Losses | (G54*(1+G10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 63 | **Total Demand** | 80 |
| 64 | Total Rec Item for stage 1 | @SUM(G58..G63) |
| 65 | **MLE PHASE II** | |
| 66 | -Measured Domestic | |
| 67 | -*Unmeasured Domestic* | |
| 68 | Washing Machines | |
| 69 | Dishwashers | |
| 70 | Manual Dishwashers | |
| 71 | Hosepipes | |
| 72 | Sprinklers | |
| 73 | Car Washing | |
| 74 | Bathing | |
| 75 | Showers | |
| 76 | Power Showers | |
| 77 | WC-High Vol | |
| 78 | WC-Dual Flush | |
| 79 | Other | |
| 80 | -Measured Non-Domestic | |
| 81 | -Unmeasured Non-Domestic | |
| 82 | -Miscellaneous Use | |
| 83 | -Total Losses | |
| 84 | **Total Demand** | |
| 85 | Total Rec Item for stage 1 | |
| 86 | Climate Variation Uncertainty Ml/d | |
| 87 | Climate Change Uncertainty | |
| 88 | Customer Meter Error | |
| 89 | ***Sub Total - Demand*** | |
| 90 | ***Demand (Incl Climate Change)*** | |
| 91 | ***Domestic Demand Ratio*** | |
| 92 | ***Decrease in Yield due to Demand Dependency*** | |
| 93 | ***Supply - Demand*** | |
| 94 | Unmeasured Population | |
| 95 | Climate change increas in pcc, scenario 1 | |
| 96 | Climate change increas in pcc, scenario | |
| 97 | Climate change increas in pcc, scenario | |
| 98 | Climate Change Uncertainty- Model Number | |

*(Table 5.39)*

*Constructed spreadsheet for the supply-demand balance for Company A*
*Columns through to D*
*Sheet 3 of 12*

| A | A | H | |
|---|---|---|---|
| 1 | **Risk Analysis Worksheet** | | |
| 2 | | | |
| 3 | | 2000 | |
| 4 | **Table of Uncertainties** | | |
| 5 | [redacted] | Rates of growth in demand | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | **Supply Side - Losses** | | |
| 11 | Loss of Yield due to Development | | 0 |
| 12 | Loss of Yield due to Pollution | 4.5*@<<RISK>>BINOMIAL(1,0)+5*@<<RISK>>BINOMIAL(1,0) | |
| 13 | Loss of Yield - Gradual Pollution | 5*@<<RISK>>BINOMIAL(1,0.1)+10*@<<RISK>>BINOMIAL(1,0)+3*@<<RISK>>BINOMIAL(1,0.3) | |
| 14 | Planned Outages | @<<RISK>>TRIANG(6.8,8.9,11) | |
| 15 | **Unplanned Outages:** | [redacted] | |
| 16 | -Due to Planned Maintenance | | 0 |
| 17 | -Due to Economic Source Use | @<<RISK>>NORMAL(0.55,0.15) | |
| 18 | -Due to Elec/Mech Failure | @<<RISK>>NORMAL(0.13,0.02) | |
| 19 | -Due to Blending Problems | @<<RISK>>NORMAL(0.02,0.005) | |
| 20 | -Due to Short Term Pollution | | 0 |
| 21 | -Due to Water Quality Spikes | @<<RISK>>NORMAL(1.42,0.65) | |
| 22 | -Due to Power Failure | @<<RISK>>NORMAL(0.2,0.04) | |
| 23 | Due to Method of Yield Analysis-GW | @<<RISK>>TRIANG(-0.1*H$28,0,0.1*H$28) | |
| 24 | Due to Method of Yield Analysis-SW | | 0 |
| 25 | Due to EA Clawback | | 0 |
| 26 | Due to Groundwater Sustainability | | 0 |
| 27 | **SUPPLY SIDE - INPUTS** | [redacted] | |
| 28 | Variation in Climate-GW | | 185 |
| 29 | Service Reservoir Contribution | | 0 |
| 30 | Variation in Climate-Rivers | | 171 |
| 31 | Variation in Climate-Reservoirs | @<<RISK>>DISCRETE(55,60,65,70,75,80,0.01,0.04,0.11,0.19,0.26,0.39) | |
| 32 | Change in Climate - GW | [redacted] | |
| 33 | **Due to Change in Climate - SW** | | |
| 34 | **Model Selection (Ignore Value)** | | |
| 35 | Climate Chg - Model 1 | | |
| 36 | Climate Chg - Model 2 | | |
| 37 | Climate Chg - Model 3 | | |
| 38 | Climate Chg - Model 4 | | |
| 39 | change in climate-Rivers | | |
| 40 | ***Sub Total - Supply*** | -@SUM(H11..H26)+@SUM(H26..H38)-H34 | |
| 41 | **Demand Side** | [redacted] | |
| 42 | Unbiased reconciliation item | | |
| 43 | Source Meter Error distribution | | |
| 44 | **MLE PHASE I** | | |
| 45 | -Measured Domestic | | |
| 46 | -*Unmeasured Domestic* | | |
| 47 | Washing Machines | | |
| 48 | Dishwashers | | |
| 49 | Manual Dishwashers | | |
| 50 | Hosepipes | | |
| 51 | Sprinklers | | |
| 52 | Car Washing | | |
| 53 | Bathing | | |
| 54 | Showers | | |
| 55 | Power Showers | | |
| 56 | WC-High Vol | | |
| 57 | WC-Dual Flush | | |
| 58 | Other | | |
| 59 | -Measured Non-Domestic | | |
| 60 | -Unmeasured Non-Domestic | | |
| 61 | -Miscellaneous Use | | |
| 62 | -Total Losses | | |
| 63 | **Total Demand** | | |
| 64 | Total Rec Item for stage 1 | | |
| 65 | **MLE PHASE II** | | |
| 66 | -Measured Domestic | | |
| 67 | -*Unmeasured Domestic* | | |
| 68 | Washing Machines | | |
| 69 | Dishwashers | | |
| 70 | Manual Dishwashers | | |
| 71 | Hosepipes | | |
| 72 | Sprinklers | | |
| 73 | Car Washing | | |
| 74 | Bathing | | |
| 75 | Showers | | |
| 76 | Power Showers | | |
| 77 | WC-High Vol | | |
| 78 | WC-Dual Flush | | |
| 79 | Other | | |
| 80 | -Measured Non-Domestic | | |
| 81 | -Unmeasured Non-Domestic | | |
| 82 | -Miscellaneous Use | | |
| 83 | -Total Losses | | |
| 84 | **Total Demand** | +G64 | |
| 85 | Total Rec Item for stage 1 | [redacted] | |
| 86 | Climate Variation Uncertainty Ml/d | @<<RISK>>NORMAL(0,(0.0133*G59)) | |
| 87 | Climate Change Uncertainty | | 0 |
| 88 | Customer Meter Error | | 0 |
| 89 | ***Sub Total - Demand*** | +H84 | |
| 90 | ***Demand (Incl Climate Change)*** | +H89+H87 | |
| 91 | ***Domestic Demand Ratio*** | (+G59+H86)/G59 | |
| 92 | ***Decrease in Yield due to Demand Dependency*** | (+H91-1)*410 | |
| 93 | ***Supply - Demand*** | +H40-H90-H92 | |
| 94 | Unmeasured Population | | 1230 |
| 95 | Climate change increas in pcc, scenario 1 | | |
| 96 | Climate change increas in pcc, scenario | | |
| 97 | Climate change increas in pcc, scenario | | |
| 98 | Climate Change Uncertainty- Model Number | | |

*(Table 5.40)*

*Constructed spreadsheet for the supply-demand balance for Company A*
*Columns through to D*
*Sheet 4 of 12*

| A | A | I | J |
|---|---|---|---|
| 1 | **Risk Analysis Worksheet** | | |
| 2 | | | **Dem fcasts** |
| 3 | | | **for 2001** |
| 4 | **Table of Uncertainties** | | to 2005 |
| 5 | [redacted] | | Percent/yr |
| 6 | [redacted] | MEAS-DOM | 4.8088 |
| 7 | [redacted] | UNMEAS-DOM | 0.126 |
| 8 | [redacted] | MEAS-NONDOM | -0.1985 |
| 9 | [redacted] | UNMEAS-NDOM | -0.15 |
| 10 | **Supply Side - Losses** | MISCELLAN | 0 |
| 11 | Loss of Yield due to Development | [redacted] | [redacted] |
| 12 | Loss of Yield due to Pollution | [redacted] | [redacted] |
| 13 | Loss of Yield - Gradual Pollution | [redacted] | [redacted] |
| 14 | Planned Outages | [redacted] | [redacted] |
| 15 | **Unplanned Outages:** | [redacted] | [redacted] |
| 16 | -Due to Planned Maintenance | [redacted] | [redacted] |
| 17 | -Due to Economic Source Use | [redacted] | [redacted] |
| 18 | -Due to Elec/Mech Failure | [redacted] | [redacted] |
| 19 | -Due to Blending Problems | [redacted] | [redacted] |
| 20 | -Due to Short Term Pollution | [redacted] | [redacted] |
| 21 | -Due to Water Quality Spikes | [redacted] | [redacted] |
| 22 | -Due to Power Failure | [redacted] | [redacted] |
| 23 | Due to Method of Yield Analysis-GW | [redacted] | [redacted] |
| 24 | Due to Method of Yield Analysis-SW | [redacted] | [redacted] |
| 25 | Due to EA Clawback | [redacted] | [redacted] |
| 26 | Due to Groundwater Sustainability | [redacted] | [redacted] |
| 27 | **SUPPLY SIDE - INPUTS** | [redacted] | [redacted] |
| 28 | Variation in Climate-GW | [redacted] | [redacted] |
| 29 | Service Reservoir Contribution | [redacted] | [redacted] |
| 30 | Variation in Climate-Rivers | [redacted] | [redacted] |
| 31 | Variation in Climate-Reservoirs | [redacted] | [redacted] |
| 32 | Change in Climate - GW | [redacted] | [redacted] |
| 33 | **Due to Change in Climate - SW** | [redacted] | [redacted] |
| 34 | **Model Selection (Ignore Value)** | [redacted] | [redacted] |
| 35 | Climate Chg - Model 1 | [redacted] | [redacted] |
| 36 | Climate Chg - Model 2 | [redacted] | [redacted] |
| 37 | Climate Chg - Model 3 | [redacted] | [redacted] |
| 38 | Climate Chg - Model 4 | [redacted] | [redacted] |
| 39 | change in climate-Rivers | [redacted] | [redacted] |
| 40 | ***Sub Total - Supply*** | [redacted] | [redacted] |
| 41 | **Demand Side** | **2000** | |
| 42 | Unbiased reconciliation item | MEAS-DOM | +G58 |
| 43 | Source Meter Error distribution | UNMEAS-DOM | +G59 |
| 44 | **MLE PHASE I** | MEAS-NONDOM | +G60 |
| 45 | -Measured Domestic | UNMEAS-NDOM | +G61 |
| 46 | *-Unmeasured Domestic* | MISCELLAN | +G62 |
| 47 | Washing Machines | LOSSES | 80 |
| 48 | Dishwashers | TOTAL | @SUM(J42..J47) |
| 49 | Manual Dishwashers | **2001** | |
| 50 | Hosepipes | MEAS-DOM | (J42*(1+J6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 51 | Sprinklers | UNMEAS-DOM | (J43*(1+J7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 52 | Car Washing | MEAS-NONDOM | (J44*(1+J8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 53 | Bathing | UNMEAS-NDOM | (J45*(1+J9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 54 | Showers | MISCELLAN | (J46*(1+J10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 55 | Power Showers | LOSSES | 79.4 |
| 56 | WC-High Vol | TOTAL | @SUM(J50..J55) |
| 57 | WC-Dual Flush | **2002** | |
| 58 | Other | MEAS-DOM | (J50*(1+J6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 59 | -Measured Non-Domestic | UNMEAS-DOM | (J51*(1+J7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 60 | -Unmeasured Non-Domestic | MEAS-NONDOM | (J52*(1+J8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 61 | -Miscellaneous Use | UNMEAS-NDOM | (J53*(1+J9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 62 | -Total Losses | MISCELLAN | (J54*(1+J10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 63 | **Total Demand** | LOSSES | 78.8 |
| 64 | Total Rec Item for stage 1 | TOTAL | @SUM(J58..J63) |
| 65 | **MLE PHASE II** | **2003** | |
| 66 | -Measured Domestic | MEAS-DOM | (J58*(1+J6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 67 | *-Unmeasured Domestic* | UNMEAS-DOM | (J59*(1+J7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 68 | Washing Machines | MEAS-NONDOM | (J60*(1+J8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 69 | Dishwashers | UNMEAS-NDOM | (J61*(1+J9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 70 | Manual Dishwashers | MISCELLAN | (J62*(1+J10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 71 | Hosepipes | LOSSES | 78.2 |
| 72 | Sprinklers | TOTAL | @SUM(J66..J71) |
| 73 | Car Washing | **2004** | |
| 74 | Bathing | MEAS-DOM | (J66*(1+J6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 75 | Showers | UNMEAS-DOM | (J67*(1+J7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 76 | Power Showers | MEAS-NONDOM | (J68*(1+J8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 77 | WC-High Vol | UNMEAS-NDOM | (J69*(1+J9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 78 | WC-Dual Flush | MISCELLAN | (J70*(1+J10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 79 | Other | LOSSES | 77.6 |
| 80 | -Measured Non-Domestic | TOTAL | @SUM(J74..J79) |
| 81 | -Unmeasured Non-Domestic | **2005** | |
| 82 | -Miscellaneous Use | MEAS-DOM | (J74*(1+J6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 83 | -Total Losses | UNMEAS-DOM | (J75*(1+J7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 84 | **Total Demand** | MEAS-NONDOM | (J76*(1+J8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 85 | Total Rec Item for stage 1 | UNMEAS-NDOM | (J77*(1+J9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 86 | Climate Variation Uncertainty Ml/d | MISCELLAN | (J78*(1+J10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 87 | Climate Change Uncertainty | LOSSES | 77 |
| 88 | Customer Meter Error | TOTAL | @SUM(J82..J87) |
| 89 | ***Sub Total - Demand*** | [redacted] | [redacted] |
| 90 | ***Demand (Incl Climate Change)*** | [redacted] | [redacted] |
| 91 | ***Domestic Demand Ratio*** | [redacted] | [redacted] |
| 92 | ***Decrease in Yield due to Demand Dependency*** | [redacted] | [redacted] |
| 93 | ***Supply - Demand*** | [redacted] | [redacted] |
| 94 | Unmeasured Population | | |
| 95 | Climate change increas in pcc, scenario 1 | | |
| 96 | Climate change increas in pcc, scenario | | |
| 97 | Climate change increas in pcc, scenario | | |
| 98 | Climate Change Uncertainty- Model Number | | |

*(Table 5.41)*

*Constructed spreadsheet for the supply-demand balance for Company A*

*Columns through to D*

*Sheet 5 of 12*

| A | A | K |
|---|---|---|
| 1 | **Risk Analysis Worksheet** | |
| 2 | | |
| 3 | | 2005 |
| 4 | **Table of Uncertainties** | |
| 5 | | Rates of growth in demand |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | **Supply Side - Losses** | |
| 11 | Loss of Yield due to Development | 1.5 |
| 12 | Loss of Yield due to Pollution | 4.5*@<<RISK>>BINOMIAL(1,(1-(0.98^5)))+5*@<<RISK>>BINOMIAL(1,(1-(0.98^5))) |
| 13 | Loss of Yield - Gradual Pollution | 5*@<<RISK>>BINOMIAL(1,0.9)+10*@<<RISK>>BINOMIAL(1,0.5)+3*@<<RISK>>BINOMIAL(1,0.4) |
| 14 | Planned Outages | @<<RISK>>TRIANG(2.51,4.43,9.39) |
| 15 | **Unplanned Outages:** | |
| 16 | -Due to Planned Maintenance | 0 |
| 17 | -Due to Economic Source Use | @<<RISK>>NORMAL(0.87,0.22) |
| 18 | -Due to Elec/Mech Failure | @<<RISK>>NORMAL(0.13,0.02) |
| 19 | -Due to Blending Problems | 0 |
| 20 | -Due to Short Term Pollution | 0 |
| 21 | -Due to Water Quality Spikes | @<<RISK>>NORMAL(1.42,0.65) |
| 22 | -Due to Power Failure | @<<RISK>>NORMAL(0.2,0.04) |
| 23 | Due to Method of Yield Analysis-GW | @<<RISK>>TRIANG(-0.1*K$28,0,0.1*K$28) |
| 24 | Due to Method of Yield Analysis-SW | 0 |
| 25 | Due to EA Clawback | 2 |
| 26 | Due to Groundwater Sustainability | 0 |
| 27 | **SUPPLY SIDE - INPUTS** | |
| 28 | Variation in Climate-GW | 185 |
| 29 | Service Reservoir Contribution | 0 |
| 30 | Variation in Climate-Rivers | 171 |
| 31 | Variation in Climate-Reservoirs | @<<RISK>>DISCRETE(55,60,65,70,75,80,0.01,0.04,0.11,0.19,0.26,0.39) |
| 32 | Change in Climate - GW | |
| 33 | **Due to Change in Climate - SW** | |
| 34 | **Model Selection (Ignore Value)** | |
| 35 | Climate Chg - Model 1 | |
| | Climate Chg - Model 2 | |
| 37 | Climate Chg - Model 3 | |
| 38 | Climate Chg - Model 4 | |
| 39 | change in climate-Rivers | |
| 40 | ***Sub Total - Supply*** | -@SUM(K11..K26)+@SUM(K26..K38)-K34 |
| 41 | **Demand Side** | |
| 42 | Unbiased reconciliation item | |
| 43 | Source Meter Error distribution | |
| 44 | **MLE PHASE I** | |
| 45 | -Measured Domestic | |
| 46 | *-Unmeasured Domestic* | |
| 47 | Washing Machines | |
| 48 | Dishwashers | |
| 49 | Manual Dishwashers | |
| 50 | Hosepipes | |
| 51 | Sprinklers | |
| 52 | Car Washing | |
| 53 | Bathing | |
| 54 | Showers | |
| 55 | Power Showers | |
| 56 | WC-High Vol | |
| 57 | WC-Dual Flush | |
| 58 | Other | |
| 59 | -Measured Non-Domestic | |
| 60 | -Unmeasured Non-Domestic | |
| 61 | -Miscellaneous Use | |
| 62 | -Total Losses | |
| 63 | **Total Demand** | |
| 64 | Total Rec Item for stage 1 | |
| 65 | **MLE PHASE II** | |
| 66 | -Measured Domestic | |
| 67 | *-Unmeasured Domestic* | |
| 68 | Washing Machines | |
| 69 | Dishwashers | |
| 70 | Manual Dishwashers | |
| 71 | Hosepipes | |
| 72 | Sprinklers | |
| 73 | Car Washing | |
| 74 | Bathing | |
| 75 | Showers | |
| 76 | Power Showers | |
| 77 | WC-High Vol | |
| 78 | WC-Dual Flush | |
| 79 | Other | |
| 80 | -Measured Non-Domestic | |
| 81 | -Unmeasured Non-Domestic | |
| 82 | -Miscellaneous Use | |
| 83 | -Total Losses | |
| 84 | **Total Demand** | +J88 |
| 85 | Total Rec Item for stage 1 | |
| 86 | Climate Variation Uncertainty Ml/d | @<<RISK>>NORMAL(0,(0.0133*J83)) |
| 87 | Climate Change Uncertainty | (@SUM(K95..K97)*K94)/1000 |
| 88 | Customer Meter Error | 0 |
| 89 | ***Sub Total - Demand*** | +K84 |
| 90 | ***Demand (Incl Climate Change)*** | +K89+K87 |
| 91 | ***Domestic Demand Ratio*** | (+J83+K86)/J83 |
| 92 | ***Decrease in Yield due to Demand Dependency*** | (+K91-1)*410 |
| 93 | ***Supply - Demand*** | +K40-K90-K92 |
| 94 | Unmeasured Population | 1218 |
| 95 | Climate change increas in pcc, scenario 1 | @IF(K$98=2,0.52,0) |
| 96 | Climate change increas in pcc, scenario | @IF(K$98=1,0.69,0) |
| 97 | Climate change increas in pcc, scenario | @IF(K$98=3,0.78,0) |
| 98 | Climate Change Uncertainty- Model Number | @<<RISK>>DISCRETE(1,2,3,0.33,0.33,0.34) |

