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Demand for Irrigation Water

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Demand for Irrigation Water

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CONTENTS

LIST OF FIGURES Page

LIST OF BOXES

~~FOREWORD AND~~ ACKNOWLEDGEMENT

In order to manage and secure proper use of the nation's water resources, the NRA needs to know the likely future demand for irrigation-water and the likely farmer response to possible NRA management options. This research project was commissioned by NRA to provide this information and advise NRA.

The research was carried out between July 1992 and July 1993 by Keith Weatherhead, Alison Place and Dr Joe Morris with assistance from colleagues at Silsoe College, Cranfield University and Dr Michael Burton of the Department of Agricultural Economics at the University of Manchester. ~~Responsibility for the report's contents rests with them.~~ (del AP)

The authors wish to thank all those organisations who provided advice and information, including the Ministry of Agriculture, Fisheries and Food (MAFF), the National Farmers Union (NFU), the United Kingdom Irrigation Association (UKIA), the Welsh Office, Country Landowners Association (CLA), the Department of the Environment (DoE), English Nature, and various irrigation equipment companies. Particular thanks are due to the members of the project's Consultative Panel (Martin Ashburn, Christopher Dandy, Oliver Doubleday, Jiggy Lloyd, David Pearce, Robin Upton, Alan Woods, Colin Wright, Richard Wright), to Gordon Bennington, Stephen Hawes, Michael Wright and Alistair Findlay, and to the many farmers who provided information through interviews and postal questionnaires. We would also like to thank Marcus White, Jerry Knox and David Sutherland who helped with data analysis and Carolyn King who word-processed the report.

Separate foreword to be done by NRA.

— by Jerry — || Richard Streater on para 1 → + more on why we needed the project, what starting the report has and its value to water resources management.

[should go in before contents page.]

foreword always seems to be written by Jan Pentreath.

Suggestion

Report size + content likely to warrant an Exec Summary - see RD Report 1 altho it is called a Summary incorrectly!

- see Guidance Note
- use headings

(+) Key Words

(+) Summary ≃ 200-300 words for abstracting.

EXECUTIVE SUMMARY

1. The project aimed to predict future growth in the demand for water for agricultural irrigation in England and Wales, and to advise on whether and how the NRA should respond to this growth.

2. A number of previous forecasts of irrigation demand overestimated growth because they were carried out following dry periods, when farmer awareness and interest in irrigation were highest. Similar bias resulting from the 1989-91 dry years should be avoided now in medium and long term projections.

3. The calculated underlying growth in agricultural irrigation in England and Wales from 1982 to 1990, after allowing for weather differences between census years, was about 1% per annum in the total area irrigated and about 2% per annum in the total volume of water used.

4. Taking account of expected changes in agricultural policy and technical, market and other factors (excluding climate change), we predict a relatively minor increase in the area farmers wish to irrigate but a larger increase in the volume of water wanted. The 'most likely' prediction for growth in volumetric demand is 1.7% per annum from 1996 to 2001 and 1% per annum from 2001 to 2021 for the 'dry' year. Within these figures, there would be a growth in irrigation of potatoes, vegetables, and soft fruit and a decline in the irrigation of grass and cereals. The on-farm economic case for irrigating sugar beet will remain marginal.

5. We believe it is in the national interest to meet these demands where possible but subject to adequate protection of the environment and full costs being charged to the beneficiaries.

6. NRA responses should include:-

- the licensing of any remaining available summer water, though not necessarily on a first-come-first-served basis;
- support for additional on-farm storage where feasible, including possibly cross-subsidies but not subsidy from government;
- undertaking NRA augmentation works, at the beneficiaries' expense, where technical factors give such works a clear advantage over on-farm storage.

7. The NRA should not become involved in judging the merits of how best to use the water on-farm.

8. At current levels, water charges are rarely significant in farmer decision making. There is some support for higher charges in return for higher reliability levels. We support recommendations to abolish charges for direct winter abstraction.

9. Issues raised by the possibility of tradeable permits and/or changes in legislation relating to licences of right are complex and contentious. We recommend the NRA instigates a full public debate as soon as possible.

10. There is widespread support for the formation of an advisory National Agricultural Water Resources Forum, including representatives of NRA, MAFF, NFU, CLA and UKIA.

~~OVERVIEW~~

EXEC SUMMARY.

Introduction

The main objectives of this project were to predict the likely future demand for irrigation water in England and Wales and to advise on whether and how the NRA should respond. The project was restricted to agricultural irrigation and took no account of any long-term climatic change.

Growth in Irrigation Demand

Past growth

Many previous studies have forecast substantial growth in the *demand* for irrigation water for agriculture and horticulture. However, these studies have often been undertaken immediately following drought periods when interest in irrigation was high, and hence overestimated the underlying demand. Projections of 6% per annum volume growth in the Advisory Council for Agriculture and Horticulture (ACAH) report (1980) have been progressively downgraded to 2% per annum volumetric growth in the Anglian Region (1990).

The best estimates of actual *underlying* growth in irrigation used over the 1982-1990 period, after allowing for weather differences between the census years, are only about 1% per annum in area and 2% per annum in volume. Most of this underlying growth was for the irrigation of maincrop potatoes. There was also a slow underlying growth in the irrigation of other vegetables, sugar beet and cereals, and an underlying decline in the irrigation of fruit and particularly grass.

These underlying changes were heavily masked by seasonal weather differences. The dry weather in 1989, '90 and '91 caused a substantial increase in *actual* irrigation on almost all crops in all regions, and a surge in licence applications. Whilst these dry year peaks are the relevant figures for water resource planning, it is important not to project these random seasonal variations forward. However, the dry years are likely to have refocussed farmer attention on the benefits of irrigation.

Present on-farm irrigation economics

Analysis of the on-farm economics of irrigation suggests that current total irrigation costs are typically £4/ha mm (£400/Ml) using direct abstraction or groundwater. Winter abstraction and storage adds another £1 - £2/ha mm. The variable costs, i.e. the cost of using a system already installed, are typically only £1.2/ha mm to £2.3/ha mm, depending on the system and degree of automation. Of course there are wide variations around all these figures.

Irrigation benefits (to the farmer) include increased yield, quality, reliability and continuity of production. Considering *yield benefits alone*, the irrigation of soft fruit, horticultural and market garden produce, brassicas, onions and potatoes appear financially attractive at present even if storage is required. Irrigation of sugar beet and some other vegetables is marginal, and may be uneconomic if storage is required. Irrigation of cereals and grass can now only be justified if surplus capacity with low variable costs already exists.

Quality and reliability benefits are substantial and often more important than yield benefits. They apply to the whole crop, and not just the yield increment. They are difficult to quantify, but fortunately follow the same pattern as yield benefits. *Quality premia alone* are often sufficient to cover full irrigation costs on soft fruit, vegetables and potatoes. *Reliability and continuity* are becoming essential marketing requirements. It is likely that in some sectors commercial production could not be contemplated without guaranteed availability of water resources.

Changes in agricultural policy

There have been major changes in the agro-economic climate in the last few years, and more are expected. Future prices and changes in cropping patterns were predicted using the Manchester University Agricultural Policy Model, for various agricultural policy scenarios. Even under the former protectionist policies, there has been a continuous decline in real commodity prices for farmers. If a policy of complete liberalisation and free trade were adopted many prices would fall much further, particularly cereals, oilseeds, sugar beet and milk. Cereals, sugar beet and grass would not be worth irrigating. Horticultural products would face greater competition, possibly increasing the importance of irrigation. Potatoes would be mainly irrigated for quality.

A less extreme scenario is predicted, involving a partial reform of the Common Agricultural Policy (CAP) and partial acceptance of the General Agreement on Trade and Tariff (GATT). Producer prices are likely to continue to fall in real terms, but horticultural produce, potatoes and field scale vegetables will be less affected. The relative advantage of irrigating these crops will increase, particularly when quality premia exist, resulting in a modest growth in the proportion irrigated.

Changes in technical and other factors

The basic methods of irrigation in England and Wales are not changing rapidly. There has been a steady move from sprinkler systems to hosereels and a tendency towards larger, more technically sophisticated equipment. Trickle (drip), minisprinkler and other solid-set systems are likely to spread further in orchards and small-scale horticultural units, but remain expensive at field level. Automation and computer control will increase.

These changes will mainly switch one application method for another, rather than increase the irrigated area, but there are implications for water demand. The newer system will have higher fixed cost but lower variable costs, which should lead to larger seasonal depths being applied. This will more than offset higher efficiency. Solid set systems cannot be moved to other crops at times of surplus capacity, which will further reduce irrigation of cereals and grass.

Scheduling systems, either by computer water-balance calculation or direct measurement, are likely to be more widely used, particularly where water is scarce or expensive. Although better scheduling should increase efficiency of water use, it is by no means clear what effect it would have on demand; as many crops are under-irrigated at present, better scheduling could well lead to higher applications.

Overall, these technical changes are likely to have little effect on the irrigated area but modestly increase the total depth applied, within a ceiling set by agronomic demand.

More fundamental changes in crops or agricultural systems, e.g. drought-tolerant potatoes, are not anticipated within the short or medium term at least. The suggested use of currently set-aside land to produce the same tonnage without irrigation would not give the quality, reliability or continuity benefits of irrigation, and could increase the use of other scarce resources. In the longer term, tillage changes allowing movement back to heavier soils and less drainage could have some opportunities, but this would be against past trends.

Predictions of future growth

By combining data on current cropping patterns with changes predicted by the Manchester model, future crop areas have been predicted. The Manchester model predictions of future commodity price levels, the analysis of on-farm irrigation economics, studies of changes in technology and other factors, and farmer and other informed opinion, have been combined to predict changes in the irrigated proportion of each crop and the depths to be applied. Combining these leads to predictions of irrigated areas and volumes, for each crop category and in total.

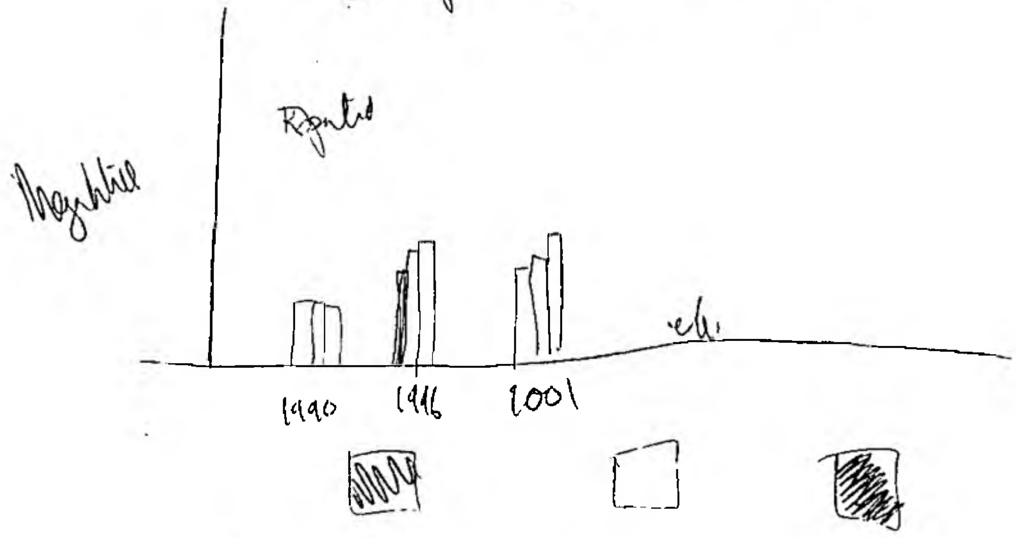
'Most likely', 'high' and 'low' estimates have been prepared for the expected agricultural policy scenario. The 'most likely' prediction is that there will be a relatively minor increase in total irrigated area in the medium and long term (approximately 0.7% and 0.3% per annum respectively). Expansion of root crop and vegetable irrigated area will be partially offset by a decline in the grass and cereal irrigated area. Growth in the total volume of water used will be greater but still modest, at 1.7% per annum from 1996 to 2001 and 1% per annum from 2001 to 2021.

The analysis predicts a large possible range around these 'most likely' values. Growths in total area and volume under the high prediction are two to three times higher. Growth remains positive but very slow under the low predictions.

'Most likely' predictions have also been made for the two extreme agricultural policy scenarios. The results fall within the high to low range described above, though interestingly both extreme scenarios give a higher most likely total volume than the expected scenario in the long term.

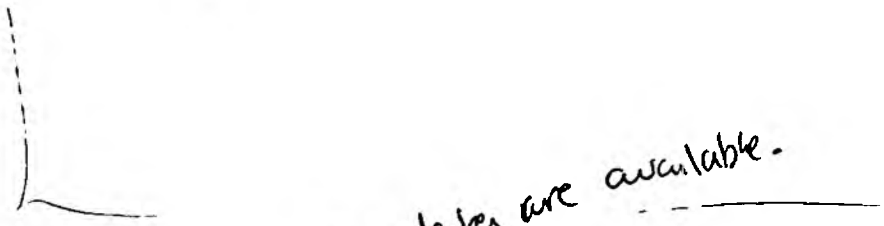
The volumetric demand predictions are summarised in the table below. It is emphasised that these are demands - actual usage will be reduced by any restrictions on water availability.

(A) Reported against Policy Scenario



(B) Extreme Scenarios

Based dry year variations



NB left as table in 9.1 so data are available.

Projections of 'dry' year volumetric demand for irrigation water in England and Wales, 1996 - 2021

	Irrigation water volume (Ml)						
	(1990)	1996	2001	2006	2011	2016	2021
Expected agricultural policy Scenario (III):							
Most likely projection	*156969*	178351	194359	206696	217764	227995	237406
High projection	*156969*	206042	242829	272720	298632	321344	341035
Low projection	*156969*	150218	151056	153972	158083	162838	167898
Extreme Scenarios, most likely projections:							
Pre-1992 policies (I)	*156969*	187815	207335	224633	239604	252953	264811
Free trade (II)	*156969*	168526	182621	198027	214166	230632	247136

Notes: 1990 values (for comparison) are actual abstraction plus 10% to allow for restrictions then in force.

NRA Responses

The study suggests that (increased) irrigation of most currently irrigated crops is both economic and in the national interest. Benefits to the consumer include higher quality produce and potentially lower prices from cost savings in production, storage and processing; national benefits include import substitution and employment protection. The NRA should seek to meet irrigation demand where possible, subject to adequate protection of the environment and full costs being charged to the beneficiaries.

Discussion with the project Consultative Panel, farmers and other interested parties suggested that the NRA responses should include:

- the licensing of any remaining available summer water, though not necessarily on a first-come first-served basis;
- support for additional on-farm storage where feasible, including possibly cross-subsidies but not subsidy from government;
- undertaking NRA augmentation works, at the beneficiaries' expense, where technical factors give such works a clear advantage over on-farm storage.

The prospect of the NRA prioritising crops for irrigation was almost universally disfavoured. The NRA should not become involved in judging the merits of how best to use the water on-farm.

At current levels, water charges are rarely significant in farmer decision making. There is some support for higher charges in return for higher reliability levels. We support recommendations to abolish charges for direct winter abstraction. The present cost recovery constraints on NRA charges make it impossible to adopt the long run marginal costing approach that would send the correct economic signals to abstractors.

Issues raised by the possibility of tradeable permits and/or changes in legislation relating to licences of right are complex and contentious. We recommend the NRA instigates a full public debate as soon as possible.

There is widespread support for the formation of an advisory National Agricultural Water Resources Forum, including representatives of NRA, MAFF, NFU, CLA and UKIA. The forum would meet say twice a year for one or two days at most (remembering representatives would be volunteers), discussing general policy guide-lines, any necessary revision to legislation, research requirements and future developments. Specific cases would be excluded except in as much as they affected general policy. It is suggested that some or all of the meetings would be held under rules of confidentiality. Recommendations produced would be purely advisory for all parties, but would form a strong basis for action.

Geoff useful CIRIA Publication Guidelines

4.7 GLOSSARY

To aid understanding, a Glossary contains, in alphabetical order, words or terms used in a specific sense in the document, jargon (if unavoidable), regional and historical usage, and words or terms from disciplines unfamiliar to the intended reader. The Glossary should contain concise definitions of major concepts if this is necessary for ease of understanding. If a word is used only once in the text, it may be sufficient to define it where it occurs.

4.8 NOTATION

Symbols used for representing quantities in the text should be listed and defined. This list should conform to BS 5775[1] or other recognised systems (particularly international) for symbols not included in that Standard. If there are few symbols, or if each is used once only, it may be more convenient to define them as they occur.

A list of symbols used, with definitions, should *always* be provided for the use of the editors, whether or not it is to be included in the printed version.

GLOSSARY

ACAH	Advisory Council on Agriculture and Horticulture
ADAS	Agricultural Development Advisory Service
AWC	available water capacity
CAP	Common Agricultural Policy
CLA	Country Landowners Association
DM	dry matter
DoE	Department of the Environment
EC	European Commission
GATT	General Agreement on Trade and Tariff
GIS	Geographical Information System
IACS	Integrated Agricultural Cropping Survey
IWEM	Institution of Water and Environmental Management
IWR	Irrigation Water Requirements (computer program)
MAFF	Ministry of Agriculture, Fisheries and Food
NFU	National Farmers Union
NRA	National Rivers Authority
NRSC	National Remote Sensing Centre
PMB	Potato Marketing Board
SSLRC	Soil Survey and Land Resources Centre
SWD	soil water deficit
UK	United Kingdom
UKIA	United Kingdom Irrigation Association

Earlier in report - with contents. — yes - see contents

(+) Notation table (Keith if you have many symbols please can you list them here. If not you don't have to do it CS)

1. INTRODUCTION

1.1 Agricultural Irrigation in England and Wales

Agricultural irrigation in England and Wales has increased and changed considerably over the last 40 years. The total areas farmers say they would have irrigated in a dry year are shown in Figure 1.1. A high growth rate until 1965 was followed by a gradual decline until the drought years of 1975 and '76, but since then the area has approximately doubled again.

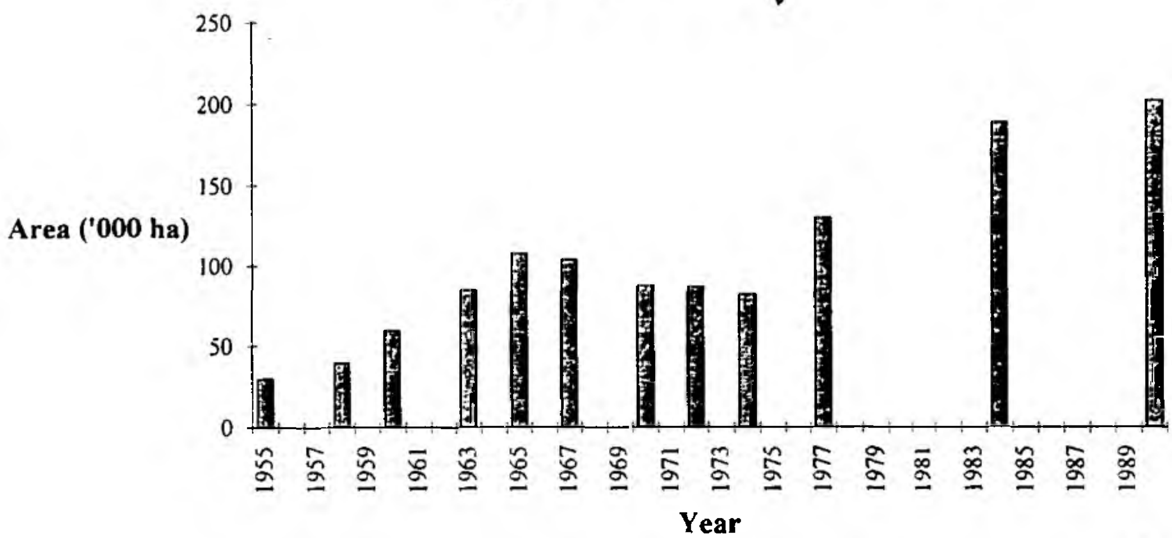


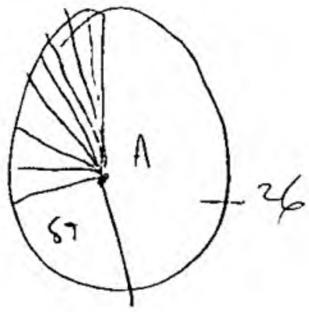
Figure 1.1 Total area likely to be irrigated in a dry year in England and Wales from 1955 to 1990 (Source: MAFF Irrigation Census)

The actual areas irrigated and depths of water applied of course varied with the rainfall pattern in each year. In a climate such as ours, the average demand may typically only be half the peak requirement, and in a wet year irrigation need for some crops may even fall to zero. This variation is a particular problem both for planning and for managing irrigation and irrigation water supplies.

Conveniently, 1990, the latest year for which MAFF irrigation data are available, was in fact a 'dry' year, and the data for areas irrigated support the dry year estimates; 178 000 ha were reported to have been irrigated. Table 1.1 shows the distribution of this irrigation between NRA Regions in terms of area and volume of water. This clearly shows the uneven geographical distribution of irrigation, with almost one half occurring in the NRA Anglian Region alone and a further quarter in the Severn Trent Region. For particular crops this is even more pronounced with, for example, 90% of irrigated sugar beet grown in these two regions. Conversely over 30% of fruit irrigation is concentrated in the Southern Region.

NB need 2 pies per table (ASP).

Pie chart



Notes = generally unnecessary

Pie Chart

Table 1.1 The distribution of irrigation between NRA regions by area and volume in 1990

	Area (%)	Volume (%)
Anglian	48	49
North West	2	2
Northumbrian	1	1
Severn Trent	25	25
South West	1	1
Southern	6	6
Thames	6	6
Welsh	3	2
Wessex	2	2
Yorkshire	7	7
TOTAL	100	100

Notes: Source: MAFF Irrigation Census, 1991.

The partition between crops is shown in Table 1.2, again by area and by volume and shows the predominance of a limited number of crops. Potatoes and sugar beet alone accounted for 50% of the area irrigated and 60% of the water applied. Table 1.3 shows the overall proportion of each crop that was irrigated; note that these proportions would be very much higher when considering eastern England alone and/or considering more specialised cropping categories. These figures emphasise the difference between crops where irrigation is a major factor and others, particularly grass and cereals, where it is an exception.

Table 1.2 The distribution of irrigation between crop category by area and volume in 1990

	Area (%)	Volume (%)
Early potatoes	5	5
Maincrop potatoes	27	39
Sugar beet	17	15
Orchard fruit	2	2
Small fruit	2	2
Vegetables for humans	16	14
Grass	9	9
Cereals	17	9
Others	5	4
TOTAL	100	100

Notes: Source: MAFF Irrigation Census, 1991.
Crop categories as per MAFF Census.

Table 1.3 The proportion of crop areas irrigated for England and Wales in 1990

	Proportion irrigated (%)
Total potatoes	41
Small fruit	29
Vegetables for humans	22
Sugar beet	16
Orchard fruit	11
Cereals	1
Grass	<<1

~~Notes:~~ Source: MAFF Irrigation Census, 1991;
MAFF Cropping Census, 1991.

In the 1950s, a typical irrigator was a horticultural smallholder using portable sprinkler systems. The introduction of mechanised overhead systems, particularly hosereel irrigators, allowed the use of irrigation on field scale agricultural crops without excessive labour demand, and contributed to the major growth in the irrigation of potatoes and sugar beet. Centre pivot and linear move overhead irrigators appeared destined to continue this trend, but their numbers seem to have stabilised, leaving hosereel irrigators as the dominant irrigation method for field crops in the UK.

On specialised cropping, in orchards and in glasshouses, there has also been a growth in trickle (drip) and other localised irrigation methods, supported by improvements in technology and latterly in computerised control. These systems can potentially apply highly controlled and efficient irrigation. However they remain relatively expensive, which limits their use, and so far this technology has not been widely adopted at field scale.

A major change has simultaneously occurred in the main reasons farmers irrigate. The original emphasis on yield increase, whilst still welcome, has been superseded by the demand for quality. Whether producing for the fresh food market or for the food processing industry, farmers are being required to supply high quality, closely specified produce at a consistent rate throughout the cropping system; the vagaries of our weather therefore make irrigation a necessity rather than a luxury.

These changes themselves alter the farmers' requirements from the water suppliers, normally the NRA. Irrigation is no longer a low cost marginal activity to boost yields when water is available, but is an integral part of an increasingly sophisticated production system. A supply failure not only leaves expensive irrigation investment idle but may render totally wasted all the previous inputs into the crop, including irrigation. Reliability of water supplies is now paramount.

Alongside the growth in irrigation application, there has of course been a growth in both licensed and actual abstraction. Although irrigation remains a relatively small user of water on a national scale, it has particular features which affect water supply. Firstly it is a consumptive user, with all of the effective irrigation lost to increased evapotranspiration. By contrast, most other users return a high proportion of their abstractions to the river systems. Secondly, most of the demand is concentrated into a relatively short period, typically 8-12 weeks per year. Thirdly it is concentrated in particular catchments, and particularly in the drier South-east of the country. Fourthly, it varies greatly from year to year, peaking in dry years just when surface water is scarcest. For these reasons, irrigation can become a very significant user in particular catchments in dry summers.

The growth in irrigation demand has been accompanied by a growth in demand by other users, again particularly in the more populated south-east, and by an increasing awareness of the need to maintain minimum river flows and aquifer water levels for environmental protection. The combined effect is that water resources in many catchments and aquifers are theoretically or actually over-committed, and in large areas additional licences are unobtainable. This situation was highlighted in the recent drought in 1990, when irrigation was severely restricted in some areas by the NRA.

Farmer pressure for additional and more reliable water supplies, coupled with NRA desire to meet the reasonable needs of abstractors whilst protecting other users and the environment, has led to pressure for major investment in water resource development. In part, this has led to this study.