*(Table 5.42)*

*Constructed spreadsheet for the supply-demand balance for Company A*
*Columns through to D*
*Sheet 6 of 12*

| A | A | L | M |
|---|---|---|---|
| 1 | **Risk Analysis Worksheet** | | |
| 2 | | | **Dem fcasts** |
| 3 | | | **for 2006** |
| 4 | **Table of Uncertainties** | | to 2010 |
| 5 | [redacted] | | Percent/yr |
| 6 | [redacted] | MEAS-DOM | 4.9428 |
| 7 | [redacted] | UNMEAS-DOM | -0.001918 |
| 8 | [redacted] | MEAS-NONDOM | -0.02854 |
| 9 | [redacted] | UNMEAS-NDOM | -0.145 |
| 10 | **Supply Side - Losses** | MISCELLAN | 0 |
| 11 | Loss of Yield due to Development | [redacted] | [redacted] |
| 12 | Loss of Yield due to Pollution | [redacted] | [redacted] |
| 13 | Loss of Yield - Gradual Pollution | [redacted] | [redacted] |
| 14 | Planned Outages | [redacted] | [redacted] |
| 15 | **Unplanned Outages:** | [redacted] | [redacted] |
| 16 | -Due to Planned Maintenance | [redacted] | [redacted] |
| 17 | -Due to Economic Source Use | [redacted] | [redacted] |
| 18 | -Due to Elec/Mech Failure | [redacted] | [redacted] |
| 19 | -Due to Blending Problems | [redacted] | [redacted] |
| 20 | -Due to Short Term Pollution | [redacted] | [redacted] |
| 21 | -Due to Water Quality Spikes | [redacted] | [redacted] |
| 22 | -Due to Power Failure | [redacted] | [redacted] |
| 23 | Due to Method of Yield Analysis-GW | [redacted] | [redacted] |
| 24 | Due to Method of Yield Analysis-SW | [redacted] | [redacted] |
| 25 | Due to EA Clawback | [redacted] | [redacted] |
| 26 | Due to Groundwater Sustainability | [redacted] | [redacted] |
| 27 | **SUPPLY SIDE - INPUTS** | [redacted] | [redacted] |
| 28 | Variation in Climate-GW | [redacted] | [redacted] |
| 29 | Service Reservoir Contribution | [redacted] | [redacted] |
| 30 | Variation in Climate-Rivers | [redacted] | [redacted] |
| 31 | Variation in Climate-Reservoirs | [redacted] | [redacted] |
| 32 | Change in Climate - GW | [redacted] | [redacted] |
| 33 | **Due to Change in Climate - SW** | [redacted] | [redacted] |
| 34 | **Model Selection (Ignore Value)** | [redacted] | [redacted] |
| 35 | Climate Chg - Model 1 | [redacted] | [redacted] |
| 36 | Climate Chg - Model 2 | [redacted] | [redacted] |
| 37 | Climate Chg - Model 3 | [redacted] | [redacted] |
| 38 | Climate Chg - Model 4 | [redacted] | [redacted] |
| 39 | change in climate-Rivers | [redacted] | [redacted] |
| 40 | ***Sub Total - Supply*** | [redacted] | [redacted] |
| 41 | **Demand Side** | **2005** | |
| 42 | Unbiased reconciliation item | MEAS-DOM | +J82 |
| 43 | Source Meter Error distribution | UNMEAS-DOM | +J83 |
| 44 | **MLE PHASE I** | MEAS-NONDOM | +J84 |
| 45 | -Measured Domestic | UNMEAS-NDOM | +J85 |
| 46 | *-Unmeasured Domestic* | MISCELLAN | +J86 |
| 47 | Washing Machines | LOSSES | 77 |
| 48 | Dishwashers | TOTAL | @SUM(M42..M47) |
| 49 | Manual Dishwashers | **2006** | |
| 50 | Hosepipes | MEAS-DOM | (M42*(1+M6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 51 | Sprinklers | UNMEAS-DOM | (M43*(1+M7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 52 | Car Washing | MEAS-NONDOM | (M44*(1+M8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 53 | Bathing | UNMEAS-NDOM | (M45*(1+M9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 54 | Showers | MISCELLAN | (M46*(1+M10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 55 | Power Showers | LOSSES | 76.6 |
| 56 | WC-High Vol | TOTAL | @SUM(M50..M55) |
| 57 | WC-Dual Flush | **2007** | |
| 58 | Other | MEAS-DOM | (M50*(1+M6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 59 | -Measured Non-Domestic | UNMEAS-DOM | (M51*(1+M7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 60 | -Unmeasured Non-Domestic | MEAS-NONDOM | (M52*(1+M8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 61 | -Miscellaneous Use | UNMEAS-NDOM | (M53*(1+M9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 62 | -Total Losses | MISCELLAN | (M54*(1+M10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 63 | **Total Demand** | LOSSES | 76.2 |
| 64 | Total Rec Item for stage 1 | TOTAL | @SUM(M58..M63) |
| 65 | **MLE PHASE II** | **2008** | |
| 66 | -Measured Domestic | MEAS-DOM | (M58*(1+M6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 67 | *-Unmeasured Domestic* | UNMEAS-DOM | (M59*(1+M7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 68 | Washing Machines | MEAS-NONDOM | (M60*(1+M8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 69 | Dishwashers | UNMEAS-NDOM | (M61*(1+M9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 70 | Manual Dishwashers | MISCELLAN | (M62*(1+M10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 71 | Hosepipes | LOSSES | 75.8 |
| 72 | Sprinklers | TOTAL | @SUM(M66..M71) |
| 73 | Car Washing | **2009** | |
| 74 | Bathing | MEAS-DOM | (M66*(1+M6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 75 | Showers | UNMEAS-DOM | (M67*(1+M7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 76 | Power Showers | MEAS-NONDOM | (M68*(1+M8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 77 | WC-High Vol | UNMEAS-NDOM | (M69*(1+M9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 78 | WC-Dual Flush | MISCELLAN | (M70*(1+M10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 79 | Other | LOSSES | 75.4 |
| 80 | -Measured Non-Domestic | TOTAL | @SUM(M74..M79) |
| 81 | -Unmeasured Non-Domestic | **2010** | |
| 82 | -Miscellaneous Use | MEAS-DOM | (M74*(1+M6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 83 | -Total Losses | UNMEAS-DOM | (M75*(1+M7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 84 | **Total Demand** | MEAS-NONDOM | (M76*(1+M8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 85 | Total Rec Item for stage 1 | UNMEAS-NDOM | (M77*(1+M9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 86 | Climate Variation Uncertainty Ml/d | MISCELLAN | (M78*(1+M10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 87 | Climate Change Uncertainty | LOSSES | 75 |
| 88 | Customer Meter Error | TOTAL | @SUM(M82..M87) |
| 89 | ***Sub Total - Demand*** | [redacted] | [redacted] |
| 90 | ***Demand (Incl Climate Change)*** | [redacted] | [redacted] |
| 91 | ***Domestic Demand Ratio*** | [redacted] | [redacted] |
| 92 | ***Decrease in Yield due to Demand Dependency*** | [redacted] | [redacted] |
| 93 | ***Supply - Demand*** | [redacted] | [redacted] |
| 94 | Unmeasured Population | | |
| 95 | Climate change increas in pcc, scenario 1 | | |
| 96 | Climate change increas in pcc, scenario | | |
| 97 | Climate change increas in pcc, scenario | | |
| 98 | Climate Change Uncertainty- Model Number | | |

(Table 5.43)
Constructed spreadsheet for the supply-demand balance for Company A
Columns through to D
Sheet 7 of 12

| A | A | N |
|---|---|---|
| 1 | **Risk Analysis Worksheet** | |
| 2 | | |
| 3 | | 2010 |
| 4 | **Table of Uncertainties** | |
| 5 | | Rates of growth in demand |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | **Supply Side - Losses** | |
| 11 | Loss of Yield due to Development | 3 |
| 12 | Loss of Yield due to Pollution | 4.5*@<<RISK>>BINOMIAL(1,(1-(0.98^10)))+5*@<<RISK>>BINOMIAL(1,(1-(0.98^10))) |
| 13 | Loss of Yield - Gradual Pollution | 5*@<<RISK>>BINOMIAL(1,1)+10*@<<RISK>>BINOMIAL(1,1)+3*@<<RISK>>BINOMIAL(1,0.5) |
| 14 | Planned Outages | @<<RISK>>TRIANG(2.51,4.43,9.39)+4.5 |
| 15 | **Unplanned Outages:** | |
| 16 | -Due to Planned Maintenance | 0 |
| 17 | -Due to Economic Source Use | @<<RISK>>NORMAL(0.87,0.22) |
| 18 | -Due to Elec/Mech Failure | @<<RISK>>NORMAL(0.13,0.02) |
| 19 | -Due to Blending Problems | 0 |
| 20 | -Due to Short Term Pollution | 0 |
| 21 | -Due to Water Quality Spikes | @<<RISK>>NORMAL(1.42,0.65) |
| 22 | -Due to Power Failure | @<<RISK>>NORMAL(0.2,0.04) |
| 23 | Due to Method of Yield Analysis-GW | @<<RISK>>TRIANG(-0.1*N$28,0,0.1*N$28) |
| 24 | Due to Method of Yield Analysis-SW | 0 |
| 25 | Due to EA Clawback | 4 |
| 26 | Due to Groundwater Sustainability | 0 |
| 27 | **SUPPLY SIDE - INPUTS** | |
| 28 | Variation in Climate-GW | 185 |
| 29 | Service Reservoir Contribution | 0 |
| 30 | Variation in Climate-Rivers | 171 |
| 31 | Variation in Climate-Reservoirs | @<<RISK>>DISCRETE(55,60,65,70,75,80,0.01,0.04,0.11,0.19,0.26,0.39) |
| 32 | Change in Climate - GW | |
| 33 | **Due to Change in Climate - SW** | |
| 34 | **Model Selection (Ignore Value)** | |
| 35 | Climate Chg - Model 1 | |
| 36 | Climate Chg - Model 2 | |
| 37 | Climate Chg - Model 3 | |
| 38 | Climate Chg - Model 4 | |
| 39 | change in climate-Rivers | |
| 40 | ***Sub Total - Supply*** | -@SUM(N11..N26)+@SUM(N26..N38)-N34 |
| 41 | **Demand Side** | |
| 42 | Unbiased reconciliation item | |
| 43 | Source Meter Error distribution | |
| 44 | **MLE PHASE I** | |
| 45 | -Measured Domestic | |
| 46 | *-Unmeasured Domestic* | |
| 47 | Washing Machines | |
| 48 | Dishwashers | |
| 49 | Manual Dishwashers | |
| 50 | Hosepipes | |
| 51 | Sprinklers | |
| 52 | Car Washing | |
| 53 | Bathing | |
| 54 | Showers | |
| 55 | Power Showers | |
| 56 | WC-High Vol | |
| 57 | WC-Dual Flush | |
| 58 | Other | |
| 59 | -Measured Non-Domestic | |
| 60 | -Unmeasured Non-Domestic | |
| 61 | -Miscellaneous Use | |
| 62 | -Total Losses | |
| 63 | **Total Demand** | |
| 64 | Total Rec Item for stage 1 | |
| 65 | **MLE PHASE II** | |
| 66 | -Measured Domestic | |
| 67 | *-Unmeasured Domestic* | |
| 68 | Washing Machines | |
| 69 | Dishwashers | |
| 70 | Manual Dishwashers | |
| 71 | Hosepipes | |
| 72 | Sprinklers | |
| 73 | Car Washing | |
| 74 | Bathing | |
| 75 | Showers | |
| 76 | Power Showers | |
| 77 | WC-High Vol | |
| 78 | WC-Dual Flush | |
| 79 | Other | |
| 80 | -Measured Non-Domestic | |
| 81 | -Unmeasured Non-Domestic | |
| 82 | -Miscellaneous Use | |
| 83 | -Total Losses | |
| 84 | **Total Demand** | +M88 |
| 85 | Total Rec Item for stage 1 | |
| 86 | Climate Variation Uncertainty Ml/d | @<<RISK>>NORMAL(0,(0.0133*M83)) |
| 87 | Climate Change Uncertainty | (@SUM(N95..N97)*N94)/1000 |
| 88 | Customer Meter Error | 0 |
| 89 | ***Sub Total - Demand*** | +N84 |
| 90 | ***Demand (Incl  Climate Change)*** | +N89+N87 |
| 91 | ***Domestic Demand Ratio*** | (+M83+N86)/M83 |
| 92 | ***Decrease in Yield due to Demand Dependency*** | (+N91-1)*410 |
| 93 | ***Supply - Demand*** | +N40-N90-N92 |
| 94 | Unmeasured Population | 1200 |
| 95 | Climate change increas in pcc, scenario 1 | @IF(N$98=2,1.09,0) |
| 96 | Climate change increas in pcc, scenario | @IF(N$98=1,1.45,0) |
| 97 | Climate change increas in pcc, scenario | @IF(N$98=3,1.64,0) |
| 98 | Climate Change Uncertainty- Model Number | @<<RISK>>DISCRETE(1,2,3,0.33,0.33,0.34) |

*(Table 5.44)*

*Constructed spreadsheet for the supply-demand balance for Company A*
*Columns through to D*
*Sheet 8 of 12*

| A | A | O | P |
|---|---|---|---|
| 1 | **Risk Analysis Worksheet** | | |
| 2 | | | **Dem fcasts** |
| 3 | | | **for 2011** |
| 4 | **Table of Uncertainties** | | to 2015 |
| 5 | [redacted] | | Percent/yr |
| 6 | | MEAS-DOM | 2.334 |
| 7 | | UNMEAS-DOM | 0.278487 |
| 8 | | MEAS-NONDOM | 0.2275 |
| 9 | | UNMEAS-NDOM | -0.07 |
| 10 | **Supply Side - Losses** | MISCELLAN | 0 |
| 11 | Loss of Yield due to Development | [redacted] | |
| 12 | Loss of Yield due to Pollution | | |
| 13 | Loss of Yield - Gradual Pollution | | |
| 14 | Planned Outages | | |
| 15 | **Unplanned Outages:** | | |
| 16 | -Due to Planned Maintenance | | |
| 17 | -Due to Economic Source Use | | |
| 18 | -Due to Elec/Mech Failure | | |
| 19 | -Due to Blending Problems | | |
| 20 | -Due to Short Term Pollution | | |
| 21 | -Due to Water Quality Spikes | | |
| 22 | -Due to Power Failure | | |
| 23 | Due to Method of Yield Analysis-GW | | |
| 24 | Due to Method of Yield Analysis-SW | | |
| 25 | Due to EA Clawback | | |
| 26 | Due to Groundwater Sustainability | | |
| 27 | **SUPPLY SIDE - INPUTS** | | |
| 28 | Variation in Climate-GW | | |
| 29 | Service Reservoir Contribution | | |
| 30 | Variation in Climate-Rivers | | |
| 31 | Variation in Climate-Reservoirs | | |
| 32 | Change in Climate - GW | | |
| 33 | **Due to Change in Climate - SW** | | |
| 34 | **Model Selection (Ignore Value)** | | |
| 35 | Climate Chg - Model 1 | | |
| 36 | Climate Chg - Model 2 | | |
| 37 | Climate Chg - Model 3 | | |
| 38 | Climate Chg - Model 4 | | |
| 39 | change in climate-Rivers | | |
| 40 | ***Sub Total - Supply*** | | |
| 41 | **Demand Side** | **2010** | |
| 42 | Unbiased reconciliation item | MEAS-DOM | +M82 |
| 43 | Source Meter Error distribution | UNMEAS-DOM | +M83 |
| 44 | **MLE PHASE I** | MEAS-NONDOM | +M84 |
| 45 | -Measured Domestic | UNMEAS-NDOM | +M85 |
| 46 | *-Unmeasured Domestic* | MISCELLAN | +M86 |
| 47 | Washing Machines | LOSSES | 75 |
| 48 | Dishwashers | TOTAL | @SUM(P42..P47) |
| 49 | Manual Dishwashers | **2011** | |
| 50 | Hosepipes | MEAS-DOM | (P42*(1+P6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 51 | Sprinklers | UNMEAS-DOM | (P43*(1+P7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 52 | Car Washing | MEAS-NONDOM | (P44*(1+P8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 53 | Bathing | UNMEAS-NDOM | (P45*(1+P9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 54 | Showers | MISCELLAN | (P46*(1+P10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 55 | Power Showers | LOSSES | 75 |
| 56 | WC-High Vol | TOTAL | @SUM(P50..P55) |
| 57 | WC-Dual Flush | **2012** | |
| 58 | Other | MEAS-DOM | (P50*(1+P6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 59 | -Measured Non-Domestic | UNMEAS-DOM | (P51*(1+P7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 60 | -Unmeasured Non-Domestic | MEAS-NONDOM | (P52*(1+P8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 61 | -Miscellaneous Use | UNMEAS-NDOM | (P53*(1+P9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 62 | -Total Losses | MISCELLAN | (P54*(1+P10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 63 | **Total Demand** | LOSSES | 75 |
| 64 | Total Rec Item for stage 1 | TOTAL | @SUM(P58..P63) |
| 65 | **MLE PHASE II** | **2013** | |
| 66 | -Measured Domestic | MEAS-DOM | (P58*(1+P6/100)) |
| 67 | *-Unmeasured Domestic* | UNMEAS-DOM | (P59*(1+P7/100)) |
| 68 | Washing Machines | MEAS-NONDOM | (P60*(1+P8/100)) |
| 69 | Dishwashers | UNMEAS-NDOM | (P61*(1+P9/100)) |
| 70 | Manual Dishwashers | MISCELLAN | (P62*(1+P10/100)) |
| 71 | Hosepipes | LOSSES | 75 |
| 72 | Sprinklers | TOTAL | @SUM(P66..P71) |
| 73 | Car Washing | **2014** | |
| 74 | Bathing | MEAS-DOM | (P66*(1+P6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 75 | Showers | UNMEAS-DOM | (P67*(1+P7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 76 | Power Showers | MEAS-NONDOM | (P68*(1+P8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 77 | WC-High Vol | UNMEAS-NDOM | (P69*(1+P9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 78 | WC-Dual Flush | MISCELLAN | (P70*(1+P10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 79 | Other | LOSSES | 75 |
| 80 | -Measured Non-Domestic | TOTAL | @SUM(P74..P79) |
| 81 | -Unmeasured Non-Domestic | **2015** | |
| 82 | -Miscellaneous Use | MEAS-DOM | (P74*(1+P6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 83 | -Total Losses | UNMEAS-DOM | (P75*(1+P7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 84 | **Total Demand** | MEAS-NONDOM | (P76*(1+P8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 85 | Total Rec Item for stage 1 | UNMEAS-NDOM | (P77*(1+P9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 86 | Climate Variation Uncertainty Ml/d | MISCELLAN | (P78*(1+P10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 87 | Climate Change Uncertainty | LOSSES | 75 |
| 88 | Customer Meter Error | TOTAL | @SUM(P82..P87) |
| 89 | ***Sub Total - Demand*** | [redacted] | |
| 90 | ***Demand (Incl Climate Change)*** | | |
| 91 | ***Domestic Demand Ratio*** | | |
| 92 | ***Decrease in Yield due to Demand Dependency*** | | |
| 93 | ***Supply - Demand*** | | |
| 94 | Unmeasured Population | | |
| 95 | Climate change increas in pcc, scenario 1 | | |
| 96 | Climate change increas in pcc, scenario | | |
| 97 | Climate change increas in pcc, scenario | | |
| 98 | Climate Change Uncertainty- Model Number | | |

*(Table 5.45)*

*Constructed spreadsheet for the supply-demand balance for Company A*

*Columns through to D*

*Sheet 9 of 12*

# Risk Analysis Worksheet

| | A | Q | |
|---|---|---|---|
| 1 | **Risk Analysis Worksheet** | | |
| 2 | | | |
| 3 | | **2015** | |
| 4 | **Table of Uncertainties** | | |
| 5 | [redacted] | | Rates of |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | **Supply Side - Losses** | | |
| 11 | Loss of Yield due to Development | | 4.5 |
| 12 | Loss of Yield due to Pollution | 4.5*@<<RISK>>BINOMIAL(1,(1-(0.98^15)))+5*@<<RISK>>BINOMIAL(1,(1-(0.98^15))) | |
| 13 | Loss of Yield - Gradual Pollution | 5*@<<RISK>>BINOMIAL(1,1)+10*@<<RISK>>BINOMIAL(1,1)+3*@<<RISK>>BINOMIAL(1,1) | |
| 14 | Planned Outages | @<<RISK>>TRIANG(2.51,4.43,9.39) | |
| 15 | **Unplanned Outages:** | [redacted] | |
| 16 | -Due to Planned Maintenance | | 0 |
| 17 | -Due to Economic Source Use | @<<RISK>>NORMAL(0.87,0.22) | |
| 18 | -Due to Elec/Mech Failure | @<<RISK>>NORMAL(0.13,0.02) | |
| 19 | -Due to Blending Problems | | 0 |
| 20 | -Due to Short Term Pollution | | 0 |
| 21 | -Due to Water Quality Spikes | @<<RISK>>NORMAL(1.42,0.65) | |
| 22 | -Due to Power Failure | @<<RISK>>NORMAL(0.2,0.04) | |
| 23 | Due to Method of Yield Analysis-GW | @<<RISK>>TRIANG(-0.1*Q$ ,0,0.1*Q$ ) | |
| 24 | Due to Method of Yield Analysis-SW | | 0 |
| 25 | Due to EA Clawback | | 4 |
| 26 | Due to Groundwater Sustainability | | 0 |
| 27 | **SUPPLY SIDE - INPUTS** | [redacted] | |
| 28 | Variation in Climate-GW | | |
| 29 | Service Reservoir Contribution | | |
| 30 | Variation in Climate-Rivers | | |
| 31 | Variation in Climate-Reservoirs | | |
| 32 | Change in Climate - GW | | 185 |
| 33 | **Due to Change in Climate - SW** | [redacted] | |
| 34 | **Model Selection (Ignore Value)** | @<<RISK>>DISCRETE(1,2,3,4,0.25,0.25,0.25,0.25) | |
| 35 | Climate Chg - Model 1 | @IF(Q$34=1,(@<<RISK>>DISCRETE(55,50,65,70,75,80,0,0.04,0.11,0.19,0.26,0.39)),0) | |
| 36 | Climate Chg - Model 2 | @IF(Q$34=2,(@<<RISK>>DISCRETE(55,50,65,70,75,80,0,0,0.04,0.21,0.29,0.46)),0) | |
| 37 | Climate Chg - Model 3 | @IF(Q$34=3,(@<<RISK>>DISCRETE(55,50,65,70,75,80,0,0.02,0.1,0.2,0.27,0.41)),0) | |
| 38 | Climate Chg - Model 4 | @IF(Q$34=4,(@<<RISK>>DISCRETE(55,50,65,70,75,80,0.02,0.06,0.11,0.19,0.25,0.37)),0) | |
| 39 | change in climate-Rivers | | 171 |
| 40 | ***Sub Total - Supply*** | -@SUM(Q11..Q26)+@SUM(Q26..Q39) | |
| 41 | **Demand Side** | [redacted] | |
| 42 | Unbiased reconciliation item | | |
| 43 | Source Meter Error distribution | | |
| 44 | **MLE PHASE I** | | |
| 45 | -Measured Domestic | | |
| 46 | -*Unmeasured Domestic* | | |
| 47 | Washing Machines | | |
| 48 | Dishwashers | | |
| 49 | Manual Dishwashers | | |
| 50 | Hosepipes | | |
| 51 | Sprinklers | | |
| 52 | Car Washing | | |
| 53 | Bathing | | |
| 54 | Showers | | |
| 55 | Power Showers | | |
| 56 | WC-High Vol | | |
| 57 | WC-Dual Flush | | |
| 58 | Other | | |
| 59 | -Measured Non-Domestic | | |
| 60 | -Unmeasured Non-Domestic | | |
| 61 | -Miscellaneous Use | | |
| 62 | -Total Losses | | |
| 63 | **Total Demand** | | |
| 64 | Total Rec Item for stage 1 | | |
| 65 | **MLE PHASE II** | | |
| 66 | -Measured Domestic | | |
| 67 | -*Unmeasured Domestic* | | |
| 68 | Washing Machines | | |
| 69 | Dishwashers | | |
| 70 | Manual Dishwashers | | |
| 71 | Hosepipes | | |
| 72 | Sprinklers | | |
| 73 | Car Washing | | |
| 74 | Bathing | | |
| 75 | Showers | | |
| 76 | Power Showers | | |
| 77 | WC-High Vol | | |
| 78 | WC-Dual Flush | | |
| 79 | Other | | |
| 80 | -Measured Non-Domestic | | |
| 81 | -Unmeasured Non-Domestic | | |
| 82 | -Miscellaneous Use | | |
| 83 | -Total Losses | | |
| 84 | **Total Demand** | +P88 | |
| 85 | Total Rec Item for stage 1 | [redacted] | |
| 86 | Climate Variation Uncertainty Ml/d | @<<RISK>>NORMAL(0,(0.0133*P83)) | |
| 87 | Climate Change Uncertainty | (@SUM(Q95..Q97)*Q94)/1000 | |
| 88 | Customer Meter Error | | 0 |
| 89 | ***Sub Total - Demand*** | +Q84 | |
| 90 | ***Demand (Incl Climate Change)*** | +Q89+Q87 | |
| 91 | ***Domestic Demand Ratio*** | (+P83+Q86)/P83 | |
| 92 | ***Decrease in Yield due to Demand Dependency*** | (+Q91-1)*410 | |
| 93 | ***Supply - Demand*** | +Q40-Q90-Q92 | |
| 94 | Unmeasured Population | | 1190 |
| 95 | Climate change increas in pcc, scenario 1 | @IF(Q$98=2,1.77,0) | |
| 96 | Climate change increas in pcc, scenario | @IF(Q$98=1,2.36,0) | |
| 97 | Climate change increas in pcc, scenario | @IF(Q$98=3,2.66,0) | |
| 98 | Climate Change Uncertainty- Model Number | @<<RISK>>DISCRETE(1,2,3,0.33,0.33,0.34) | |

Constructed spreadsheet for the supply-demand balance for Company A (Table 5.46)
Columns through to D

| A | A | R | S |
|---|---|---|---|
| 1 | **Risk Analysis Worksheet** | | |
| 2 | | | **Dem fcasts** |
| 3 | | | **for 2016** |
| 4 | **Table of Uncertainties** | | to 2020 |
| 5 | [redacted] | | Percent/yr |
| 6 | | MEAS-DOM | 2.0783 |
| 7 | | UNMEAS-DOM | 0.363376 |
| 8 | | MEAS-NONDOM | 0.224943 |
| 9 | | UNMEAS-NDOM | -0.07 |
| 10 | **Supply Side - Losses** | MISCELLAN | 0 |
| 11 | Loss of Yield due to Development | [redacted] | |
| 12 | Loss of Yield due to Pollution | | |
| 13 | Loss of Yield - Gradual Pollution | | |
| 14 | Planned Outages | | |
| 15 | **Unplanned Outages:** | | |
| 16 | -Due to Planned Maintenance | | |
| 17 | -Due to Economic Source Use | | |
| 18 | -Due to Elec/Mech Failure | | |
| 19 | -Due to Blending Problems | | |
| 20 | -Due to Short Term Pollution | | |
| 21 | -Due to Water Quality Spikes | | |
| 22 | -Due to Power Failure | | |
| 23 | Due to Method of Yield Analysis-GW | | |
| 24 | Due to Method of Yield Analysis-SW | | |
| 25 | Due to EA Clawback | | |
| 26 | Due to Groundwater Sustainability | | |
| 27 | **SUPPLY SIDE - INPUTS** | | |
| 28 | Variation in Climate-GW | | |
| 29 | Service Reservoir Contribution | | |
| 30 | Variation in Climate-Rivers | | |
| 31 | Variation in Climate-Reservoirs | | |
| 32 | Change in Climate - GW | | |
| 33 | **Due to Change in Climate - SW** | | |
| 34 | **Model Selection (Ignore Value)** | | |
| 35 | Climate Chg - Model 1 | | |
| 36 | Climate Chg - Model 2 | | |
| 37 | Climate Chg - Model 3 | | |
| 38 | Climate Chg - Model 4 | | |
| 39 | change in climate-Rivers | | |
| 40 | ***Sub Total - Supply*** | | |
| 41 | **Demand Side** | **2015** | |
| 42 | Unbiased reconciliation item | MEAS-DOM | +P82 |
| 43 | Source Meter Error distribution | UNMEAS-DOM | +P83 |
| 44 | **MLE PHASE I** | MEAS-NONDOM | +P84 |
| 45 | -Measured Domestic | UNMEAS-NDOM | +P85 |
| 46 | *-Unmeasured Domestic* | MISCELLAN | +P86 |
| 47 | Washing Machines | LOSSES | 75 |
| 48 | Dishwashers | TOTAL | @SUM(S42..S47) |
| 49 | Manual Dishwashers | **2016** | |
| 50 | Hosepipes | MEAS-DOM | (S42*(1+S6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 51 | Sprinklers | UNMEAS-DOM | (S43*(1+S7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 52 | Car Washing | MEAS-NONDOM | (S44*(1+S8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 53 | Bathing | UNMEAS-NDOM | (S45*(1+S9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 54 | Showers | MISCELLAN | (S46*(1+S10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 55 | Power Showers | LOSSES | 75 |
| 56 | WC-High Vol | TOTAL | @SUM(S50..S55) |
| 57 | WC-Dual Flush | **2017** | |
| 58 | Other | MEAS-DOM | (S50*(1+S6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 59 | -Measured Non-Domestic | UNMEAS-DOM | (S51*(1+S7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 60 | -Unmeasured Non-Domestic | MEAS-NONDOM | (S52*(1+S8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 61 | -Miscellaneous Use | UNMEAS-NDOM | (S53*(1+S9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 62 | -Total Losses | MISCELLAN | (S54*(1+S10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 63 | **Total Demand** | LOSSES | 75 |
| 64 | Total Rec Item for stage 1 | TOTAL | @SUM(S58..S63) |
| 65 | **MLE PHASE II** | **2018** | |
| 66 | -Measured Domestic | MEAS-DOM | (S58*(1+S6/100)) |
| 67 | *-Unmeasured Domestic* | UNMEAS-DOM | (S59*(1+S7/100)) |
| 68 | Washing Machines | MEAS-NONDOM | (S60*(1+S8/100)) |
| 69 | Dishwashers | UNMEAS-NDOM | (S61*(1+S9/100)) |
| 70 | Manual Dishwashers | MISCELLAN | (S62*(1+S10/100)) |
| 71 | Hosepipes | LOSSES | 75 |
| 72 | Sprinklers | TOTAL | @SUM(S66..S71) |
| 73 | Car Washing | **2019** | |
| 74 | Bathing | MEAS-DOM | (S66*(1+S6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 75 | Showers | UNMEAS-DOM | (S67*(1+S7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 76 | Power Showers | MEAS-NONDOM | (S68*(1+S8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 77 | WC-High Vol | UNMEAS-NDOM | (S69*(1+S9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 78 | WC-Dual Flush | MISCELLAN | (S70*(1+S10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 79 | Other | LOSSES | 75 |
| 80 | -Measured Non-Domestic | TOTAL | @SUM(S74..S79) |
| 81 | -Unmeasured Non-Domestic | **2020** | |
| 82 | -Miscellaneous Use | MEAS-DOM | (S74*(1+S6/100))*(1+@<<RISK>>NORMAL(0,$C3/200)) |
| 83 | -Total Losses | UNMEAS-DOM | (S75*(1+S7/100))*(1+@<<RISK>>NORMAL(0,$C4/200)) |
| 84 | **Total Demand** | MEAS-NONDOM | (S76*(1+S8/100))*(1+@<<RISK>>NORMAL(0,$C5/200)) |
| 85 | Total Rec Item for stage 1 | UNMEAS-NDOM | (S77*(1+S9/100))*(1+@<<RISK>>NORMAL(0,$C6/200)) |
| 86 | Climate Variation Uncertainty Ml/d | MISCELLAN | (S78*(1+S10/100))*(1+@<<RISK>>NORMAL(0,$C7/200)) |
| 87 | Climate Change Uncertainty | LOSSES | 75 |
| 88 | Customer Meter Error | TOTAL | @SUM(S82..S87) |
| 89 | ***Sub Total - Demand*** | [redacted] | |
| 90 | ***Demand (Incl Climate Change)*** | | |
| 91 | ***Domestic Demand Ratio*** | | |
| 92 | ***Decrease in Yield due to Demand Dependency*** | | |
| 93 | ***Supply - Demand*** | | |
| 94 | Unmeasured Population | | |
| 95 | Climate change increas in pcc, scenario 1 | | |
| 96 | Climate change increas in pcc, scenario | | |
| 97 | Climate change increas in pcc, scenario | | |
| 98 | Climate Change Uncertainty- Model Number | | |

*(Table 5.47)*

*Constructed spreadsheet for the supply-demand balance for Company A*

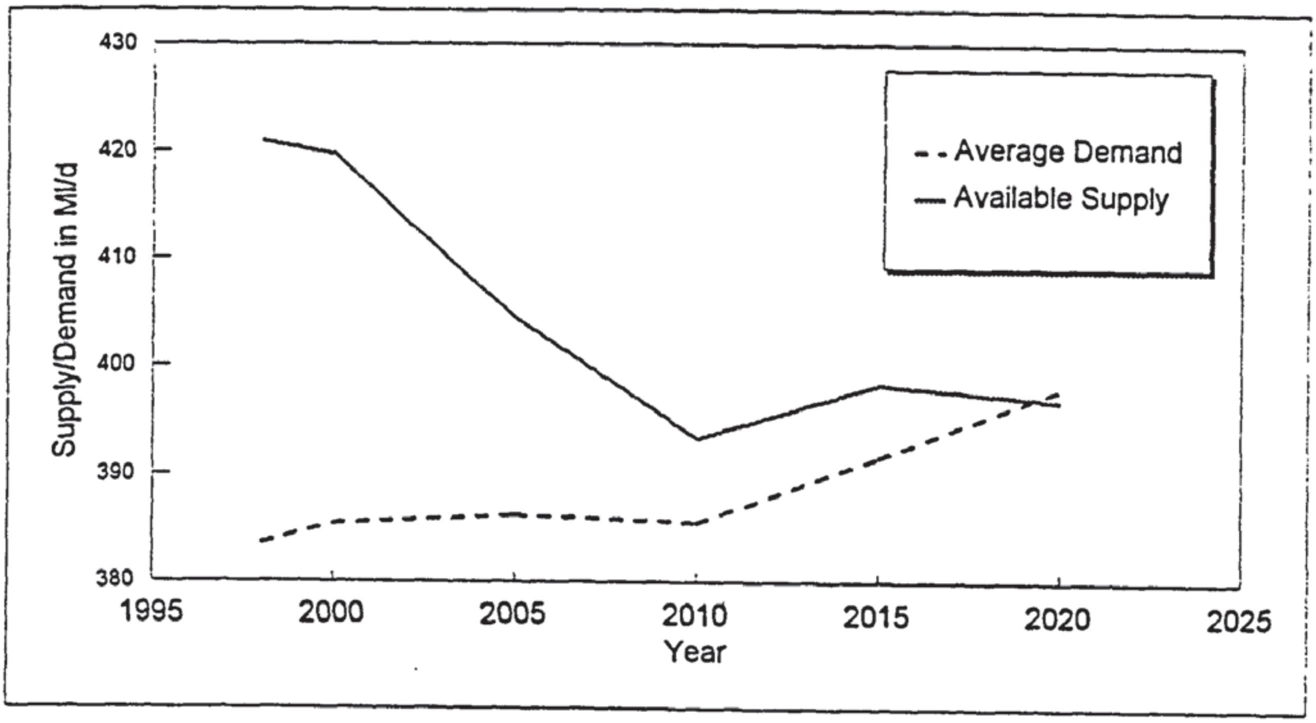
*Columns through to D*

*Sheet 11 of 12*

| A | A | T |
|---|---|---|
| 1 | **Risk Analysis Worksheet** | |
| 2 | | |
| 3 | | 2020 |
| 4 | **Table of Uncertainties** | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | **Supply Side - Losses** | |
| 11 | Loss of Yield due to Development | 6 |
| 12 | Loss of Yield due to Pollution | 4.5*@<<RISK>>BINOMIAL(1,(1-(0.98^20)))+5*@<<RISK>>BINOMIAL(1,(1-(0.98^20))) |
| 13 | Loss of Yield - Gradual Pollution | 5*@<<RISK>>BINOMIAL(1,1)+10*@<<RISK>>BINOMIAL(1,1)+3*@<<RISK>>BINOMIAL(1,1) |
| 14 | Planned Outages | @<<RISK>>TRIANG(2.51,4.43,9.39) |
| 15 | **Unplanned Outages:** | |
| 16 | -Due to Planned Maintenance | 0 |
| 17 | -Due to Economic Source Use | @<<RISK>>NORMAL(0.87,0.22) |
| 18 | -Due to Elec/Mech Failure | @<<RISK>>NORMAL(0.13,0.02) |
| 19 | -Due to Blending Problems | 0 |
| 20 | -Due to Short Term Pollution | 0 |
| 21 | -Due to Water Quality Spikes | @<<RISK>>NORMAL(1.42,0.65) |
| 22 | -Due to Power Failure | @<<RISK>>NORMAL(0.2,0.04) |
| 23 | Due to Method of Yield Analysis-GW | @<<RISK>>TRIANG(-0.1*T$. ,0,0.1*T$ ) |
| 24 | Due to Method of Yield Analysis-SW | 0 |
| 25 | Due to EA Clawback | 4 |
| 26 | Due to Groundwater Sustainability | 0 |
| 27 | **SUPPLY SIDE - INPUTS** | |
| 28 | Variation in Climate-GW | |
| 29 | Service Reservoir Contribution | |
| 30 | Variation in Climate-Rivers | |
| 31 | Variation in Climate-Reservoirs | |
| 32 | Change in Climate - GW | 185 |
| 33 | **Due to Change in Climate - SW** | |
| 34 | **Model Selection (Ignore Value)** | @<<RISK>>DISCRETE(1,2,3,4,0.25,0.25,0.25,0.25) |
| 35 | Climate Chg - Model 1 | @IF(T$34=1,(@<<RISK>>DISCRETE(55,50,65,70,75,80,0,0.04,0.11,0.19,0.26,0.39)),0) |
| 36 | Climate Chg - Model 2 | @IF(T$34=2,(@<<RISK>>DISCRETE(55,50,65,70,75,80,0,0,0.04,0.21,0.29,0.46)),0) |
| 37 | Climate Chg - Model 3 | @IF(T$34=3,(@<<RISK>>DISCRETE(55,50,65,70,75,80,0,0.02,0.1,0.2,0.27,0.41)),0) |
| 38 | Climate Chg - Model 4 | @IF(T$34=4,(@<<RISK>>DISCRETE(55,50,65,70,75,80,0.02,0.06,0.11,0.19,0.25,0.37)),0) |
| 39 | change in climate-Rivers | 171 |
| 40 | ***Sub Total - Supply*** | -@SUM(T11..T26)+@SUM(T26..T39) |
| 41 | **Demand Side** | |
| 42 | Unbiased reconciliation item | |
| 43 | Source Meter Error distribution | |
| 44 | **MLE PHASE I** | |
| 45 | -Measured Domestic | |
| 46 | *-Unmeasured Domestic* | |
| 47 | Washing Machines | |
| 48 | Dishwashers | |
| 49 | Manual Dishwashers | |
| 50 | Hosepipes | |
| 51 | Sprinklers | |
| 52 | Car Washing | |
| 53 | Bathing | |
| 54 | Showers | |
| 55 | Power Showers | |
| 56 | WC-High Vol | |
| 57 | WC-Dual Flush | |
| 58 | Other | |
| 59 | -Measured Non-Domestic | |
| 60 | -Unmeasured Non-Domestic | |
| 61 | -Miscellaneous Use | |
| 62 | -Total Losses | |
| 63 | **Total Demand** | |
| 64 | Total Rec Item for stage 1 | |
| 65 | **MLE PHASE II** | |
| 66 | -Measured Domestic | |
| 67 | *-Unmeasured Domestic* | |
| 68 | Washing Machines | |
| 69 | Dishwashers | |
| 70 | Manual Dishwashers | |
| 71 | Hosepipes | |
| 72 | Sprinklers | |
| 73 | Car Washing | |
| 74 | Bathing | |
| 75 | Showers | |
| 76 | Power Showers | |
| 77 | WC-High Vol | |
| 78 | WC-Dual Flush | |
| 79 | Other | |
| 80 | -Measured Non-Domestic | |
| 81 | -Unmeasured Non-Domestic | |
| 82 | -Miscellaneous Use | |
| 83 | -Total Losses | |
| 84 | **Total Demand** | +S88 |
| 85 | Total Rec Item for stage 1 | |
| 86 | Climate Variation Uncertainty Ml/d | @<<RISK>>NORMAL(0,(0.0133*S83)) |
| 87 | Climate Change Uncertainty | (@SUM(T95..T97)*T94)/1000 |
| 88 | Customer Meter Error | 0 |
| 89 | ***Sub Total - Demand*** | +T84 |
| 90 | ***Demand (incl Climate Change)*** | +T89+T87 |
| 91 | ***Domestic Demand Ratio*** | (+S83+T86)/S83 |
| 92 | ***Decrease in Yield due to Demand Dependency*** | (+T91-1)*410 |
| 93 | ***Supply - Demand*** | +T40-T90-T92 |
| 94 | Unmeasured Population | 1189 |
| 95 | Climate change increas in pcc, scenario 1 | @IF(T$98=2,2.54,0) |
| 96 | Climate change increas in pcc, scenario | @IF(T$98=1,3.39,0) |
| 97 | Climate change increas in pcc, scenario | @IF(T$98=3,3.81,0) |
| 98 | Climate Change Uncertainty- Model Number | @<<RISK>>DISCRETE(1,2,3,0.33,0.33,0.34) |

*(Table 5.48)*

*Constructed spreadsheet for the supply-demand balance for Company A*
*Columns through to D*
*Sheet 12 of 12*



*(Figure 5.11)*
*Model snapshot for Company A prior to simulation*
*Graph shows average supply and average demand conditions*

# CHAPTER SIX - WORKED ANALYSIS

## 6.1 INTRODUCTION TO CHAPTER

Within Chapter 4 discussion focused on the scoping of individual sources of uncertainty across various dimensions. These sources of uncertainty were then taken forward to Chapter 5 where, using a combination of historic data, analysis and expert judgement, quantities are assigned. Chapter 5 concludes with the setting up of the analytical simulation model which describes each individual source of uncertainty across various time horizons and for the complete supply-demand balance.

Within Chapter 6, the discussion will focus on the analytical output from the model derived in Chapter 5 and will particularly note the significance of individual sources of uncertainty in terms of their correlation with the supply-demand position.

The Chapter will also consider, from a modelling perspective, the number of iterations required to achieve a prescribed overall level of accuracy within the simulation model.

Within Chapters 7 and 8, the model will be taken one stage further, firstly by considering ways of reducing uncertainties within the supply-demand equation and, secondly, by introducing solutions, such as resource development, which, of themselves, also have in-built uncertainties.

## 6.2 POLICY ASSUMPTIONS FOR SUPPLY-DEMAND PROJECTIONS

The spreadsheet model in Section 5.7.7 excludes a number of uncertainties either because they are considered non-material or because they are considered beyond the scope of this research. In addition there are a number of general policy assumptions which avoid the need for specific uncertainties to be considered. Section 6.2 defines each of these three sets of assumptions in further detail.

In stating the case for exclusions and assumptions, and while extensive attention has been given to quantifying uncertainties, the reader should note that the principal objectives of this research are to describe a methodology and to demonstrate application. In practice it will be unlikely that the analyst is able to quantify all possible uncertainties and some degree of assumption will be inevitable. A sensible combination of assumption and quantification is needed to eliminate the need for arbitrary planning margins.

### 6.2.1 General Assumptions

General policy assumptions which need to be made in advance of the worked analysis are those relating to:-

**i) Achievement of leakage targets**

The analysis in Section 6.4 assumes no uncertainty with regard to the achievement of leakage targets. The legitimacy of planning allowances in discussed in Section 4.9, noting that it is considered inappropriate for a company to seek allowance, and consequent funding, as a result of its belief that it cannot meet its mandatory leakage targets.

**ii) Operation of surface reservoirs and river intake systems**

Company A has a pre-determined set of operating rules for its single season reservoir. No attempt has been made within this research to consider whether these operating rules are appropriate or whether some measure of conjunctive use would improve the overall resource position. Likewise, the river intake for Company A is considered to be fully regulated and supported sufficient to eliminate uncertainty.

**iii) Climate change**

It is assumed within this research that there is sufficient evidence to accept that climate change will take place. The precise impact of climate change, however, is clearly uncertain and is substantially different depending on which climate change model is used. Assigning uncertainties to climate change was discussed in Section 5.3.5 on the supply side and 5.4.5 on the demand side. Reducing climate change uncertainty is considered further in Section 7.2.1.

**iv) Treatment Works Losses**

Process water can be lost as a result of effluent discharge, filter back-washing and for various other reasons. It is assumed within this research that treatment works losses have already been deducted from source reliable yield and do not, therefore, require further consideration. This assumption is reasonable given that treatment works losses tend to be constant for a constant source yield.