1.2 Project Objectives

The main project objective was to advise on the likely future demand for irrigation water in England and Wales, up to the year 2021. Following discussions with NRA, it was agreed that the project would be limited to agricultural and horticultural irrigation, excluding irrigation for landscape and leisure, and that the effects of potential climate change would not be included at this stage. The full objectives are given in Box 1.1.

1.3 Report Layout

Chapter 2 reviews previous irrigation demand forecasts and discusses the methodologies used in those and in this study. Chapter 3 reviews the data available, presents them re-aggregated into NRA regions and discusses the trends over the last ten years. In Chapter 4, the theoretical irrigation requirements for each NRA Region are calculated. Chapter 5 presents the farm level economic analysis, and then the national agricultural sector forecasts. Chapter 6 discusses technical and other factors that could change demand. These results are combined in Chapter 7 to develop 'most likely', 'high' and 'low' projection of irrigation demand under various scenarios. Chapter 8 discusses how the NRA might respond. Conclusions and recommendations are presented in Chapter 9.

✓ - dropped box 7. ye.

Box 1.1 Specific project objectives

This is forecasts,

1. To review and quantify past trends in irrigation, (licensed and actual) in each of the 10 Regions of the Authority.
2. To identify relevant sources of information and any inadequacy in the collection of data on irrigation, either by the NRA or by others and recommend improvements.
3. To review previous forecasts of irrigation demand made by the NRA, its predecessors, by ACAH ("Water for Agriculture: Future Needs", February 1980) and any others.
4. To quantify the potential theoretical needs for irrigation in each Region, based on climate, soil type, likely cropping patterns and other technical factors.
5. To examine market forces and other influences on individual farmers and deduce their likely irrigation demands, in aggregate for each Region.
6. To examine the overall agro-economic situation, nationally and internationally, and its potential evolution over the next 20 to 30 years; identify likely scenarios of required food production in England and Wales and alternative ways of achieving such production; deduce a range of future irrigation requirements and the principal factors which may determine them.
7. To identify any other relevant factors (e.g. potential for more efficient use of water by trickle irrigation, night time irrigation) likely to influence irrigation demands.
8. To compare all the technical, market and economic factors and deduce the 'most likely', 'high' and 'low' irrigation forecasts for each Region.
9. To advise on the NRA's options for response to those forecasts, including:
    - a licensing such summer water as may be available, with reference only to individual farmers' crop requirements.
    - b As above but constrained by some overriding national food production objective (perhaps to be negotiated by MAFF).
    - c Licensing winter water only (i.e. insisting on farm storage reservoirs).
    - d Undertaking, in appropriate circumstances, NRA augmentation works to make summer water available.
10. To advise how the NRA could liaise with Government and/or with the farming industry regarding future provision of water for irrigation.

2. PREVIOUS FORECASTS

2.1 Review

The Advisory Council for Agriculture and Horticulture (ACAH) enquiry and subsequent report Water for Agriculture: Future Needs (1980) remains the most influential study in this field. The enquiry was held in a period when there was substantial interest and growth in irrigation resulting from the drought years of 1975 and 1976 and the predictions made reflect this.

Projections from 1977 to the year 2000 included a growth in irrigated area by 150% to 309 000 ha (4% per annum) and in water use by 300% to 350 000 Ml (6% per annum) for the fifth driest year in twenty. The ACAH figures are now generally considered to have been excessive, but it is worth remembering these figures were for the dry year and assumed no limitations on water availability; they should not be compared with actual figures under conditions where licences may be unobtainable or restricted. The error of predicting that grassland would account for 40% of the demand by 2000 shows how unforeseen external factors such as milk quota and commodity price changes can affect irrigation demand forecasts. Excluding grassland from the predictions leaves estimates more comparable to those being shown by the latest surveys.

Much of the forecasting work in relation to irrigation demand has been carried out by Anglian Water Authority/NRA Anglian Region. This reflects the large irrigated area and the high proportion of available water supplies used for irrigation within the Region. National Opinion Poll Market Research Ltd. (1979) carried out a postal questionnaire survey for the Anglian Water Authority in 1977. The replies suggested high growth rates ranging from 8 to 30% per annum (48 to 280% increase in volume applied over five years). However these results were again undoubtedly biased by carrying out the survey immediately after two drought years. Roughton and Clarke (1978) moderated the NOP results and considered other factors when presenting their views as evidence to the ACAH enquiry.

Subsequent internal forecasts by the Anglian Water Authority (1982, 1988) were based on the above forecasts, but used a lower growth rate based on the actual rate of development and ADAS advice. The forecasts were further downgraded by the NRA Anglian Region (1990) reflecting observations of lower use of licensed quantities and restrictions on the expansion of agricultural production.

Figure 2.1 shows the predicted volumes for the Anglian Region based on the above forecasts, together with the actual licensed and abstracted values. (The forecasts are for dry years and the actual abstractions depend on the weather). Clearly forecasts were biased upwards in the wake of the 1975 and 1976 droughts, and have been regularly revised downwards to reflect slower actual growth.

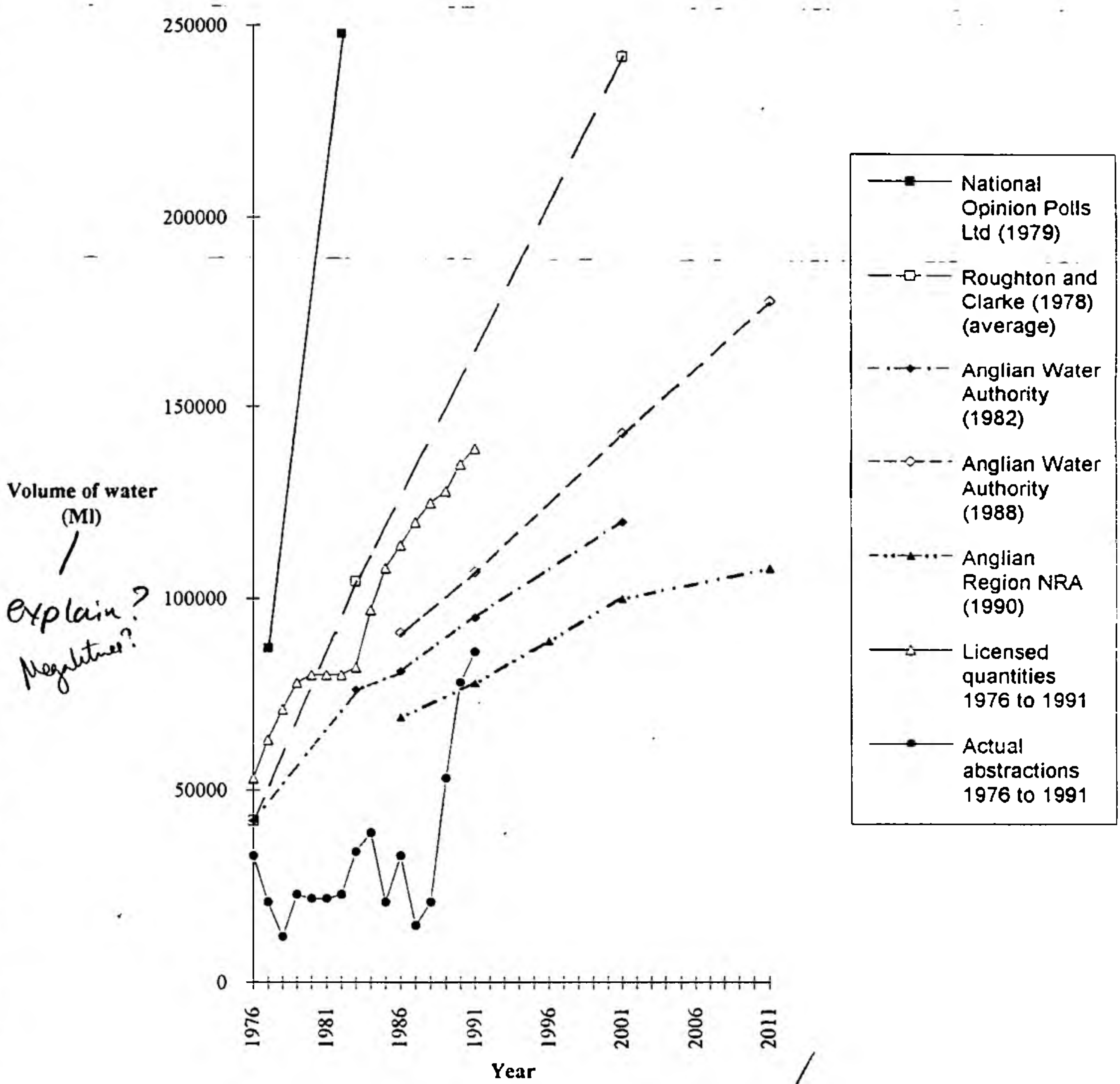


Figure 2.1 Anglian Region forecasts for the volume of water used in spray irrigation, together with licensed and abstracted quantities. (Note: due to differing assumptions these forecasts are not directly comparable. Refer to Appendix A for further details).

Some of the localised factors inhibiting irrigation demand were highlighted by the study on water resources and demand in the Middle Level (University of Newcastle upon Tyne, 1990). Although fears of a large unsatisfied demand for water in this area led the NRA Anglian Region to commission the study, the report concluded that irrigation was in fact limited by the rotation and disease constraints on irrigated cropping and was unlikely to increase substantially. National growth rates cannot simply be applied to individual catchments; in some catchments irrigation growth is constrained and conversely in others growth must be at more than the national average rates.

In the NRA Severn Trent Region, Ejikeme (1989) studied the spray irrigation requirements of the Severn Basin, comparing licensed and actual abstractions and calculating theoretical need using soil water balance methods. As in many other studies, it was found that actual abstractions were much less than licensed abstractions even in dry years.

Dempsey (1992) combined Ejikeme's calculated theoretical requirements with irrigated areas from the 1984 MAFF irrigation survey to estimate irrigation requirements. Dempsey identified 1989 and 1986 as representing the driest and fifth driest years respectively in the previous 20 years for the Severn Trent Region and he compared theoretical requirements with actual abstractions. Actual abstractions were much lower than those theoretically required.

Sir William Halcrow and Partners (1992) carried out a study for the NRA South West Region which included an irrigation demand forecast. Upper and lower growth rates of 4% and 1% were selected from literature reviews and a study of national trends. These were combined with an unrealistic assumption of 100% uptake of licensed quantity to forecast irrigation demand to 2021. This report also emphasised that local factors would constrain demand in some catchments.

A comprehensive study of spray irrigation in the NRA South West Region was undertaken by Sainsbury (1992). She reported that the accuracy of the NRA spray irrigation returns was questionable, citing numerous omissions, errors and inconsistencies. Her study concluded that significant increases in the area spray irrigated in the Region were unlikely as most of the Grade 1 and 2 land was already intensively cropped.

This aspect of land suitability was addressed by Leeds-Harrison and Rounsevell (1993) in a paper examining the climatic and soil factors influencing agricultural demand for water. They developed a map of droughtiness across England and Wales by combining soil moisture holding capacities with soil moisture deficits, using existing databases. Whilst this approach is less accurate than using daily water balance methods, it needs much less data and could provide a simpler tool for irrigation demand forecasts on a spatial basis. By combining the results with databases of tillage constraints due to rainfall, they produced land suitability maps for potatoes. This method could be used to show whether an expansion of irrigated crops is feasible in a particular catchment.

The growth potential of trickle irrigation has been a concern of the NRA, partly because it is outside the spray irrigation licensing requirement and partly because of the claimed efficiency benefits. Kay (1992) concluded that it was still unlikely to be used on arable crops due to its capital cost, and although it would probably be used increasingly for orchards, soft fruit and protected cropping, it would remain a relatively small proportion of irrigation capacity. A fuller review of each of the above forecasts is given in Appendix A.

2.2 Discussion of methodologies

Almost all the above forecasts are based on an analysis of past irrigation data and subjective growth rate estimates, either for all irrigation, irrigation of individual crops or irrigation using specific techniques. This is a reasonable approach but has failed to give accurate results for a number of reasons.

Firstly it has been difficult to disentangle the effects of recent weather from the irrigation returns. Surveys carried out soon after dry years inevitably show high interest in irrigation. The concept of the 'dry year' used in MAFF surveys is subjective. The use of actual irrigation quantities since 1982 addresses this subjectivity problem, but it is now necessary to allow for the effect of the weather on these actual quantities when looking for underlying trends. Weather effects will never be entirely eliminated, since the actual sequence of wet or dry years clearly influences farmer sentiment and finance.

The second main problem has been the difficulty of building in the effects of external factors on irrigation demand. Informed sources agree that these are likely to be more important than factors such as changes in water charges. Most growth rates have been based on past growth rates and at best subjectively varied to take a few other factors into account. Superimposed on these fundamental problems, there are of course all the problems of inaccurate data and variability between catchments, farmers and crops.

It is also important to note that all forecasts implicitly contain an assumption about NRA policy e.g. the ACAH forecasts assumed that water would be made available. The actual outcome will inevitably depend on the level of restrictions applied to licence applications and abstractions.

The alternative fundamental approach is to predict irrigation requirements from a study of soils, crops and weather, and use farm economic models to predict which crops farmers will grow and whether they will irrigate them. The first part of this methodology was used for example by Cowton (1981) to predict the theoretical maximum irrigation requirements for potatoes in Kent, assuming all suitable land was included in a potato rotation and irrigated. These assumptions however limit the use of this approach. For a few areas where high grade land is limited (e.g. the South West), or for crops which virtually all have to be irrigated (e.g. potatoes on light land in East Anglia), reasonable assumptions can be made. Generally, however, models are unable to predict accurately either land use or irrigation from fundamental data due to the complexity in farmer decision making. This is particularly so for crops where only a small percentage is irrigated and the model must identify the exceptions rather than the rule.

A combination of methodologies is however possible, where models are used to help predict trends from a baseline determined from statistical data. This combination methodology has been adopted in this project.

3. IRRIGATION DATA AND CURRENT TRENDS

3.1 Irrigation Data

3.1.1 MAFF Irrigation Census data

Background

The most accessible national statistics on agricultural irrigation in England and Wales are those collected through the MAFF "Irrigation of Outdoor Crops" censuses. A question in the annual MAFF "Agricultural and Horticultural Cropping" census questionnaire asks: "do you irrigate outdoor crops?". This is used as a trigger for sending an irrigation questionnaire. Completing the cropping census questionnaire is obligatory; the irrigation census questionnaire is voluntary.

Irrigation censuses have been carried out roughly tri-annually, recently in 1974, '77, '82, '84, '87, and '90. A further survey was carried out in 1992, but results are not yet available. The publication date is normally the following year; years shown in this report are the years to which the data apply.

Until 1977, irrigators were asked for the areas they would irrigate 'in a dry year', broken down by crop category. Because of doubts about the subjective definition of a dry year, from 1982 onwards the main question was changed to ask for the areas actually irrigated and also the volumes actually applied, again broken down by crop category. The questionnaire also asks for information on the water source, water storage and in-field equipment. For the dry year, only the total area and volume are now requested, and only the 1984 figures were published at county level. Although there have been minor changes in wording as a result of experience, the questions have been kept essentially the same since 1982, giving now four sets of directly comparable data ('82, '84, '87, '90).

The base data received by MAFF have to be adjusted statistically to take account of forms which were sent out but not returned. For 1974 and 1977 the published county level data are unadjusted; the differences between unadjusted and adjusted national totals give an indication of the error in each category (15-20% in 1974, 10-12% in 1977). The data published from 1982 onwards are already adjusted; no indication is given of the size of the adjustments.

Individual farm replies are aggregated by MAFF on the basis of farm office postal addresses into parish, county and national totals. Because of confidentiality restrictions prohibiting the publication of data referring to four or less holdings, parish totals are not freely available. These restrictions can also affect county level totals, and published figures intentionally suppress some data; this occurs particularly in counties with little irrigation.

Exclusions

It should be noted that these MAFF data exclude irrigation applied under the following headings:-

- irrigators not defined as agricultural holdings, and hence not completing the cropping census return e.g. golf, landscape and residential irrigation;
- subirrigation by raising water tables (assuming farmers would not consider this as irrigation);
- irrigation of indoor crops e.g. glasshouses.

Accuracy

Potential errors in the MAFF data include:

- irrigators failing to receive or return the cropping census questionnaire;
- irrigators failing to respond positively to the trigger question;
- irrigators failing to receive or return the irrigation questionnaire;
- irrigators incorrectly completing the irrigation questionnaire;
- data collation errors.

Since the returns are strictly confidential to the MAFF statisticians, there should be no reason for irrigators deliberately to provide incorrect information (though this cannot be discounted in a small minority of cases). However experience with similar questions on surveys suggests that errors are inevitable. Random errors may cancel out in totals; more significant are errors leading to consistent under- (or over-) recording.

MAFF statisticians are able to adjust for non-returned forms, but must assume them to be a random sample. The trigger question is potentially a problem. Irrigators who have not irrigated at all in a wet year may reply no, and hence not receive the irrigation questionnaire. Data on their equipment and reservoirs would temporarily 'disappear' from the statistics. This may explain some of the apparent fluctuation in the numbers of reservoirs.

Figures relating to a 'dry year' are subjective, and likely to be influenced by perceptions of weather over the past few years. Figures relating to actual irrigated areas are likely to be fairly accurate, though mobile systems used to apply a single small irrigation over an essentially unirrigated crop can distort figures. The volume figures for individual crops are less dependable. At best they reflect what the farmer believes he or she applied, perhaps adjusted so that the total matches the metered volume, itself subject to error.

Due to the confidentiality constraints, it is impossible for anyone other than MAFF to check returns on a statistically representative farm-by-farm basis. In any case the cost would probably outweigh the benefit. Woodley and Stansfield (1986) state that comparisons at county level between MAFF and NRA data for 1982 gave "acceptable" correlation for volumes (of course both sets of figures may be incorrect). Attempts to check accuracy for the admittedly limited number of farmers in the interviews failed because none had kept copies, and indeed several could not recall seeing the form; this raises the question of whether the most suitable persons are completing them.

Despite the above reservations, the authors believe the MAFF national data are broadly correct, particularly in regards to trends, providing they are interpreted in relation to the weather for the year in question. At regional level, accuracy is likely to be much lower outside the main irrigated regions.

Recommendations for improvement

The following recommendations are made:

1. NRA should ask MAFF to consider rewording the trigger question, to "did you irrigate/are you able to irrigate if necessary?".

2. NRA should ask MAFF to consider separating winter abstraction from summer abstraction in the volume by source question.

3. NRA should ask MAFF to continue producing data at county level; this is no longer routine, and data for this study had to be specially processed and cleared. Alternatively data could be supplied already processed by MAFF into NRA regions.

4. NRA should ask MAFF to consider recompiling the data on a catchment/aquifer basis. This would require asking the location of the main abstraction point(s) and using a geographical information system (GIS) to identify catchments and aquifer boundaries, but it is quite feasible. Catchment and aquifer based totals would be much more useful to NRA.

Data for NRA regions *

For this study, the county level data have been aggregated into NRA regions. A difficulty arises because NRA boundaries follow catchment boundaries rather than county or even parish boundaries. Where a county falls into more than one NRA Region, the county figures have normally been split proportional to the area in each Region; i.e. assuming the irrigated farms are uniformly spread over the county. An exception to this rule was made where the overlap occurs in mountain areas where irrigation is unlikely; here the irrigated area was subjectively allocated to the appropriate Region. Whilst a split at parish level would theoretically be more accurate, it is believed the figures would not be significantly changed or improved within the level of accuracy of the base data.

Table 3.1 presents a summary of the MAFF irrigation census data for 1982, '84, '87 and '90 aggregated by NRA regions as described above. More comprehensive data showing irrigated areas and volumes for each crop are given in Appendix B.

Suggestion -
footnote - to explain now 8 Regions?
(merge between Northumbria + Yorkshire; Severn + Wessex.)

Table 3.1 Summary of MAFF irrigation data for the 10 NRA Regions for 1982, '84, '87 and '90

	Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire
					Area irrigated (ha)					
1982	48770	2029	1037	22305	1123	10999	11565	3649	3116	4917
1984	67942	3513	1276	31446	1944	11239	6323	4664	3276	8978
1987	36345	1029	238	20995	1186	6305	5372	3146	1941	5229
1990	85561	3174	1217	43917	1997	11040	11247	4999	3075	11800
					Volume of water applied (Ml)					
1982	25101	1001	450	12574	674	5416	3405	1961	1809	2698
1984	44868	2286	899	22476	1442	7687	5115	3145	2808	6654
1987	14606	424	96	9402	702	2981	2358	1567	1355	2211
1990	70016	2173	800	35748	1554	8578	8828	3516	2618	8698

Notes: Source: MAFF Irrigation Census.

3.1.2 MAFF Agricultural and Horticultural Cropping Census data

Background

Data on the areas of crops grown are available on an annual basis from the MAFF Agricultural and Horticultural Cropping Census. Data are published at county and national level. Although the larger number of farms included means the confidentiality restrictions are less important than in the irrigation census, data at parish level are still difficult to obtain.

The accuracy of these data in aggregated form should be significantly better than the MAFF Irrigation Census area data, due to the larger sample sizes.

Data for NRA regions

Table 3.2 shows a summary of the MAFF cropping census data for 1982, '84, '87 and '90 aggregated by NRA regions as described previously. The areas for each of the irrigation census crop categories are given in Appendix C.

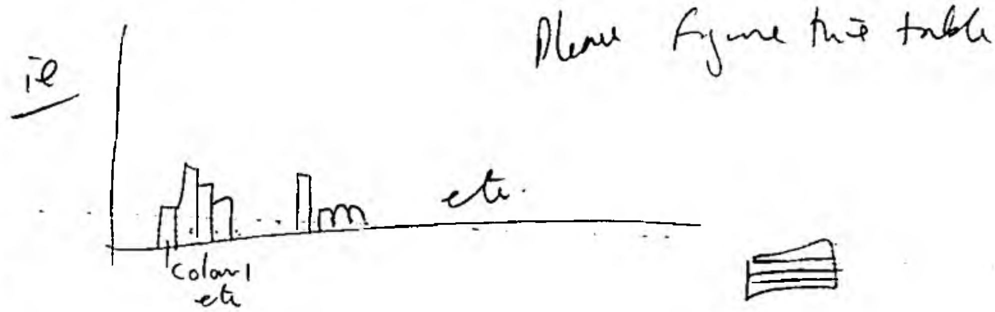


Table 3.2 Summary of MAFF cropping data for the 10 NRA Regions for 1982, '84, '87 and '90

	Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire
					Area cropped (ha)					
1982	1895703	711487	417174	1487540	736988	596131	650765	1135897	661704	769316
1984	1870323	708737	406397	1476284	737724	590119	643578	1148519	659118	752467
1987	1777643	708955	406754	1440664	730310	560239	607525	1161310	642348	739132
1990	1724703	703939	394215	1401756	716498	535390	573606	1149892	624661	729477

Notes: Source: MAFF Cropping Census.

3.1.3 NRA Irrigation Data

Background

All abstractions from surface or groundwater for agricultural spray irrigation require a licence under the Water Resources Act 1991. Most abstractors are required to meter their abstractions and complete an annual return giving details of actual abstraction. In theory at least, the NRA should have an excellent database of the water used for overhead irrigation.

Methods of collecting and storing data on both licensed and abstracted quantities have in the past varied considerably between NRA regions. The majority have, or are in the process of developing, computer databases and a national abstraction licensing database has recently received Government approval and is in the first phase of development. Most regions are now entering licence information and annual totals from current abstraction returns. Historic abstraction data are variously held on paper or microfiche. Some have been lost or were never archived. Details of the information held by each Region and available to this project are given in Appendix D. It must be recorded that numerous anomalies appear to exist in the data; even NRA records of data supplied for the Department of the Environment (DoE) figures do not always match the figures published.

The year end month varies between NRA regions. For DoE returns (Section 201 forms), years until 1983 run to December; from 1984/5 onwards years run from April to March. Whilst the choice of year end would not affect summer abstraction data, it would affect the 'year' of winter abstraction. Using a March year end ensures refilling of reservoirs occurs in the same data year as the irrigation demand.

Exclusions

It should be noted that NRA irrigation data exclude the following:

- irrigators taking water from mains supply (this would be aggregated into the abstraction data of the water suppliers);
- trickle or drip irrigation;
- subirrigation through pipes or by raising water tables e.g. in the Fens;
- surface irrigation (virtually unused in the UK).

Irrigation from the mains supply is relatively expensive and generally confined to small areas such as glasshouses and small horticultural units. The MAFF data suggest mains supply for irrigating outdoor crops is 4000 Ml per annum or about 3% of the total irrigation volume. There are no comparable figures for the use of mains supply for irrigating indoor crops.

The total area of agricultural outdoor cropping equipped for trickle irrigation was around 2000 ha in the mid '70s but has declined to around 1400 ha (MAFF Irrigation data). Kay (1992) suggests that this figure has stabilised and no significant growth is expected. He points out that as trickle systems are permanent and used on high value crops, they are likely to be used to apply full irrigation and maintain moist soils; depths applied are therefore likely to be higher than for the mobile overhead systems. Even so, his estimated total annual use of 2300 Ml is still relatively small. He estimates that 25% of this comes from the mains supply. Again, there are no comparable figures for the use of trickle irrigation on indoor crops, but probably the majority of this comes from mains supplies.

Subirrigation is practised on a limited scale in the Fens and in other low lying areas. Drain water levels are maintained artificially high and water is fed laterally to the root zone through the soil or buried pipes. In pumped drainage schemes, the rise in water table is achieved by reducing or stopping pumping; in others, weirs are used. Where drain-flow is insufficient, water may be back-pumped; this would still not require an abstraction licence. Crop water use under correctly managed technical subirrigation is likely to be less than for fully irrigated crops under overhead irrigation, since surface evaporation is avoided and rainfall effectiveness and irrigation efficiency should be very high. High water use can occur however if water tables are raised over unnecessarily large areas (subirrigating non-responsive crops or even Set-Aside as well as the intended crops), if ditch levels are raised too highly, or if water tables have been allowed to fall and then raised. Although most areas of technical subirrigation are small, the concentration of such schemes into limited areas can result in significant errors in the irrigation water demand data locally (University of Newcastle upon Tyne, 1990).