### 6.2.2 Uncertainties considered non-material

There are a number of uncertainties which are considered non-material within this research. These are as follows:

**i) Availability of service reservoir storage over the critical period**

Company A has a policy of allowing a proportion of its service reservoir storage to be drawn down during peak week. The worked analysis within this research, however, is based on the calculation for average day and, clearly, the volume of water within service reservoirs is immaterial over a 365-day period. As such, no allowance for service reservoir storage has been made within the spreadsheet described in 5.7.7.

**ii) Resilience of groundwater yield to variation in climate and to climate change**

Company A takes all of its groundwater from a sandstone aquifer with characteristics similar to those described in Section 4.3. The sandstone aquifer is considered to be sufficiently robust that both climate and climate change are not material to yield. The issue of sustainability of groundwater is considered to be material and may overlap with the impact of climate change, but is dealt with by considering clawback by the Environment Agency. Supply side losses are discussed in Section 4.3.

**iii) Bankside Storage**

Company A has sufficient bankside storage for its major river abstraction to meet demand for around three weeks in the event that river abstraction is unavailable. This effectively ensures that there is no constraint on peak capacity from the works as a result of inferior river quality. The effect of bankside storage over a 365-day period is, however, marginal and has therefore not been considered for the specific example which relates to the average day requirement for Company A.

**iv) Frequency of meter reading and backlog of meter billing**

It is clearly the case that, the greater the frequency of meter reading, the lower the reliance on estimated information. The accuracy of forecasts should therefore improve as a result. The improvement in accuracy as a result of this component or as a result of reducing any backlog of meter billing, however, is not considered material in the context of this research.

**v) Impact of blending schemes on outage distributions**

Section 4.3.12 discusses the impact of blending different sources of water together on the distribution of planned and unplanned outages. For Company A it is the declared policy to promote treatment as an alternative to blending and it is therefore considered unnecessary to give material consideration to this component of uncertainty.

**vi) Population forecast uncertainty**

During the 1970's population projections varied wildly year on year, largely as a result of differing assumptions with regard to birth-rate and mortality. These vastly different assumptions were partly to blame for the planning submissions for water resource schemes as discussed in Chapter 2. By the 1990's growth in domestic population within the UK had almost ceased. For Company A population numbers have now been stationary for almost 15 years and are forecast to remain stationary for the foreseeable future. In essence this means that mortality and birth have now reached a state of equilibrium and that housing development is catalysed only as a result of housing demolition and the continuing decline in household occupancy. For the purpose of this research uncertainty in population projections is considered to be non-material.

**vii) Domestic measured property numbers**

Section 5.4.3.2 notes that, although there is uncertainty within measured domestic property numbers, this uncertainty has only a second order effect. It is considered non-material within the context of this research.

**viii) Demand side meter error**

Section 5.4.6 discusses work carried out by Prasifka (1988) in the area of demand side meter error. Whilst accepting that this represents an area of significant uncertainty it is, as with property numbers, a second order influence on the supply-demand balance. It is considered non-material within this research.

### 6.2.3 Uncertainties considered beyond scope of research

In addition to uncertainties which are considered non-material there are a number of uncertainties which are considered either too complex or too cumbersome to be dealt with in this research. A number of these may offer the opportunity for further research, a point which will be picked up again within Chapter 9. Uncertainties considered to be beyond the scope of this research are:

### i) System capacity and system pressure

It is self evident that the ability of the distribution system to transfer water from source to customer is a direct function of the mains transfer capacity and the sufficiency of pressure within the system. Over a period of time, pressures and transfer capacities vary such that they influence directly those components of demand which are pressure related. Excluding leakage, examples might include garden watering, power showers and simply examples as brushing teeth in an unplugged basin. No allowance has been made for the effect of variation in pressure on demand within this research on the grounds of complexity.

### ii) Future industry regulation and tariffs

As with bulk supplies it is difficult to predict the extent to which the industry regulator will influence the behaviour of the water industry. These influences will extend into areas of abstraction licensing, clawback by the Environment Agency, the need for water treatment, the provision of bulk supplies and various other areas. Whether these influences turn out to be of material significance is considered to be unpredictable at this stage and beyond the scope of this research.

### iii) Climatic persistence

Section 4.3.8 demonstrates that there is evidence that climatic persistence exists between years, such that hot summers tend to follow hot summers, wet winters follow wet winters, and so on. For medium term operational planning, perhaps more than for long term resource planning, this feature of climatic persistence should allow both demand prediction and supply prediction to be carried out more accurately. Climatic persistence has been assumed to be absent on the grounds of complexity. It is considered that the industry would benefit from further research in this area.

### iv) Extreme events

Section 4.8 describes the difference between contingency planning and emergency planning and that it is inappropriate to incorporate emergency planning under the heading of the supply-demand balance. Assigning uncertainties to extreme events is considered, therefore, to be beyond the scope of this research.

### v) Uncertainty and organisational size

Section 5.4.7 notes that there is a relationship between organisational size and the point at which a contingent event becomes an emergency event. This relationship also holds when considering potential future planning applications. For example, a company which supplies 500 Ml/d and receives a request from a developer for a new supply of 5 Ml/d would have no difficulty in considering the likelihood of the application in the context of its own supply-demand position. By contrast, a smaller company with an existing demand of, say, 50 Ml/d may need to consider the proposed application under the label of emergency planning. The relationship between organisational size and the way in which it handles uncertainties is considered to be of material significance but again beyond the scope of this research. The industry would benefit from further investigation in this area.

## 6.3 OUTPUTS AND SETTINGS

The risk analysis spreadsheet for Company A, described in Section 5.7 and shown within Tables 5.37 through 5.48, contains 166 statistical input distributions and six required outputs; one for each time slice.

Simulation settings for the @Risk analysis adopt an automatic programme stop on achieving sequential 2% convergence for 100 iteration blocks and use latin hypercube sampling (see Section 3.4.2).

## 6.4 RESULTS AND OBSERVATIONS

The standard output format for the @Risk package is to describe, both graphically and numerically, the form of the output distributions. In particular, the package reports on the shape of the distribution: mean, standard deviation, variance, skewness, kurtosis, and also the percentile points at 5% intervals. This report, for the worksheet described in Section 5.7, is presented as Table 6.1.

The most useful line of the report in Table 6.1 is the description of the supply-demand balance at the design level of service, in this case the 5 percentile. This is equivalent to the level of service described in 6.7.

The data contained in Table 6.1 for the worst event, best event, expected event (1 in 2) and the 5 percentile (1 in 20 event) is presented in graphical form as Figure 6.1. The graph shows that, for example, in the year 2000 all scenarios other than the worst event have a supply-demand surplus yet by the year 2020 all scenarios other than the best event have a supply-demand deficit. In this respect the worst event is the simulated outcome where the highly unlikely combination of events results in the greatest shortfall of supply over demand. Increasing the number of iterations tends to capture a more extreme combination of events although the level of service this combination represents is unlikely to be meaningful.

Section 8.6 considers the effect of reducing the level of service in terms of the benefit to customer bills.

## 6.5 SENSITIVITY ANALYSIS

Using @Risk to run a sensitivity analysis results in a table of input variables, ranked in order of how critical the input variable is to the output distribution. In other words, if the input variable changes, does it have a major or minor impact on the output variable? Table 6.2 shows the top 15 ranking input variables for the supply-demand imbalance in the year 2005. A negative correlation means that the output declines as the input variable increases.

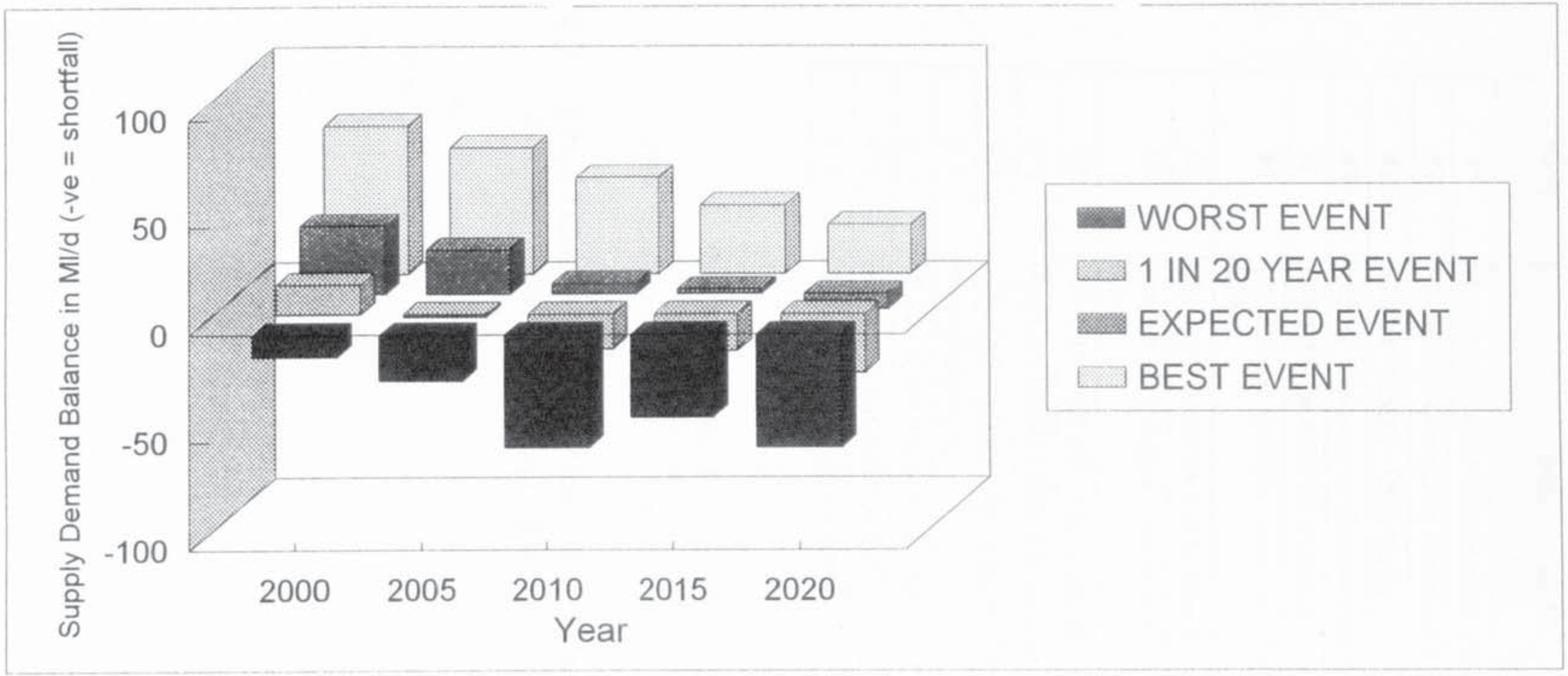
For the most significant input variable in Table 6.2, that due to method of groundwater yield analysis, there is a -0.66 correlation between method of groundwater yield analysis and the supply-demand balance. Correlation is a measure of explained variation in the output variable; such that a change in the input variable always, sometimes or never coincides with a corresponding change in the output variable.

Reducing uncertainty will be most beneficial when directed towards those variables which have the largest correlation with the output.

| | Output Distribution for Year | | | | |
|---|---|---|---|---|---|
| **Parameter** | **2000** | **2005** | **2010** | **2015** | **2020** |
| Minimum = | -10.69 | -21.74 | -52.44 | -38.31 | -52.69 |
| Maximum = | 68.78 | 58.76 | 44.55 | 31.95 | 23.41 |
| Mean = | 32.16 | 20.58 | 4.32 | 1.16 | -8.4 |
| Std. Deviation = | 11.16 | 12.78 | 11.97 | 9.91 | 10.51 |
| Variance = | 124.65 | 163.46 | 143.51 | 98.25 | 110.48 |
| Skewness = | -0.11 | -0.12 | -0.12 | -0.48 | -0.48 |
| Kurtosis = | 2.89 | 2.85 | 3.06 | 3.46 | 3.64 |
| Errors Calc. = | 0 | 0 | 0 | 0 | 0 |
| Mode = | 35 | 20.52 | 3.32 | 2.09 | -8.93 |
| 5 Percentile | 13.91 | -0.57 | -15.79 | -16.85 | -27.48 |
| 10 Percentile | 17.78 | 3.81 | -10.98 | -11.63 | -21.6 |
| 15 Percentile | 20.25 | 7.23 | -8.19 | -8.7 | -18.75 |
| 20 Percentile | 22.61 | 9.67 | -5.61 | -6.4 | -16.42 |
| 25 Percentile | 24.52 | 11.69 | -3.63 | -4.68 | -14.69 |
| 30 Percentile | 26.29 | 13.88 | -1.77 | -3.14 | -13.08 |
| 35 Percentile | 27.64 | 15.83 | 0.08 | -1.83 | -11.54 |
| 40 Percentile | 29.13 | 17.51 | 1.62 | -0.51 | -10.23 |
| 45 Percentile | 30.97 | 19.04 | 3.09 | 0.67 | -8.95 |
| 50 Percentile | 32.58 | 20.76 | 4.56 | 1.73 | -7.87 |
| 55 Percentile | 33.8 | 22.42 | 5.82 | 2.97 | -6.51 |
| 60 Percentile | 35.36 | 24.13 | 7.19 | 4.15 | -5.13 |
| 65 Percentile | 36.81 | 25.86 | 9.06 | 5.33 | -3.91 |
| 70 Percentile | 38.37 | 27.79 | 10.62 | 6.67 | -2.58 |
| 75 Percentile | 39.89 | 29.73 | 12.41 | 7.95 | -1.15 |
| 80 Percentile | 41.78 | 31.71 | 14.56 | 9.65 | 0.11 |
| 85 Percentile | 43.82 | 34.07 | 16.89 | 11.22 | 1.96 |
| 90 Percentile | 46.46 | 37.03 | 19.63 | 13.25 | 4.09 |
| 95 Percentile | 50.14 | 41.4 | 24.24 | 16.06 | 7.6 |

*(Table 6.1)*

*Output distribution parameters for time slices 2000 through 2020 for Company A*
*All values within table are in Ml/d*



**Definition of Events:**

| | |
|---|---|
| Worst event: | Highest supply-demand shortfall from simulation |
| 1 in 20 event: | Supply-demand condition defined such that 19 in 20, or 95%, of events are less severe (have a lower shortfall). |
| 1 in 2 event: | 50% of events are worse or better. |
| Best event: | As for worst event but 'lowest' shortfall or highest surplus. |

*(Figure 6.1)*
*Graph shows supply-demand balance for Company A for the period 2000-2020*
*for varying levels of service*

| Rank | Input Variable | Correlation Coefficient |
|---|---|---|
| #1 | Due to Method of Groundwater Yield Analysis | -0.66386 |
| #2 | Variation in Climate on Reservoir Yield | 0.538459 |
| #3 | Climate Variation Uncertainty | -0.45673 |
| #4 | Loss of Yield due to Gradual Pollution | -0.17574 |
| #5 | UNMEAS-DOMESTIC Forecast Error / Year | -0.06328 |
| #6 | Unplanned outages due to Water Quality Spikes | -0.04924 |
| #7 | Unplanned outages due to Blending Problems | 0.049074 |
| #8 | Unplanned outages due to Economic Source Use | 0.048857 |
| #9 | MEAS-NONDOMESTIC / Forecast error / Year | -0.04845 |
| #10 | UNMEAS-DOMESTIC / Forecast error / Year | -0.0351 |
| #11 | Unplanned outages due to power failure | -0.01878 |
| #12 | Planned Outages | -0.01831 |
| #13 | MEAS-DOMESTIC / Forecast error / Year | -0.01258 |
| #14 | Unplanned outages due to Elec/Mech Failure | -0.00595 |
| #15 | MISCELLANEOUS / Forecast error / Year | 0.004851 |

*(Table 6.2)*
*Sensitivity Analysis results for the supply-demand balance*
*for Company A for the year 2005*
*Input variables are ranked by correlation coefficient with the output variable*

## 6.6 RELATIONSHIP BETWEEN THE NUMBER OF INPUT VARIABLES AND REQUIRED NUMBER OF ITERATIONS

It is clearly the case that increasing the number of variables within the @Risk spreadsheet will increase computer run time. In addition, because simulation has linear complexity, then the relationship between the number of variables and computer run time might also be expected to be linear. In theory, this relationship holds true providing that the number of iterations required to reach convergence is independent of the number of input variables.

Each simulation run is different because different random numbers are generated. Hence, for a given level of convergence (the allowable degree of variation in the output distribution between successive groups of 100 iterations) the number of required iterations will be different. It is not obvious in advance, however, whether the number of iterations required is materially affected by the number of input variables.

The result of an experiment which increases the number of input variables, up to 400, is shown in Figure 6.2. Note first that the computer run time is a feature of the particular computer used, 16Mb, 100Mhz Pentium, and will be different for different PCs. Note also that the relationship between run time and number of input variables is linear across the range 0 to 300 because the range of iterations required to reach convergence remains constant. Above 350 inputs the run time increases exponentially and appears to represent the limit of the software on the particular PC.

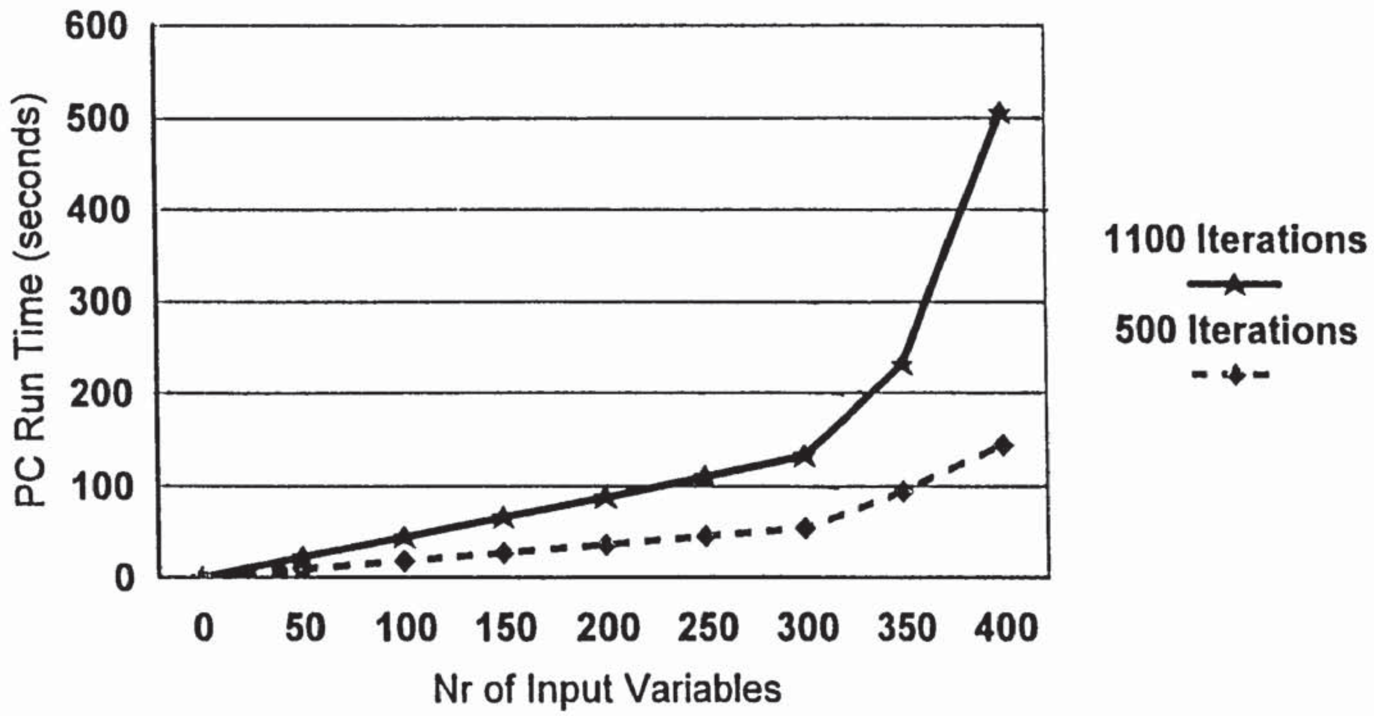
Although the relationship between input variables and run time is linear, the relationship between output variables and run time is not. For example, when five outputs were selected, such as the five time slices for Company A, then the time to reach convergence increased 10-fold. This is because each output variable reaches convergence at different times and overall convergence requires all five variables to converge simultaneously. Having said that, an overall run time of around 10 minutes for the example in 6.4 is not considered to be of concern.

## 6.7 CHOICE OF LEVEL OF SERVICE

Section 2 examines those factors which affect resource provision and compares these with future resource needs. As part of this assessment, it is first necessary to decide the acceptable level of failure of water resource, since it is clearly impractical to design for every eventuality.

Design levels could conceivably be different for each resource zone because of the different demands they present. For example, one resource zone may supply a disproportionate number of hospitals or dialysis patients which cannot manage without water, whilst another zone may supply a large number of industrial customers with their own back up storage which could cope with short periods of water shortage. Therefore, the variation in composition of customer base across the company area could warrant variations in design levels. Company A has effectively only a single resource zone and variations in design level are, therefore, inappropriate.

Determination of appropriate design levels depends on the consequence of failure and invariably coincides with one of the common statistical sampling points (1 in 20, 1 in 50, etc.).



Graph result is non transferable to PC of different specification
Graph is for a single output variable

*(Figure 6.2)*
*Performance of @Risk package for a 16Mb, 100 Mhz Pentium PC*
*Graph shows relationship between computer run time and number of iterations for a convergence of 2% on the single output variable*

In the case of average day resource provision, the consequences of failure are marginal licence exceedence in the first instance, followed by potential source depletion, with demand restrictions as the obvious next step. Company A designs for a level of failure which requires demand restriction no more frequently than once in every 20 years. The method of risk analysis within this report calculates resource need for a 1 in 20 year combined series of events.

The science behind choosing a 1 in 20 (or 5 percentile) level of service stems from a policy viewpoint that a failure of the level of service standard should occur on average only once during a generation of customers, considered to be approximately 20 years. The benefit to the customer of reducing this standard is considered in 8.6.

## 6.8 SUMMARY OF CHAPTER

Following the setting up of the spreadsheet at the end of Chapter 5, Chapter 6 reports on the output from the analysis having first noted policy assumptions within the analysis. The chapter then notes uncertainties of most significance. This leads into Chapter 7, in which a number of areas of uncertainty will be discussed in terms of whether or how they can be reduced. Chapter 8 will give a numerical example of how a reduction in uncertainty converts into a reduction within a supply-demand imbalance.

# CHAPTER SEVEN - CURRENT AND POTENTIAL OPTIONS FOR REDUCING UNCERTAINTY

## 7.1 INTRODUCTION TO CHAPTER

Having assessed, within Chapter 6, a specific quantification of the supply-demand balance, it is appropriate to consider those factors which might influence uncertainty as an aid to future research. In particular, Table 6.2 describes the top 15 ranking input variables for the supply-demand imbalance in the year 2005.

The degree of correlation between the input variable and the output function depends both on uncertainty but also on natural variation within the input variable itself. For example, reservoir yield will vary year on year with climate regardless of whether the method of yield analysis is accurate or not. This element of variability can therefore never be reduced. From Table 6.2, the two input variables of most significance are due to the method of yield analysis and to climate variation uncertainty. Reducing uncertainty within these two components is considered within Section 7.2.

Chapter 7 is divided into two sections: Section 7.2 considers options for reducing uncertainty on the supply side of the equation and Section 7.3 considers options on the demand side of the equation.

A numerical example of the impact of reducing one source of uncertainty is presented within Chapter 8.

## 7.2 SUPPLY SIDE OPTIONS FOR REDUCING UNCERTAINTY

There are various options for reducing uncertainty on the supply side of the equation. Two areas of material significance derive from Table 6.2 and relate to the method of yield analysis and to uncertainty as a result of climate variation. Uncertainty within yield analysis is divided into three sub-headings; the calculation of resource yield, the sustainability of source yield and the length of record for groundwater and surface water history. Other areas, considered to be of significance, are source meter accuracy, water quality stability and climate change.

Discussion commences with climate change.

### 7.2.1 Climate Change

Chapter 6 demonstrates that climate change is the most significant area of uncertainty within the supply-demand balance. Climate changes impact upon both the supply side of the equation in terms of its implications for source yield and also on the demand side of the equation. The key area of uncertainty (Hadley Centre, 1995) is the lack of understanding of cloud processes, an area where further research will be critical if the Water Industry is to significantly improve understanding. Running the model described in 5.7.7, but excluding climate change, improves the supply-demand balance by almost 5 Ml/d (around 1½% of demand). Likewise, taking an average of climate change models improves the position by 2.5 Ml/d. There is therefore a reasonable likelihood, assuming that the true climate change model is not the most severe of the current spread of models, that an improvement in uncertainty will result in an improved supply-demand balance. Using a typical capital value for resource development of £500,000 per Ml/d, then it is easy to see that the industry would be well advised to continue its research in this area.

Clearly, the extent to which uncertainty surrounding climate change can be improved is beyond the scope of this research. The fact that considerable sums of money can be justified in ensuring its improvement is self evident.

### 7.2.2 The Calculation of Resource Yield

There are various techniques available for the assessment of resource yield and a number of these are discussed within Chapters 2, 4 and 5. Methods of calculation can always be improved, although there is a view amongst resource planners that the use of behavioural analysis for calculating surface water yield offers a fairly reliable technique. The calculation of groundwater yield (UKWIR, $1995_c$), however, is thought by many to be only moderate in accuracy, despite being a very pragmatic and simple tool to use.

Given that necessity is the mother of invention, then groundwater yield methods are likely to be re-explored during the planning phase for the next Periodic Review, in 2003/04. The extent to which it is necessary to review groundwater yield will depend on the performance of the Water Industry over the next five years in its ability to meet supplies and also on the view of the Environment Agency on matters of groundwater sustainability and clawback.

### 7.2.3 The Length of Record for Groundwater and Surface Water History

Section 4.3.3.2 discusses the importance of length of record when calculating groundwater and surface water yield. This is important for surface water yield when the length of record does not include key historic droughts, particularly if these have been the worst droughts on record.

For groundwater yield, the methodology proposed by UKWIR ($1995_c$), relies heavily on a historic sequence of groundwater record. Specifically, the method requires that the water level during the worst drought on record is used as the measure of reliable yield.

Given the relationship between length of record and reliability of result, then the uncertainty surrounding the result should increase over time as the length of record increases. It is beyond the scope of this research to evaluate the extent to which this uncertainty will reduce, but, by means of example, Chapter 8 will consider a reduction in uncertainty from +/- 10% down to +/- 5%.

### 7.2.4 The Sustainability of Source Yield

One of the major areas of debate over the last decade has been the extent to which aquifers can support long term abstraction at their current rate. For the Environment Agency this is a matter of immediate concern because of the environmental impact of excess abstraction. For the water company, the issue tends to be much more long term because pumps can always be lowered and boreholes deepened in order to secure historic source yield.

A number of issues of sustainability will have been dealt with through the second and third Periodic Reviews. Nevertheless, the Environment Agency still has a very long list of groundwater sites where it considers over-abstraction to be a serious problem. The manner in which source sustainability is viewed tends to be a function of available funding at the time of each price review and with the on-going pressure on prices it is likely to continue to be the case that resolution of the issue of sustainability, from a clawback perspective, will take many years.

Other causes of source loss, such as that due to borehole deterioration and the influence of localised pumping, should stabilise over the longer term.

### 7.2.5 Water Quality Stability and Changes in Legislation

One of the major uncertainties surrounding continued use of a source is whether the quality of the raw water will deteriorate to the point where it exceeds one, or more than one, current or future European Water Quality Standards. If the quality deteriorates to a point where the source becomes uneconomic, particularly where this is due to a change in legislation such that the standard is lowered, then considerable uncertainty will exist over the future of the source. The view amongst experts is that the pressure for increasing standards is increasing and likely to prevail. This is likely to increase uncertainty in this area rather than decrease it.

In terms of water quality trends associated with long-standing manmade influences, such as nitrates and pesticides, then it is likely that the passage of time will see a more stable relationship develop. Once water quality levels have stabilised then the analyst will know whether to make allowance for treatment or possible abandonment, or whether the source has stabilised at a level which is acceptable. This will reduce overall uncertainty. Understanding these effects can be enhanced by further research into the area of groundwater modelling and its relationship with geo-chemistry and surface activity.

### 7.2.6 Source Meter Accuracy

Section 4.3.10 clearly shows the extent to which the inaccuracy of source meters can influence the supply-demand balance. Furthermore, source meters tend to underestimate the volume of water is being abstracted. In practical terms, this means that a water company which seeks to improve the accuracy of its source meters will effectively be declaring to the Environment Agency that it is taking more water out of the ground than previously. This has the effect of reducing the company's overall resource stock as constrained by its licensed capacity. Clearly, therefore, the company has little incentive to improve accuracy in this area since it will then have to either seek to increase its abstraction licence or, much more significantly, to develop alternative resources to match the shortfall.

The initiative for improving the accuracy of source meters is almost certain to come from the Environment Agency, although they are likely to take a long term view of the problem because of the cost implications on the water industry if large numbers of meters are to be replaced. There is a view amongst resource planners that the overall under-registration of abstraction will reduce over longer term and clearly the significance of a reduction in uncertainty within this component should ensure future research.

## 7.3 DEMAND SIDE OPTIONS FOR REDUCING UNCERTAINTY

There are various options for reducing uncertainty on the demand side of the equation. Table 6.2 demonstrates in particular that demand forecasting accuracy and stability have a material impact on the output distribution.

### 7.3.1 Demand Forecasting Accuracy

Chapter 4 discusses the various types of techniques which might be applied to forecasts of water demand. Over the past 20 years there is little doubt that the techniques have improved, although there is still considerable uncertainty remaining. This is particularly so when predicting the industrial demand for water, which is hardly surprising given that the structure of British industry continues to change and, at the local level, is difficult to predict.

Nevertheless, there is certain to be increased pressure from regulators to improve forecasting techniques given the obvious relationship between demand forecasts and the regulatory process. Increased research into the behaviour of domestic customers, coupled with increased certainty over leakage targets, is very likely to improve demand forecasting accuracy over the medium to long term. In addition Section 2.4 notes the possible significance of Kondratieff cycles to industrial output forecasting. This may also merit further research.

### 7.3.2 Demand Forecasting Stability

Chapter 4 demonstrates that, even though there is some evidence that forecasting methods are improving, there is even more evidence that accuracy is a function of variability. In other words, if the demand for water is generally not changing year on year, then it is clearly a very simple exercise to forecast accurately. With the introduction of sprinkler metering, the metering of new households, the development of a price control mechanism, the continued decline of manufacturing industry and the saturation of customers who have showers, washing machines and other modern appliances, then growth in demand is likely to slow down over the medium term. Inevitably, this will result in an overall improvement in demand forecast stability and an overall reduction in uncertainty.

### 7.3.3 The Acceptability of Target/Mandatory Levels of Leakage

Section 5.4.3.5 notes that it would be inappropriate to consider mandatory levels of leakage as uncertain, since the penalty for non-achievement removes any uncertainty. However, if, over the longer term, mandatory targets are removed and the level of leakage allowed to float, then the uncertainty will, ironically, increase.

Clearly, if the leakage target in year 2020 is allowed to vary then the supply-demand imbalance increases. However, to assign uncertainty assumes a measure of uncontrollability of leakage and, in practice, it is more likely that a company will decide its own internal target and seek reasonably close control of it.

In the context of this research mandatory targets are considered likely to prevail for a considerable number of years.

### 7.3.4 Improved Understanding of the Impact of Metering

Section 5.4.3.2 notes that the number of measured households, for much of the water industry, is relatively small compared to those as yet unmeasured. This is because meters are often only installed at new properties or when a customer seeks one under a meter option scheme. As a result, the length of historical record is quite short which makes forecasting of measured per capita highly uncertain, often using unmeasured per capita, and an appropriate reduction for the effect of metering, as a surrogate.

With the passage of time the uncertainty surrounding measured per capita is likely to improve as the impact of metering on domestic components of demand are better understood. Further research is required in this area.

### 7.3.5 Meter Penetration and the Ability to Control Demand Through the Price Mechanism

As new, measured, houses replace old unmeasured ones and as meters become cheaper or subsidised, then the extent of meter penetration will increase. Furthermore, as tariffs are guided more toward a long run marginal cost approach, then price control mechanisms will become more sophisticated. At the extreme, it should become possible to control demand simply by increasing price; assuming that the price elasticity relationship is sufficiently steep to elicit a customer response.

It is clearly the case that any control mechanism will reduce uncertainty. This is likely to be a major factor in containing the required degree of headroom in the longer term and offers a significant opportunity for further research.

### 7.3.6 The Extent of Garden Watering and the Relative Impact of Climate Variability

Arguably, the most uncertain component of future domestic demand is that due to garden watering, particularly if the analyst is designing to meet a critical summer condition. The degree of uncertainty surrounding this component will depend on several factors, including:-

i) the geographic region and the degree of climate variability impacting on the frequency and intensity of garden use,

ii) whether the company has a policy which requires sprinklers to be metered,

iii) whether the prevailing political climate favours or frowns upon garden watering as a customer activity,

iv) whether garden use, if metered, is controlled through a marginal pricing mechanism. Uncertainty surrounding the above is unlikely to be critical for an average day analysis of supply and demand. As the time period reduces, the importance of the above factors will increase and require further research.

## 7.4 SUMMARY OF CHAPTER

Chapter 7 describes a number of areas where further research into the reduction of uncertainty might be beneficial. Within Chapter 8 a numerical example demonstrates how such a reduction in uncertainty converts into a saving in required headroom and consequent financial savings which accrue to the customer.

# CHAPTER EIGHT - ALTERNATIVE SOLUTIONS TO THE SUPPLY-DEMAND BALANCE

## 8.1 INTRODUCTION TO CHAPTER

Chapter 7 considered how uncertainty within the supply-demand balance might be reduced. Clearly, any reduction in uncertainty reduces the spread of possible outcomes and hence reduces any imbalance between supply and demand for a given level of service. Chapter 8 begins by discussing generic ways of reducing a supply-demand imbalance, including the reduction in uncertainty, and how these alternatives can be compared using a risk analysis approach to financial appraisal. Chapter 8 then demonstrates a simple overall solution which includes uncertain resource development schemes, as well as a reduction in one specific source of uncertainty. The chapter also demonstrates how risk analysis can be used to calculate the benefit of a reduced level of service; should the customer be prepared to accept it.

## 8.2 POLICY MIX

Throughout this research the term supply-demand balance has been used very deliberately; rather than the traditional description of resource position which is either supply surplus or supply shortage. The reason for this, as described in Chapters 1 and 2, is that it is no longer acceptable or appropriate to assume that water resource development is the automatic solution to a supply-demand imbalance. In fact, by early 1999, the opposite is invariably suggested, in that some form of demand constraint should be the preferred solution to any imbalance.

In practice, the common sense approach advocated by most sectors within the UK water industry is to adopt a "twin track" solution. Twin track refers to the parallel implementation of both demand management and water resource development schemes. The argument for a twin track approach typically includes issues such as:-

i) a single track approach for demand management ignores the economic argument that water resource development may be more cost effective,

ii) a single track approach for water resource development often ignores the environmental costs of such schemes, particularly where demand restraint is not considered as an alternative,

iii) a single track approach for demand management is high risk, with little known of how successful they might be or, more importantly, how long they might take to be successful,

iv) water resource development, even if it is more expensive, is often more certain. Furthermore, resource schemes may take many years to reach development, hence they cannot be implemented quickly if demand management options fail to deliver the required savings.

The twin track approach therefore advocates a combination of solutions to a supply-demand shortfall which is widely referred to as the policy mix. The policy mix and how it should be appraised in financial terms is discussed in detail in Paying for Growth (OFWAT, 1993).

A policy mix will consist of a selection of schemes from a list, typically, as follows:

i) water resource development,
ii) compulsory metering,
iii) selective metering - such as sprinkler users,
iv) sophisticated tariff charges for metered users to reduce demand at critical times using a price control mechanism,
v) leakage reduction,
vi) pressure reduction,
vii) flow control devices within meters to restrict maximum rates of flow,
viii) customer education to seek reduction in water use directly, particularly garden watering,
ix) reduced levels of service, such as an increased frequency of hosepipe bans.

Each option within the policy mix is uncertain, and seeking an optimum solution without taking these uncertainties into account may well result in an over expensive or inadequate proposal. However, by adopting the same risk-based approach to the solution, then different packages can be compared on a like for like basis for a given level of service. A simple application of scheme comparison, using a net present value (NPV) approach is described in 8.3.

## 8.3 USING THE SIMULATION MODEL TO DERIVE SOLUTIONS

Suppose a company has only two choices for meeting a supply-demand imbalance as follows. (Note that the schemes are described in over-simplistic terms simply to demonstrate technique).

**Option 1**

Option 1 is to develop a moderately certain groundwater scheme with an expected yield distribution of 10 Ml/d (minimum), 15 Ml/d (expected) and 20 Ml/d (maximum). The scheme is expected to take five years to develop, with 70% of the yield available by Year 4. The scheme will cost £1m in Year 1, £0.5m in Years 2 and 3, £1m in year 4 and £2m in Year 5.

**Option 2**

Option 2 is to develop an uncertain groundwater scheme with an expected yield distribution of 0 Ml/d (minimum), 15 Ml/d (expected) and 30 Ml/d (maximum). Scheme development is as for option 1 with costs identical throughout except for a Year 5 cost of £1.9m.

Both options assume the same operating and treatment costs and a triangular probability distribution of yield. Ignoring risk, a traditional financial appraisal, using a discount rate of 10%, would conclude as shown in Table 8.1. Assuming that the resource, when developed, has no redundant capacity (i.e. it is capable of being fully used within a supply-demand shortfall) then option 2 appears preferable, in purely financial terms, at £101.96/Ml compared to £103.65/Ml for option 1.

However, it is intuitively obvious that option 2 is much more uncertain than option 1 and a simulation of a triangular distribution of (0, 15, 30 Ml/d) at the 5% level suggests a yield of 4.6 Ml/d compared with the expected value of 15 Ml/d. This reduces the NPV of resource provision in table 10.1 by 70% (from 15 Ml/d down to 4.6 Ml/d) and increases the £/Ml accordingly, from £101.96 Ml to £328.20 /Ml.

This example, although trivial, serves to demonstrate the danger of excluding uncertainty from the comparison of solutions.

# RESOURCE DEVELOPMENT - FINANCIAL APPRAISAL OF 2 OPTIONS

| OPTION 1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | YEAR | | | | | | |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| CAPITAL INVESTMENT IN £M | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 0 |
| YIELD IN Ml/d | 0 | 0 | 0 | 0 | 10.5 | 15 | 15 |
| DISCOUNT FACTOR @ 10% | 1.00 | 0.91 | 0.83 | 0.75 | 0.68 | 0.62 | |
| DISCOUNT RATE YEARS 6 TO INFINITY | | | | | | | 5.64 |
| NPV OF INVESTMENT | 1.00 | 0.45 | 0.41 | 0.38 | 0.34 | 1.24 | 0.00 |
| TOTAL NPV OF INVESTMENT IN £M | 3.83 | | | | | | |
| Ml OF RESOURCE PROVIDED IN EACH YEAR | 0 | 0 | 0 | 0 | 3832.5 | 5475 | 5475 |
| NPV OF RESOURCE | 0.00 | 0.00 | 0.00 | 0.00 | 2617.65 | 3399.54 | 30904.67 |
| TOTAL NPV OF RESOURCE IN Ml | 36921.87 | | | | | | |
| £ PER Ml OF SCHEME (NPV OF INVESTMENT/ NPV OF RESOURCE) | 103.65 | | | | | | |

| OPTION 2 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | YEAR | | | | | | |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| CAPITAL INVESTMENT IN £M | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 1.9 | 0 |
| YIELD IN Ml/d | 0 | 0 | 0 | 0 | 10.5 | 15 | 15 |
| DISCOUNT FACTOR @ 10% | 1.00 | 0.91 | 0.83 | 0.75 | 0.68 | 0.62 | |
| DISCOUNT RATE YEARS 6 TO INFINITY | | | | | | | 5.64 |
| NPV OF INVESTMENT | 1.00 | 0.45 | 0.41 | 0.38 | 0.34 | 1.18 | 0.00 |
| TOTAL NPV OF INVESTMENT IN £M | 3.76 | | | | | | |
| Ml OF RESOURCE PROVIDED IN EACH YEAR | 0 | 0 | 0 | 0 | 3832.5 | 5475 | 5475 |
| NPV OF RESOURCE | 0.00 | 0.00 | 0.00 | 0.00 | 2617.65 | 3399.54 | 30904.67 |
| TOTAL NPV OF RESOURCE IN Ml | 36921.87 | | | | | | |
| £ PER Ml OF SCHEME (NPV OF INVESTMENT/ NPV OF RESOURCE) | 101.96 | | | | | | |

*(Table 8.1)*
*Financial appraisal of two resource development options excluding uncertainty*

Note that this example appears to be severely cautious because only one scheme is being pursued. However, a portfolio of schemes mitigates risk considerably. For example, ten identical schemes with a triangular distribution of (0,15,30) produce, at the 5% level, an average yield per scheme of 11.2 Ml/d. In practice, the supply-demand balance is a function of an existing situation as well as a proposed one. This effectively dilutes the risk of imbalance even further.

## 8.4 UNCERTAINTY ATTACHING TO THE SOLUTIONS TO A SUPPLY-DEMAND IMBALANCE

One distinct advantage of a simulation technique is that it is linearly complex, a feature which is described in more detail in Chapter 3 and shown in Figure 5.9. Specifically, linear complexity means that changes to the length and complexity of the simulation program have only a pro rata effect on computer run time. This benefit is also described in Section 6.6, which considers the relationship between the number of variables and computer run time. This means that the worksheet example, described in Chapter 5 and analysed within Chapter 7, can be extended to include an uncertain solution to the supply-demand balance without material consequence to the complexity of the worksheet. In simple terms, a water resource solution, for example, can be added to the supply side inputs within the worksheet and any material change in other uncertainties can be considered simply by deleting the effect of the previous uncertainty and adding in the new one.

Compounding the reduction in uncertainty across individual sources of input to the supply-demand equation serves to reduce any imbalance and thus save water resource development or demand management costs.

## 8.5 WORKED EXAMPLE - UNCERTAIN RESOURCE DEVELOPMENT AND IMPROVED CALCULATION OF GROUNDWATER YIELD

This section considers a worked example which seeks to reduce the supply-demand imbalance described in Section 6.4. The solution comprises three resource development schemes of uncertain yield together with a proposal to improve the technique for analysing groundwater yield by 50%.

The three resource development schemes are:

i) an expansion of the output from an existing groundwater source through the drilling of an additional borehole. The geology of the source is well known and the existing yields are stable. It is estimated that the minimum yield will be 5 Ml/d, the expected yield will be 10 Ml/d and the maximum yield 15 Ml/d. The assumed distribution is triangular and development is in the year 2000,

ii) a new green field site, for which extensive field studies have already been completed, but where the geology is uncertain and the yield unproven. The minimum yield is taken to be 0 (in the event that the scheme is abandoned), the expected yield is 10 Ml/d and the maximum yield is 15 Ml/d. The distribution is triangular and the scheme is developed in the year 2005,

iii) recently constructed boreholes with yield parameters which suggest that sustainability is in doubt in the longer term. There is evidence of major geological faulting which may cause a barrier to groundwater recharge. The Environment Agency have imposed a 10-year time limited licence. Triangular distributions for the years 2000, 2005 and 2010 are shown in Table 8.2.

| **Year** | **2000** | | | **2005** | | | **2010** | | |
|---|---|---|---|---|---|---|---|---|---|
| Parameters | Min | Expected | Max | Min | Expected | Max | Min | Expected | Max |
| Yield Ml/d | 5 | 8 | 11 | 3 | 7 | 10 | 0 | 6 | 9 |

*(Table 8.2)*
*Triangular distributions for an uncertain resource development scheme for Company A*

In addition the groundwater yield method was considered within Chapter 5 to have an uncertainty of +/- 10% expressed as a triangular distribution. Within this example, it is proposed to reduce this uncertainty to +/- 5% through the development of an improved technique.