NRA licence data

Basic licence information includes:

- licence number and 'application' number (one licence may have several applications, e.g. for different abstraction points);
- national grid reference of abstraction point(s);
- source name;
- licence holder;
- year issued (start date);
- year revoked/due for renewal (end date).

Licences (and applications under each licence) specify the maximum abstraction permitted *per year* and *per day*; the two figures are independent of each other. Confusingly, annual quantities are often divided by 365 and quoted in daily units.

Spray irrigation licences can be agricultural or non-agricultural (e.g. golf courses); some NRA regions appear to combine both categories in their records and hence in returns to DoE. Records may further distinguish by use e.g. potatoes, golf.

Licences can restrict the period when abstraction is permitted, e.g. winter abstraction only. This may be recorded on databases by specifying the start and end months or simply specifying the use as winter abstraction, frost protection or storage fill. The winter abstraction period may vary between regions.

Most records distinguish between source categories by use of a code, into at least groundwater, surface water and tidal, and sometimes into subdivisions of these. Codes are also used to identify catchments or hydrometric areas.

Many of the definitions and distinctions used in these classifications have derived from local practice in the previous water authorities. They are not necessarily compatible between regions. Because of these differences in definitions, it is only possible to compare annual totals. These are shown in Table 3.3.

NRA Abstraction Data

Most licences require the licence holder to install an accurate water meter and to maintain records on the amounts of water actually abstracted. Not all abstractors are required to submit 'returns'; this depends on the licence conditions. Those who are required to submit returns may need to provide figures for daily, monthly or annual abstractions. These data may be required once a year, or occasionally in some regions at the end of each month in times of restrictions. Meters are normally read manually, which can be labour intensive if daily records are required, although the Severn Trent Region is now encouraging the use of electronic data loggers which are returned at the end of the season; it has also experimented with telemetry systems for larger users to provide real-time data.

Not all those required to submit returns do so. Regions vary in how they allow for these non-returns in their assessment of total abstracted quantity.

Table 3.3 Regional licensed volumes for spray irrigation

	Anglian	North West	Northumbrian	South West	Severn Trent	Southern	Thames	Welsh	Wessex	Yorkshire
	Licensed volume per year (Ml)									
1982	80264	-	-	515	35958	-	-	-	-	10101
1983	81870	-	227	549	37604	-	11060	4380	-	10897
1984	96871	-	357	1132	39946	-	11133	-	-	11274
1985	108077	-	439	1452	-	-	11461	-	7373	11791
1986	113734	-	526	1495	48657	-	11534	-	7300	14416
1987	119720	-	544	1622	49463	-	11644	-	7081	15248
1988	125195	-	572	1651	50142	-	11206	-	7227	17756
1989	128480	-	572	1663	-	-	10987	6205	12629	18370
1990	134685	-	857	1701	-	-	10658	-	12410	18933
1991	139065	-	857	1793	-	-	-	7446	13578	20380
1992	-	5517	865	2015	58953	25894	-	-	-	-

Notes: Sources: NRA Regions;
Where no data are presented, these are unavailable.

There is no reason to doubt the accuracy of the licence data; the problem is more with non-accessibility and with aggregating licences issued with different conditions. The accuracy of the abstraction data however is extremely doubtful. Potential errors include:

- unsatisfactory specification and installation of meters;
- failure to recalibrate regularly;
- deterioration of meters since installation/recalibration;
- inaccurate reading/recording of meter;
- deliberate under- or over-recording.

Opinions vary widely about the accuracy of metered readings, and it is probable there is the same range in the accuracy itself. At one extreme, many of the large and more sophisticated irrigators are confident in the accuracy of their meters and check them against (and use them in) their own scheduling. At the other extreme, smaller and older installations often fail to meet the relevant standards (though this does not of itself imply inaccuracy) and are more likely to have damaged or broken meters. Several studies report meters missing altogether, with returns being estimated. Clearly the higher standards of installation now required and the regular NRA inspections are gradually improving metering accuracy. Permanent installations are likely to be more accurately metered than systems using portable pumps where meters can be differently installed (or omitted) from day-to-day.

Where problems do occur in metering installation, they are likely to lead to under-recording rather than over-recording. Gradual deterioration of the meter will usually lead to increasing under-recording. Blockage of the impeller by weeds will lead to under-recording or non-recording until the blockage is cleared. Discounting occasional reports of wind turning impellers and excepting the occasional case where water returns to the source from beyond the meter (e.g. from a pressure relief valve), it is therefore likely that the meter readings are too low rather than too high. However, no data on whether the overall error is significant are available.

Inspection of returns show that the monthly figures are often constant. This pattern is quite unrealistic for direct summer abstraction and suggests either fabricated data or that the metered annual total has simply been spread equally between the months. The authors suggest monthly abstracted totals are generally unreliable; fortunately these data seem to have no use anyway.

The possibility of deliberate under-recording is a sensitive issue. The abstractor's water bill is directly related to the volume reported, and in many instances is almost an honesty box payment. However the sums involved are relatively small and the authors suggest most returns are honestly reported. Greater incentives to under-report would arise where a licence is smaller than required and the abstractor actually exceeds the licensed quantity. Remarkably, some returns do actually show over-abstraction, indicating commendable honesty.

A summary of available NRA data of abstracted volumes from 1982 to 1992 by NRA Region is given in Appendix D Table D.1. Readers interested in the accuracy of NRA data are referred to Sainsbury (1992).

Recommendations for improvement

The following recommendations are made:

1. NRA should expedite the introduction of its national abstraction and licensing database, and consider using a GIS based system to allow aggregation of data by catchment and aquifer.

2. NRA should review whether daily and monthly abstraction data are required. Data on short-term variation can be better obtained using dataloggers or telemetry on a few larger systems, and applied statistically to other abstractors if necessary.

3. NRA should continue to work towards more accurate metering; however over-zealous application of standards and over-frequent recalibration of meters should be avoided, as the costs can easily exceed any benefits.

4. NRA should carry out a pilot study to estimate the accuracy of metering and establish a correction factor. If appropriate, the NRA should then consider helping establish an on-site recalibration service.

5. NRA should consider making both licence and abstraction data available to interested parties. The volume abstracted by one abstractor from the national resource is a legitimate interest of other water users. The authors believe this move would also improve the quality of the abstraction data.

3.1.4 Potato Marketing Board data

Detailed statistics on potato production in Great Britain are available from the Potato Marketing Board (PMB, 1992). These include data on planting and yield against year and variety, imports, exports and prices, together with limited information on proportions irrigated. Table 3.4 summarises the areas planted and irrigation applied from 1987 to 1991. The totals agree reasonably well with the MAFF data.

Table 3.4 Potato production in Great Britain

	Area planted (ha)				
	1987	1988	1989	1990	1991
Great Britain:					
Early potatoes	14230	15294	15322	13799	14328
Maincrop potatoes	136890	139766	136486	140261	140039
Total	151120	155060	151808	154060	154367
% irrigated	30	30	42	38	37
England and Wales:					
Total	124195	128525	125877	128119	128671

Notes: Source: Potato Marketing Board, 1992.

3.1.5 Sugar Beet Industry data

British Sugar and Brooms Barn Experimental Station have collected data on the irrigation of sugar beet from experimental sites and field surveys. The annual British Sugar Specific Field Surveys were complemented by an additional questionnaire relating to the irrigated fields in 1984 and 1985. This provided detailed data on the soil types, irrigation method, scheduling method and cropping pattern (Dunham et al., 1987). Between 1980 and 1986 the percentage of the national crop irrigated was estimated to have varied between 5% and 15% depending on weather, confirming the MAFF data for 1982 and 1984. Table 3.5 shows the other crops irrigated in conjunction with sugar beet, and confirms how closely the irrigation of sugar beet, potatoes and cereals are interrelated. Experimental sites and on-farm trials have provided data on yield benefits (Dunham 1988, Dunham 1990, Dunham and Clarke 1992).

Table 3.5 Other crops irrigated in conjunction with sugar beet 1984-85

Number of fields surveyed	129
Number of surveyed fields where the farm irrigated other crops:	
Potatoes	101
Winter cereals	50
Spring cereals	39
Grass	26
Carrots, peas, beans, dwarf beans, onions	44
None	3

Notes: Source: Dunham et al., 1987.

3.1.6 Remote Sensing Data

The use of remote sensing from satellites to obtain crop information is an exciting and rapidly developing technology. Silsoe College, as a regional centre of the National Remote Sensing Centre Ltd, has been using remote sensing in an operational check on the accuracy of cropping data in the MAFF Integrated Agricultural Cropping Survey (IACS). The technology can distinguish between the main crops of interest and can provide data on crop type and area on a detailed grid basis. The ability to manipulate data directly in a GIS allows totals to be calculated on a catchment/aquifer basis and directly compared with the locations of abstraction points.

At present it is not possible to distinguish directly between irrigated and unirrigated cropping in the UK climate, though by combining crop and soil data the intended irrigation of some crops, e.g. potatoes on light soils, can be inferred.

Although there are no published data of use for this study yet, the combination of remote sensing and GIS promises to be a valuable technology in the not too distant future.

3.1.7 IACS data

Detailed cropping information is also being collected under the IACS scheme. Again there are no published data available yet, and the details of accessibility are not clear; confidentiality restrictions will again apply. However aggregated data from IACS may provide an alternative, or supplement, to other MAFF cropping data in the future.

3.1.8 Other data

A number of other data sources were investigated during this project, but while some provide useful data on particular aspects of irrigation, none have the general coverage of the MAFF and NRA data.

Irrigation equipment suppliers and installers each have commercially confidential information on new and replacement systems they have dealt with. Information given in confidence by individuals has been useful for building the general picture, but it would be difficult to obtain reliable totals and no attempt has been made.

Individual farmers have been very willing to give additional data. A total of 150 abstractors were randomly selected by the NRA Anglia Region and sent questionnaires requesting information on their irrigation and irrigation systems; 33 % were returned completed. The UKIA volunteered to send the same questionnaire to 125 farming members and to provide in confidence the aggregated results for this study; 38 % were returned completed. A small number of irrigators were interviewed face-to-face to pilot these questionnaires and to provide additional information. The results have been used in various parts of this report and in compiling models of typical systems for the economic study.

Co-operatives, merchants and customers also hold considerable data on irrigation practices. One group of potato processors for example holds records of the soils, irrigation applied and yield field by field for each of its growers. However these are regarded as highly commercially confidential and cannot be accessed.

3.2 Derived Data

Dividing the MAFF data for volume of water applied by the MAFF data for area irrigated gives the average depth applied. Dividing the MAFF data for area irrigated by the MAFF cropping data gives the proportion of the crop that is irrigated. Appendix E gives the average depths applied to each crop category and the percentage of each crop category irrigated in each NRA Region for 1982, '84, '87 and '90 respectively.

3.3 Current Trends

Since 1982 the MAFF irrigation data for specific crops have referred to actual irrigation applied in that year rather than the dry year intentions. The total areas irrigated and total volumes applied are shown in Figure 3.1. Any calculation of underlying trends must take into account differences in the weather in these years (irrigation seasons). Figure 3.2 shows the theoretical crop water requirements for maincrop potatoes and sugar beet grown in a soil with medium available water capacity (AWC) in East Anglia. Comparison with long term weather data shows that in irrigation terms, 1982 and 1984 were fairly average years, 1987 was a 'wet' year and 1990 a typical "1 in 5" design dry year. Using the relative theoretical crop water requirements as an indicator of climate in a multiple regression analysis, the underlying growth rates were calculated for irrigation area and volume for each crop (Table 3.6).

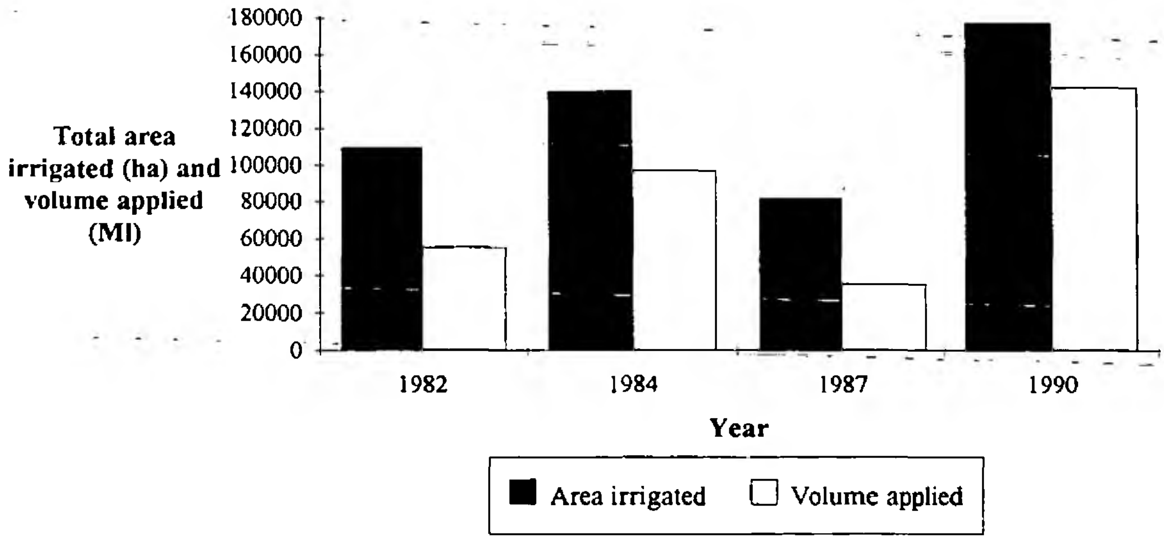


Figure 3.1 Total area irrigated and total volume applied in England and Wales, 1982 to 1990 (Source: MAFF Irrigation Census)

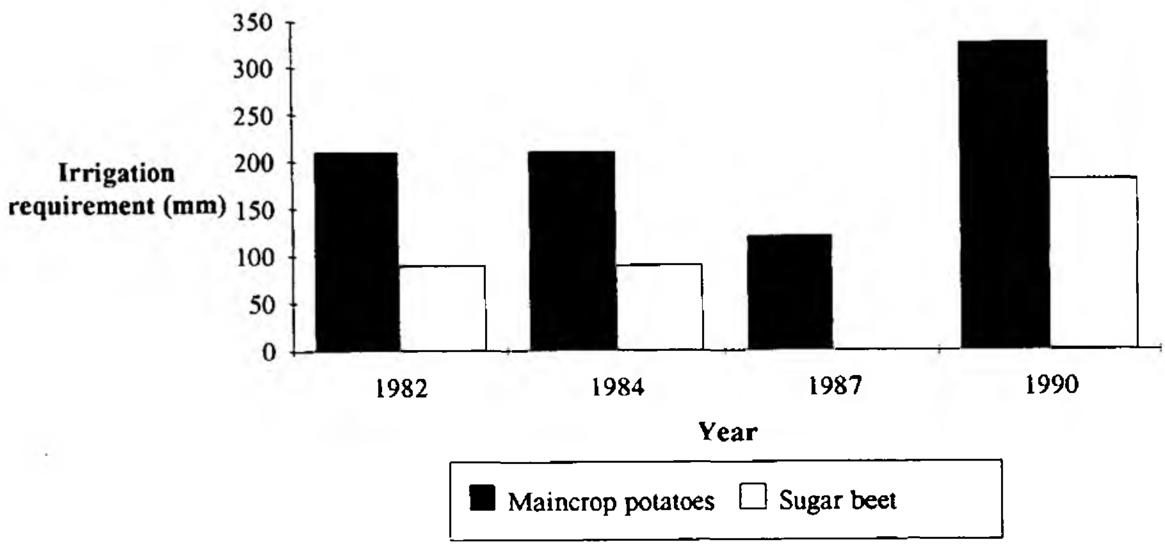


Figure 3.2 Theoretical crop irrigation requirement for maincrop potatoes and sugar beet grown on a medium available water capacity soil in East Anglia, 1982 to 1990

Underlying growth rates in the area, volume & depth of irrigation, 1982-1990.

title needs improving - audience

Table 3.6 Underlying growth rates in the area irrigated, total volume and depth of water applied to selected crops and overall, 1982-1990 (warning - individual values have a low statistical significance level)

	% change per annum on 1990 value		
	Area	Volume	Depth
Early potatoes	-1	0	+1
Maincrop potatoes	+5	+4	-2
Sugar Beet	+1	+1	0
Orchard fruit	-6	-5	0
Small fruit	-5	-2	+2
Vegetables	+1	+1	0
Grass	-8	-6	+1
Cereals	+1	+1	+1
Other	+2	+4	+2
Overall	+1	+2	+1

It must be noted that the statistical reliability of these results is low. Each is based on only the four available data points and there are two independent variables. The analysis assumes linear relationships between the theoretical demand and the area irrigated, volume and depth applied, and linear underlying trends against year. Equipment and water supply constraints in the 1990 dry year, coming at one end of the dataset, may have distorted underlying trends downwards. Better results will be attainable when the 1992 data are available. However, the results to date suggest a major growth in maincrop potato irrigation, a slow growth in sugar beet, vegetable, cereal and 'other' irrigation, and a decrease in grass, orchard fruit and small fruit irrigation over this period. Overall, they suggest that the total area irrigated and the total volume applied have been increasing at underlying growth rates of 1% and 2% per annum respectively, over the 1982 to 1990 period.

4. POTENTIAL THEORETICAL DEMANDS

4.1 Aims

The aim of this Chapter is to quantify the potential theoretical needs for irrigation within each NRA Region, based on climate, soil type, likely cropping patterns and other technical factors.

The term "potential theoretical demand" needs careful definition. The maximum additional water that could theoretically be used by the total cropped area could be calculated but the result would be virtually meaningless, since most crops will never be irrigated. At the more practical level, Chapter 7 attempts to quantify the most likely demand, i.e. the volumes farmers are most likely to want to apply on the crops they are most likely to wish to irrigate. In this Chapter, potential theoretical demand is calculated as the agronomically optimum application for the major irrigated crops.

It is important to note that the potential theoretical demand is not a fixed 'ceiling'; the calculations must make assumptions based on current agronomic and irrigation practice. Changes in these assumptions would alter the potential theoretical demand.

4.2 Methodology

A computer model developed at Silsoe College (Irrigation Water Requirements) has been used to calculate potential theoretical demand, based on historical weather data. The model requires data on the crop, the soil and the potential evapotranspiration at the site to estimate daily water use. This is combined with rainfall data in a daily water balance to calculate daily soil water deficit (SWD). Irrigation decisions are based on an irrigation plan set by the user (e.g. in May and June when SWD reaches 30 mm, apply 25 mm). For each year of the weather records, the model outputs data on crop water use, irrigation applied and proportional yield loss due to any water stress.

For this study six climatic zones have been used. These are based on the 52 climatic areas defined by the Meteorological Office (Smith 1984), grouped according to the published mean values of the annual maximum soil water deficits from 1941 to 1970. A similar methodology was used by Bailey and Minhinick (1989). For each zone, a representative weather station was then sought to provide the daily weather records. Ultimately four stations were used, with data being combined for one zone and irrigation not being needed in the wettest (Table 4.1).

Three soils were chosen to represent soil types with low, medium and high available water capacities respectively (Table 4.2).

Irrigation plans for the selected crops were based on schedules originally suggested in MAFF (1984). Although this is no longer published, the schedules are typical of current practice (Table 4.3). Carrots were used as an example for vegetables. A schedule for fully irrigated permanent grassland was included for comparison.

Table 4.1 Climatic zones and representative weather stations

Climatic zone	Mean value of maximum SWD (mm)	Representative weather station
A	0-25	not required
B	26-50	Yarner Wood, Devon
C	51-85	data generated
D	86-95	Shawbury, Shropshire
E	96-113	Gatwick, E.Sussex
F	114-125	Wattisham, Suffolk

Table 4.2 Characteristics of the three representative soils (low, medium and high AWC)

		Low AWC	Medium AWC	High AWC
Topsoil depth	(m)	0.3	0.3	0.3
Topsoil total AWC	(mm/m)	110	170	300
Topsoil easily AWC	(mm/m)	70	110	220
Subsoil total AWC	(mm/m)	70	150	300
Subsoil easily AWC	(mm/m)	50	110	220
Maximum deficit under bare soil (mm)		17	17	17

Table 4.3 The irrigation-plans for selected crops on low, medium and high AWC soils

Crop	Period	mm water applied at mm deficit		
		Low AWC	Medium AWC	High AWC
1st early potatoes	May to June	15 at 25	25 at 30	25 at 30
Main crop potatoes	May to July	15 at 15	15 at 15	15 at 15
	August	25 at 25	25 at 35	25 at 35
Sugar beet	May	25 at 25	25 at 30	25 at 50
	June	25 at 35	25 at 35	35 at 50
	July	25 at 45	40 at 50	45 at 100
	August	25 at 55	50 at 75	55 at 125
Permanent grassland	May to August	25 at 25	25 at 25	25 at 25
Vegetables (carrots)	Throughout season	25 at 25	40 at 50	n.a.

The model was run for each permutation of climatic zone, soil and crop over the duration of available weather records. Irrigation demands were then ranked. The 20% exceedance values, approximately equivalent to the fifth highest demand in twenty years, are given in Table 4.4. It is emphasised that these are theoretical demands under the assumptions stated, net of any losses; they should not be used to assess demand on any particular farm.

To give an indication of the total volumes represented by these theoretical demands, the 20% exceedance depths have been multiplied by the 1990 irrigated crop areas for each NRA Region as calculated in Chapter 3 (Table 3.1). For simplicity, within each Region the crop has been split between the climatic zones on a proportional area basis and the medium available water capacity (AWC) soil values used throughout. The results are given in Table 4.5. More accurate results should be obtained from the GIS-based MAFF-funded study being undertaken by Silsoe College.

The theoretical requirements calculated for 1990 have also been multiplied by the 1990 irrigated crop area on the same basis (Table 4.6) to allow comparison with the actual values calculated in Table 3.1.

Table 4.4 The calculated 20% exceedance irrigation requirements, equivalent to the fifth highest demand in twenty years, for selected crops, for the five climatic zones and the three soil types

		Irrigation requirement (mm)				
Climatic zone	Soil type (AWC)	Early potatoes	Main crop potatoes	Sugar beet	Vegetables (carrots)	Permanent grass
B	Low	30	170	65	125	125
	Med	25	170	55	80	125
	High	25	170	0	na	125
C	Low	35	190	70	130	160
	Med	30	185	65	80	160
	High	30	185	0	na	160
D	Low	45	215	80	140	190
	Med	40	200	75	80	190
	High	40	200	0	na	190
E	Low	50	250	125	175	210
	Med	45	235	115	140	210
	High	45	225	50	na	210
F	Low	60	275	140	175	210
	Med	50	260	125	160	210
	High	50	260	55	na	210

Table 4.5 The 20% exceedance values of the theoretical irrigation water requirement by NRA Regions for selected crops, based on 1990 irrigated crop areas

	Theoretical irrigation water requirement (Ml)				
NRA Region	Early potatoes	Main crop potatoes	Sugar beet	Vegetables (carrots)	Permanent grass
Anglian	1 905	56120	22 787	22 405	10 438
North West	90	1 432	79	549	541
Northumbrian	7	832	21	42	254
Severn Trent	792	25 794	6 975	4 228	8 000
South West	138	856	9	290	891
Southern	555	5 197	2	4 874	2 663
Thames	242	6 734	1 591	3 923	2 348
Welsh	280	1 470	177	496	834
Wessex	88	1 159	115	356	2 559
Yorkshire	87	8 136	941	499	1 654
Total	4 183	107 730	32 699	37 661	30 191

Table 4.6 1990 theoretical irrigation requirements by NRA Regions for selected crops

	Theoretical irrigation water requirement (Ml)				
NRA Region	Early potatoes	Main crop potatoes	Sugar beet	Vegetables (carrots)	Permanent grass
Anglian	2 046	69 533	31 835	27 718	13 446
North West	129	1 703	122	686	676
Northumbrian	9	902	32	49	343
Severn Trent	1 063	32 078	10 507	5 562	9 744
South West	191	999	14	365	1 135
Southern	703	6 266	3	5 806	3 303
Thames	282	8 312	2 196	4 866	2 957
Welsh	398	1 760	276	629	1 049
Wessex	126	1 413	154	446	3 046
Yorkshire	118	9 656	1 506	653	2 085
Total	5 066	132 622	46 644	46 779	37 784

4.3 Discussion

The theoretical irrigation requirements (depths) shown in Table 4.4 appear high for the wetter climatic zones, but agree reasonably with the reported applications on the large irrigated farms in East Anglia. They are substantially higher than the corresponding values obtained by Bailey and Minhinick, who allowed much larger soil water deficits to develop before irrigation. This emphasises the sensitivity of these theoretical values to the assumptions inherent in the analysis.

The volumes calculated in Table 4.6 can be compared with the actual volumes applied in 1990. As might be expected, there are a few anomalies (the apparent over-irrigation of early potatoes is due to a difference in definition) but the overall results support previous studies suggesting that between 40% and 60% of the potential theoretical demand (as defined) is actually being applied. This discrepancy between theoretical demand and actual applications is not surprising. The theoretical demand assumes the full crop water requirements will always be met, but for a variety of agronomic, economic and resource limitation reasons, it is often sensible or necessary to apply less.

For example:

- The benefits of irrigation often suffer from the law of diminishing returns, so that the last mm produces less benefit than the preceding one. If equipment or water resources are limited, it may be better to partially irrigate the whole crop rather than fully irrigate part of it.
- Irrigation is expensive, both in fixed costs to provide a given capacity and in variable costs to use it. It is uneconomic to design systems to meet the absolute peaks in demand, or to use them to apply the full biological demand. The theoretical break-even will depend on the irrigation system and the crop; generally permanent systems on high value crops should apply a higher proportion of the theoretical demand than portable systems on low value crops.
- Portable systems can be used to partially irrigate adjacent lower priority cropping at times of spare capacity. These crops enter the statistics as having been under-irrigated, biasing the average depths down.

Because of these and other reasons, demand projections should not be based directly on theoretical irrigation requirements

5. MARKET AND AGRO-ECONOMIC FACTORS

5.1 Introduction

This Chapter reviews the costs and benefits of irrigation in England and Wales at farm level, and examines market and agro-economic factors which are likely to influence the demand for irrigation water.

The economic benefits of irrigation have been a major influence on the willingness of farmers to invest in irrigation in Britain. The appraisal of irrigation investment and use involves the identification of the extra benefits and costs attributable to irrigation, over and above those associated with non-irrigated systems of crop production (Morris, 1983; Morris and Day, 1985). Irrigation reduces the variation in the yield and quality of crops compared to rainfed systems and, in some cases, allows the production of crops that would otherwise be infeasible. However, irrigation is capital intensive and relatively expensive, especially if investment in water storage is necessary.

5.2 Irrigation Costs

5.2.1 Comparative costs

The costs of irrigation vary considerably according to local circumstances such that generalisation is difficult. Costs vary according to:

- the irrigation requirements of the crop;
- the nature of the source (whether surface or ground water);
- the need for water storage;
- the size, configuration and topography of the irrigated area and its distance from and height above the water source;
- the type of application system.

Irrigation costs have been estimated for four infield application systems (hosereels, sprinklers, trickle and centre pivots) over relevant irrigated areas, and for alternative water supply situations (surface or borehole sources abstracting directly or involving reservoirs, either clay or PVC lined). Details of the costs and assumptions are given in Appendix F.

The capital or initial investment costs without storage are typically £2000 - £2500 per hectare, depending on the system characteristics (Table 5.1). Water storage can increase capital costs by as much as 40%. Table 5.1 also shows the annual fixed costs (amortization of capital costs plus insurance) and annual variable costs (repairs, fuel, labour and water), and the average costs per mm depth of water applied for the selected systems. The unit cost of a hosereel system with direct abstraction from a surface source is about £4.0/ha mm applied (1 ha mm = 0.01 Ml). Using a groundwater source increases costs to £4.1/ha mm (assuming the same mains delivery system). Sprinkler systems show similar average costs per unit of water applied.

Water storage adds significantly to average costs: an extra 33% and 50% for unlined and PVC lined reservoirs respectively compared to direct abstraction. Average costs are about £5/ha mm to £6/ha mm for storage based systems, although cost savings are evident for large reservoirs.

Table 5.1 Summary of average total costs of irrigation

Water source:	Surface		Borehole		Surface		Surface		Surface		Borehole	
Direct/Storage:	Direct		Direct		Storage (unlined)		Direct		Direct		Direct	
Application:	Hosereel		Hosereel		Hosereel		Sprinkler sets		Trickle tape		Centre pivot	
	£	%	£	%	£	%	£	%	£	%	£	%
Capital costs per ha	2291		2670		4060		1780		2278		2119	
Annual costs per ha												
Fixed	317	64	351	68	495	75	233	45	489	76	274	65
Variable												
repairs	85	17	76	15	96	15	76	15	103	16	59	14
fuel	47	9	51	10	56	8	22	4	11	2	51	12
labour	12	2	12	2	12	2	147	29	5	1	12	3
water	36	7	23	4	4	1	36	7	32	5	23	5
subtotal	180	36	162	32	168	25	282	55	152	24	145	35
Total	497	100	514	100	663	100	515	100	641	100	419	100
Costs per ha mm	3.98		4.11		5.30	(5.89 lined)	4.12		5.13		3.35	
of which:												
Fixed	2.53		2.81		3.96	(4.48 lined)	1.87		3.91		2.19	
Variable	1.44		1.30		1.34	(1.42 lined)	2.25		1.22		1.16	

Trickle tape systems cost about £5.1/ha mm assuming the infield tape can be used a second time. Centre pivots offer economies of scale with average costs of about £4/ha mm to £3.4/ha mm over the range of 80 ha to 100 ha.

The structure of average costs is important. With the exception of labour intensive sprinkler systems, fixed costs account for between two thirds and three quarters of average total costs. The greater the investment in automation and water storage, the greater is the relative importance of fixed costs. Once the irrigation investment has been made, farmers will be particularly interested in recovering operating costs. Variable costs are typically only £1.2/ha mm to £1.4/ha mm for mobile and automated trickle systems. For sprinkler sets they are about £2.3/ha mm due to higher labour costs.

The composition of variable costs is itself important, showing likely sensitivity to changes in operating cost parameters. For hosereels for instance, repairs and maintenance account for about 15% of total costs (50% of variable costs), fuel for about 10%, and labour for 2%. The percentage of average total costs attributable to water charges varies according to the source and season of abstraction. For direct abstraction, water accounts for about 7% of total costs (but about 20% of variable costs). For groundwater systems this reduces to about 4%, and for winter storage to about 1%. The new pricing regime introduced in 1993 increased water charges for spray irrigation but their relative share of irrigation costs has not changed significantly.

The analysis of costs thus confirms that water charges by themselves are not a significant influence on farmer irrigation investment and operation. Access to water is the key factor.

Under the present water pricing regime, direct abstraction offers some cost advantage. Lower water charges for winter abstraction do not compensate for the additional investment cost of reservoirs. But, in many areas of irrigation potential, additional summer water is either not available or unreliably available. Thus, further irrigation development is likely to require additional investment in winter storage.

There are limited data on actual farm irrigation costs with which to compare the above estimates. A study of 23 irrigation systems in the eastern counties of England by Vavarigos and Hinton (1990) in the mid 1980s confirmed the great variation in system size, water use, crops irrigated and costs. In 1993 prices, capital costs varied from £500 to almost £3000 per hectare, and average total costs were typically about £8.5/ha mm, of which about one third was the cost of operation. Many elements of these costs were based on "considered estimates" by farmers and the researchers rather than on actual records. Interest was charged at the current rate of 14% and not adjusted for inflation. Adjustment of the underlying assumptions in the Vavarigos and Hinton study to conditions prevailing in the 1990s would make their estimates of costs more compatible with those described above.

5.2.2 Sensitivity analysis

Table 5.2 shows the % change in average costs per unit of water applied in response to a 10% change in selected cost parameters, whether this be due to changes in unit prices or quantities.

Given the relatively high commitment of investment capital required, irrigation costs are particularly sensitive to capital costs and factors which influence fixed costs, such as interest rate and depreciation life. For instance, a plus or minus 10% change in real interest rate (from the 6% basic assumption), results in a (+/-) 3% change in average fixed costs and a (+/-) 2% change in average total cost.

Table 5.2 Sensitivity analysis of irrigation costs

	+/- % Change in costs for a +/- 10% change in cost element																	
Water source:	Surface			Borehole			Surface			Surface			Surface			Borehole		
Direct/Storage:	Direct			Direct			Storage reservoir			Direct			Direct			Direct		
Application:	Hosereel			Hosereel			Hosereel			Sprinkler			Trickle			Centre pivot		
Area (ha):	24			24			24			24			24			100		
	FC	VC	TC	FC	VC	TC	FC	VC	TC	FC	VC	TC	FC	VC	TC	FC	VC	TC
Capital costs	10	3	7	10	5	8	10	6	9	10	3	6	10	7	9	10	4	8
Fixed costs																		
Interest rate	3	-	2	3	-	2	3	-	2	3	-	1	2	-	1	3	-	2
Life of asset	4	-	6	6	-	4	6	-	5	6	-	3	7	-	6	6	-	4
Variable costs																		
Repairs	-	5	2	-	5	1	-	6	1	-	3	1	-	7	2	-	4	1
Fuel	-	3	1	-	3	1	-	3	1	-	1	*	-	1	*	-	4	1
Labour	-	1	*	-	1	*	-	1	*	-	5	3	-	*	*	-	1	*
Water	-	2	1	-	1	*	-	1	*	-	1	1	-	2	1	-	2	1

Notes: * less than 0.5%
FC = Annual Fixed Costs; VC = Annual Variable Costs; TC = Annual Total Costs
(e.g. a 10% rise in water charges results in a 2% rise in variable costs and a 1% rise in total costs of surface/hosereel irrigation)

Average total irrigation costs are less sensitive to changes in variable cost items. Under present price regimes, the costs of fuel, labour, and water considered separately do not have a major influence on average total costs, although the sensitivity varies between systems. The analysis confirms the insensitivity of average total, and indeed average variable costs, to water charges.

5.3 Irrigation Benefits

The main objectives of farmers regarding irrigation are to increase the level and reliability of added-value and profits from farming. The benefits of irrigation compared to rainfed farming are usually perceived in terms of higher and less variable crop yields, improved and assured product quality, and continuity and reliability in production and marketing. Irrigation of field scale vegetables, such as potatoes and onions, and of fruit and horticultural crops is especially important for meeting the needs of an increasingly competitive and quality oriented market.

Quality and quantity are difficult factors to separate. A high yielding, poor quality crop has limited market value. The food market, increasingly concentrated into a small number of influential merchants, processors and retailers, demands quality produce in reliable quantities at the right time.

The assessment of irrigation benefits requires the identification of the value of extra yields and quality premia attributable to the irrigation investment.

5.3.1 Yield response to irrigation

The additional crop yield due to irrigation is determined by crop type and variety, the stage in the crop growth cycle when water is applied, the standard of crop husbandry, and environmental factors, especially soils and climate. Yield response to irrigation varies particularly according to rainfall; not only the total, but also the distribution of rainfall during the growing season.

Furthermore, the need for and response to irrigation varies significantly according to soil type. Lighter, more drought prone soils offer large potential responses. Irrigation has helped to maintain and improve the yields of field scale root and vegetable production which has switched to light soils mainly to facilitate mechanical harvesting and better timeliness of planting and harvesting.

The Agricultural Development and Advisory Service (ADAS) drew on "available experimental data and field experience for well managed crops in areas of established need in order to estimate average yield responses per ha mm of water applied" (ADAS 1977, MAFF 1984). Table 5.3 gives these yield responses and expresses them in terms of extra value-added (extra output less extra input) before irrigation costs in 1993 prices. These so-called net margins show the average yield benefit per unit of water applied to the main irrigated crops. For example, on average, irrigation of main crop potatoes generates a yield benefit of £5.44/ha mm of water applied. Benefits per unit of water are highest for soft fruit, followed by horticultural crops, field vegetables and root crops. Cereals and grass give relatively low benefits to irrigation.

Table 5.3 Average yield response of crops to irrigation and related financial benefits

	Crop price £/t	Extra crop costs £/t	Extra net margin £/t	Crop response t/ha mm	Extra net margin £/ha mm
Maincrop potatoes	80.00	12.00	68.00	0.08	5.44
Early potatoes	125.00	18.75	106.25	0.08	8.50
Sugar beet	38.40	3.84	34.56	0.13	4.49
Winter wheat	93.00	2.79	90.21	0.02	1.62
Winter barley	90.00	2.70	87.30	0.02	1.57
Spring barley	90.00	2.70	87.30	0.02	1.57
Winter field beans	95.00	2.85	92.15	0.04	3.69
Spring field beans	95.00	2.85	92.15	0.04	3.69
Peas - dried	105.00	3.15	101.85	0.04	4.07
Peas - vining	125.00	3.75	121.25	0.04	4.85
Cabbage	150.00	22.50	127.50	0.14	17.85
Carrots	80.00	12.00	68.00	0.03	2.04
French beans	175.00	35.00	140.00	0.06	8.40
Runner beans	365.00	73.00	292.00	0.05	14.60
Brussel sprouts	230.00	46.00	184.00	0.04	7.36
Cauliflower	300.00	60.00	240.00	0.07	16.80
Lettuce	400.00	80.00	320.00	0.03	9.60
Onions	110.00	22.00	88.00	0.08	7.04
Grass-graze	91.20	0.00	91.20	0.03	2.28
Grass-silage	91.20	20.06	71.14	0.03	1.78
Strawberries	700.00	140.00	560.00	0.03	14.00
Raspberries	1240.00	248.00	992.00	0.03	24.80
Blackcurrants	550.00	110.00	440.00	0.03	13.20
Dessert apples	350.00	70.00	280.00	0.02	4.20

Additional costs	% of extra gross output
combineable crops	3
sugar beet	10
potatoes and field scale vegetables	15
fruit and horticultural	20
grass grazed	0
grass silage	22

Notes: Average response based on ADAS, 1977 and MAFF, 1984.
Extra costs include additional harvesting, handling, drying, and where relevant, direct packaging and marketing costs. Estimates based on Nix, 1992; Hinton and Housden, 1992; and Vaughan and Crane, 1991.

On grassland, in areas of irrigation need, the average response in dry matter (DM) yield is equivalent to an extra 25% of yield without irrigation (Garwood, 1979). This is equivalent to about 0.025 t DM/ha mm. Irrigation can also stabilise the growth of grass during the season and lengthen the grazing period. Research at the Grassland Research Institute showed that irrigation water could substitute for moderate applications of nitrogen, and that high levels of nitrogen could not be used by grassland in low rainfall areas without irrigation (Garwood, 1979). The irrigation of grassland is most beneficial for high performance dairy systems (Doyle and Elliot, 1983). However, the value of grass energy produced is limited to the equivalent cost of purchased feed. Thus grass is worth about £91/t DM (11,400 MJ/tDM x 80% utilisation factor x £.01/MJ). This is not very different from the value of cereals, which in turn are not very responsive to irrigation.

More recent data includes the results of MAFF/ADAS Experimental Husbandry Farms, especially Gleadthorpe, reported in Bailey (1990). Carr et al. (1991) analysed data from a number of sources on irrigation yield benefits in the UK. Drawing on these and other sources, Table 5.4 summarises the yield response to irrigation classified by high, medium and low crop response years. For the most part these were years of low, medium and high rainfall respectively (but the definition of the adequacy of rainfall varies between crops). Irrigation gives greatest yield response and related yield benefits in dry years.

Yield response to irrigation was also estimated using the Silsoe College Irrigation Water Requirements model. Actual seasonal weather records over a twenty-four year period were used to estimate the likely differences in yield between irrigated and non-irrigated crops for selected crops for a location of low mean rainfall and soils with moderate AWC. Table 5.5 shows the average annual yield response obtained and the average annual application rate. These yield benefits are also expressed in terms of value-added before irrigation costs. Potatoes, and field vegetables gave high average yields and benefits; those for sugar beet, peas, cereals and grass were limited. This ranking was confirmed by Vavarigos and Hinton (1990) who solicited the "considered opinions" of farmers regarding crop yield response.

5.3.2 Quality benefits

The benefits of quality assurance are substantial. They relate to the whole crop and not just to the increment in yield due to irrigation.

Quality premia are the differences in unit prices obtained by commodities which qualify for different quality classifications. These classifications may be defined by statute such as those set by MAFF and EEC for fruit and vegetables. They may be set independently by buyers and sellers in the market, such as quality criteria set by supermarket purchasers. Statutory classifications often refer to commodity size, shape and colour. Independent classifications are often more closely defined according to purchaser requirements (e.g. potato sugar content for crisping quality).

Contract farming, whereby growers undertake to produce and supply for a particular buyer, is becoming more common, especially for high cost, high value crops which target a particular market segment. Total quality assurance, including reliability of supply, is an important element of this process. Failure to meet consistently the quality criteria results in the rejection of commodities, the resultant dumping of low grade produce onto lower priced, residual and more volatile markets, and difficulties in negotiating future contracts.

There is evidence in some sectors that irrigation is a necessity for commercially sustainable production, and increasingly a pre-condition for the negotiation of contracts with major buyers (Morris, 1993). Where this applies, the benefit of irrigation is the increased added-value (extra gross margin less irrigation and other additional farm level costs such as labour and machinery) of the irrigated crop compared to some alternative rainfed crop such as winter wheat.

Table 5.4 Crop response to irrigation by type of season and related financial benefits

	Potential yields (t/ha)	Reductions in yield without irrigation (t/ha)			Average water applied by type of season (mm)			Value of average response (£/ha mm)		
		*High response years	Medium response years	Low response years	High response years	Medium response years	Low response years	High response years	Medium response years	Low response years
Maincrop potatoes	40.00	23.80	7.50	0.50	165	115	75	9.81	4.43	0.45
Early potatoes	25.00	9.00	3.50	1.00	100	60	45	9.56	6.20	2.36
Sugar beet	42.00	21.00	9.00	0.90	147	90	50	4.94	3.46	0.62
Winter wheat	7.30	1.50	0.70	0	40	30	20	3.38	2.10	0
Winter barley	6.00	1.50	0.70	0	40	30	20	3.27	2.04	0
Spring barley	5.00	1.50	0.70	0	40	30	20	3.27	2.04	0
Winter field beans	4.00	2.00	1.20	0.80	40	30	20	4.61	3.69	3.69
Spring field beans	3.70	0.93	0.74	0.37	40	30	20	2.13	2.27	1.70
Peas - dried	3.70	1.85	1.11	0.37	55	40	25	3.43	2.83	1.51
Peas - vining	4.80	2.40	1.44	0.48	55	40	25	5.29	4.37	2.33
Cabbage	25.00	25.00	12.50	2.50	120	90	60	26.56	17.71	5.31
Carrots	37.00	9.00	6.00	1.00	100	80	50	6.12	5.10	1.36
French beans	6.00	4.20	2.70	0.90	80	60	40	7.35	6.30	3.15
Runner beans	21.00	14.70	9.45	3.15	80	60	40	53.66	45.99	23.00
Brussel sprouts	12.50	6.00	3.00	1.00	80	60	40	13.80	9.20	4.60
Cauliflower	15.00	7.50	2.00	0.50	80	60	40	22.50	8.00	3.00
Lettuce	12.00	4.80	2.00	0.50	80	60	40	19.20	10.67	4.00
Onions	28.00	17.60	4.10	2.20	80	60	40	19.36	6.01	4.84
Grass-graze	6.00	3.00	2.00	0.50	80	55	40	3.42	3.32	1.14
Grass-silage	6.00	3.00	2.00	0.50	80	55	40	2.67	2.59	0.89
Strawberries	6.50	1.95	0.98	0.33	80	55	30	13.65	9.93	6.07
Raspberries	4.00	2.00	1.20	0.01	75	50	25	26.45	23.81	0.40
Blackcurrants	6.00	3.00	2.10	0.60	70	50	30	18.86	18.48	8.80
Dessert apples	11.00	5.50	2.75	1.10	100	80	60	15.40	9.63	5.13

Notes: *Closely correlated with dry, medium and wet summers.

Source: After Bailey, 1990.

Table 5.5 Average response and value added from irrigation due to yield increase alone (Silsoe College's Irrigation Water Requirements scheduling model)*

	Average potential yield t/ha	Yield without irrigation %	Irrigation water applied mm	Extra yield due to irrigation t/ha	Yield benefit £/ha	Yield benefit £/ha mm
Potatoes						
- maincrop	40	65	200	14.0	952	4.8
- early	25	86	38	3.5	372	9.8
Sugar beet	42	96	76	1.7	59	0.8
Carrots	37	84	95	5.9	401	4.2
Peas	3.7	91	68	0.3	32	0.5
Onions	28	58	115	11.8	1038	9.0
Grass	6	77	183	1.4	128	0.8
Runner beans	21	88	48	2.5	730	8.3

Notes: * 24 years weather data on medium AWC soils in dry area. Based on average yields assuming adequate water.

It is difficult to generalise quality premia. The importance of quality can be illustrated with the case of potatoes (Box 5.1).

Box 5.1 Quality Premia: the example of potatoes

About 6 M tonnes of potatoes are consumed in Britain each year, of which 5 M tonnes are produced domestically. The main market segments are raw potatoes (loose and pre-pack at 56% and 10% of total consumption respectively), and potato products (canned, crisping and frying products at 7%, 11% and 16% of total consumption respectively). Prices vary significantly within and between the various market segments, and through the season. Varietal and quality price differences are substantial and reflect the requirements of the various market segments. With respect to raw potatoes, average prices (in 1993 values) shortly after harvest typically range from £30/t or so for outgrades through £50/t for general ware, to between £90/t and £120/t for unblemished pre-pack quality. Most potatoes for the processed market are delivered under contracts which specify quantity and quality and achieve prices of about £60/t to £70/t.

Within these market sectors, prices range according to quality of sample, with buyers adjusting prices according to the likely percentage of outgrades. Samples with common scab may command £50/t or less compared to as much as £200/t for superior grade. As the marketing year proceeds, the premia for quality tend to increase, particularly as potatoes of poor initial quality do not store well. In years of general surplus, the discounting of poor quality potatoes can be substantial: large quantities were sold for £10/t in early 1993, some were given away free for cattle feed, others were left in the field.

Much irrigation of potatoes is motivated by quality assurance for tuber size, shape, colour, and condition. In very general terms the quality premium for supplying the next best market, or avoiding discount due to poor quality, appear to be at least £30/t. Thus on a 40 t/ha crop, irrigation to ensure a good quality product could generate an extra £1200/ha, equivalent to £9.6/ha mm at 125 mm of irrigation water applied.

The restructuring of the potato market involving greater liberalisation of production associated with the reform of the Potato Marketing Board, the further concentration of potato merchanting and processing into fewer hands, and possibly greater competition from the rest of Europe, will further emphasise the importance to growers of quality and supply assurance. This is likely to reinforce the importance of irrigation within an integrated production and marketing system.

Irrigation plays a similar role in the production and marketing of many field scale vegetables, orchard and horticultural crops. In many instances, as with potatoes, commercial production would be prejudiced by the absence of irrigation.

Table 5.6 indicates the average benefits per ha mm of irrigation water applied assuming quality premia of 10%, 20% and 30%. Irrigation is an important factor in the achievement of the 20% to 30% price differentials that often distinguish first and second quality horticultural produce. These benefits are substantial: they apply to the whole crop and are often greater than the benefits of extra yield.

Table 5.6 Crop quality benefits

	Potential yields (t/ha)	Average price (£/t)	Mean irrigation water applied (mm)	Benefit due to irrigation by quality price premium 10%	20% (£/ha mm)	30%
Maincrop potatoes	40	80	117	* 2.73	5.46	8.19
Early potatoes	25	125	68	4.62	9.24	13.86
Sugar beet	42	38	96	1.69	3.37	5.06
Winter wheat	7	93	30	2.29	4.57	6.86
Winter barley	6	90	30	1.82	3.64	5.45
Spring barley	5	90	30	1.52	3.03	4.55
Winter field beans	4	95	30	1.28	2.56	3.84
Spring field beans	4	95	30	1.18	2.37	3.55
Peas - dried	4	105	40	0.98	1.96	2.94
Peas - vining	5	125	40	1.52	3.03	4.55
Cabbage	25	150	89	4.21	8.42	12.63
Carrots	37	80	76	3.90	7.80	11.70
French beans	6	175	59	1.77	3.54	5.30
Runner beans	21	365	59	12.90	25.81	38.71
Brussel sprouts	13	230	59	4.84	9.68	14.52
Cauliflower	15	300	59	7.58	15.15	22.73
Lettuce	12	400	59	8.08	16.16	24.24
Onions	28	110	59	5.19	10.37	15.56
Grass-graze	6	91	58	0.95	1.90	2.84
Grass-silage	6	91	58	0.95	1.90	2.84
Strawberries	7	700	54	8.36	16.71	25.07
Raspberries	4	1240	50	10.02	20.04	30.06
Blackcurrants	6	550	50	6.67	13.33	20.00
Dessert apples	11	350	79	4.86	9.72	14.58

Notes: *e.g. 40 t/ha x £80/t x 10% premium divided by 117 mm/ha = £2.73/ha mm

5.4 Irrigation Feasibility

The financial feasibility of irrigation depends on how farmers perceive the relative benefits and costs of irrigation both in absolute terms and compared to other possible income generating opportunities.

Using estimates from Tables 5.1 and 5.3 above, Figure 5.1 compares the costs of irrigation with the benefits of yield response. From a new investment viewpoint, irrigation must deliver benefits of £4.0/ha mm in order to recover average total costs; £5.9/ha mm where PVC lined reservoirs are required. Once installed, however, irrigation is relatively cheap to use: operating costs at about £1.4/ha mm are about one third of total costs. Existing irrigators who do not recover the total average costs would, however, eventually find it difficult to replace worn out capital items. This conclusion is consistent with that of Vavarigos and Hinton (1990). Their study suggested that farmers were able to recover operating costs by a sufficient margin, but not in all cases would this have been sufficient to recover the full costs as estimated by the authors.

With respect to yield response, irrigation appears to be most financially attractive for soft fruit, horticultural and market garden produce, brassicas, onions and potatoes. It is marginally worthwhile for sugar beet and unattractive for cereals and other combinable crops and grass. Where surplus capacity exists, irrigation on low response crops such as cereals and grass could be justified for the reasons given above. This is often the case where the major investment has been justified against a crop such as potatoes. Most irrigation of cereals occurs where cereals are grown on light land in rotation with potatoes.