The application of the above uncertain resource developments, combined with the improved groundwater yield technique is shown in worksheet format in Table 8.3. The numerical result of the worksheet described in 8.3, when simulated and reported at the 5% level, is described within Table 8.4. Table 8.4 describes the supply-demand balance before introducing a solution (as detailed in Section 6.4) and post solution. Both situations are reported at the 5% level, hence deducting the pre- and post-solution results gives the net impact of the proposed solution.

| | A | B | C |
|---|---|---|---|
| | YEAR | | |
| | 2000 | 2005 | 2010 |
| 1. Scheme 1 | @<<Risk >> Triang (5,10,15) | @<<Risk>> Triang (5,10,15) | @<<Risk>> Triang (5,10,15) |
| 2. Scheme 2 | 0 | @<<Risk>> Triang (0,10,15) | @<<Risk>> Triang (0,10,15) |
| 3. Scheme 3 | @<<Risk>> Triang (5,8,11) | @<<Risk>> Triang (3,7,10) | @<<Risk>> Triang (0,6,9) |
| 4. Total | @Sum (A1..A3) | @Sum (B1..B3) | @Sum (C1..C3) |
| 5. Groundwater Yield Ml/d | 185 | 185 | 185 |
| 6. Groundwater Yield Uncertainty | @<<Risk>> Triang (-.1 x A5, 0, .1 x A5) | @<<Risk>> Triang (-.1 x A5, 0, .1 x A5) | @<<Risk>> Triang (-.1 x A5, 0, .1 x A5) |
| 7. Improved Uncertainty | 0.5 x A6 | 0.5 x B6 | 0.5 x C6 |
| 8. Total Solution | +A4+A7 | +B4+B7 | +C4+C7 |

*(Table 8.3)*
*Worksheet format for SDB solution for Company A*

Note that the solution in line 8 of Table 8.3 is not simulated separately. It must form an integral part of the supply-demand spreadsheet, in this case increasing the number of input variables from 166 to 194. To deal with the solution separately would treat uncertainties as additive across percentiles, which they are not.

Note also that whilst it is necessary to plan schemes at a given level of service, in practice schemes will be brought forward or deferred based on actual results achieved during development.

| Year | Original SDB Condition from Section 8.4<br>A | New SDB Condition<br>B | Solution described in Table 10.3<br>C=A-B |
|---|---|---|---|
| 2000 | 13.91 | 25.66 | 11.75 |
| 2005 | -0.57 | 17.46 | 18.03 |
| 2010 | -15.79 | 0.88 | 16.67 |
| 2015 | -16.85 | -3.01 | 13.84 |
| 2020 | -27.48 | -13.51 | 13.97 |

*(Table 8.4)*
*Numerical impact of solution described in table 8.3 on the supply-demand condition for Company A, described in section 6.4*
*(Figures are in Ml/d and a negative value indicates a shortfall in supply)*

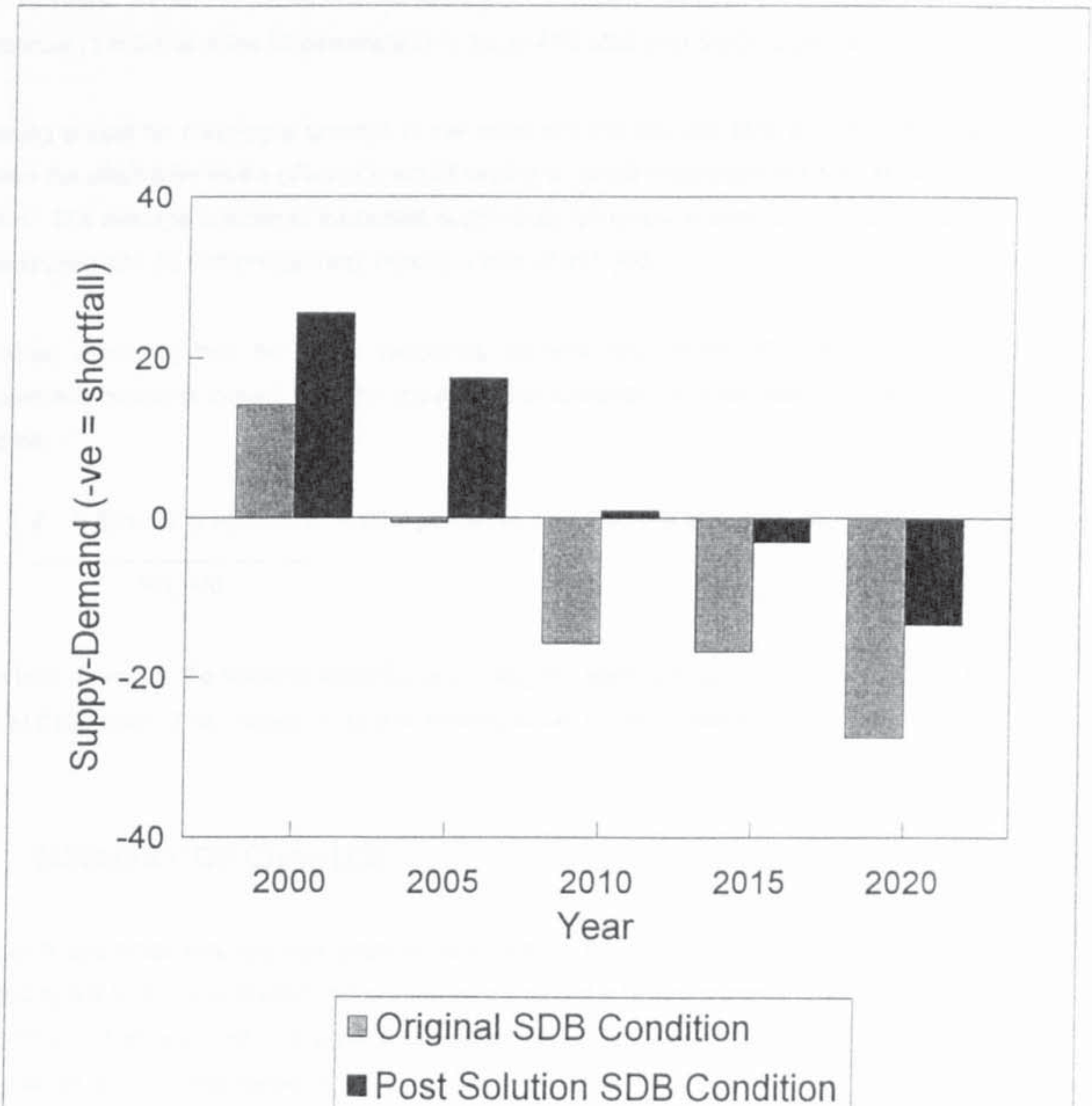
Table 8.4 and Figure 8.1 show that the indicative solution described in Section 8.5 would be sufficient to meet the declared level of service until approximately the year 2011.

Note that the output values can vary, typically, by +/- 5% between simulations. The values in Column B in Table 8.4 represent the average of three simulations.

## 8.6 THE BENEFIT OF A REDUCED LEVEL OF SERVICE

Section 6.7 advises that Company A wishes to meet a combination of events for the average day supply-demand condition such that a failure in levels of service only occurs once every 20 years, on average. However, it is clearly the case that meeting high standards of service has a cost to the customer.

At each periodic review each water company carries out major market research on customer preferences. However, in the absence of risk analysis, it is difficult to see how any water company could identify customer willingness to pay for alternative standards of service. By reference to Table 6.1 and to an estimated unit cost of meeting a supply-demand imbalance, it is a simple exercise to do so for the case of Company A.



*(Figure 8.1)*

*Graph showing impact of water resource development and improved groundwater yield technique on supply-demand condition described in section 6.4*

Suppose, for example, that Company A wishes to reduce its standard of service for water resource provision from a failure (described in Section 6.8) once every 20 years to a failure once every 10 years. Table 6.1 shows that the average difference in resource provision between the 5 percentile (1 in 20) and the 10 percentile (1 in 10) is 4.88 Ml/d over the 20-year horizon.

Assuming a cost for meeting a shortfall in the order of £750,000 per Ml/d then the difference between the alternative levels of service would require a capital investment of £750,000 x 4.88 = £3.66m. The average number of properties supplied by Company A over the period is 516,000 (unmeasured) and 35,000 (measured), making a total of 551,000.

Therefore, assuming that the water resources scheme has infinite life, and ignoring the non-domestic customer impact, then the impact on the customer, for a net cost of capital of 10%, would be:

$$\frac{\pounds\ 3.66 \times 10^{6} \times 10^{2} \times 10\%}{551{,}000} = 66.4 \text{ pence per customer per annum}$$

At the time of writing, the average water bill (excluding the sewerage service) for the UK is in the order of £120/year. This change in level of service would therefore deduct 0.55% from a typical bill.

## 8.7 SUMMARY OF CHAPTER

Chapter 8 describes how the risk analysis approach to the supply-demand equation can be adapted to aid both the appraisal and calculation of solutions to any shortfall. The chapter also shows how a change in customer level of service can be costed through simple risk analysis and pricing as an aid to market research.

Chapter 9, which follows, concludes and summarises the thesis.

# CHAPTER NINE - CONCLUSIONS

## 9.1 INTRODUCTION TO CHAPTER

Chapter 9 is the final chapter within this research and will serve firstly as a summary of key observations and conclusions. Discussion will then focus on benefits deriving from the research, a discussion of whether the original objectives have been satisfied, and the opportunities for future research which have arisen.

The chapter finishes with a number of concluding remarks.

## 9.2 SUMMARY OF HISTORICAL OBSERVATIONS

The structure of this research, shown in Figure 1.1, identifies that the research is divided into five functional sections which are then divided into a number of individual chapters. The first of these sections is described as background study and concentrates on the historical evolution of resource planning techniques, which begins with discussion of early water resource planning in the 1920's. Particular observations note the extent to which the protracted planning process, which required a separate Act of Parliament, generated a form of momentum for resource development, such that schemes were developed , sometimes despite the match between development and demand growth. Early emphasis for resource planning was to ensure national health and hygiene and, in the end, parliamentary applications would invariably succeed.

By the 1960's it was not uncommon for water resource development proposals to be accompanied by a public enquiry. Chapter 2 notes in particular the case of the Shrewsbury Water Order and the remarkable compounding of contingency allowances which accompanied the proposal for resource development. Despite the very limited evidence to justify the need for the resource development the application largely succeeded. The emphasis remained one of a customer-driven need for water as an essential product and errors in demand growth were argued away on the basis that demand was growing too quickly for errors in justification to be important.

By the early 1980's a number of the major resource developments commissioned during the 1970's were receiving adverse publicity. Pearce (1982) was particularly outspoken with notable criticism of the Kielder Reservoir Scheme in Northumberland. Other adverse assessments included a review of the Rutland Water Scheme (Herrington, 1982).

By the late 1970's and early 1980's water resources planning, and particularly demand forecasting, went through a re-focusing stage and a number of notable methodologies were developed, in particular Archibald (1983) and Thackray *et al* (1981). By 1985 privatisation of the water industry was included within the Government's agenda paving the way for an eventual regulatory process and a significant review of water resource planning techniques.

## 9.3 PRINCIPAL UNCERTAINTIES IDENTIFIED

In Chapter 4, Section 4.2 provides a scoping study of sources of uncertainty drawing on internal and external research and on the individual experiences of the author. The results of this scoping study were presented within Tables 4.1, 4.2, 4.3 and 4.4. Approximately 80 sources of uncertainty were identified within the tables and around 60 of these were considered in more detail within Chapter 5. Of these 60, there were a number of overlapping uncertainties leaving around 40 discrete uncertainties to be quantified.

Following discussion within Chapter 5, uncertainties were either quantified or, in some cases, labelled as requiring further research. A few uncertainties turned out to be non-material within the context of this research. Of those uncertainties which remained the '@Risk' package undertakes a sensitivity analysis which compares the significance of the input distribution to the output distribution. Section 6.5 discusses sensitivity analysis in further detail and notes a ranking of the most important input distributions for this particular simulation. These rankings are repeated in Table 9.1.

| Rank | Input Variable |
|---|---|
| #1 | Due to Method of Groundwater Yield Analysis |
| #2 | Variation in Climate on Reservoir Yield |
| #3 | Climate Variation Uncertainty |
| #4 | Loss of Yield due to Gradual Pollution |
| #5 | UNMEAS-DOMESTIC FORECAST ERROR/YEAR |
| #6 | Unplanned outages due to Water Quality Spikes |
| #7 | Unplanned outages due to Blending Problems |

*(Table 9.1)*
*Ranking of principle sources of uncertainty derived for the supply-demand balance for Company A*

Cont'd ......

| Rank | Input Variable |
|---|---|
| #8 | Unplanned outages due to Economic Source Use |
| #9 | MEAS-NONDOMESTIC FORECAST ERROR/YEAR |
| #10 | UNMEAS-DOMESTIC FORECAST ERROR/YEAR |
| #11 | Unplanned outages due to power failure |
| #12 | Planned Outages |
| #13 | MEAS-DOMESTIC FORECAST ERROR/YEAR |
| #14 | Unplanned outages due to Elec/Mech Failure |
| #15 | MISCELLANEOUS FORECAST ERROR/YEAR |

*(Table 9.1)*
*Ranking of principle sources of uncertainty derived for the supply-demand balance for Company A*

Most notable within Table 9.1 are the primary sources of uncertainty from a significance point of view. These are uncertainties associated with climate change, climate variation, the assessment of groundwater yield and uncertainties within demand forecasting techniques. These primary uncertainties are likely to be common to any analysis of the supply-demand balance.

## 9.4 KEY OBSERVATIONS FROM SIMULATION MODEL

Chapter 5 quantifies uncertainties identified within Chapter 4 and describes the positioning of these uncertainties within the '@Risk' simulation model described in Section 5.7.7. Prior to simulation the @Risk package delivers, for each uncertainty, its expected value. As such the pre-simulation spreadsheet shown as Table 5.36 represents the average supply-demand condition which includes the expected value of planning allowances but excludes consideration of uncertainty surrounding them. This average supply-demand condition is shown as Figure 5.11. The level of service described by Figure 5.11 is the 50 percentile, or 1 in 2 event. In other words, given that the spreadsheet is returning the expected value, then the outturn supply-demand balance is equally likely to be better or worse than the spreadsheet value.

Comparison between the average supply-demand condition and the 5 percentile level of service required for Company A can be seen in Table 6.1. This shows, for example, that the 5 percentile for the year 2020 has a 27.48 Ml/d shortfall whereas the 50 percentile for the same year has a 7.87 Ml/d shortfall. The difference between the expected event, therefore, and the required level of service for Company A is 19.61 Ml/d in 2020. This figure represents 4.93% of the demand forecast for 2020 and is the additional supply-demand requirement to cater for uncertainty at the 5% (1 in 20 year) level. The effective planning margins to cater for uncertainty, expressed as a percentage of forecast demand for each incremental time slice, are shown in Table 9.2.

| **Variable** | **2000** | **2005** | **2010** | **2015** | **2020** |
|---|---|---|---|---|---|
| Demand forecast in Ml/d extracted from table 7.26 | 385.56 | 385.42 | 386.27 | 391.69 | 398.05 |
| Difference between expected event (50 percentile) and 1 in 20 event (5 percentile) extracted from table 8.1. Difference represents the impact of considering uncertainty at the 5% level. Figures in Ml/d. | 18.67 | 21.33 | 20.35 | 18.58 | 19.61 |
| Effective planning allowance due to the inclusion of uncertainty at the 5% level. | 4.84% | 5.53% | 5.27% | 4.74% | 4.93% |

*(Table 9.2)*
*Effective planning margin due to the effects of including uncertainty at the 5% level*

Note that the figures in the above table represent only the effect of uncertainty at the 5% level. As such they do not describe total planning allowances, but rather the additional allowance due to uncertainty above the expected value. By example, the total planning allowance for the year 2020 would need to include, *inter alia,* an allowance of 5.44 Ml/d for planned outages and 2.62 Ml/d for unplanned outages. The definition of what is included or excluded from the classical method of describing planning allowances is outside of the scope of this research. However, by reference to Table 5.36, it is easy to see that the addition of allowances for outages increases the total allowance for the year 2020, including the effect of uncertainty at the 5% level, from 19.61 to 27.67 Ml/d, or from 4.93% to 6.95%.

The simulation also reveals the effects of changes in service levels again described within Table 6.1 and Section 8.6 appraises the financial benefit of changing standards of service from a customer perspective.

## 9.5 BENEFITS OF THE RESEARCH

Section 1.1 notes that at the outset of this research the water industry had no consistent, meaningful, or integrated methodology for calculating the balance between water supply and water demand. Correcting this situation has been the principal purpose of this research and this requirement is considered to have been achieved. More specifically, there are a number of ancillary and component benefits of the research as follows:

i) the provision of a methodology for the analysis of multiple sources of uncertainty within the supply-demand balance. The analysis can range from the simple to the complex and is likely to be more important for those companies where the most significant sources of uncertainty prevail. This research suggests, at least for the case of Company A (a hypothetical water company), that material sources of uncertainty are those associated with climate change, climate variation, the calculation of groundwater yield and the overall accuracy of demand forecasts;

ii) the provision of a methodology which is considered to be sufficiently objective and robust that it will satisfy the requirements of regulators for a water resource development proposal or subsequent public enquiry;

iii) an insight into those uncertainties, although not exhaustive, which should be considered when appraising the supply-demand balance. These uncertainties are described initially within Tables 4.1, 4.2 and 4.3, representing the outcome of the scoping study, and latterly within Sections 6.2.2 and 6.2.3 where they are considered either to be too material or beyond the scope of this research;

iv) examples of how individual sources of uncertainty, where the available information ranges from pure judgement, through to historic and experimental data, can be quantified using continuous and discrete probability distributions;

v) an insight into those uncertainties which are not well understood by the water industry and where further research is considered worthwhile. Opportunities for further research are described in Section 9.7;

vi) the provision of a meaningful technique for appraising solutions to the supply and demand balance such that the uncertainty surrounding solutions can be considered as an integral part of the prevailing supply-demand condition. This ensures that it is the customer level of service which prevails as the design tool , even during the appraisal of solutions.

## 9.6 COMPARISON WITH ORIGINAL OBJECTIVES

Section 1.5 lists nine main objectives of this research which are slightly different in scope from the original objectives listed within Appendix IV. There are various reasons for this; firstly because of the need for commercial confidentiality, secondly because of complexity and, finally, where the original importance of the objective was misconceived and subsequently proved of lesser value during this research. The main objectives in Section 1.5 are the revised objectives which evolved during the research and which have all been satisfied. Comparison with the original objectives follows.

The original intention of this research was to produce an integrated method for evaluating both local and national water resource need. The reasons for the project pertinent at the time were that the water industry had no consistent meaningful or integrated methodology for developing and utilising water resource planning allowances. This meant excessive capital investment as a result of over-design or sub-standard levels of service as a result of under-design. The former problem creates difficulties with the economic regulator, OFWAT, and the latter creates difficulties with the environmental regulator, the Environment Agency.

Individual objectives of the research were firstly to critically review historic need and secondly to review post water industry privatisation research under the direction of UKWIR. Both of these objectives have been satisfied. The third objective was to carry out a scoping exercise across different groups of planning allowances. These planning allowances were subsequently grouped, within Chapter 4, into four different categories, or dimensions, as an aid to the scoping exercise. The scoping exercise revealed a total of 79 separate sources of uncertainty, although a number of these were subsequently considered immaterial or beyond the scope of this research. In addition a number of the sources of uncertainty overlapped considerably. Of the original list of 79 uncertainties around 40 were carried forward to the discussion within Chapter 4. The objective of the scoping exercise was achieved.

The fourth objective was to appraise, investigate and report on the nature of individual sources of uncertainty, the likely acceptance of each by the regulator, and how each allowance impacts on the balance between water supply and water demand. This discussion and analysis forms the basis for Chapters 4 and 5 and has been substantially achieved. It is fair to say, however, that a number of uncertainties have very weak evidence in support of quantification and in these areas substantial engineering judgement has been necessary.

The fifth objective was to combine together individual planning allowances in the light of statistical distribution and dependency. Achieving this objective required the development of the spreadsheet-based risk analysis package described in Section 3.5 and subsequently demonstrated in Section 5.7.7. A numerical example is reported in Section 6.4. The only uncertainties which were considered to be inter-dependent were those due to the relationship between domestic demand and the yield of surface water resource; although multiple inter-dependencies can be included, if required, using correlation matrices.

The sixth objective was to argue and report upon the meaning of different levels of water resource risk from the point of view of a water industry customer. Very little work was done in this area although Section 6.8 notes the benefit to the customer in terms of changing the design level of service.

The seventh objective was to investigate and report on combining planning allowances to form a national figure. This aspect of the research has not been carried out because other areas of the research turned out to be more significant and more complex than original thought, making the initial overall list of objectives too broad for completion as a single piece of research. However, the procedures and methodology developed during this research could be utilised to achieve this objective.

The eighth objective was to produce a methodology which demonstrated how companies could financially appraise the reduction in uncertainty within the supply-demand balance. Chapter 8, and Section 8.5 in particular, address this issue and satisfy this objective.

The ninth objective was to develop software which allows the calculation of future resource need. The fifth objective by definition ensured that this objective was satisfied.

The tenth objective was to calculate future resource need for the South Staffordshire Water Company. Given that this document is to be placed in the public domain then it is considered inappropriate to declare any information which might be considered commercially confidential.

The requirement for a numerical analysis has been satisfied using anonymous data for Company A.

The eleventh and final objective was to produce a set of definitions appropriate to this research consistent with the water industry standard. This objective has been achieved through the presentation of a definitions section in appendix I.

## 9.7 OPPORTUNITIES FOR FUTURE RESEARCH

There are various sections within this research where the opportunities for further research are identified. Chapter 7 notes in particular a number of areas where the opportunity to reduce uncertainty might be beneficial, based in part on the ranking of uncertainties within Chapter 6.