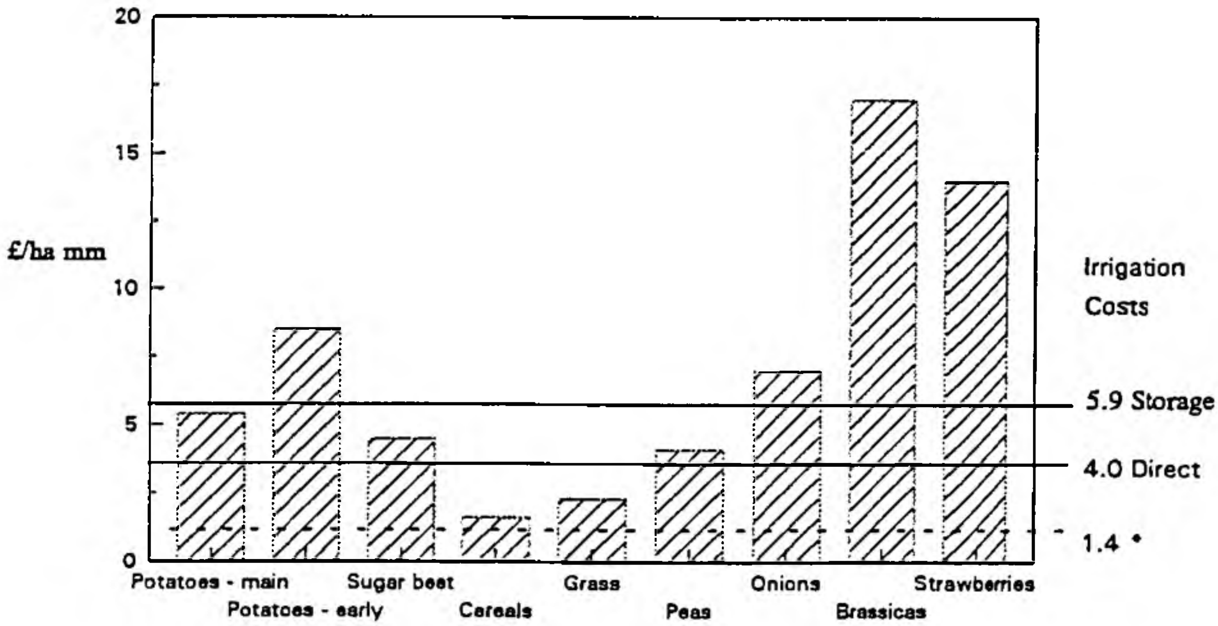


Figure 5.1 Comparison of benefits due to yield responses and irrigation costs

Notes: Benefits = Extra net margin due to yield response.
Costs = Average total costs for direct abstraction and water storage system (hosereel).
* Irrigation running costs; repairs, fuel, labour, water charges.

With respect to quality benefits, the same pattern emerges. Quality premia on soft fruit, horticultural produce, field vegetables and potatoes are often sufficient in themselves to recover full costs.

Investment in water storage or more expensive application systems reduces the feasibility of irrigation, especially for marginal crops such as sugar beet and carrots.

Table 5.7 examines the sensitivity of irrigation feasibility to changes in cost and benefit parameters. The table shows the plus or minus percentage change in a variable necessary to make irrigation break-even. For example, for a direct abstraction hosereel system on main crop potatoes, average costs are £3.98/ha mm and average benefits from yield increase alone are £5.44/ha mm (Table 5.3), giving a value-added after irrigation costs of £1.46/ha mm. The latter would be reduced to zero if either the unit price or the yield response of potatoes fell by 27%, or the costs of irrigation rose by 37%. The table also shows the percentage increase in price on the whole crop (not just the extra yield due to irrigation) necessary to recover irrigation costs, i.e. the required quality premium. A 6% improvement in potato prices due to better quality would pay for the costs of irrigation.

The sensitivity analysis confirms that the feasibility of irrigation is relatively stable for fruit, horticultural produce, field vegetables and potatoes in terms of changes in average prices, crop yield response and irrigation costs. These crops are also particularly responsive in terms of quality benefits. Relatively small percentage increases in quality-price premia are required to justify irrigation. In this respect, irrigation must be one part of total quality management. By comparison, cereals and grass require very large favourable changes in crop response, prices or costs to ensure feasibility.

The analysis of sensitivity for the more expensive water storage based systems follows a similar pattern. The achievement of a predictable, quality crop is the key to irrigation feasibility.

5.5 Future Prospects

Over the foreseeable future, the terms of trade for agriculture are likely to continue to deteriorate. Input costs are likely to inflate more than output prices. Market deregulation, trade liberalisation and reduced support for commodity prices will hasten this process.

The terms of trade for irrigation are likely to be similarly affected: rising costs and declining revenues. Crops which are presently marginal for irrigation are likely to become more so, especially where the need for water storage raises irrigation costs. The move to lower input:lower output systems encouraged by Set-Aside on crop land and quota on milk and livestock production will reinforce this position. For example, irrigation on grassland is, for the most part, feasible only in the context of intensive silage based systems, and there are likely to be limited incentives for further development of such systems.

For crops where quality assurance is critical, however, the role of irrigation is likely to become more important. This is the case for fruit, horticultural produce and field vegetables. Irrigation will be viewed as an integral part of a sophisticated production and marketing system.

Table 5.7 Sensitivity analysis of changes in benefit:cost parameters to breakeven for hosereel systems with and without storage

	Crop price (£/t)	Extra net margin (£/t)	Crop response (t/ha mm)	Percentage change in variable to breakeven: Direct abstraction hosereel system: Unit price or yield response (%)	Quality premium (% of base price)	System costs (%)	Winter storage hosereel system: Unit price or yield response (%)	Quality premium (% of base price)	System costs (%)
Maincrop potatoes	80.00	68.00	0.08	-27	6	37	8	9	-8
Early potatoes	125.00	106.25	0.08	-53	4	114	-31	6	44
Sugar beet	38.40	34.56	0.13	-11	12	13	31	17	-24
Winter wheat	93.00	90.21	0.02	145	4	-59	263	7	-72
Winter barley	90.00	87.30	0.02	153	5	-61	275	7	-73
Spring barley	90.00	87.30	0.02	153	5	-61	275	7	-73
Winter field beans	95.00	92.15	0.04	8	4	-7	60	6	-37
Spring field beans	95.00	92.15	0.04	8	4	-7	60	6	-37
Peas - dried	105.00	101.85	0.04	-2	4	2	45	6	-31
Peas - vining	125.00	121.25	0.04	-18	3	22	21	5	-18
Cabbage	150.00	127.50	0.14	-78	3	348	-67	5	203
Carrots	80.00	68.00	0.03	95	6	-49	189	9	-65
French beans	175.00	140.00	0.06	-53	3	111	-30	4	43
Runner beans	365.00	292.00	0.05	-73	1	267	-60	2	148
Brussel Sprouts	230.00	184.00	0.04	-46	2	85	-20	3	25
Cauliflower	300.00	240.00	0.07	-76	2	322	-65	2	185
Lettuce	400.00	320.00	0.03	-59	1	141	-39	2	63
Onions	110.00	88.00	0.08	-43	5	77	-16	7	20
Grass-graze	91.20	91.20	0.03	75	4	-43	158	6	-61
Grass-silage	91.20	71.14	0.03	124	6	-55	231	8	-70
Strawberries	700.00	560.00	0.03	-72	1	252	-58	1	138
Raspberries	1240.00	992.00	0.03	-84	0	523	-76	1	321
Blackcurrants	550.00	440.00	0.03	-70	1	232	-55	1	124
Dessert apples	350.00	280.00	0.02	-5	1	6	40	2	-29

Note: Irrigation costs £ per ha mm:	Direct abstraction	Winter storage
Average fixed costs	2.54	4.47
Average variable costs	1.44	1.42
Average total costs	3.98	5.89

5.6 Price and Crop Area Forecasts and Implications for Irrigation

Predictions of future prices for agricultural commodities and future crop areas were made using the Manchester University Agricultural Policy Model (Burton, 1992). This model, which simulates the structure and operation of the UK agriculture sector as a whole, was used to generate estimates of the direction and extent of change in selected agricultural output commodity prices, agricultural input prices, yields, and crop areas.

The model was run for alternative scenarios which describe possible future agricultural policy. The scenarios range from the extremes of protectionism and high levels of support to agriculture (such as that which prevailed before the recent MacSharry European Community (EC) Common Agricultural Policy (CAP) reforms) to complete trade liberalisation (as promoted by the General Agreement on Trade and tariff (GATT)). These policy scenarios are described in terms of likely changes (from the current base) in producer prices, yields and areas over the period to 2021. The implication of these changes for the irrigation sector and water demand is then considered.

It must be emphasised that the confidence of prediction reduces with time into the future. Reasonable confidence is held for the short term (to 1996). This is reduced significantly for the medium term (to 2001). Beyond 2001, any predictions can be no better than speculative. They are mainly extrapolations of trends, whereas in reality they are likely to be replaced by other scenarios not yet identified.

5.6.1 Scenario I: pre-reform status

This scenario describes that which prevailed in 1992 prior to the MacSharry CAP reform. Support prices are kept high by protectionist measures and intervention purchasing. With the exception of potatoes, sugar beet and milk, support is not restricted by quota. This scenario is likely to give the most favourable set of producer prices. However, following the trend of the last 20 years, this 'no change' scenario will not prevent the continuous decline in real commodity prices to farmers.

Table 5.8 presents the estimated future changes under the pre-reform scenario for producer prices, yields and areas. In the short (1996) and medium (2001) term, prices of commodities supported by intervention (e.g. cereals, milk, oilseed) change in line with the reductions in support. The prices of non-supported crops (mainly horticultural) mainly change in line with the reduction in real consumer expenditure on food. Incremental improvements in yields are based on the extrapolation of the past. The reduction in grass area is taken up mainly by an increase in arable crops. The total horticulture area declines, although with some expansion from a small base in soft fruit.

The predicted price changes for this scenario can be compared with those identified in the sensitivity analysis of irrigation benefit and cost parameters (Table 5.7). The price reductions (to year 2001) do not significantly change the feasibility of irrigation. The irrigation of sugar beet becomes less attractive with time under Scenario I.

Table 5.8 Estimated changes in producer prices, yields and area under the pre-reform status simulation (Scenario I)

Change in producer prices (1993=1)	1996	2001	2006	2011	2016	2021
Potatoes	0.931	0.965	0.994	1.019	1.036	1.045
Sugar beet	0.970	0.922	0.875	0.832	0.791	0.753
Apples	0.984	0.945	0.905	0.864	0.824	0.785
Stone fruit	0.990	0.963	0.935	0.908	0.881	0.853
Soft fruit	0.980	0.930	0.880	0.829	0.778	0.727
Root veg	1.072	1.089	1.067	1.038	1.005	0.968
Brassica	1.002	0.981	0.952	0.920	0.887	0.854
Protected veg.	0.868	0.844	0.849	0.841	0.820	0.790
Feed wheat	0.897	0.726	0.590	0.482	0.395	0.325
Feed barley	0.924	0.755	0.628	0.524	0.440	0.371
Oil seed rape	0.882	0.712	0.576	0.468	0.381	0.313
Salad crops	0.863	0.839	0.844	0.836	0.814	0.783
Milk	0.954	0.869	0.793	0.726	0.665	0.612

Change in yields (1993=1)	1996	2001	2006	2011	2016	2021
Early potatoes	1.032	1.086	1.139	1.193	1.247	1.300
Potatoes	1.044	1.118	1.192	1.266	1.339	1.413
Sugar beet	1.055	1.067	1.068	1.068	1.068	1.068
Wheat	1.067	1.179	1.292	1.404	1.516	1.628
Barley	1.054	1.144	1.234	1.324	1.414	1.504
Oil seed rape	1.067	1.179	1.291	1.402	1.514	1.626
Milk	1.024	1.075	1.135	1.206	1.287	1.380

Change in area (1993=1)	1996	2001	2006	2011	2016	2021
Early potatoes	0.984	0.957	0.934	0.912	0.894	0.876
Potatoes	0.960	0.882	0.816	0.755	0.703	0.656
Sugar beet	1.001	1.002	1.002	1.002	1.002	1.002
Orchard fruit	0.930	0.826	0.742	0.672	0.616	0.570
Soft fruit	1.288	1.458	1.510	1.532	1.533	1.520
Field veg.	0.928	0.877	0.853	0.836	0.824	0.817
Protected veg.	1.066	1.010	0.942	0.897	0.870	0.857
Grass	0.976	0.938	0.904	0.872	0.843	0.820
Wheat	1.093	1.237	1.380	1.520	1.657	1.776
Barley	1.111	1.268	1.373	1.456	1.522	1.561
Oil seed rape	0.927	0.840	0.818	0.802	0.782	0.750
Total hort.	0.952	0.912	0.891	0.874	0.863	0.855

5.6.2 Scenario II: complete liberalisation and free trade

Scenario II implies the implementation of the GATT proposals for trade in agricultural commodities: complete liberalisation and free trade. Commodity prices would move towards world market prices. World prices are likely in most cases to be higher under a liberalised trading regime than under one of protectionism which results in dumping on to a residual world market. In this scenario, farmers would still derive income support, but not tied to prices or production quotas. Prices to farmers are likely to fall somewhere between 1992 protectionist levels and current (1993) world market levels. Little is known about how farmers are likely to respond to world market prices in the event of the removal of production and trade constraints, and the consequent interaction between supply and prices.

Scenario II uses the results of other studies to estimate the initial fall and subsequent annual change in prices as a consequence of liberalisation. Estimating the production of sugar beet and potatoes after quota removal is particularly difficult. Sugar beet prices are based on predicted world levels. Potato prices are based on predicted domestic demand, assuming a target volume is produced similar to that under the present (1993) quota regime.

Table 5.9 contains the predicted changes in prices, yields and areas for Scenario II. Those commodities which have enjoyed government support show severe reductions in prices, notably cereals, oilseeds, sugar beet and milk. The impacts on horticultural prices are similar to those under Scenario I: real prices fall by about 5% to 15% depending on crop type over the period to 2001. The horticultural area remains constant compared to a decline in Scenario I.

For the most part, because Scenario II results in a greater percentage reduction in prices than Scenario I, the feasibility of irrigation for yield response is further compromised. A 40% reduction in sugar beet prices would render irrigation infeasible. Irrigation of potatoes for yield improvement would be marginal: irrigation for quality assurance would be the main justification. Horticultural produce would face greater competition from quality imports, although export opportunities may improve for specialist products. Horticultural prices appear strong relative to other sectors. This could reinforce the importance of irrigation for yield and quality assurance. Cereals would not be worth irrigating, except as part of root crop rotations on light land. Cheaper cereal-based animal feeds are likely to reduce the advantage of irrigation for grass production.

5.6.3 Scenario III: CAP reform

The third Scenario falls between the extremes of Scenarios I and II. This relates to the current policy regime introduced in 1992/93 which involves a reform of CAP and a move towards partial acceptance of GATT. The intention is to reduce support prices towards world market levels over the next three years and introduce base areas and reference numbers of animal as limits for support. These measures are apparent in the new Set-Aside Scheme which aims to reduce cereal prices by 30% and take 15% of the cropped area out of production over the next three years, and in the livestock quota system which limits support payments per head to a given herd size.

Producer prices are likely to continue to fall in real terms, reducing the absolute feasibility of irrigation especially for crops traditionally subject to Government support. Horticulture and field scale vegetables are less affected, and therefore become relatively attractive. In this respect, the case for irrigation for quality assurance is strengthened.

Table 5.10 contains the predicted changes in prices, yields and areas for Scenario III. These were produced by averaging the values in Tables 5.8 and 5.9. It is this third scenario that is expected, and used for the irrigation demand predictions.

Table 5.9 Estimated changes in producer prices, yields and area under the liberalisation simulation (Scenario II)

	Change in producer prices (1993=1)					
	1996	2001	2006	2011	2016	2021
Potatoes	0.898	0.802	0.810	0.811	0.805	0.792
Sugar beet	0.639	0.607	0.576	0.548	0.521	0.495
Apples	0.982	0.928	0.885	0.843	0.802	0.761
Stone fruit	0.988	0.951	0.922	0.892	0.864	0.836
Soft fruit	0.978	0.910	0.855	0.801	0.749	0.697
Root veg.	1.046	0.946	0.919	0.891	0.863	0.832
Brassica	0.996	0.940	0.910	0.880	0.849	0.816
Protected veg.	0.867	0.844	0.880	0.891	0.884	0.861
Feed wheat	0.558	0.450	0.364	0.294	0.239	0.196
Feed barley	0.614	0.465	0.381	0.310	0.254	0.209
Oil seed rape	0.679	0.588	0.510	0.443	0.387	0.339
Salad crops	0.863	0.839	0.876	0.888	0.879	0.856
Milk	0.863	0.766	0.683	0.607	0.540	0.479
	Change in yields (1993=1)					
	1996	2001	2006	2011	2016	2021
Early potatoes	1.032	1.086	1.139	1.193	1.247	1.300
Potatoes	1.044	1.118	1.192	1.266	1.339	1.413
Sugar beet	1.055	1.067	1.068	1.068	1.068	1.068
Wheat	1.067	1.179	1.292	1.404	1.516	1.628
Barley	1.054	1.144	1.234	1.324	1.414	1.504
Oil seed rape	1.067	1.179	1.291	1.402	1.514	1.626
Milk	0.994	1.046	1.106	1.176	1.254	1.342
	Change in area (1993=1)					
	1996	2001	2006	2011	2016	2021
Early potatoes	0.984	0.957	0.934	0.912	0.894	0.876
Potatoes	0.966	0.911	0.847	0.791	0.742	0.699
Sugar beet	1.001	1.002	1.002	1.002	1.002	1.002
Orchard fruit	0.930	0.826	0.742	0.672	0.616	0.570
Soft fruit	1.306	1.546	1.619	1.667	1.689	1.687
Field veg.	0.965	1.057	1.034	1.012	0.996	0.984
Protected veg.	1.068	1.010	0.901	0.832	0.789	0.763
Grass	0.973	0.952	0.926	0.898	0.869	0.850
Wheat	1.091	1.108	1.143	1.171	1.185	1.163
Barley	1.157	1.238	1.309	1.393	1.464	1.496
Oil seed rape	0.831	1.291	1.826	2.438	3.160	3.937
Total hort.	0.986	1.082	1.060	1.041	1.026	1.014

Table 5.10 Estimated changes in producer prices, yields and area under CAP reform (Scenario III)

Change in producer prices (1993=1)	1996	2001	2006	2011	2016	2021
Potatoes	0.915	0.884	0.902	0.915	0.920	0.919
Sugar beet	0.804	0.764	0.726	0.690	0.656	0.624
Apples	0.983	0.937	0.895	0.853	0.813	0.773
Stone fruit	0.989	0.957	0.929	0.900	0.872	0.845
Soft fruit	0.979	0.920	0.868	0.815	0.763	0.712
Root veg	1.059	1.018	0.993	0.965	0.934	0.900
Brassica	0.999	0.961	0.931	0.900	0.868	0.835
Protected veg.	0.867	0.844	0.865	0.866	0.852	0.826
Feed wheat	0.728	0.588	0.477	0.388	0.317	0.260
Feed barley	0.769	0.610	0.504	0.417	0.347	0.290
Oil seed rape	0.780	0.650	0.543	0.456	0.384	0.326
Salad crops	0.863	0.839	0.860	0.862	0.847	0.820
Milk	0.908	0.817	0.738	0.666	0.603	0.545

Change in yields (1993=1)	1996	2001	2006	2011	2016	2021
Early potatoes	1.032	1.086	1.139	1.193	1.247	1.300
Potatoes	1.044	1.118	1.192	1.266	1.339	1.413
Sugar beet	1.055	1.067	1.068	1.068	1.068	1.068
Wheat	1.067	1.179	1.292	1.404	1.516	1.628
Barley	1.054	1.144	1.234	1.324	1.414	1.504
Oil seed rape	1.067	1.179	1.291	1.402	1.514	1.626
Milk	1.009	1.061	1.120	1.191	1.270	1.361

Change in area (1993=1)	1996	2001	2006	2011	2016	2021
Early potatoes	0.984	0.957	0.934	0.912	0.894	0.876
Potatoes	0.963	0.897	0.832	0.773	0.722	0.677
Sugar beet	1.001	1.002	1.002	1.002	1.002	1.002
Orchard fruit	0.930	0.826	0.742	0.672	0.616	0.570
Soft fruit	1.297	1.502	1.565	1.600	1.611	1.604
Field veg.	0.947	0.967	0.944	0.924	0.910	0.900
Protected veg.	1.067	1.010	0.922	0.865	0.830	0.810
Grass	0.975	0.945	0.915	0.885	0.856	0.835
Wheat	1.092	1.173	1.262	1.346	1.421	1.469
Barley	1.134	1.253	1.341	1.425	1.493	1.529
Oil seed rape	0.879	1.065	1.322	1.620	1.971	2.343
Total hort.	0.969	0.997	0.975	0.958	0.944	0.934

5.6.4 General conclusions

The following conclusions are drawn from the preceding analysis:

- The average profitability of agricultural and horticultural production is likely to continue to fall in real terms: output prices will increase less than input prices.
- This process will be greater, the greater the degree of trade liberalisation and removal of support to agriculture.
- The absolute profitability of irrigation will be similarly affected: benefits will increase less than costs. Crops presently of marginal profitability to irrigate are likely to become unprofitable due to declining real prices.
- For some crops, however, especially potatoes, field scale vegetables and horticultural produce, prices are likely to remain relatively favourable. The relative advantage (compared to rainfed cropping) of irrigation of these crops is likely to increase, especially where there are opportunities for obtaining quality related price premia. Overall, there is likely to be some contraction in the areas of these crops (due to yield improvements and competition from imports), but within this sector some modest increase in the proportion irrigated together with an increase in the depths of water applied is predicted.

6. TECHNICAL AND OTHER FACTORS

This Chapter discusses possible changes in technical, management and agronomic factors which might influence the future demand for irrigation water.

6.1 Application Methods

6.1.1 Overhead moving systems

Most irrigation water in England and Wales is applied through hosereel irrigators, fitted with either a raingun or a boom. These machines are inaccurate and energy-inefficient. However they are also rugged, versatile, labour-efficient and fit in well to the typical highly mechanised UK farm. They are therefore expected to retain their dominant position for the short term at least. Similar machines are used for similar reasons in much of N Europe and N E USA.

From the water use point of view, the main problem with hosereel irrigators is non-uniformity of application, particularly when windy. While farmers under-irrigate, this leads to non-uniform cropping rather than waste of water, but it would lead to low water use efficiency if higher levels of irrigation adequacy were sought, e.g. on high-value crops. Research is underway (e.g. at Silsoe and Le Tholonet, France) to minimise wind distortion, but this is as likely to increase as decrease total water use.

Although conventional portable sprinkler systems are versatile, high labour costs in UK meant they were often used to apply infrequent large applications, resulting in poor water use efficiency. Their use has been declining steadily; many of the systems still recorded in MAFF data are now only used as back-up or for odd corners. Scope for further water savings is limited.

Mechanised laterals, mostly centre pivots, enjoyed growth during the early 1980s. These machines can apply small, frequent applications with high accuracy, and could potentially give improved water use efficiencies. Restrictions on siting and portability appear to have stifled this growth, at least temporarily.

Overall, it appears there may be a slow improvement in water use efficiency from overhead moving systems, but it may not necessarily lead to less water use.

Concern is often expressed over potential evaporation losses from overhead irrigation. Extrapolation from Keller (1990) suggests that such losses are below 2% under UK climatic conditions.

6.1.2 Trickle (drip) systems

Many claims are made about the benefits of trickle (drip) irrigation, including increased crop yield and increased water use efficiency. The crop water needs are unchanged, but evaporation losses from leaves and the soil surface are avoided.

Kay (1992) reports that despite its attractions trickle accounts for only 1% of irrigation in England and Wales and that it is confined to high value crops. He further predicts that no significant growth will occur unless trickle costs drop substantially and/or water availability is severely restricted. His findings still appear valid, although there is some suggestion that cheap trickle tape systems are becoming more financially attractive.

There has been some worry that trickle systems would be adopted as a way of circumventing spray irrigation licence requirements. This does not appear to be happening, but it is an unnecessary anomaly that could distort the market. It is recommended that the NRA seek an amendment to the Water Resources Act to include trickle irrigation alongside spray irrigation.

Like all permanent (solid-set) systems, trickle irrigation has high fixed costs and low variable costs. These systems are likely to be used to apply greater total application depths. Any growth in trickle irrigation at the expense of portable sprinklers or hosereels is therefore likely to lead to increased water use, albeit at higher water use efficiencies.

6.1.3 Solid set minisprinkler and minispray systems

For many orchard and horticultural crops, these systems have particular advantages. They are less water efficient than trickle, since they wet the soil surface, but are less likely to block and easier to manage. They already fall within the licensing regulations. The comments about permanent systems also apply to these systems.

6.2 Distribution and Storage

Almost all distribution systems in the UK use pressurised pipes. Unlike most European countries, there is no potential for water saving by reducing canal losses. No data on irrigation pipe leakage has been found, but it is probably small. Irrigation mains are generally newer than water supply mains and only pressurised for a small portion of the year.

Reductions in percolation and evaporation losses from reservoirs might be made by using more linings and surface covers. However, any savings would mostly be in winter abstracted water.

Any reduction in the real cost of water storage would encourage winter abstraction. Construction costs appear to have fallen during the recession, but this may not be sustainable. Increased safety and environmental constraints have increased some costs.

6.3 Scheduling

The use of scheduling has increased markedly, and this trend should continue. It is believed that about 70% of irrigation is on farms now using one or more of the technical methods of scheduling, though it is not necessarily being used for all the fields or even all the crops. Larger farms and those growing more valuable crops are likely to use more accurate scheduling. Further research and development of scheduling methods under UK conditions is required.

Better scheduling should increase water use efficiency, but paradoxically if it confirms farmers are under-irrigating, it may increase water use.

The calculation of potential theoretical demand demonstrated the effect of choice of schedule on irrigation demand. A schedule designed to maintain high soil water levels for maximum production will demand more water than one designed to conserve water. There is no single "correct" schedule. Water can be conserved by infrequent irrigations (thus keeping the surface dry), leaving a deficit (so that rainfall can be stored) and reducing irrigation during low response growth periods. However, quantity and quality of production may be compromised, and there can be greater losses if irrigation subsequently has to be stopped. Reliable supplies allow farmers to conserve water by taking greater risks with scheduling.

6.4 On-Farm Water Conservation

There are numerous possibilities for on-farm water conservation. For example bed systems in place of ridges, tied ridges to stop runoff and tillage changes to increase rooting depths, can all increase the effectiveness of summer rainfall. Tramlines systems might allow some crops to move (back) to heavier soils requiring less irrigation. Closer shallower pipe drains and higher open drain water levels would retain more winter rainfall for summer use. Water table control and subirrigation has attractions.

Much basic research has been carried out on these and similar techniques, but mostly for optimising production rather than water conservation. This research needs to be reviewed and where necessary revised. The economic case for adopting any such techniques will depend on the cost and availability of water.

6.5 New Varieties and Crops

Potentially there could be big reductions in irrigation demand if plant breeding or genetic engineering could produce drought tolerant crops, or simply crops that required less irrigation e.g. by rooting deeper or maturing earlier. Scab-resistant potatoes would require less irrigation early in the season. We are unaware of any major break-through in this area. It seems just as likely that new crops introduced for other attributes will be sensitive to water-stress and add to irrigation demand. This is an unknown in the longer term.

6.6 Summary

Changes in technical and other factors could have very significant effects on irrigation demand. Many changes are likely to occur for reasons other than water conservation; the changes in irrigation demand will be unplanned side-effects. Realistically, innovations take a long time to affect the majority of farmers, so only those changes already underway are important for short and even medium term predictions. These changes appear to suggest a trend towards greater seasonal application depths.

7. PROJECTIONS

7.1 Introduction

This Chapter aims to produce 'most likely', 'high' and 'low' irrigation demand forecasts. The forecasts are for a design 'dry' year like 1990, since the dry year is the one of most concern to the NRA.. For each crop category for each year to 2021, the total crop area, the fraction to be irrigated and the depth to be applied are predicted and used to calculate the (demanded) irrigated area and volume of water, nationally and then for each NRA Region. The predictions are based on the expected agricultural policy scenario (III). The national 'most likely' predictions under Scenarios I and II are also produced, for comparison only.

All values in this Chapter refer to demand. Actual values will be reduced by any restrictions on water availability.

7.2 Methodology

7.2.1 Agricultural policy scenarios

The forecasts are based on agricultural policy Scenario III (Section 5.6), using crop area and price projections midway between Scenario I (pre-reform status) and Scenario II (liberalisation and free trade). The national 'most likely' projections for Scenarios I and II are produced for comparison only.

7.2.2 Crop areas

Future crop areas are predicted by combining the 1992 MAFF cropping data with the estimated changes predicted by the Manchester model (Section 5.6). The partition between early and maincrop potatoes has been estimated from recent PMB and MAFF data.

7.2.3 Irrigated fraction of total crop areas

The fractions of the crop areas to be irrigated are based on the 1990 (dry year) irrigated fractions derived from MAFF data (Section 3.2) together with estimated change factors.

The initial annual percentage changes of the irrigated fractions assumed for 'most likely', 'high' and 'low' predictions under agricultural policy Scenario III are shown in Table 7.1. The values for the 'most likely' projections under Scenarios I and II are shown in Table 7.2. These values are based on a consideration of current levels and trends (Section 3.3), changes expected due to the price effects of the relevant agricultural policy Scenario (Section 5.6), changes expected due to technological and other factors (Chapter 6), expert opinions and the authors' views.

For declining fractions, a compound rate of decline has been assumed, i.e. at 5% per annum decline, each year 5% of the remaining irrigated fraction is lost. The fraction will thus approach zero asymptotically. For increasing fractions, the analysis first converts the initial percentage change to a percentage of the 1990 *unirrigated* fraction, uses this to calculate the compound rate of decline in the remaining unirrigated fraction each year, and then calculates the irrigated fraction for the year concerned. This ensures that increasing fractions approach 1 (i.e. 100%) asymptotically.

The values used for the 'most likely' predictions assume a continuing growth in the fraction of potatoes and vegetables to be irrigated, driven by the demand for quality. As sugar beet is mostly grown in rotation with these crops, the sugar beet fraction is also therefore likely to rise unless beet prices drop very substantially, as in Scenario II. The growth in the orchard fruit fraction mainly offsets a decline in the total area, leaving the same irrigated area. Small fruit is also likely to see a steady growth in irrigated fraction for quality and continuity assurance. The fractions of grass and cereals irrigated are predicted to decline substantially due to the forecast price reductions.

7.2.4 Average depths

The average depth predictions are based on the 1990 (dry year) average depths derived from MAFF data (Section 3.2) together with estimated change factors derived as above. An arbitrary 10% has been added to the 1990 figures to allow for drought restrictions in force at the time.

The initial annual percentage changes in the depths of water applied assumed for 'most likely', 'high' and 'low' estimates under agricultural policy Scenario III are shown in Table 7.1. The values for the 'most likely' projections under Scenarios I and II are shown in Table 7.2'. Modest changes only are assumed, with growth due to quality demands and moves towards permanent systems on fruit and some vegetables.

Compound rates of change down towards zero or up towards an upper asymptote are again assumed and calculated as for the irrigated area fractions. It is difficult to base the upper asymptote on a theoretical economic optimum because of variation in local conditions such as climate and soils. The upper limit is therefore set arbitrarily at twice the 1990 average depth for that crop. In fact, as the growth rates assumed are small, this limit is never approached and is not critical.

Table 7.1 Estimated initial percentage changes per annum in fraction of crop irrigated and depth of irrigation water applied for 'most likely' (ML), 'high' (H) and 'low' (L) predictions under Scenario III

	Initial % change per annum (see text)					
Scenario III	Fraction of crop irrigated			Depth of irrigation water applied		
Projection:	ML	H	L	ML	H	L
Early potatoes	+2	+4	0	+1	+2	0
Maincrop potatoes	+4	+6	+2	+1	+2	0
Sugar beet	+2	+3	0	0	+1	-1
Orchard fruit	+3	+4	+2	+2	+3	+1
Small fruit	+3	+4	+1	+2	+4	+1
Vegetables	+3	+5	+2	+2	+4	0
Grass	-4	-2	-8	0	0	-2
Cereals	-5	0	-7	0	0	-2
Other	+1	+2	0	+1	+2	0

Table 7.2 Estimated initial percentage changes per annum in fraction of crop irrigated and depth of irrigation water applied for 'most likely' (ML) projections under Scenarios I and II

	Initial % change per annum (see text)		
	Fraction of crop irrigated		Depth of irrigation water applied
Scenario:	I	II	I & II
Projection:	ML	ML	ML
Early potatoes	+3	+1	+1
Maincrop potatoes	+5	+3	+1
Sugar beet	+2	0	0
Orchard fruit	+3	+3	+2
Small fruit	+3	+3	+2
Vegetables	+4	+2	+2
Grass	-2	-5	0
Cereals	0	-8	0
Other	+1	+1	+1

7.3 Results

7.3.1 National predictions for expected Scenario III

Tables 7.3 and 7.4 summarize the predictions of irrigated areas and irrigated water volumes respectively over the period 1996 to 2021 for the 'most likely', 'high' and 'low' predictions for the expected agricultural policy Scenario III.

The most likely prediction is that irrigation areas in a dry year will rise from a level of 185 000 ha in 1996 to a medium term (year 2001) level of 191 000 ha (Table 7.3). Speculative projections into the long term suggest modest increases to 197 000 ha by year 2011 and 202 000 ha by year 2021. The variation either side of the 'most likely' estimate reflects the assumptions regarding rates of change in the irrigated grass and cereal areas.

For the 'most likely' prediction, the unconstrained demand for irrigation water volume in a dry year is predicted to rise from the 1996 estimated level of 178 000 Ml to 194 000 Ml by the year 2001, an increase of 9 % (Table 7.4). The most likely long term estimate for year 2021 is 237 000 Ml. The low and high estimates are about +/- 20% either side of the most likely prediction for year 2001, but this gap widens to about +/- 40% for year 2021.

7.3.2 National projections for Scenarios I and II

Tables 7.5 and 7.6 contain estimates of the projected irrigated areas and irrigation water volumes respectively for the 'most likely' projection under agricultural policy Scenario I (pre-reform) and Scenario II (post-liberalisation), for comparison only.

Scenario I could be regarded as the most favourable policy Scenario for British farmers, albeit one which is unlikely to recur. Scenario II is the least favourable Scenario with the virtual removal of price support to farmers.

Compared to the 'most likely' predictions for the expected Scenario (III), Scenario I would lead to an additional 11% in the area irrigated and 7% in volumes applied by year 2001, rising to an extra 25% and 12% respectively by year 2021.

Scenario II would lead to a reduction (relative to the 'most likely' predictions) of 9% and 6% in areas and volumes respectively by year 2001. By year 2021, the irrigated area would be about 5% less than the 'most likely' prediction, but the irrigation volume would be about 4% greater. These alternative Scenarios fall within the boundaries of the high and low estimates for the predicted Scenario.

Table 7.3 Predicted irrigated areas 1996-2021 for 'most likely' (ML), 'high' (H) and 'low' (L) projections under Scenario III

	Predicted irrigated area (ha)					
	1996	2001	2006	2011	2016	2021
SCENARIO III ML						
Potatoes early	9951	10377	10706	10956	11152	11290
Potatoes main	57566	60741	62136	62523	62329	61636
Sugar beet	34747	37791	40751	43656	46506	49304
Orchard fruit	3344	3341	3322	3300	3283	3272
Small fruit	4885	6309	7214	7992	8632	9137
Veg. for humans	29300	33499	36024	38431	40785	43179
Grass	12097	9564	7550	5953	4695	3735
Cereals	23299	19363	16120	13307	10869	8697
Others	9802	10256	10705	11149	11588	12022
Total	184992	191241	194528	197266	199839	202272
SCENARIO III H						
Potatoes early	10816	11622	12135	12440	12611	12677
Potatoes main	62364	67717	70149	70854	70544	69463
Sugar beet	36567	41053	45385	49597	53692	57673
Orchard fruit	3511	3607	3663	3697	3723	3748
Small fruit	5117	6768	7860	8799	9568	10171
Veg. for humans	32128	38509	42749	46613	50218	53713
Grass	13690	11998	10501	9179	8025	7077
Cereals	31695	34041	36625	39073	41247	42653
Others	10347	11239	12111	12964	13797	14611
Total	206237	226555	241179	253215	263425	271785
SCENARIO III L						
Potatoes early	8950	8950	8950	8950	8950	8950
Potatoes main	52444	56687	60666	64399	67901	71186
Sugar beet	31055	31055	31055	31055	31055	31055
Orchard fruit	3177	3455	3730	4002	4271	4536
Small fruit	4406	4607	4804	4998	5187	5372
Veg. for humans	27857	30240	32558	34812	37005	39138
Grass	9370	6176	4070	2683	1768	1165
Cereals	20507	14266	9925	6905	4803	3342
Others	9250	9250	9250	9250	9250	9250
Total	167017	164687	165009	167054	170191	173995

Note: Precision is spurious but kept to prevent anomalies.

Table 7.4 Predicted irrigation water volumes 1996-2021 for 'most likely' (ML), 'high' (H) and 'low' (L) projections under Scenario III

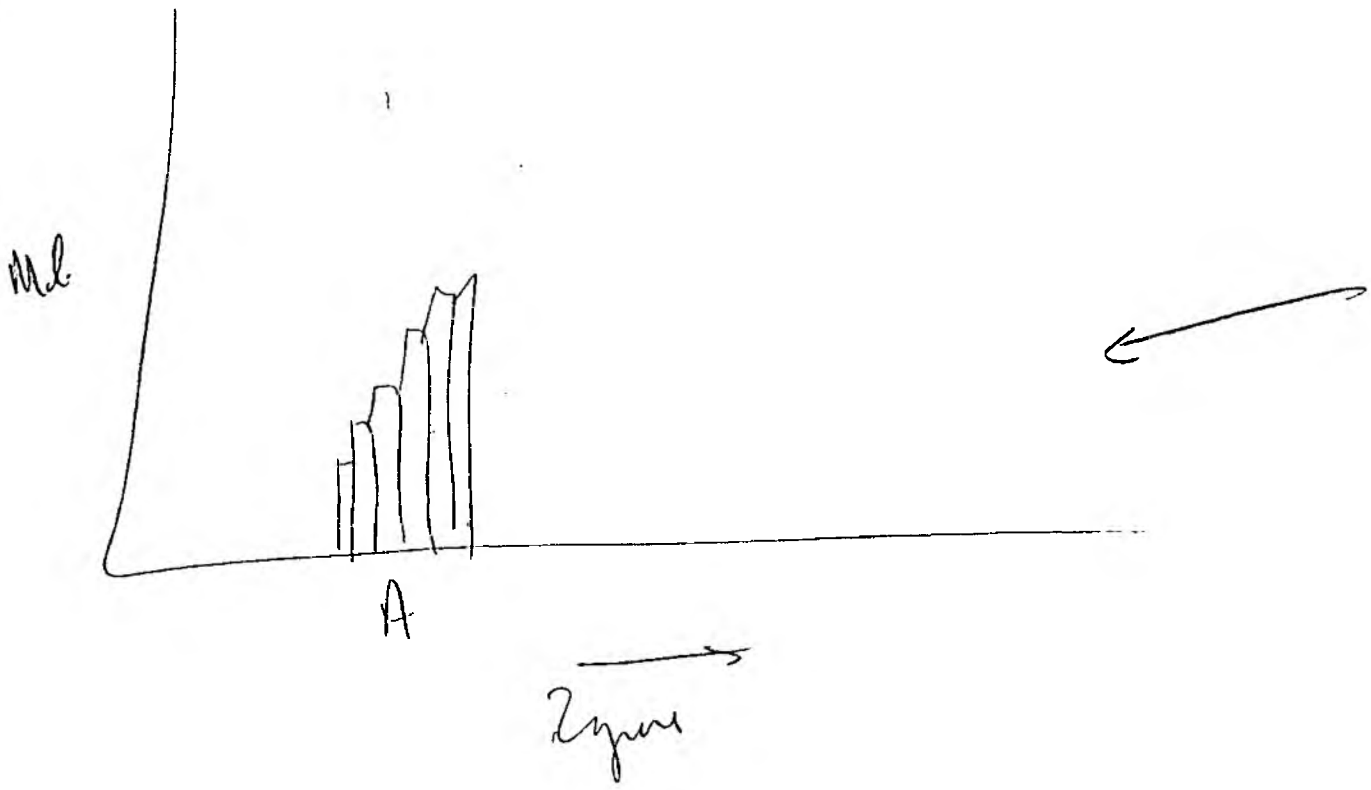
	Predicted irrigation water volumes (Ml)					
	1996	2001	2006	2011	2016	2021
SCENARIO III ML						
Potatoes early	9269	10087	10820	11475	12069	12594
Potatoes main	78148	86053	91526	95441	98317	100208
Sugar beet	27129	29505	31816	34084	36310	38494
Orchard fruit	3854	4144	4385	4593	4782	4959
Small fruit	5505	7653	9311	10878	12297	13542
Veg. for humans	25268	31095	35584	40030	44467	48976
Grass	10830	8562	6760	5330	4203	3343
Cereals	10646	8847	7365	6080	4966	3974
Others	7704	8412	9130	9854	10583	11316
Total	178351	194359	206696	217764	227995	237406
SCENARIO III H						
Potatoes early	10604	12265	13627	14730	15631	16346
Potatoes main	89112	104152	114814	122287	127439	130549
Sugar beet	30221	35407	40698	46091	51560	57082
Orchard fruit	4238	4793	5249	5630	5957	6244
Small fruit	6300	9321	11762	14022	16005	17671
Veg. for humans	30269	40589	48957	56848	64290	71419
Grass	12256	10742	9402	8218	7185	6336
Cereals	14482	15554	16734	17853	18846	19489
Others	8560	10009	11477	12954	14430	15899
Total	206042	242829	272720	298632	321344	341035
SCENARIO III L						
Potatoes early	7876	7876	7876	7876	7876	7876
Potatoes main	67259	72700	77803	82591	87082	91295
Sugar beet	22828	21709	20645	19633	18671	17756
Orchard fruit	3478	3947	4431	4927	5433	5948
Small fruit	4717	5147	5581	6016	6452	6888
Veg. for humans	21561	23406	25200	26945	28642	30293
Grass	7331	4184	2286	1163	517	159
Cereals	8300	5219	3282	2064	1298	816
Others	6868	6868	6868	6868	6868	6868
Total	150218	151056	153972	158083	162838	167898

Table 7.5 Projected irrigated areas 1996-2021 under Scenarios I and II

	Projected irrigated area (ha)					
	1996	2001	2006	2011	2016	2021
SCENARIO I ML						
Potatoes early	10400	11046	11499	11807	12015	12135
Potatoes main	59830	63317	65071	65411	64941	63852
Sugar beet	34747	37791	40751	43656	46506	49304
Orchard fruit	3344	3341	3322	3300	3283	3272
Small fruit	4852	6125	6964	7654	8216	8663
Veg. for humans	30127	32682	35689	38572	41349	44153
Grass	13712	11910	10371	9044	7900	6951
Cereals	31727	35908	40065	44136	48100	51548
Others	9802	10256	10705	11149	11588	12022
Total	198541	212375	224437	234729	243899	251899
SCENARIO II ML						
Potatoes early	9469	9868	10240	10586	10909	11209
Potatoes main	55207	61268	66774	71775	76317	80442
Sugar beet	31055	31055	31055	31055	31055	31055
Orchard fruit	3344	3758	4164	4564	4956	5341
Small fruit	4918	5487	6022	6525	6998	7442
Veg. for humans	28398	30827	33190	35489	37724	39899
Grass	11341	8776	6790	5254	4066	3146
Cereals	19199	12654	8340	5497	3623	2388
Others	9802	10256	10705	11149	11588	12022
Total	172734	173950	177282	181894	187235	192944

Table 7.6 Projected irrigation water volumes 1996-2021 under Scenarios I and II

	Projected irrigation water volumes (Ml)					
	1996	2001	2006	2011	2016	2021
SCENARIO I ML						
Potatoes early	9687	10737	11622	12366	13003	13536
Potatoes main	81221	89703	95849	99850	102438	103811
Sugar beet	27129	29505	31816	34084	36310	38494
Orchard fruit	3854	4144	4385	4593	4782	4959
Small fruit	5467	7429	8988	10417	11704	12839
Veg. for humans	25980	30336	35253	40177	45081	50080
Grass	12276	10662	9285	8097	7073	6223
Cereals	14496	16407	18306	20166	21978	23553
Others	7704	8412	9130	9854	10583	11316
Total	187815	207335	224633	239604	252953	264811
SCENARIO II ML						
Potatoes early	8819	9592	10349	11088	11806	12503
Potatoes main	74945	86800	98358	109565	120383	130784
Sugar beet	24246	24246	24246	24246	24246	24246
Orchard fruit	3854	4661	5497	6352	7220	8095
Small fruit	5542	6655	7773	8880	9969	11029
Veg. for humans	24489	28615	32785	36965	41129	45255
Grass	10154	7857	6079	4704	3640	2817
Cereals	8772	5782	3811	2511	1655	1091
Others	7704	8412	9130	9854	10583	11316
Total	168526	182621	198027	214166	230632	247136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7.3.3 Regional projections

The analysis has been repeated for each NRA Region, using the 1992 crop areas and 1990 fractions of crop irrigated and depths of water applied calculated (for each crop category in each Region) from MAFF data in Chapter 3. The same crop area change factors, fractions of area irrigated change factors, and depth of water applied change factors have been used for each Region as for the national projections (Table 7.1). The resulting regional volumetric demand predictions are given in Table 7.7. The water demand grows at different rates in different regions, reflecting the different crop mixes and different starting points. A small correction has been applied to the regional figures to avoid a rounding error when comparing with national totals.

Table 7.7 Predicted irrigation water volumes for each NRA Region, 1996-2021, for the 'most likely' (ML) projections under Scenario III

	Irrigation water volumes (Ml)						
	1990	1996	2001	2006	2011	2016	2021
Anglian	77015	89366	98262	105269	111591	117464	122916
North West	2577	2944	3264	3545	3821	4097	4371
Northumbrian	880	994	1055	1106	1153	1197	1238
Severn Trent	39324	45020	48000	50096	51783	53214	54410
South West	1711	1881	2022	2150	2284	2424	2567
Southern	9436	10401	12076	13382	14610	15758	16823
Thames	9712	9052	9429	9606	9769	9930	10089
Welsh	3867	4428	4931	5355	5762	6156	6532
Wessex	2880	2938	3065	3175	3299	3433	3572
Yorkshire	9568	11327	12253	13013	13693	14322	14889
Total	156969	178351	194359	206696	217764	227995	237406

One difficulty with these regional predictions is the discrepancy between the 1990 MAFF-based data and the NRA's own 1990 abstraction data (Chapter 3). Whilst this is in reasonable agreement at the national level, there are considerable differences at the regional level. Some of the differences in definitions, exclusions and year-end were discussed in Chapter 3, together with the possible sources of error in both sets of data. Some error may also have been introduced by the assumptions made when reaggregating the MAFF data into NRA Regions.

All the predictions presented, nationally and regionally, are based on the MAFF data. It is not possible to use the methodology with the NRA data, since the NRA does not record irrigated area and depths applied, nor distinguish between crops irrigated. However, an equivalent prediction using the NRA 1990 abstraction data for the baseline can be obtained by substituting these values for the 1990 MAFF data and adjusting all the predicted values by the same ratios. An allowance must again be made for drought restrictions in force in 1990.

Although national and regional predictions implicitly take into account the continuation of any existing movement of cropping between soil types, the regional figures presented do not take into account any movement of irrigated cropping between regions. It may be worth re-analysing the data to allow for this when additional data from the 1992 irrigation census becomes available.

7.4 Conclusion

The 'most likely' predictions for the expected agricultural policy Scenario suggest that there will be relatively minor increases nationally in the irrigated area over the medium and long term (0.7% increase per annum from 1996 to 2001, then 0.3% increase per annum from 2001 to 2021). Expansion of root crop and vegetable irrigation will be offset by a decline in the irrigated area of grass and cereals. Modest increases are predicted in the unconstrained demand for irrigation water: 1.7% per annum from 1996 to 2001; 1% per annum from 2001 to 2021.

These predictions are modest compared to those made in the 1970s and 1980s, reflecting the different circumstances and incentives facing the agricultural sector and irrigation sub-sector in the 1990s and beyond.

8. NRA RESPONSES

8.1 Introduction

This Chapter discusses whether and how the NRA should respond to the increased demand for irrigation water, and how it should liaise with government and the farming industry.

The demand for water in 1990 severely strained available resources. Some 140 000 Ml were applied, including 67 000 Ml from watercourses. Total on-farm storage capacity was only 39 000 Ml, and not all of that would have been used; probably 30 000-40 000 Ml came from direct summer abstraction from watercourses. A further 52 000 Ml came from groundwater sources, again mostly summer abstraction.

The mostly likely projection foresees an additional 50 000 Ml demand by 2001 and another 50 000 Ml by 2021. Much of this extra demand will be in areas already short of water. Clearly a period of conflict could be ahead if clear responses are not agreed now.

8.2 The National Interest

It has been questioned *whether* the NRA should respond to farmer demand for additional water, or even allow direct summer abstraction at all, given the environmental side-effects of abstraction and excess agricultural production. Although farmers demand more water, is it in the national interest to provide it?

The benefits of irrigation to farmers were discussed in Chapter 5. Benefits to the consumer include high quality produce and potentially lower prices from cost savings in production, storage and processing. There are also substantial import substitution benefits to the nation, supporting the balance of payments and UK employment. Specific data on these aspects however are not readily available.

Within a theoretical perfect market economy, prices and activities would adjust to produce an optimum allocation of scarce resources. The farmer demand would then be a good indication of the national interest.

The present water market however is far from perfect. On the farmer side, optimum cropping is distorted by subsidies, quota systems and other restrictions. On the NRA side, the cost recovery constraint on charges means it is impossible to adopt a long run marginal costing approach; environmental costs cannot be fully incorporated (even if they could be quantified) and abstraction charges are too low to have any significant incentive effect. The market itself is constrained by the inability to buy and sell water rights.

It is not the objective of this study to make recommendations on improving the market; however these points are relevant when considering whether the NRA should seek to meet farmer demand.

On the farm side, the distortions are not as great as might at first appear. Most of the major irrigated crops, and particularly the high quality produce irrigators are aiming for, are already outside price support systems. The quotas on potato production are due to be removed. Cereal and milk production is in excess of demand, but irrigation of cereals and grass is forecast to decline rapidly anyway. Sugar beet is the main exception. In as much as the EC support for sugar beet prices reflects a policy desire to grow sugar in Europe, then it is as valid to use water as any other resource; if the policy were simply to protect farm incomes, then this would not be a good use of any resource.

The volumetric water demand predictions under the free trade and liberalisation Scenario (II) are not greatly different from those for the expected agricultural policy Scenario (III). This suggests that the farm price distortions are not significantly infiating the total demand for water.

On the NRA side, it is recognised that charges are far too low to send the 'correct' economic signals to the market. However, the on-farm economic analysis confirmed that water charges were a relatively insignificant cost. Even substantial increases would have only marginal effect on demand (although they would reduce farm income).

The major missing factor in pricing is the cost of abstraction to the environment. This is extremely difficult to evaluate. However, winter abstraction and on-farm reservoir storage probably have net environmental benefits. Any argument should therefore be between direct abstraction and storage, rather than whether to supply water at all.

The on-farm economic analysis supports Rees et al. (1993) in stating that the value added by irrigation for some crops is considerable; irrigation is by no means always a low value use of water. By contrast, they argue, considerable water savings could be made by industry at low cost by recycling and use of other water efficient technologies.