Opportunities for future research are suggested for the following reasons:-

i) the uncertainty has been considered and found significant. In these circumstances any reduction in uncertainty may be beneficial, although research should target areas where uncertainty is partly controllable, such as due to analytical techniques;

ii) the uncertainty has not been considered on the grounds of complexity, scope or lack of information. Most of these instances involve studies of climate behaviour. Intuitively a number of these uncertainties are believed to be worth further study. However, this is not to suggest that this research contains an unacceptable error of omission. Error of omission is discussed in 5.7.5.

Uncertainties considered significant and likely to benefit from further study are detailed below.

i) Sections 5.3.6 and 7.2.6 observe that source meter error, although significant, influences only the baseline position for supply-demand forecasting. Since source meter error does not appear as an uncertainty beyond phase I normalisation then it will not be identified through sensitivity analysis as significant or otherwise. Nevertheless common sense suggests that this area of uncertainty would benefit from study. In particular, how much overall uncertainty is reduced if source meters can be made more accurate.

ii) Section 5.4.2 considers uncertainty within baseline demand components. This uncertainty prevails because water demands are only partly measured, hence there is uncertainty between the addition of demand components and the volume of water put into supply. This uncertainty will reduce as techniques for assessing unmeasured demand improve, or when the proportion of measured demand increases. Research into improved 'per-capita' calculations remains a major focus for the water industry.

iii) Sections 5.3.7 and 7.2.2 note that the UKWIR method of groundwater yield (UKWIR, 1995$_c$) suggests no real evidence of accuracy although there is an anecdotal view of +/- 10%. This issue is assessed to be Number 1 on ranking of uncertainties based on the accuracy assumptions.

iv) Demand forecasts are always uncertain and it is intuitively obvious that these uncertainties increase with time. Assessing the degree of uncertainty within these forecasts, however, requires a combined view of past performance and improved technique. Scenario, or 'what if' analysis may also be insightful. Sections 5.4.3, 7.3.1, 7.3.2 , 7.3.4 and 7.3.5 consider demand forecast accuracy in further detail.

The difficulty with forecast methods, particularly when they are 'improved', is that it takes many years to identify whether they are better or not. This is particularly true with water demand forecasts because of external influences, such as climate. A view of past forecasting performance is also a function of forecast stability (see sections 4.5.13). Put simply it is easy to forecast a constant growth rate or, better still, a horizontal projection. This variable, for the assumptions given in section 5.4.3.6, is ranked widely within table 9.1 and is considered to be a major opportunity for further research into reducing uncertainty.

v) Understanding which of the climate change models within UKWIR/EA (1997$_b$ ) is the most accurate will significantly reduce uncertainty within the supply-demand balance; both in terms of the assumed effect on demand and the assumed effect on yield. This source of uncertainty was discussed in more detail in sections 5.4.5 and 7.2.1.

Uncertainties considered to be beyond the scope of this research typically on the grounds of complexity but, which may merit further study, are:-

i) The relationship between groundwater yield and climate variability or climate change. This issue is discussed further in Sections 5.3.5, 6.2.3 (iii) and 7.2.1.

ii) In Section 5.4.1 normalising demand due to climate has been carried out superficially by comparing trends. A more correct analysis would involve deriving a relationship between demand and climate.

iii) Climate variability on demand can be particularly significant if critical periods for design are short, such as peak week. In these circumstances research into the relationship between climate and demand would be invaluable. This issue is discussed further in sections 5.4.4, 7.3.6 and 6.2.3 (iii).

iv) The relationship between uncertainty and organisational size is important because large organisations should be able to construct a portfolio of uncertainties to mitigate risk. The significance of this may be appreciable; particularly given the wide spread of organisational sizes within the water industry. This is discussed further in Section 5.4.7 and 6.2.3. (v).

v) The dependency relationship between domestic demand and sampled source yield is considered in 5.4.8 but may benefit from an improved understanding of the relationship between climate and supply - demand. This issue is also discussed in Sections 7.2.1 and 6.2.3 (iii).

## 9.8 CONCLUDING REMARKS

It is appropriate at the conclusion to this research to repeat that the principle intention at the outset, to provide a robust and workable methodology for the calculation of the supply-demand balance, has been satisfied. Likewise it is considered that, except for minor variations as described in Section 9.6, key objectives have been achieved. The research is therefore considered to be concluded.

However, throughout the thesis, either as a result of complexity or an opportunity to reduce existing uncertainty, issues have been identified which would warrant further research. Many of these future opportunities surround the uncertain relationship between climate and water demand. This is either as a result of climate change, climate variation or climate persistence, and which together suggest that uncertainty, when appraising the supply-demand balance, will remain in the longer term.

Finally, it is important to reflect on the contribution to knowledge which this research provides. Chapter 4 provides a significant original contribution by scoping approximately eighty sources of uncertainty across the supply-demand balance. Chapter 5 is also an original contribution in that it seeks to quantify approximately 40 of the uncertainties within Chapter 4 in a manner which allows risk equations, or probability distributions, to be assigned.

Chapter 5 concludes by incorporating sources of uncertainty, together with supply and demand components, into a formulated spreadsheet using the '@ Risk' package. Within Chapter 6 the reader is shown an example of how the output from the '@ Risk' package is used to determine the supply demand balance and from which, in Chapter 8, it is possible to appraise alternative solutions to meeting any imbalance. Chapter 8 also demonstrates how it is possible to use the spreadsheet to assess the impact on customers bills in the event of changing declared levels of service.

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APPENDIX I

## DEFINITIONS AND ABBREVIATIONS

Many of the definitions and abbreviations which follow have been extracted from the UKWIR/EA Report Nr. 97/WR/14/1; Definitions of Key Terms for Water Resources Practitioners. These are shown with an asterisk. All other definitions have been developed as part of this research.

**Abstraction*** - The removal of water from any *source*, either permanently or temporarily.

**Abstraction Licence** - The authorisation granted by the Environment Agency to allow the removal of water from a *source*.

**ACORN*** - A Classification Of Residential Neighbourhoods (ACORN) is a socio- demographic classification of neighbourhoods published by CACI Limited. The system is based on the assumption that people who live in similar neighbourhoods are likely to have similar behavioural and consumption habits.

**Annual Average Daily Demand** - The cumulative demand in a year, divided by the number of days in the year.

**Aquifer*** - A geological formation, group of formations or part of a formation that can store and transmit water in significant quantities.

**Aquifer Properties*** - The properties *(permeability, transmissivity, specific yield* and *storage coefficient)* of an aquifer that determine its hydraulic behaviour and its response to abstraction.

**Available Storage*** - The storage volume available to offset the impact of component or strategic capacity failure.

**Average Day Peak Week Ratio*** - The ratio of average daily demand in the peak 7-day period in the year (ADPW) to annual average daily demand (ADD). (Note that "demand" is measured as *distribution input*).

**Base Year** - The starting point for a demand forecast. The data for the base year may need to be normalised to remove unusual influences such as extreme climate.

**Behavioural Analysis*** - The analysis of data, typically over a long term series, which is used to describe or derive a model of changes in the data, often with the intention of predicting the future behaviour of the variable being analysed.

**Bias** - A tendency, often without intent, to distort the likelihood of an event, believing that it occurs more, or less, often than in practice.

**Bulk Supply** - A supply of water across the boundary of a neighbouring water supplier; either given or received.

**Consumption Monitor*** - A sample of properties whose *consumption* is monitored in order to provide information on the consumption and behaviour of properties served by a company.

**Correlation** - The measure of dependency. A perfect correlated model allows for perfect prediction.

**Delphic Assessment*** - The consensus view of a panel of experts.

**Demand Management*** - The implementation of policies or measures which serve to control or influence the *consumptions* or waste of water. (This definition can be applied at any point along the chain of supply).

**Demand Management Option*** - A single measure or a combination of measures (e.g. a public awareness campaign using both leafleting and radio advertising), taken to influence the demand for water.

**Dependent Events** - Events in a model which depend on others. Typically it is the dependent event which is predicted, based on a number of independent inputs, e.g. UK interest rates are a function of world interest rates, inflation and so on.

**Deployable Output*** - The output of a commissioned *source* or group of *sources* or of bulk supply as constrained by:-

- environment
- licence, if applicable
- pumping plant and/or well/aquifer properties
- raw water mains and/or aqueducts
- transfer and/or output main
- treatment
- water quality

**Distribution Input*** - The amount of water entering the distribution system at the *point of production*. This is the quantity usually measured as *demand* by customers.

**Distribution Losses*** - Made up of losses on trunk mains, service reservoirs, distribution mains and communication pipes. Distribution losses are *distribution input less water taken.*

**Distribution System Operational Use (DSOU)*** - Water knowingly used by a company to meet its statutory obligations, particularly those relating to water quality. Examples include mains flushing and air scouring.

**Drawdown*** - The reduction in *rest water level* resulting from abstraction.

**Gearing (financial)** - The ratio of debt (loans from banks) to equity (shareholders funds). The higher the ratio, the higher the risk of bankruptcy, but, normally, the lower the cost of borrowing.

**Groundwater*** - Water within the *saturated zone* of an *aquifer.*

**Headloss*** - Loss in pressure across an appliance or device or between two points in a pipe, channel or *aquifer.*

**Headroom** - Defined as the buffer included between supply and demand, to cater for planning margins. The extent of headroom will vary with planning standards.

**Households*** - Properties (normally occupied) receiving water for domestic purposes which are not factories, offices or commercial premises.

**Hydrological Yield*** - The unconstrained output of a source that can be sustained by the catchment or *aquifer* feeding the source.

**Independent Events** - Events which do not depend on others in the same model. Independent events usually represent inputs to models, although true independency (represented by a statistical correlation of 0) is uncommon.

**Iterations** - The number of times a procedure is repeated.

**Latent Demand*** - The increase in demand which might occur if the supply and distribution system did not impose physical constraints. (This definition can be applied at any point along the chain of supply).

**Leakage*** - The sum of *distribution losses* and *underground supply pipe losses.*

**Likelihood** - A measure of how likely. Another term for probability.

**Maximum Likelihood Estimation (MLE)*** - A statistical technique where a *reconciliation item* is distributed to the largest and least certain components of an estimate of the magnitude of a variable. The technique can be applied to the reconciliation of a *water balance,* for example.

**Micro-Component Analysis*** - The process of deriving estimates of present or future consumption based on expected changes in the individual components of customer use.

**Minimum Night Flow*** - The minimum flow into a discrete distribution area during the night. Used by water companies to determine leakage.

**Model** - A representation of a real life problem with a series of defined inputs used to predict an outcome.

**Non-Households*** - Properties receiving water for domestic purposes, but which are not occupied as domestic premises, i.e. factories, offices and commercial premises, cattle troughs. They also include properties containing multiple households which receive a single bill (e.g. block of flats).

**Normalisation** - The act of adjusting data to remove the effect of unusual influence. For example, "normalised" use of water would be lower than that used during hot weather.

**Operational Allowance*** - A deduction made from *deployable output,* usually for efficiency reasons.

**Outage** - A temporary (less than 12 months) loss of source yield.

**Outage Allowance*** - The value of allowable *outage* expressed in Ml/d. (Not that outage allowances are a subset of *planning allowances.* The value of the allowance is based on the most critical resource planning period).

**Parity** - A mathematical relationship between the measured and unmeasured use of water such that a measured customer would pay the same as an unmeasured customer if both groups used the same amount of water.

**Peak Demand*** - The highest demand that occurs, measured either hourly, daily, weekly, monthly, or yearly, over a specified period of observation. (Note; usually measured as *distribution input*).

**Peak Factors*** - Ratios of peak demand observed over discrete intervals within a year, to the average demand in that year.

**Planned Outage*** - A foreseen and pre-planned *outage* resulting from a requirement to maintain source works asset serviceability.

**Planning Allowance** - A legitimate addition to demand or a reduction from supply, which a prudent company would make allowance for within its supply-demand balance.

**Planning Standard** - The level of service provided to customers, typically expressed in terms of demand restriction frequency and/or intensity.

**Precautionary Principle*** - Where significant environmental damage may occur, but knowledge on the matter is incomplete, decisions made should err on the side of caution.

**Random Numbers** - Independently derived numbers, usually generated by computer algorithm hence described as 'pseudo' random. Random numbers may be converted into any statistical distribution. A common misconception is that they must always be uniformly distributed.

**Reconciliation Item*** - The difference between the estimates of the magnitude of a variable and the sum of the estimates of the individual components of that variation. (See *Maximum Likelihood Estimation)*.

**Resource Zone*** - The largest possible zone in which all resources, including external transfers, can be shared and hence the zone in which all customers experience the same risk of supply failure from a resource shortfall.

**Restrictions*** - Enforceable restrictions on demand (e.g. hose pipe bans).

**Risk*** - A measure of the probability and magnitude of an event and the consequence(s) of its occurrence.

**Risk** - The threat or worth of a situation as determined by multiplying its consequence by its likelihood. Often associated, confusingly, just with likelihood.

**Scenario Analysis** - A simple, but sometimes effective, method of handling uncertain options by considering the implications of a discrete number of alternatives. Scenarios often follow a high, medium, low type of format often without, regrettably, assigning likelihood.

**Simulation** - An efficient evaluation of multiple scenarios, usually by computer. Simulation of scenarios which contain likelihoods allows an output risk to be determined.

**Source*** - A named input to a *resource zone*. A multiple well/spring source is a named place where water is abstracted from more than one operational well/spring.

**Source works*** - All assets used between and including the point of *abstraction* and the point at which water is first fit for purpose. These include:-

abstraction works
reservoir and river intakes
boreholes
raw water storage
pumping plant and mains
water treatment plant
treated water storage
treated water pumping plant

**Stratified Sample** - A sample 'directed' towards segments of a probability distribution in circumstances where random sampling would be slow or inefficient. Stratified sampling, however, produces statistically imperfect results.

**Supply Pipe Losses*** - The sum of *underground supply pipe losses* and *above ground supply pipe losses*.

**Total Leakage*** - The sum of *distribution losses* and *underground supply pipe losses*.

**Treatment Works Losses*** - The sum of structural water loss and both continuous and intermittent over-flows.

**Uncertainty** - The state of being unsure of something

**Unplanned Outage*** - An *outage* caused by an unforeseen or unavoidable legitimate *outage* event affecting any part of the *source works* and which occurs with sufficient regularity that the probability of occurrence and severity of effect may be predicted from previous events or perceived *risk*.

**Unrestricted Demand*** - The demand for water when there are no enforceable restrictions in place.

**Water Balance*** - The allocation of total *distribution input* across its constituent components.

**Water Delivered*** - Water delivered to the *point of delivery*.

**Water Delivered Billed*** - *Water delivered* less *water taken unbilled*. It can be split into *unmeasured household, measured household, unmeasured non-household* and *measured non-households water delivered billed.*

**Water Table*** - The surface of a body of *unconfined* groundwater at which the pressure is equal to atmospheric.

**Water Taken Unbilled*** - *Water taken illegally unbilled* plus *water taken legally unbilled.*

**Well Loss*** - The headloss resulting from flow of groundwater across the well face, including any part of the *aquifer* affected by drilling, and any gravel pack or lining tube, and vertically within the well.

## ABBREVIATIONS

**AMP*** - Asset Management Plan

**DG*** - Director General (of Water Services)

**DG1*** - Performance Indicator Nr. 1 "Water Availability", reported to the Director General of Water Services "OFWAT"

**DG4*** - Performance Indicator Nr. 4 "Hosepipe Restrictions", reported to the Director General of Water Services "OFWAT"

**EA*** - Environment Agency (formerly National Rivers Authority)

**mgd*** - Million gallons per day

**Mld, Ml/d, Ml/day*** - Megalitres per day. Megalitre = one million litres (1,000 cubic metres)

**NRA*** - National Rivers Authority (now incorporated within the UK Environment Agency)

**OFWAT*** - Office of Water Services

**OPCS*** - Office of Population, Censuses and Surveys

**PER CAPITA CONSUMPTION (pcc)*** - Consumption per head of population

**PRV*** - Pressure Reducing Valve in fixed head form, i.e. outlet pressure always at a specific value regardless of down stream conditions, or flow modulated at the valve site.

**SDB*** - Supply-Demand Balance

**SIC*** - Standard Industrial Classification

**UKWIRL/UKWIR*** - United Kingdom Water Industry Research Limited (see report cover)

**WCA*** - Water Companies' Association

**WSA*** - Water Services Association

# COMPANY A
# SOURCE OUTAGE DATABASE
# EXTRACT FOR 1996

| LEGEND |
|---|
| SOURCE KEY |
| AW |
| BV |
| BB |
| CC |
| CR |
| CK |
| FR |
| HG |
| HK |
| KV |
| LH |
| MF |
| MG |
| MB |
| MG |
| PH |
| PR |
| SS |
| SF |
| ST |
| SA |
| SM |
| SL |
| TV |
| WW |

| LEGEND | |
|---|---|
| OUTAGE REASON DESCRIPTION | CODE |
| Avoidable planned maintenance. | PLA |
| Planned maintenance of such duration that outage during peak periods cannot be avoided. | PLP |
| Optional outages for tariff management | ECO |
| Unplanned outage due to electrical/mechanical failure | UME |
| Consequential unplanned outage because of outage at a blended source | UBL |
| Unplanned outage due to pollution incident of less than 12 months duration. | UPO |
| Water quality outages between 1 day and 1 year duration. | UWQ |
| Unplanned incident caused by water quality spikes Outages of less than 1 day duration. | USP |
| Outage due to power failure. | UPF |

# DATABASE - COMPANY A

| YR | MN | DY | TIME | STN | REASN | DURATION | | MITIGATION | | OUTPUT | | OUTPUT LOSS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | LINE | | | Dys | Hrs | PEAK | AVERAGE | RATE | | PEAK | AVERAGE |
| | | | YEARS | | | | | NO=1 | NO=1 | AV | PK | MI | MI |
| | | END | | | | | | | | | | | |
| 96 | 1 | 10 | 96.03 | PH | PLA | 9 | 0 | 0 | 1 | 15 | 15 | 0.0 | 135.0 |
| 96 | 1 | 11 | 96.03 | CR | UME | 1 | 0 | 1 | 1 | 2 | 2 | 2.0 | 2.0 |
| 96 | 1 | 17 | 96.05 | LH | PLA | 1 | 0 | 0 | 1 | 5 | 5 | 0.0 | 5.0 |
| 96 | 2 | 6 | 96.10 | PH | PLA | 6 | 0 | 0 | 1 | 15 | 15 | 0.0 | 90.0 |
| 96 | 2 | 12 | 96.12 | LH | PLA | 12 | 0 | 0 | 1 | 5 | 5 | 0.0 | 60.0 |
| 96 | 2 | 12 | 96.12 | HK | UME | 0 | 12 | 1 | 1 | 6 | 6 | 3.0 | 3.0 |
| 96 | 2 | 12 | 96.12 | HK | PLA | 0 | 10 | 0 | 1 | 6 | 6 | 0.0 | 2.5 |
| 96 | 3 | 7 | 96.19 | LH | UME | 0 | 3 | 1 | 1 | 5 | 5 | 0.6 | 0.6 |
| 96 | 3 | 7 | 96.19 | HG | ECO | 0 | 8 | 0 | 1 | 9 | 9 | 0.0 | 3.0 |
| 96 | 3 | 8 | 96.19 | HG | ECO | 0 | 8 | 0 | 1 | 9 | 9 | 0.0 | 3.0 |
| 96 | 3 | 9 | 96.19 | HG | ECO | 0 | 8 | 0 | 1 | 9 | 9 | 0.0 | 3.0 |
| 96 | 3 | 25 | 96.24 | SF | PLA | 25 | 0 | 0 | 1 | 2 | 2 | 0.0 | 50.0 |
| 96 | 3 | 26 | 96.24 | HG | ECO | 0 | 8 | 0 | 1 | 9 | 9 | 0.0 | 3.0 |
| 96 | 3 | 26 | 96.24 | CH | ECO | 0 | 4 | 0 | 1 | 10 | 15 | 0.0 | 1.7 |
| 96 | 4 | 5 | 96.26 | CC | PLA | 5 | 0 | 0 | 1 | 7 | 7 | 0.0 | 35.0 |
| 96 | 4 | 6 | 96.27 | MG | UME | 0 | 5 | 1 | 1 | 6 | 6 | 1.3 | 1.3 |
| 96 | 4 | 6 | 96.27 | CH | PFM | 0 | 2 | 1 | 1 | 10 | 15 | 1.3 | 0.8 |
| 96 | 4 | 6 | 96.27 | CK | PFM | 0 | 2 | 1 | 1 | 10 | 10 | 0.8 | 0.8 |
| 96 | 4 | 6 | 96.27 | HG | PFM | 0 | 2 | 1 | 1 | 9 | 9 | 0.8 | 0.8 |
| 96 | 4 | 6 | 96.27 | KV | PFM | 0 | 2 | 1 | 1 | 12 | 12 | 1.0 | 1.0 |
| 96 | 4 | 6 | 96.27 | PH | PFM | 0 | 2 | 1 | 1 | 15 | 15 | 1.3 | 1.3 |
| 96 | 4 | 6 | 96.27 | AW | PFM | 0 | 2 | 1 | 1 | 18 | 18 | 1.5 | 1.5 |
| 96 | 4 | 30 | 96.33 | LH | PLA | 30 | 0 | 0 | 1 | 5 | 5 | 0.0 | 150.0 |
| 96 | 5 | 1 | 96.34 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 5 | 2 | 96.34 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 5 | 3 | 96.34 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 5 | 4 | 96.34 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 5 | 5 | 96.35 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 5 | 11 | 96.36 | CH | PFM | 0 | 2 | 1 | 1 | 10 | 15 | 1.3 | 0.8 |
| 96 | 5 | 11 | 96.36 | CK | PFM | 0 | 2 | 1 | 1 | 10 | 10 | 0.8 | 0.8 |
| 96 | 5 | 11 | 96.36 | HG | PFM | 0 | 2 | 1 | 1 | 9 | 9 | 0.8 | 0.8 |
| 96 | 5 | 11 | 96.36 | KV | PFM | 0 | 2 | 1 | 1 | 12 | 12 | 1.0 | 1.0 |
| 96 | 5 | 11 | 96.36 | PH | PFM | 0 | 2 | 1 | 1 | 15 | 15 | 1.3 | 1.3 |
| 96 | 5 | 11 | 96.36 | AW | PFM | 0 | 2 | 1 | 1 | 18 | 18 | 1.5 | 1.5 |
| 96 | 5 | 11 | 96.36 | PR | PFM | 0 | 2 | 1 | 0 | 18 | 20 | 1.7 | 0.0 |
| 96 | 6 | 30 | 96.50 | LH | PLA | 30 | 0 | 0 | 1 | 5 | 5 | 0.0 | 150.0 |
| 96 | 7 | 2 | 96.51 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 7 | 3 | 96.51 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 7 | 4 | 96.51 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 7 | 5 | 96.51 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 7 | 6 | 96.52 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 7 | 7 | 96.52 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 7 | 8 | 96.52 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 7 | 9 | 96.52 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 7 | 10 | 96.53 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 7 | 10 | 96.53 | HK | ECO | 0 | 4 | 0 | 1 | 6 | 6 | 0.0 | 1.0 |
| 96 | 7 | 11 | 96.53 | HK | ECO | 0 | 6 | 0 | 1 | 6 | 6 | 0.0 | 1.5 |

# DATABASE - COMPANY A

| YR | MN | DY | TIME | STN | REASN | DURATION | | MITIGATION | | OUTPUT | | OUTPUT LOSS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | LINE | | | Dys | Hrs | PEAK | AVERAGE | RATE | | PEAK | AVERAGE |
| | | | YEARS | | | | | NO=1 | NO=1 | AV | PK | MI | MI |
| | | END | | | | | | | | | | | |
| 96 | 7 | 31 | 96.58 | LH | PLA | 31 | 0 | 1 | 1 | 5 | 5 | 155.0 | 155.0 |
| 96 | 8 | 2 | 96.59 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 8 | 3 | 96.59 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 8 | 4 | 96.59 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 8 | 5 | 96.60 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 8 | 6 | 96.60 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 8 | 7 | 96.60 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 8 | 8 | 96.61 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 8 | 9 | 96.61 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 8 | 10 | 96.61 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 8 | 11 | 96.61 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 8 | 31 | 96.67 | LH | PLA | 31 | 0 | 1 | 1 | 5 | 5 | 155.0 | 155.0 |
| 96 | 9 | 3 | 96.67 | CH | PFM | 0 | 1 | 1 | 1 | 10 | 15 | 0.6 | 0.4 |
| 96 | 9 | 3 | 96.67 | CK | PFM | 0 | 1 | 1 | 1 | 10 | 10 | 0.4 | 0.4 |
| 96 | 9 | 3 | 96.67 | HG | PFM | 0 | 1 | 1 | 1 | 9 | 9 | 0.4 | 0.4 |
| 96 | 9 | 3 | 96.67 | KV | PFM | 0 | 1 | 1 | 1 | 12 | 12 | 0.5 | 0.5 |
| 96 | 9 | 3 | 96.67 | PH | PFM | 0 | 1 | 1 | 1 | 15 | 15 | 0.6 | 0.6 |
| 96 | 9 | 3 | 96.67 | AW | PFM | 0 | 1 | 1 | 1 | 18 | 18 | 0.8 | 0.8 |
| 96 | 9 | 6 | 96.68 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 9 | 7 | 96.69 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 9 | 8 | 96.69 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 9 | 9 | 96.69 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 9 | 11 | 96.70 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 9 | 13 | 96.70 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 9 | 14 | 96.71 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 9 | 15 | 96.71 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 9 | 17 | 96.71 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 9 | 19 | 96.72 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 9 | 23 | 96.73 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 9 | 30 | 96.75 | KV | PLA | 30 | 0 | 0 | 1 | 12 | 12 | 0.0 | 360.0 |
| 96 | 10 | 10 | 96.78 | CH | PFM | 0 | 2 | 1 | 1 | 10 | 15 | 1.3 | 0.8 |
| 96 | 10 | 10 | 96.78 | CK | PFM | 0 | 2 | 1 | 1 | 10 | 10 | 0.8 | 0.8 |
| 96 | 10 | 10 | 96.78 | HG | PFM | 0 | 2 | 1 | 1 | 9 | 9 | 0.8 | 0.8 |
| 96 | 10 | 10 | 96.78 | KV | PFM | 0 | 2 | 1 | 1 | 12 | 12 | 1.0 | 1.0 |
| 96 | 10 | 10 | 96.78 | PH | PFM | 0 | 2 | 1 | 1 | 15 | 15 | 1.3 | 1.3 |
| 96 | 10 | 10 | 96.78 | AW | PFM | 0 | 2 | 1 | 1 | 18 | 18 | 1.5 | 1.5 |
| 96 | 10 | 10 | 96.78 | PR | PFM | 0 | 2 | 1 | 0 | 18 | 20 | 1.7 | 0.0 |
| 96 | 10 | 11 | 96.78 | KV | PFM | 0 | 2 | 1 | 1 | 12 | 12 | 1.0 | 1.0 |
| 96 | 10 | 11 | 96.78 | PH | PFM | 0 | 2 | 1 | 1 | 15 | 15 | 1.3 | 1.3 |
| 96 | 10 | 11 | 96.78 | AW | PFM | 0 | 2 | 1 | 1 | 18 | 18 | 1.5 | 1.5 |
| 96 | 10 | 11 | 96.78 | PR | PFM | 0 | 2 | 1 | 0 | 18 | 20 | 1.7 | 0.0 |
| 96 | 10 | 31 | 96.83 | KV | PLA | 31 | 0 | 0 | 1 | 12 | 12 | 0.0 | 372.0 |
| 96 | 11 | 1 | 96.84 | CH | PFM | 0 | 2 | 1 | 1 | 10 | 15 | 1.3 | 0.8 |
| 96 | 11 | 1 | 96.84 | CK | PFM | 0 | 2 | 1 | 1 | 10 | 10 | 0.8 | 0.8 |
| 96 | 11 | 1 | 96.84 | HG | PFM | 0 | 2 | 1 | 1 | 9 | 9 | 0.8 | 0.8 |
| 96 | 11 | 1 | 96.84 | KV | PFM | 0 | 2 | 1 | 1 | 12 | 12 | 1.0 | 1.0 |
| 96 | 11 | 1 | 96.84 | PH | PFM | 0 | 2 | 1 | 1 | 15 | 15 | 1.3 | 1.3 |

# DATABASE - COMPANY A

| YR | MN | DY | TIME | STN | REASN | DURATION | | MITIGATION | | OUTPUT | | OUTPUT LOSS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | LINE | | | Dys | Hrs | PEAK | AVERAGE | RATE | | PEAK | AVERAGE |
| | | | YEARS | | | | | NO=1 | NO=1 | AV | PK | MI | MI |
| | | END | | | | | | | | | | | |
| 96 | 11 | 1 | 96.84 | AW | PFM | 0 | 2 | 1 | 1 | 18 | 18 | 1.5 | 1.5 |
| 96 | 11 | 1 | 96.84 | PR | PFM | 0 | 2 | 1 | 1 | 18 | 20 | 1.7 | 1.5 |
| 96 | 11 | 1 | 96.84 | KV | PFM | 0 | 2 | 1 | 1 | 12 | 12 | 1.0 | 1.0 |
| 96 | 11 | 1 | 96.84 | PH | PFM | 0 | 2 | 1 | 1 | 15 | 15 | 1.3 | 1.3 |
| 96 | 11 | 1 | 96.84 | AW | PFM | 0 | 2 | 1 | 1 | 18 | 18 | 1.5 | 1.5 |
| 96 | 11 | 1 | 96.84 | PR | PFM | 0 | 2 | 1 | 1 | 18 | 20 | 1.7 | 1.5 |
| 96 | 11 | 5 | 96.85 | HP | UME | 0 | 4 | 1 | 1 | 2 | 2 | 0.3 | 0.3 |
| 96 | 11 | 5 | 96.85 | CK | UME | 0 | 4 | 1 | 1 | 10 | 15 | 2.5 | 1.7 |
| 96 | 11 | 30 | 96.92 | KV | PLA | 30 | 0 | 0 | 1 | 12 | 12 | 0.0 | 360.0 |
| 96 | 12 | 1 | 96.92 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 12 | 1 | 96.92 | HK | ECO | 0 | 4 | 0 | 1 | 6 | 6 | 0.0 | 1.0 |
| 96 | 12 | 2 | 96.92 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 12 | 2 | 96.92 | HK | ECO | 0 | 4 | 0 | 1 | 6 | 6 | 0.0 | 1.0 |
| 96 | 12 | 3 | 96.92 | HG | ECO | 0 | 4 | 0 | 1 | 9 | 9 | 0.0 | 1.5 |
| 96 | 12 | 3 | 96.92 | HK | ECO | 0 | 4 | 0 | 1 | 6 | 6 | 0.0 | 1.0 |
| 96 | 12 | 4 | 96.93 | CH | UME | 0 | 4 | 1 | 1 | 10 | 15 | 2.5 | 1.7 |
| 96 | 12 | 4 | 96.93 | CK | UME | 0 | 4 | 1 | 1 | 10 | 10 | 1.7 | 1.7 |
| 96 | 12 | 4 | 96.93 | HG | UME | 0 | 4 | 1 | 1 | 9 | 9 | 1.5 | 1.5 |
| 96 | 12 | 4 | 96.93 | KV | UME | 0 | 4 | 1 | 1 | 12 | 12 | 2.0 | 2.0 |
| 96 | 12 | 4 | 96.93 | PH | UME | 0 | 4 | 1 | 1 | 15 | 15 | 2.5 | 2.5 |
| 96 | 12 | 4 | 96.93 | AW | UME | 0 | 4 | 1 | 1 | 18 | 18 | 3.0 | 3.0 |
| 96 | 12 | 8 | 96.94 | PH | UME | 0 | 4 | 1 | 1 | 15 | 15 | 2.5 | 2.5 |
| 96 | 12 | 8 | 96.94 | AW | UME | 0 | 4 | 1 | 1 | 18 | 18 | 3.0 | 3.0 |
| 96 | 12 | 8 | 96.94 | PR | UME | 0 | 4 | 1 | 1 | 18 | 20 | 3.3 | 3.0 |
| 96 | 12 | 8 | 96.94 | KV | UME | 0 | 4 | 1 | 1 | 12 | 12 | 2.0 | 2.0 |
| 96 | 12 | 13 | 96.95 | PH | UME | 0 | 4 | 1 | 1 | 15 | 15 | 2.5 | 2.5 |
| 96 | 12 | 13 | 96.95 | CH | UME | 0 | 4 | 1 | 1 | 10 | 15 | 2.5 | 1.7 |
| 96 | 12 | 13 | 96.95 | CK | UME | 0 | 4 | 1 | 1 | 10 | 10 | 1.7 | 1.7 |
| 96 | 12 | 13 | 96.95 | HG | UME | 0 | 4 | 1 | 1 | 9 | 9 | 1.5 | 1.5 |
| 96 | 12 | 17 | 96.96 | KV | UME | 0 | 4 | 1 | 1 | 12 | 12 | 2.0 | 2.0 |

## Tables describing Events leading up to Privatisation of the Water Industry and Government Recommendations to the Water Industry within and following Agenda for Action in 1996

| | |
|---|---|
| February 1985: | The Minister of State for the Environment announces during a debate on the water authorities (return on assets) that the government "will be examining the possibility of a measure of privatisation in the industry". |
| April 1985: | A discussion paper is sent to the chairmen of the Regional Water Authorities (RWA's) by the Minister for Housing and Construction (Ian Gow) on the implications of the possible introduction of a measure of privatisation into the water industry. The chairmen endorse Roy Watt's (chairman of Thames Water) recommendation that the concept of integrated river management be maintained. |
| February 1986: | Publication of the government White Paper "Privatisation of the Water Industry in England and Wales" (Cmnd. 9734), which advocates that the industry be sold off as it stands, with only the functions of flood protection and land drainage retained in the public sector. |
| March 1986: | Consultation paper on Water and Sewerage Law. |
| April 1986: | Consultation paper on "The Water Environment : the next steps". |
| June 1986: | In response to lobbying from organisations such as the Confederation of British Industry (CBI) and the Country Landowners Association (CLA) - alarmed that control of environmental and regulatory matters would be retained by privatised companies, and insistent that "poachers" should not also be "gamekeepers" - Environment Secretary Nicholas Ridley postpones water privatisation plans. |
| July 1987: | Consultation paper on "the National Rivers Authority - proposals". |
| October 1987: | The greatest stock market crash in history occurs. Many small investors get their fingers burnt in the ill-timed sale of British Petroleum. |
| December 1987: | Government statement issues on "the National Rivers Authority - policy". |
| May 1988: | Public Utility Transfers and Water Charges Act 1988 receives Royal Assent. RWA's may proceed with restructuring in preparation for privatisation. |
| June 1988: | Water Authority restructuring commences. |
| November 1988: | Publication and first reading of the Water Bill. |
| December 1988: | Second reading of the Water Bill. |
| July 1989: | Water Bill receives Royal Assent. |

*(Table A1)*

*Water Privatisation : Calendar of Events 1985 - 1989*

*(extracted from MacLean, 1993)*

| Organisation | | Recommendation |
|---|---|---|
| Water Companies | • | prepare fresh estimates of the reliable yields of water resource systems; |
| | • | establish further detailed measurements of household water use; |
| | • | conduct further studies of the implications of climate change on demand for water; |
| | • | extend the penetration of metering; |
| | • | develop more sophisticated tariff structures; |
| | • | increase efforts to promote water conservation; |
| | • | improve leakage measurement, control and reporting; |
| | • | enter into dialogue with customers about security of supply; and |
| | • | draw up plans for timely development of new water resources where demand cannot be managed to remain within existing resource capability. |
| Environment Agency | • | co-ordinate the fresh estimating of the reliable yields of water resource systems and publish the resulting information; |
| | • | lead the testing of those estimates against climate change scenarios; |
| | • | revise as necessary its national and regional water resources strategies in consultation with the water companies; and |
| | • | be fully involved with water companies' new resource development plans. |
| OFWAT | • | monitor and, as necessary, enforce water companies' performance of their duty to promote the efficient use of water by their customers; |
| | • | monitor, report and, as necessary, take further action on leakage control; |
| | • | be fully involved with water companies' new resource development plans; and |
| | • | consider the financial implications of new water resources and supply schemes as necessary in the course of its normal price regulation activities. |
| DWI | • | check that all water supplies are monitored in accordance with and meet regulatory quality requirements; |
| | • | check that water treatment processes comply with regulatory requirements; and |
| | • | take enforcement action if regulatory requirements are not met. |

*(Table A2)*
*DoE Recommendations to the Water Industry and Regulator*
*(Extracted from Agenda for Action, 1996)*

| DEPUTY PRIME MINISTER'S WATER SUMMIT, 19 MAY 1997: 10-POINT PLAN - SUMMARY | | Govern-ment Action | Water Company Response | Water Resources Management | |
|---|---|---|---|---|---|
| | | | | Impact | Timescale |
| 1 | **Mandatory Leakage Targets**<br>the Director General of Water Services will set tough mandatory targets for total leakage which will enforce a substantial reduction in leakage over the next five years. | ◆ | | High | Short |
| 2 | **Free Supply Pipe Leak Detection and Repair**<br>The Government expects all water companies to provide a free leakage detection and repair service for supply pipes owned by household customers. | | ◆ | Medium | Short |
| 3 | **New Duty to Conserve**<br>Water companies will be placed under a statutory duty to conserve water in carrying out their functions. | ◆ | | Low | Medium |
| 4 | **Vigorous Promotion of Water Efficiency**<br>Water companies must carry out with vigour, imagination and enthusiasm their duty to promote the efficient use of water by their customers. For example, they should all:-<br>- provide free simple water saving devices, e.g. to reduce toilet flush volumes<br>- offer free water efficiency audits to household customers; and<br>- make greater efforts to encourage water-efficient gardening. | | ◆<br>◆<br>◆<br>◆ | Medium<br>Medium<br>Medium<br>Medium | Medium<br>short<br>Medium<br>Medium |
| 5. | **Role of Environmental Task Force**<br>Water companies should consider the role which the Government's Environment Task Force can play in improving the efficiency of water use. | | ◆ | Low | Short |
| 6. | **New Water Regulations**<br>The Government will make new water regulations which will include significantly tighter requirements for water efficiency. The Government will also explore other ways of encouraging water efficiency in industry and agriculture, including the use of "best practice" programmes like those which have been successful in the energy sphere. | | | Medium | Medium |
| 7. | **Review of Water Charging**<br>The Government will review the system of charging for water, including future use of rateable values and metering policy. The review will cover debt recovery arrangements (including disconnection) and use of pre-payment units. | ◆ | | High | Medium/ Long |
| 8. | **Compensation for Drought Restrictions**<br>The Government is asking all water companies which have not already done so to agree with the Director General of Water Services the amendments to their licences which other companies have already accepted, requiring compensation payments to customers affected by drought-related restrictions. All water companies should consider making compensation payments to customers who are advised to boil water or retrain from using mains water because potentially harmful contamination has occurred. | | ◆ | Low | Short |
| 9 | **Publishing Performance Details**<br>All water companies should publish at local level easily understood details of their performance in meeting targets for leakage reduction, water supply and drinking water quality, together with information on investment in the water service and the resulting benefits to the environment. | | ◆ | Low | Medium |
| 10 | **Review of Abstraction Licensing System & Drought Contingency Plans**<br>The Government will review the water abstraction licensing system and arrangements for bulk transfer of water. A key aim will be to ensure that the environment is given due weight in decisions on the use of water. The Government expects each water company to agree a detailed, publicly available drought contingency plan with the Environment Agency. This will be made a statutory requirement when the opportunity arises. | ◆<br>◆ | ◆ | High<br>Low | Long<br>Short |

*(Table A3)*
*UK Government 10 Point Plan*
*(after Agenda for Action, 1996)*

## Proposal for PhD Research by Jack Carnell

# THE INTEGRATED EVALUATION OF LOCAL AND NATIONAL FUTURE WATER RESOURCE NEED

## PROJECT BRIEF

### Introduction

1.1 This project brief describes a proposal to carry out research in the field of water resource planning, following a doctoral research programme. The project is likely to span the water resource and mathematics functions at the academic level.

### Background and Problem Definition

2.1 Future water resource need is traditionally described in terms of shortfall at a given level of risk, e.g. there is a 1 in 20 year change of a 5 Ml/d shortfall to meet peak week demand. This is a sound method of presentation, but the solution is generally derived by calculating the resources available during a drought period and dividing by the demand during this period. However, to do so is to misunderstand the interaction of the various factors which influence the supply-demand balance, for example, the level of planned and unplanned source outages tends to be higher in cold years and demand can be highest in the winter when burst mains are particularly prevalent. This approach also assumes that resource availability in drought periods can be sensibly calculated, which is also open to doubt.

### Project Need

3.1 The Water Industry has no consistent, meaningful or integrated methodology for developing and utilising water resource planning allowances and, hence, cannot evaluate future water resource need in a comprehensive manner. Over design results in excessive capital investment with under design resulting in sub-standard DG1 and DG4 Levels of Service. (DG1 and DG4 are Water Industry indicators describing customer service in the areas of water resource provision (DG1) and demand management (DG4).

3.2 The current levels of inconsistency render both funding by OFWAT and development approval by the NRA significantly more cumbersome and time consuming than they should be. With water resources development costs running at around £1,000,000 per megalitre then the benefits of more effective and efficient capital planning are obvious.

3.3 With current industry-wide inconsistency problems with the reporting of DG1 and DG4 then this project should attract a high industry profile.

**Outline Research Proposal**

4.1 The overall aim of the project will be to produce an integrated methodology for the calculation of future water resource need.

4.2 Broad objectives, in pursuit of the overall project objective, are as follows:-

i) To critically review historic research and publications in the field of predicting future resource need.

ii) To critically review post Water Industry privatisation research and publications, in particular, the projects carried out under the direction of UKWIR (The United Kingdom Water Industry Research).

iii) To carry out a scoping exercise to assess the full potential range of water resource planning allowances. The primary groupings will be:-

1. Demand Allowances
2. Resource Allowances
3. Source Yield Allowances
4. Operational Allowances

iv) To appraise, investigate and report on how the spectrum of planning allowances might be dealt with in isolation, in particular: the nature of the allowance, its likely acceptability by the Regulator, and how the allowance impacts upon the balance between water supply and water demand.

v) To investigate how each planning allowance could be combined together, in light of its statistical distribution and dependency (if any) in order to produce a meaningful result at a given level of risk.

vi) To argue and report upon the meaning of different levels of water resource risk from the point of view of a Water Industry customer.

vii) To investigate and report on how individual water company planning allowances might be combined together to form a national figure for water resource need, particularly considering the resource savings which could be made if the National Rivers Authority were in a position to control Inter-Company resource transfers.

viii) To produce a methodology which demonstrates how companies could financially appraise the benefits of source loss mitigation measures, such as the provision of standby plant or bankside storage.

ix) To develop software which allows calculation of future resource need based on the planning allowances evaluated within this study.

x) To calculate future resource need for the South Staffordshire Water PLC.

xi) Produce a set of definitions, consistent with the Water Industry standard, to cover issues arising from this study which are, as yet, undefined.

## PROJECT MANAGEMENT

### Outline Plan

5.1 It is expected that this project will form a 4 - 5 year part time PhD. A project Organogram with broad headings is appended.

### Finance

5.2 This project will be financed externally by South Staffordshire Water PLC.

### Management

5.3 The Internal Supervisor will be Dr. P.D. Hedges, Dept. of Civil Engineering.

The Associate Supervisor will be Dr. M.K. Hussey, Business School.

The External Supervisor will be Mr. D.P. Fifield, Engineering Director, South Staffordshire Water PLC.

5.4 Additional members may be co-opted as necessary.

### Dissemination of Results

6.1 The research will be presented to the sponsor and to the Water Industry via the Water Companies' Association.

**Jack Carnell**
**March 16th 1995**

Attached: Project Organogram