From the above, we suggest that (increased) irrigation of most irrigated crops is both economic and in the national interest; the case nationally for irrigating sugar beet depends on agricultural policy objectives and is marginal for farmers; the irrigation of grass and cereals would be against the national interest but is declining anyway. Local factors may make even the latter sensible in particular areas.

We believe therefore it would be in the national interest for the NRA to seek to meet irrigation demand where possible, subject to adequate protection of the environment and full costs being charged to the beneficiaries.

8.3 NRA Options for Response

A number of specific possible NRA responses, as suggested by the NRA (a to d below) and others were discussed with the project Consultative Panel, farmers and other interested parties. Their comments and the authors' views are discussed below. Many water supply problems are site-specific and only general principles could be addressed; there will be local exceptions to every general guideline.

(a) *Licensing such summer water as may be available, with reference only to individual farmers' crop requirements.*

Summer water is the cheapest source, and it makes national economic sense to ensure that any remaining summer water is utilised, though probably on short-term licences where uncertainty exists. Environment constraints would have to be clearly assessed. It would be sensible to check applications against crop requirements, particularly if there is any prospect of tradeable permits. This is not as simple as it sounds, as cropping patterns change. It would be more equitable to offer remaining or new resources to all eligible farmers, perhaps allocating it by auction or ballot, rather than using the present first-come first-served basis.

(b) *As (a) but constrained by some overriding national food production objective (perhaps to be negotiated by MAFF).*

The prospect of the NRA prioritising crops on licences was almost universally disfavoured. It was thought impractical given the complexity of scheduling and prioritisation, other than for simplistic bans ("no irrigation of cereals") which could lead to non-optimal use of water. The overwhelming consensus was that the farmer is in the best position to decide on the best use of available water on his or her farm on a day-to-day basis. Transfer of water or water rights between farmers within catchments could facilitate the best use of available water within that area.

There is some agreement that Government may have a role nationally to control production of subsidised crops (e.g. similar to milk quotas and Set-Aside) but it is not clear that restricting irrigation is the optimum way to achieve this.

We recommend the NRA does not become involved in trying to decide the relative merits of irrigating different crops or applying different depths, beyond ensuring that licence applications are not excessive. Once water is allocated, each farmer should decide how best to use it.

(c) *Licensing winter water only (i.e. insisting on on-farm storage reservoirs).*

Licensing winter water only, if summer water was available without environmental or other restraints, would appear to have no merits other than as a public relations exercise.

It is certain, however, that winter water and on-farm storage will have to play an increasing role if extra demand is to be met. This is seen as potentially environmentally beneficial if reservoirs are well designed. From the farmer viewpoint, such water is reliable, i.e. not subject to restrictions, and hence allows more conservative scheduling. However, storage is expensive and on some sites not technically feasible.

There is widespread support for policies that would encourage on-farm storage but with the minimum of compulsion. There were some doubts about who should pay for any subsidies; water price incentives rather than grants are favoured to encourage on-farm storage. An increased differential between summer and winter abstraction charges was favoured.

We would support Rees et al. (1993) in recommending to the NRA that winter abstraction charges be dropped altogether, and we suggest that the metering requirements on winter abstraction might then be relaxed, giving further small but useful cost savings.

We also suggest that the NRA consider offering free advice to existing summer abstractors on the feasibility, cost and benefits of switching to winter storage.

(d) *Undertaking, in appropriate circumstances, NRA augmentation works to make summer water available.*

This option was less favoured unless economies-of-scale make it significantly cheaper than farmer owned or on-farm storage. Farmers would need very strong guarantees that the water would indeed be available in a drought; even so public pressure might make summer abstraction for irrigation controversial. The issue of who pays is a major concern, since all abstractors would gain reliability. Farmers generally are prepared to pay more for reliable supplies, but the level is likely to be a subject for controversy.

(e) *Other*

A number of other options were discussed, but most had limited applications. Promoting the conjunctive use of surface, groundwater and storage, where feasible, would reduce the risks of supply failure. Confined aquifers which recharge slowly might be reserved for drought years. Promoting technical and management improvement in irrigation would have some merit. The re-use of effluent would have potential public relations risks if not real health risks.

The question of water pricing policy and the possibility of tradeable permits is contentious, and has many implications for the irrigation industry. There are many potential merits in such a system, but some disquiet at the prospect of windfall profits for existing licence holders. The issues are much wider than can fairly be dealt with here, and we recommend this as a priority topic for discussion by the forum proposed below. The fact that tradeable permits have been discussed at all inevitably affects farmer behaviour and is probably partly responsible for the surge in licence applications.

8.4 NRA Liaison with Government and the Farming Industry

The NRA is required to manage water resources so as to meet the reasonable needs of abstractors while at the same time conserving the water environment and securing the proper use of the water resource. The main Government ministry involved, MAFF, is responsible for securing food production but is increasingly concerned with protection of the agricultural environment; indeed policy responsibility for Water Resources for Agriculture in MAFF has recently moved to the Environmental Protection Division. The farming industry has profitable production as its primary objective, but has strong longer term interests in sustainability and environmental conservation, if only to protect its own future. We suggest these objectives should be complementary rather than conflicting, and that co-operation will be more advantageous than confrontation for all parties.

Relationships between the NRA and the irrigated farming industry started badly as a result of conflict during the recent drought, but have improved greatly. Regular bilateral meetings between the NRA and organisations including the CLA, NFU, UKIA and groups of irrigators are held at national, regional and local level. The formation of catchment committees, and the preparation by the NRA of catchment plans, regional water resource plans and now a national water resource plan, are providing a more rational framework within which to negotiate.

It is strongly recommended that these bilateral meetings be combined into an advisory National Agricultural Water Resource Forum. This would include representatives of NRA, MAFF, CLA, NFU and UKIA. Catchment committees could be represented separately or through the UKIA.

The Forum would meet say twice a year for one or two days at most (remembering that many representatives would be volunteers), discussing general policy guidelines, any necessary revision to legislation, research requirements and future developments. Specific cases would be excluded except in as much as they affected general policy. It is suggested that some or all of the meetings would be held under rules of confidentiality. Recommendations produced would be purely advisory for all parties, but would form a strong basis for action.

Consultations with representatives of the organisations mentioned have produced very favourable responses to these ideas, and the proposal could be implemented rapidly. Additional cost implications are minimal, given that the forum would replace existing bilateral meetings.

A specific mention does need to be made regarding Wales. The Welsh Office and the NFU for Wales must be consulted and offered participation; given the relatively small amount of irrigation in Wales, they might prefer to delegate participation to others.

Our recommendation is specifically related to agricultural irrigation. However, when appropriate, relevant bodies on the Forum could also discuss non-irrigation agricultural water requirements. Similarly, representatives of other water using bodies, e.g. sports turf irrigators, and environmental interest groups, could be invited to relevant meetings.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The predictions for the growth in demand for water for agricultural irrigation in England and Wales are summarised in Table 9.1. It is emphasised that these are demands and actual usage will be reduced by any restrictions on water availability. No allowance is made in these figures for any long term climatic change.

Table 9.1 Projections of volumetric demand for irrigation water in England and Wales, 1996 - 2021

	Irrigation water volume (Ml)						
	(1990)	1996	2001	2006	2011	2016	2021
Expected agricultural policy Scenario (III):							
Most likely projection	*156969*	178351	194359	206696	217764	227995	237406
High projection	*156969*	206042	242829	272720	298632	321344	341035
Low projection	*156969*	150218	151056	153972	158083	162838	167898
Extreme Scenarios, most likely projections:							
Pre-1992 policies (I)	*156969*	187815	207335	224633	239604	252953	264811
Free trade (II)	*156969*	168526	182621	198027	214166	230632	247136

Notes: 1990 values (for comparison) are actual abstraction plus 10% to allow for restrictions then in force.

We believe it is in the national interest to meet these demands where possible, subject to adequate protection of the environment and full costs being charged to the beneficiaries. Recommendations on the NRA responses are given below.

9.2 Recommendations

The following recommendations are made for improving irrigation data:

- NRA should ask MAFF to consider rewording the Irrigation Census trigger question, to "did you irrigate/are you able to irrigate if necessary?".

Number

- NRA should ask MAFF to consider separating winter abstraction from summer abstraction in the volume by source question in the Irrigation Census.

- NRA should ask MAFF to continue producing irrigation census data at county level; this is no longer routine, and data for this study had to be specially processed and cleared. Alternatively data could be supplied already processed by MAFF into NRA regions.

- NRA should ask MAFF to consider recompiling irrigation census data on a catchment/aquifer basis. This would require asking the location of the main abstraction point(s) and using a geographical information system (GIS) to identify catchments and aquifer boundaries, but it is quite feasible. Catchment and aquifer based totals would be much more useful to the NRA.

- NRA should expedite the introduction of its National Abstraction and Licensing Database, and consider using a GIS based system to allow aggregation of data by catchment and aquifer.

- NRA should review whether daily and monthly abstraction data are required. Data on short-term variation can be better obtained using dataloggers or telemetry on a few larger systems, and applied statistically to other abstractors if necessary.

- NRA should continue to work towards more accurate metering; however over-zealous application of standards and over-frequent recalibration of meters should be avoided, as the costs can easily exceed any benefits.

- NRA should carry out a pilot study to estimate the accuracy of metering and establish a correction factor. If appropriate, the NRA should then consider helping establish an on-site recalibration service.

- NRA should consider making both licence and abstraction data available to interested parties. The volume abstracted by one abstractor from the national resource is a legitimate interest of other water users. The authors believe this move would also improve the quality of the abstraction data.

- NRA should seek amendments to the Water Resources Act to bring trickle irrigation and pumping for subirrigation within the licensing requirements.

The following recommendations are made for responding to the predicted growth in irrigation water demand:

- NRA should seek to meet increased irrigation demand where possible, subject to adequate protection of the environment and full costs being charged to the beneficiaries.

- NRA should *not* become involved in trying to decide the relative merits of irrigating different crops or applying different depths, beyond ensuring that licence applications are not excessive. Once water is allocated, each farmer should decide how best to use it.

- NRA should consider abolishing winter abstraction charges and relaxing the metering requirements on winter abstraction. Free advice could be offered to existing summer abstractors on the feasibility, cost and benefits of switching to winter storage.

To improve liaison between the NRA, Government and the farming industry, it is recommended that:

- The NRA should support the establishment of an advisory National Agricultural Water Resource Forum, including representatives of NRA, MAFF, CLA, NFU and UKIA.

The following recommendations are made for updating the irrigation demand forecasts:

- NRA should update the calculations of underlying growth rates when the 1992 MAFF Irrigation Census data become available.

- NRA should review this forecast and produce revised forecasts at regular intervals.

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APPENDIX A REVIEW OF PREVIOUS FORECASTS

→ Project Record.

CONTENTS

1. National Opinion Polls Market Research Ltd., 1979. Survey of demand for irrigation water. Anglian Water Authority

2. Roughton, J.L. and Clarke, K.F., 1978. Evidence for the Advisory Council for Agriculture and Horticulture in England and Wales on the future water needs of the agriculture and horticulture industries. Anglian Water Authority

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1. National Opinion Polls Market Research Ltd., 1979
Survey of demand for irrigation water. Anglian Water Authority

Following the 1976 drought and the subsequent increase in the number of applications for new spray irrigation licenses in the Anglian Region, the Anglian Water Authority (AWA) asked National Opinion Polls Ltd. (NOP) to conduct a survey, with the help of the National Farmers Union (NFU), to investigate the extent of spray irrigation within the area, assess changes in its use and establish the factors behind these changes. Questionnaires were sent to one in five NFU members, a total of 3,300 farmers, of whom 65% responded. These included irrigators and non-irrigators.

Irrigators (12% of all surveyed farmers in the AWA area) were asked, for each crop, the irrigated area, the depth of water they would normally apply in a dry summer, and the depth of water they would ideally like to apply if there were no restrictions. A range of 68 to 138 mm with restrictions and 80 to 198 mm if the water was available were suggested depending on the crop. The differences ("potential increase") ranged from 8 mm for cereals to 60 mm for orchards. Potatoes and sugar beet, with a potential increase of 38 mm, would have 30-40% more water applied were the farmers given a free hand. It was not made clear in the questionnaire which restrictions on irrigation were meant, and the authors pointed out that farmers may have construed 'freedom from restrictions' as the removal of technical barriers as well as the provision of unlimited water.

The number of irrigators, irrigated area, and volumes applied followed similar distribution patterns across the five river divisions. The implication was taken to be that the nature and implementation of irrigation across the five divisions was uniform, with only the extent varying from division to division. Why certain river divisions had low levels of irrigation was not addressed.

Irrigators were also asked about the situation five years previously (1972) and what they considered the situation would be in five years time (1982). Areas and volumes were examined for each river division. In addition, non-irrigating farmers were asked if they were likely to irrigate in five years time, to which 20% replied yes.

By grossing up survey results, estimates were made of irrigated areas in the Anglian Region for: a) five years previously (1972); b) current (1977); c) five years hence (1982); and d) current plus new irrigators in five years time. Estimates of applied volumes were made for the above and e) current plus new irrigators with no restrictions, in five years time.

Based on "statements of intent", irrigated areas were estimated to increase from 86 000 hectares in 1977 to 126 000 ha with current irrigators or 259 000 ha with current and potential irrigators in 1982. These irrigated areas represent 3.5%, 5.1% and 10.5% of total cropped area respectively. Volumes of water applied were estimated to increase from 87 000 Ml (1977) to 129 000 Ml with current irrigators, 248 000 Ml with current and potential irrigators (1982), or 333 000 Ml with current and potential irrigators at stated maximum irrigation depth required "if there were no restrictions". These substantial increases were thought an indication of the rapid growth in demand if not in consumption of water for irrigation, but the authors urged that this was seen in the context of the then widespread awareness of the economic benefits of irrigation, tempered by the concern over short-term problems of capital investment.

Irrigation of individual crops in terms of land area were shown to have remained and be likely to remain in the same relative order. Exceptions to the overall doubling of irrigated area from 1972 to 1982 were beans and cereals, which were predicted to treble in area irrigated (although this contradicted a general opinion that irrigation of cereals was impractical).

Looking at volumes applied, grass was found to be the most rapidly developing amongst then current irrigators (given no restrictions).

2. Roughton, J.L. and Clarke, K.F., 1978
Evidence for the Advisory Council for Agriculture and Horticulture in England and Wales on the future water needs of the agriculture and horticulture industries.
Anglian Water Authority

In this report, Roughton and Clarke presented their views on the future needs of irrigation water in the Anglian Region. Their forecasts were based in part on the NOP survey results, tempered by the consideration of factors suggested by NOP which might indicate an increase or decrease in demand, and taking account of policies adopted by the Government, the EEC, and the Authority itself.

Water used for irrigation in the 1976 drought year amounted to 33 000 Ml. They estimated that this could have totalled 42 000 Ml if it had not been for requests from the Authority to limit abstraction. The figure of 42 000 Ml represented approximately 80% of the licensed quantity and was selected as a datum on which to base forecasts.

The NOP survey had suggested a 280% increase over five years in the volume required for irrigation. Factors considered which might increase demand included increased mechanisation, increased investment and the demand for better quality produce. Those which might reduce demand included the cost of irrigation equipment, non-availability of capital, and the fact that licence applications after the 1976 drought, if all granted, would have represented a growth rate of only about 20% per annum.

Anglian Water Authority policy considerations included the fact that it was unlikely to promote irrigation use, likely to continue to promote conservation works as necessary to meet farmers demands, and likely to accept that there was a place for regional and farm water storage works, depending on local factors.

The Government White paper in 1975 "Food from our own resources" had stated its intention to encourage increased food production. The 1977 Agricultural Economic Development Committee report "Agriculture into the 1980s" had suggested a lack of water could be a constraint to any growth. Roughton and Clarke concluded that growth in irrigation could be directly related to whether or not the Government chose to encourage it.

With regard to EEC policy, the view stated was that the Authority should act as a supplier of raw material, not as a policy maker in this field. The authors recommended that the Authority continued to seek to meet agricultural demands as far as it appeared economic, whilst looking to Government for guidance on what was economic in the wider context of EEC and world economics.

Roughton and Clarke presented a forecast of irrigation demand as upper and lower bounds. The upper bound required an economic climate encouraging food production, dry summers, available water, Government encouraging irrigation, the positive factors as mentioned above, and the trend towards larger farms more intensively managed by better trained farmers to continue.

The highest growth rates envisaged by the NOP survey were still viewed as being unrealistic even if all the above were combined, due to its over-optimism. To produce the upper bound it was therefore assumed that:

- existing irrigators' expectations for growth would be fulfilled;
- potential irrigators' expectations would be half fulfilled;
- depth of water applied would be half-way between that which farmers apply at present and the maximum they would like to apply; and
- the growth thus indicated for the period to 1982 would continue to 2001 at the same rate.

The Lower bound required the opposite of the above to be the case, and it was assumed that:

- existing irrigators' expectations for growth would be half-fulfilled;
- potential irrigators' expectations would be quarter-fulfilled;
- depth of water applied would not increase; and
- the growth thus indicated for the period to 1982 would continue from 1983 to 2001 at half the rate.

The predicted demands for the Anglian Region, starting in 1976 at a base of 42 000 Ml, ranged from 56 000 to 133 000 Ml in 1983, 60 000 to 240 000 Ml in 1991 and 74 000 to 365 000 Ml in 2001.

3. Advisory Council for Agriculture and Horticulture in England and Wales, 1980 Water for Agriculture: Future needs

This inquiry was commissioned by MAFF in 1978 "in the light of the Government's intention to produce an overall strategy and policy for water, to consider and advise on the future needs of the agricultural and horticultural industries for water, and the measures necessary to promote its efficient use". Although asked to look at all the water requirements of the agricultural and horticultural industries, ACAH focused attention primarily on irrigation, seeing this as the field in which the greatest changes were likely to occur and where the most exacting pressures on supply would be.

ACAH forecast a 150% increase in area 'likely to be irrigated in a dry year', from 123 000 ha in 1977 (MAFF census data) to 309 000 ha in the year 2000. For individual crops, the increases in area ranged from zero (cereals) to 190% (maincrop potatoes). The figures were dependent on a number of assumptions and were regarded as an upper limit to irrigation demand. The report anticipated that this increase in irrigated area would be divided among the regions in the same proportions as was current.

Annual water demand estimates were based on the figure of 86 000 Ml in England and Wales. This figure was an estimate obtained by multiplying MAFF census returns of 'area likely to be irrigated', by 'the theoretical optimum quantity of water, applied to the entire area', given no restrictions on water availability. This was then scaled down by 50% to take account of farmers' under-application of water due to limitations on the mobility of equipment, shortage of labour and inadequate technical knowledge of the plant water requirements.

ACAH forecast an 80% and 300% increase in water demand by the years 1985 and 2000 respectively, giving demands of 157 000 and 350 000 Ml. These estimates were for the needs in the fifth driest year in twenty and assumed water would be applied at 65% of the theoretical optimum rate in 1985 and 80% in the year 2000. Total water demand in the year 2000 would be accounted for mostly by grassland demand (40%) and maincrop potatoes (22%). The projected increase in demand was thought likely to be proportionately more in the East and southern England, and to represent the upper limit of the range of likely outcomes.

Protected crop areas were expected to remain the same, using 12 000 Ml per year from the public supply. Daily peak consumption by spray irrigators was estimated to rise from 4100 Ml in 1977 to 5800 Ml in 1985 and to 10 000 Ml in 2000. These figures were derived from estimated areas of crops requiring June irrigation and the peak daily transpiration rate of each.

The assumptions made by ACAH in preparing these forecasts included:

1. By the year 2000 there would be a modest increase in the total volume of food moving into human consumption in the UK.

2. The efficiency of irrigation would continue to improve.

3. There would be an expansion of domestic agricultural production.

4. Profitability and demand for individual commodities in relation to each other would not change substantially.

5. The cost of water applied would continue to represent broadly the same proportion of total irrigation costs;

6. No fundamental technology changes would occur affecting the demand for water.

7. There would be an increasing awareness on the part of the farmer of the benefits of irrigation.

8. There would be no major climatic changes.

9. Water would be available.

In addition, it was expected that:

10. There would be a continued trend of concentration of crops into areas best suited for their production.

11. There would be fewer workers on the land, but that these would be more highly skilled.

12. Fuel costs would double by the year 2000.

13. The squeeze on margins would continue, and the majority of farmers would respond by intensifying production.

14. Market requirements would exercise a growing influence over methods of agricultural production - pressure would come from all parts of the marketing structure and affect a much wider range of produce.

The heavy demands on capital investment and the year to year uncertainties about the profitability of irrigation caused ACAH to question whether they were over-optimistic in their estimates of the extent of irrigation expansion in the year 2000, despite the benefits they foresaw. They decided it was in the national interest that irrigation should expand.

Supply constraints were seen to present the biggest obstacles to the desirable expansion of water use in agriculture, mostly in drier and highly productive parts of eastern, central and southern England. The Council examined the licensing system, charging policies, and storage as areas which could be influenced to improve supplies, and recommended:

1. Licenses to be more closely related to needs, fewer barriers put in the way of newcomers seeking licences to abstract, and a greater incentive given for those not fully utilising their licences to reduce the quantities specified therein.
This could be achieved by a) farmers co-operating voluntarily to stagger direct abstractions; b) transfer of licences encouraged where available water supplies have been fully allocated, with farmers permitted to buy and sell amongst themselves; c) failing this, the Authorities should be allowed to re-allocate licensed quantities with compensation.

2. Charges altered to a) encourage winter abstractions into storage reservoirs, with winter water costs only matching administrative costs; b) prevent the loss of summer flush water by charging abstraction of this at winter rates.

3. Storage to be encouraged on a farm co-operative basis to reduce waste of good land and water by a) MAFF continuing to grant aid for on-farm storage schemes; b) farmer co-operative storage schemes continuing to be eligible for MAFF grant aid; c) Water Authorities responding to farmer needs and providing storage facilities or river regulation schemes for the primary benefit of agriculture, perhaps obtaining capital contribution from the beneficiaries.

The ACAH forecast was later questioned on three counts:

1. It was based on 1977 MAFF irrigation survey data (i.e. area 'likely to be irrigated in a dry year') which were probably inflated by the effect of the 1976 drought on farmers' attitudes.

2. The ACAH figure of water used in 1977 (86 000 Ml) was over twice that of the Water Data Unit's figure (42 000 Ml) based on returns of actual use. All three components in the calculation of this figure (area irrigated, uniform application to the entire area, 50% application rate) were considered to be over-optimistic. Lack of reliable information about the actual take-up of water by the industry was noted as being an obstacle to the study.

3. It was thought unlikely that water application rates would increase from 50% to 80% of theoretical need.

4. Cowton M.I., 1981
A Technique for the assessment of irrigation need: a case study for potatoes
MSc Thesis, Silsoe College, Cranfield Institute of Technology

Using a number of sources of data on soil water capacities, crop responses to irrigation, and weather, a technique was developed in this study to make a comprehensive assessment of irrigation need.

Soil survey information and experimental results from maincrop potatoes were used to determine limiting deficits on different soil classes in Kent. Weekly assessments of the potential soil moisture deficit for three regions in this County (represented by three meteorological stations) were calculated from potential transpiration and rainfall data for the period 1961 to 1980. By comparing the potential soil moisture deficits with the specified limiting deficits, estimates of the potential irrigation need of each soil class (A to D) for the growth of main crop potatoes were derived for each year. A probability analysis was carried out to obtain the net amount of water required to meet irrigation need for 12, 15 and 18 years of 20.

Water needs varied from 124 to 315 mm, more droughty soils showing a greater irrigation requirement. Within a soil class, the greater the number of years out of 20 for which irrigation needs were required to be met, the greater the water need. Between the three regions, irrigation need varied considerably, the variation being mostly consistent across soils types.

Consideration of the area of each of those soils which would support potatoes within each Region enabled the estimation of total volumes required. These were 236, 306 and 441 million cubic meters for 12, 15 and 18 years out of 20 respectively, each reduced by two thirds if a three year rotation is corrected for.

5. Anglian Water Authority, 1982
Forecasts of demand for direct water use and for in-river needs

In this report, Anglian Water considered the demands for spray irrigation amongst those of sub-irrigation, 'other' agriculture, the Central Electricity Generating Board, and 'other' industry.

The datum for the forecast of future demand was the 'unrestricted' 1976 spray irrigation demand of 42 000 Ml (i.e. 80% of the licensed quantity, which Roughton and Clarke (1978) had considered would have been used in the dry year 1976 if the Authority had not asked for abstractions to be limited).

The NOP survey results were used as a base of this forecast. NOP had predicted a potential four-fold increase in volume required in a dry year, for 1977 to 1982. These results were judged to be optimistic and not to represent realistic forecasts. Guided by the survey data and likely influencing factors on future irrigation demands, a subjective judgement of potential rate of increase of demand was made.

Taken into consideration were:

1. 'Upper' and 'lower' bounds as described by Roughton and Clarke (1978), applied to NOP growth rates;

2. subsequent advice from ADAS that total irrigated area would increase 3-fold to 300 000 ha by 2001, but incorporating an assumption that home food production would not increase;

3. that the cost of water for irrigation would rise above the current 5% of irrigators' total costs, possibly affecting demand;

4. that energy costs (10-20% of irrigators' total costs) could become increasingly important.

'Low', 'medium' and 'high' forecasts of irrigation demand, between 1976 and 2001, developed from Roughton and Clarke upper and lower bounds, were therefore adopted as being 2-fold (half the 'lower' bound rate), 3-fold (the 'lower' bound), and 4.5-fold (quarter way between 'upper' and 'lower' bounds) respectively. These compare with ACAH forecasts of 4-fold between 1980 and 2000.

The growth rate was thought unlikely to be the same for each River Division; the NOP survey showed current demand suppressed in some areas. Divisional forecasts were therefore taken to be the mean of i) the calculation as above and ii) figures proportional to agricultural area (by 2001).

'Most likely ' annual irrigation demands for the Anglian Region were predicted to be 81 000, 95 000 and 120 000 Ml for 1986, 1991 and 2001 respectively. High and low demands for 1991 were 130 000 and 68 000 Ml, and for 2001 were 180 000 and 81 000 Ml.

6. Anglian Water Authority, 1988
Forecasts of demand for direct water use and for in-river needs, Operations Directorate (Draft)

The format of this operations directorate followed that of the Anglian Water 1982 forecasts where spray irrigation was considered amongst other direct water uses.

The dry year demand continued to be considered the most relevant for planning purposes, and this was once more taken to be 80% of the licensed quantity. 80% of the 1986 (most recent) licensed quantity was used as the datum for forecasts in this report and amounted to 91 000 Ml. (In fact, abstracted volumes were only 60% and 30% of the licensed quantities in 1976 and 1986 respectively).

It was noted that despite the ACAH Committee recommending that forecasts be improved and regularly updated by some 'Central Agency', they remain subjective based on: 1. the ACAH forecast of four-fold increase between 1980 and 2000; 2. the Water Industries response of 2-3 fold rate of increase; 3. incentives to irrigate such as financial, reduced labour requirements with improved equipment, increasing scientific farm management, increasing investment, better quality produce and easier harvesting, and economic pressures to concentrate vegetable farming in light soils of East Anglia; 4. disincentives to irrigate such as: restrictions on capital and labour, better investment opportunities (possibly), possible lack of knowledge and expertise, and pressures to reduce over-production.

The actual growth in spray irrigation demand to 1986 had been marginally above the 'most likely' prediction in the Anglian Water 1982 forecast (91 000 Ml against 81 000 Ml). No reason was seen to change these forecasts appreciably.

'Most likely' spray irrigation demand was estimated for each of the five divisions based on the 1986 demand, for 1991, 2001 and 2011. Divisional figures were adjusted as in the previous forecast (Anglian Water, 1982) to allow for differences in current irrigation practices. Figures thus produced were found to be implausible for Lincoln and Oundle divisions because of current irrigation demand per unit area being low in these cases, thus these figures were reduced by 20% and 50% respectively.

Forecasts of spray irrigation demands in the Anglian Region were 107 000 Ml for 1991, 143 000 Ml for 2001, and 178 000 Ml for 2011.

7. **Dutta S.C.H., 1989**
Irrigation demand forecasting: a methodology and case studies in Eastern England
PhD Thesis, Silsoe College, Cranfield Institute of Technology

Dutta developed a methodology for forecasting irrigation water demand on a farm or within a more extensive study area. The Irrigation Water Demand (IWD) model developed combined two existing models: Irrigation Management Services (IMS) model for estimating crop water requirements, and a linear programming package LPFARM for optimising water use. The IWD model was applied to eight selected case study farms and a study area of 13800 ha in the River Ivel catchment in eastern England.

Soil, crop and weather data were collated, and weekly and seasonal irrigation water requirements were derived. These estimates of water requirements were then entered into LPFARM together with other farm and study area data, and the economically optimum amount of water to be applied was determined.

In the study area it was found that over the period 1980 to 1988, the declared farm water abstractions ranged from 4% to 50% of the licensed quantity of water. Most of the eight farms studied in detail were operating either with no water meter of with a non-functioning one. Water abstractions as declared by the farmers to the Water Authority were in most cases guessed or estimated.

Lack of scientific water management methods and the non-availability of soil moisture instruments made it difficult for farmers to follow a well designed irrigation schedule. Most of the crop fields studied in 1987 and 1988 were apparently under-irrigated, with the average water application over 63 crop fields (comprising 18 different crops) found to be 64% of the theoretical demand. Approximately 25% of crop fields were left unirrigated despite water need. Over-irrigation was found in a few cases, particularly on highly responsive or high-value crops.

It was found that most farms required more water in addition to the licensed amount in order to meet theoretical needs of the crops grown. Likewise, the study area needed a 50% addition to the existing licensed amount of water to meet future crop water demands. Low summer flows in the River Ivel would not support the expansion of direct surface water abstraction.

8. **Ejikeme E.M., 1989**
Spray irrigation requirements in Severn Basin
MSc Thesis, University of Birmingham

Most licences for abstractions granted in the Severn Trent Region since the 1963 Water Resources Act and under Section 57 of the 1991 Act include conditions which restrict abstractions when the river flow falls below a prescribed level at a key gauging station. Severn Trent operates a phased system of thresholds, each of increasing severity: early licences are restricted at the primary level, with more recent licences restricted at the secondary or tertiary levels However, spray irrigation water abstractions are putting increasing pressure on summer flows in the tributaries of the River Severn in the Severn Basin and the primary objective of this project was to determine the current and likely future impact of spray irrigation demand on these river flows.

An assessment of spray irrigation trends in the River Perry sub-catchment revealed that due largely to the adoption of a system whereby many new licences granted are tied to existing ones, both the number of holdings and the licence entitlement were fairly constant between 1977 and 1988, with fluctuations in abstractions mostly reflecting rainfall patterns. Licensed quantities were found to excessively outweigh needs. Only 47.8% of licensed quantity was used in the drought year 1976, and it was considered unlikely that abstractions would exceed 60% of the licensed quantity even in the absence of restrictions. The author suggested that licence entitlements ought to be closer to spray irrigation needs.

Ejikeme also calculated theoretical irrigation water requirements in mm using the water balance sheet approach. Calculated needs were adjusted in line with the existing irrigation practice in the study catchment to obtain estimates of needs for the fifth driest and driest years in twenty (1981 and 1976 respectively). For main crop potatoes these values were 96 and 120 mm (including a field application loss of 35% to account for inefficient irrigation application during the period of scab control). Total requirements for the 20 years from 1990 to 2010 were calculated making assumptions on the number of years irrigation would occur and the irrigation amount. These ranged from 75 mm for winter wheat to 1680 mm for potatoes, totalled over 20 years.

It was suggested that an increasing scientific approach to irrigation scheduling had led to a greater unanimity between spray irrigators, and that this might be the cause of marked short term fluctuations in river flows. To test this, eight irrigators in one sub-catchment were equipped with data loggers to measure actual spraying rates. Correlations in patterns of fluctuations between the daily changes in abstractions and river flows were seen in all three sub-catchments, but this study was considered inadequate to firmly establish a causal relationship between irrigation and river flow. It was recommended that abstractions should be more adequately monitored via a network of gauging stations.

9. Anglian Region NRA, 1990
Forecasts of abstraction demands for water; public water supply and direct abstraction

The forecasts for agricultural spray irrigation presented in this document had been extended and revised from the latest available base data of 1986. The previously used ratio of 80% 'potential gross abstraction' to licence quantity was reduced to 60% to allow for crop rotation. It was felt that allowance was also required for 'excess licensed quantities' which were becoming evident.

Assumptions made included: no overall regional increase in root crop production; a two-fold increase in demand for the Northern area over the period 1986 to 2011 (50% increase elsewhere) to allow for a high latent demand; and, no major move to develop resources specifically for spray irrigation but demands to be met increasingly from storage of winter flows.

This approach resulted in demand forecasts lower than previous ones which were largely based on unlimited growth in agricultural production. The spray irrigation demands were, for the Anglian Region, 78 000 Ml for 1991, 89 000 Ml for 1996, 100 000 Ml for 2001, and 108 000 Ml for 2011.

10. University of Newcastle upon Tyne, 1990
Water resources and demands in the Middle Level. Anglian Region NRA

A fear of a large latent demand for spray irrigation water in this area of severe seasonal water shortages led to the commission of this study to appraise demands and resources. The objectives were to (1) develop integrating models of water resources (simulating supply availability), agro-hydrology (simulating the atmosphere-crop, soil-water and surface-water subsystems), and agro-economics (projecting future cropping patterns and irrigation use for representative farm models based on key farm management criteria); and (2) improve the understanding of the factors driving demand for irrigation water within the Middle Level and the availability and reliability of all relevant water resources.

A survey of 22 irrigating farmers in the study areas revealed the following points:

1. the potato crop is very important and the area is constrained by rotational reasons rather than quotas, which are often purchased to achieve rotational requirements. Farmers were moving from a 5/6 year rotation to 6/7 year to overcome problems with nematodes on root crops.

2. Few farmers saw much immediate future in novel or different crops. Vegetables other than carrots, onions and peas were seen as too specialised and too high a financial risk. Labour intensive crops were seen as a problem also because of the difficulty in attracting workers to the area.

3. Growth areas were the letting of land to carrot growers, and the renting of land and associated quota for potatoes. Where a licence exists there is a market in irrigation water in both the carrot and potato situations. The owner of both land and licence provides water, labour and machinery and charges a rate per ha/mm on average of £1.50 to £1.80, although one farmer charged £2.40 and another £4.80 per ha/mm for the first 25 mm application and then £0.60 per ha mm for subsequent ones.

4. Set-Aside had not been seriously considered by anyone, although about 50% were registered for it.

5. Most farmers had invested in licences and machinery primarily for use on potatoes with a few also considering carrots and onions. Some had experimented with sugar beet and cereals with no perceived success. One farmer had a licence but no machinery, planning to hire in irrigation plant if necessary.

6. General dissatisfaction with the ADAS irrigation recommendations was expressed. Some had based their investment decisions on them but now considered that they were more appropriate to more droughty soils. Farmers without licences of right (the majority) expressed concern over cessation limits and once SWD for the start of irrigation had been reached, they put on as much water as possible (usually 25 mm) for fear of not being able to irrigate later in the season. In more recent irrigation seasons (1987 and '88) with their high summer rainfall, several farmers reported that potato crops had yielded poorly due to rainfall immediately following irrigation. This problem could be reduced by using lower application rates (e.g. 12 mm), but this may need investment in equipment with greater accuracy of application and capable of applying smaller quantities (e.g. boom-type rather than rainguns).

7. Despite saying that potatoes would remain the only irrigated crop in the future, few growers had any precise idea of the benefits accruing other than that it improved quality by controlling common scab and gave a more even sized sample, especially where they were aiming for the pre-packed market. When asked to put a value on this, most said about

£10/tonne at present. Perceived yield increases with irrigation in 'normal' years were none or 5 to 7.5 t/ha (split half and half), with two thinking it was 12.5 to 17.5 t/ha. Just one farmer had compared irrigated to non irrigated crops and arrived at a yield increase of 7.5 t/ha.

Results of combined simulations of resource availability, land use, and national and on-farm economics, revealed a largely stable system where further investment in irrigation equipment was not particularly worthwhile and a significant latent demand for irrigation was thought unlikely.

Conclusions, as policy implications, drawn from the study were as follows:

1. The present level of demand for spray irrigation (mainly for potatoes) was thought likely to continue, but not expected to increase greatly. Renewal of existing temporary licences was recommended.

2. Intensity of use was found to be constrained by several factors such that the existing licensed volume was unlikely to be utilised. Increasing licences by as much as 100% in the Middle level was thought not to have any serious effect on the system performance.

3. Demand for spray irrigation represented only 10% of total resource transfers into the Middle Level, and it was suggested that other demands merited more serious consideration.

11. Halcrow, Sir William and Partners, 1992
Water resources development strategy. NRA, South West Region

Water demand for spray irrigation was one of several abstraction types reviewed in this report. In considering the resource implications of existing spray irrigation demands, it was noted that the distribution of spray irrigation licenses in the South West Region are very localised, and that in terms of maximum daily demands, 70% of the water is taken from surface sources and 30% from groundwater.

Forecasts of irrigation growth were based on an upper bound growth rate of 4% and a lower bound of 1% per annum, chosen from a review of literature and the national historic trends. Uptake of 100% of licensed entitlement was assumed in the absence of reliable information to the contrary.

The 1991 total spray irrigation licensed peak daily quantity of 85.4 Ml was used as the base from which a 35% (to 115.1 Ml) and 224% (to 276.8 Ml) increase in peak daily demand by the year 2021 was forecast for lower and upper bounds respectively. A cautious response to increased demand was recommended in those areas of already high demand (the Exe, Clyst and Otter valleys and West Cornwall), where new abstractions may be permitted only in the winter months.

12. Kay M.G., 1992
A review of trickle irrigation use in England and Wales for the National Rivers Authority. Silsoe College, Cranfield Institute of Technology

This report examined the current status and future trends in trickle irrigation used outdoors and under glass (and plastic) in England and Wales.

The area irrigated by trickle in 1990 (MAFF irrigation census) was 1420 ha (0.86% of total irrigated area), on 600 holdings - a slight decline over early 1980s levels. System costs, problems with blockages and changes in cultural practices in orchards were suggested as reasons for the decline in trickle use. The trickle area is concentrated in the South East (53%), Anglia, West Midlands and the South West. These are the areas where the high value crops (soft fruit and orchards) commonly grown with trickle are also concentrated.

Water use for trickle was estimated by (1) calculating the average water use per ha from MAFF data available on water use for all irrigation methods; and (2) assessing crop water requirements for those crops likely to be irrigated by trickle. Using the first approach, current total trickle water use was estimated to be 1000 Ml. However, differences between methods of application were hidden in this data and the second approach estimated a requirement of 2300 Ml based on a 75% application efficiency (evidence suggests that farmers tend to use more water when they use trickle).

It was not possible to separate out the main sources of trickle supply but informed opinion suggested that approximately 25% comes from the public supply; 60% of this being in the South East. In comparison, 3% of total irrigation volume from public supplies.

Future growth in trickle area was not anticipated but a combination of a reduction in system costs and increased concerns over water availability could lead more fruit growers to change to trickle irrigation, with trickle irrigated areas of soft fruit and orchards increasing by up to 5600 ha. Further cost reductions and/or serious water shortages would be needed before the use of trickle on row crops such as vegetables and potatoes became widespread.

Area under glass and plastic was 1798 ha in 1990, trickle irrigating an estimated 25% resulting in a total water use of 4000 Ml. The high investment costs involved in setting up new facilities had discouraged growth in the area under glass in recent years and the demand for water was thought likely to remain static.

13. Sainsbury R., 1992
Non Mains Agricultural Demand. Stage 1: Regional geographic overview of agricultural and non agricultural demand for spray irrigation. NRA South West Region

This report was the first stage of a feasibility study intended to determine whether agricultural demand for water can be forecast more accurately in the NRA South West Region. The project objectives were to examine the current level of spray irrigation (including its distribution across the Region and over the year), to assess the viability of using licence returns as a basis for spray irrigation demand forecasting, and to identify the more significant influences on spray irrigation demand.

Returns for spray irrigation abstractions (both agricultural and non-agricultural) for the years 1986 to 1990 were analysed and revealed a general trend towards increased uptake of authorised quantities, with weather being the predominant influence. Average annual uptake as a percentage of authorised quantity ranged between 47.4% (1988) and 71.4% (1989) although the lowest and highest uptake in any catchment was 0% and 429% respectively. Only 3 catchments (out of 57) had total abstractions of over 100% of authorised volumes. In the calculation of actual uptake , it was assumed that licence holders who had not submitted returns had abstracted the full authorised quantity. However, the number of returns submitted in the drought years 1989 and 1990 was less than submitted previously, casting some doubt over the validity of this assumption.

Possible reasons for non-returns included exemption, water not used (thus return assumed to be unnecessary), and over abstraction (therefore wanting to minimise the bill). Return submissions were often irregular, or submitted information was suspiciously constant, the same quantities shown each year. Some returns gave no indication of units, and some were inadequately completed giving only an annual total and not its distribution throughout the year. Returns data often contradicted information received on enforcement visits. Not surprisingly it was concluded that the accuracy of returns data is questionable and the need was recognised for these to be improved to enable the determination of actual use and forecast future demands.

Trends in areas cropped in the South West (total horticultural crops and potatoes) were obtained from MAFF data for 1981 to 1989. Both have been relatively stable, with potatoes peaking in 1984. The report concludes that as spray irrigation occurs mostly on land of agricultural grade 1 or 2, and as these areas are already intensively cropped, there is unlikely to be a significant rise in spray irrigation water demand, although small annual increases are anticipated.

Recommendations made included: to implement the legal right to revoke licences; to continue the implementation of licence conditions for spray irrigation abstractions (e.g. off-stream winter filled storage would reduce reliance on prescribed flow conditions); to research farmer practice particularly where no returns are submitted; to encourage scientific scheduling of irrigation (although this may increase quantities used, it may reduce over-licensing if they are issued on this basis); to promote installation of loggers to provide real time abstraction data; and to classify spray irrigation licences into 1st, 2nd and 3rd degree licences based on the catchment position (to facilitate targeting of specific catchments or individuals for drought management).

14. Leeds-Harrison P.B. and Rounsevell M.D.A., 1993
The impact of dry years on crop water requirements in eastern England, Journal of the Institution of Water and Environmental Management

In this paper, factors which influence the demand for water in agricultural crop production were examined and related to recent climatic conditions in the UK.

These factors included soil water availability in the crop root zone and potential soil moisture deficit calculated on a monthly basis from the cumulative difference between rainfall and potential evapotranspiration during the growing season. A measure of 'droughtiness' was derived from the difference, its numerical value indicating the shortfall in crop water demand.

This integrated approach was used to demonstrate regional variation in agricultural water demand. A map of England and Wales was produced showing average droughtiness for main crop potatoes for the period 1961 to 1975. The East of England shows an average droughtiness of 0 to -50 mm. For East Anglia in 1990 this value was calculated to be approximately -145 mm (range -125 to -175 mm); three times the long term average.

The effects of droughtiness on crop potential were illustrated using land evaluation techniques. Land suitability for potatoes was classified into well, moderate, marginal and unsuited, based on droughtiness and machine work day (MWD) criteria (where excessive water affects timeliness of tillage operations). The threshold for yield restrictions in the absence of irrigation occurs at a droughtiness of +50 mm (moderately suited). Thus the maximum droughtiness value of -175 mm outlined above for East Anglia in 1990 indicates an irrigation requirement of 225 mm of water.

15. Dempsey P., 1992
The impact of spray irrigation on water resources in the Severn Trent Region and the potential for improved demand management. Severn Trent Region NRA

This report considered methods used for estimating short term and long term demand for spray irrigation (necessary for operational resource management and resource planning purposes respectively), and estimated the potential regional demand based on current irrigation strategies and theoretical crop water requirements.

The irrigation requirements of specified crops in the Severn Trent Region were calculated for the driest and fifth driest years in 20 years. A frequency analysis on effective rainfall in the River Tern catchment established that these corresponded to potential soil moisture deficits of 275 mm and 157 mm, closest to 1989 and 1986 respectively. Crop water requirements for these years as determined by Ejikeme (1989) were used with irrigated areas from the 1984 MAFF irrigation survey to provide an estimate of irrigation requirements. Annual quantities of 23 000 and 31 200 Ml were estimated to be required for the 5 in 20 and 1 in 20 years respectively, as compared with actual abstractions for 1986 and 1989 of 9100 and 14 900 Ml. It was suggested that currently available resources should not be expected to be sufficient to provide for demand in a 1 in 20 drought, but that increased provision may be necessary to satisfy demand in the planning year.

Crop water requirements were also used to provide an estimate for total irrigation needs from 1990 to 2010. Based on 14 years of data, the average annual demand over the twenty year period was estimated to be 16 600 Ml.

The need for caution was stressed when using aggregated data It was suggested that estimates could be improved by looking at localised crop water requirements or by ascertaining detailed irrigation data from farmer surveys. The report stresses that exogenous economic and political factors may be as or more significant than water availability to future farm production decisions.

Attention was given to demand monitoring (assessing actual abstractions) and demand management options (licence restrictions):

In 1988 a pilot scheme was set up in the Upper Severn area to demonstrate the use of various technologies for automated data collection. Initially eight sites were established consisting six data loggers and two real time installations. A formalised scheme had since been developed to encourage farmers to purchase and install loggers. Take up of the logger system had been limited, most likely due to the expense and the closer monitoring then feasible by the authority. Some discrepancy was found between logged data and meter returns, thought to be due mostly to technological problems with the loggers. The loggers proved robust in the field, with potential problems at the connection with the meter and with risk of damage at mobile installations or remote sites. Logger performance assessment and consideration of incentives to encourage take up were recommended.

Real-time irrigation monitoring had been considered a means of accounting for short term fluctuations in flows at control points, which could have been caused by sudden irrigation abstractions. Two real-time systems were installed but their costs and installation requirements led to the conclusion that the data-loggers were a more appropriate technology for this application.

Severn Trent Region already operated a phased system of prescribed flow restrictions which provided an element of fairness when resources are stretched. However, in very dry years restrictions may be in force in some areas for a very large proportion of the season and was suggested that prescribed flows could be relaxed in less sensitive rivers.

Financial incentives could be applied through the charging system to promote water conservation and careful scheduling. However, these have in effect been reduced in the Severn Trent Region under the new national charging system. (Previously 75% of the fee was based on quantity abstracted; this has been reduced to 50%).

Take up by farmers of winter storage or conjunctive use of surface and groundwater sources has been poor - capital costs and reluctance to cooperate with other irrigators have been found to be the reasons (NRA 1992, Augmenting Resources for Agriculture in Severn Trent Region, draft report).

Of the management options discussed, greater control over existing licences in low flow periods was considered the most attractive and least cost option. It may require subsidies for winter storage in exchange for licence capacity, or low flow augmentation from perhaps regulation releases of groundwater.

APPENDIX B MAFF IRRIGATION CENSUS DATA AGGREGATED IN NRA REGIONS

Table B.1 Summary of MAFF irrigation data for the 10 NRA Regions in 1982

		Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Totals
Area Irrigated (ha)	Potatoes harvested before 31/7	2980	172	14	1623	231	1224	293	1176	116	223	8050
	Potatoes harvested after 31/7	9528	562	274	5825	160	1522	965	540	323	2081	21780
	Sugar beet	10646	74	14	4028	1	9	251	167	11	598	15800
	Hops	10	0	0	28	0	110	0	23	0	0	170
	Orchard fruit	1725	1	0	240	4	816	232	62	30	0	3110
	Small fruit	1041	127	2	775	33	877	363	179	160	74	3630
	Vegetables for humans	6018	497	63	1750	166	2960	1810	781	382	422	14850
	Grass	4847	393	362	4224	439	1789	1503	488	1768	658	16470
	Cereals	9492	108	296	3370	42	130	549	82	107	705	14880
	Others	1536	90	22	456	70	667	449	166	142	164	3760
	Total	48770	2029	1037	22305	1123	10999	11565	3649	3116	4917	109510
Volume of water applied (Ml)	Potatoes harvested before 31/7	1905	105	12	1006	136	551	177	588	69	132	4680
	Potatoes harvested after 31/7	6903	310	157	3952	98	967	841	307	282	1383	15200
	Sugar beet	5518	30	5	2215	0	9	144	82	1	246	8250
	Hops	0	0	0	17	0	40	0	14	0	0	70
	Orchard fruit	1152	1	0	186	3	580	153	57	20	0	2150
	Small fruit	456	50	1	398	28	498	192	86	102	40	1850
	Vegetables for humans	2478	236	12	956	107	1419	801	449	214	159	6830
	Grass	2945	240	187	2545	285	1156	858	285	1050	440	9990
	Cereals	3243	19	75	1217	14	35	128	23	28	248	5030
	Others	509	0	0	116	2	141	84	28	18	21	920
	Total Volume	25101	1001	450	12574	674	5416	3405	1961	1809	2698	55090
Volume by source (Ml)	Watercourse	10530	583	391	7632	409	2699	1567	979	1217	1534	27540
	Spring	1467	20	1	226	126	197	182	273	58	42	2590
	Well	1816	31	0	379	1	88	146	60	29	0	2550
	Borehole	6242	118	32	1814	67	1036	835	78	231	1097	11550
	Lake	2434	217	52	1239	96	509	436	473	266	130	5850
	Gravel/Clay	460	4	2	273	0	117	100	20	9	116	1100
	Mains	283	69	1	200	26	963	279	57	151	51	2080
	Other source	1179	36	10	335	1	60	184	36	9	0	1850
	Total volume	24351	1067	478	12067	724	5678	3709	1990	1959	2957	54980
	Area equipped for Trickle						not available					
No of self-propelled irrigators:	Boom-type	196	10	0	50	14	41	24	24	33	7	400
	Rain guns	1214	77	33	533	46	268	181	105	76	148	2680
No of holdings equipped with:	Sprinklers	1247	185	24	682	184	651	440	304	238	175	4130
	Spraylines	524	179	32	445	133	381	282	195	203	107	2480
	Rainguns (not self propld)	175	39	1	130	46	74	64	59	63	40	690
	Trickle	186	31	1	134	43	234	109	44	56	43	880
	Other	89	9	0	38	23	65	50	2	38	16	330
Reservoir Capacity (Ml)	Earth or lined earth						not available					
	Other storage tanks						not available					
Number of reservoirs:	Earth or lined earth						not available					
Frost protection:	Area equipped (ha)						not available					
Dry year position:	Area likely to be irrigated (ha)						not available					
	Volume likely to be applied (Ml)						not available					

Table B.2 Summary of MAFF irrigation data for the 10 NRA Regions in 1984

		Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Totals
Area irrigated (ha)	Potatoes harvested before 31/7	2802	211	26	1476	321	1077	302	1137	131	249	7730
	Potatoes harvested after 31/7	16677	1007	331	7960	374	2027	1176	660	447	3893	34550
	Sugar beet	16828	184	32	6442	24	57	271	231	38	1392	25500
	Hops						not available					
	Orchard fruit	1586	0	0	341	7	881	219	142	55	0	3230
	Small fruit	1114	86	14	498	55	1028	381	85	151	138	3550
	Vegetables for humans	7429	715	125	2232	293	3610	1493	799	347	386	17430
	Grass	5206	794	465	4935	635	1584	1407	1139	1700	1046	18910
	Cereals	14408	340	148	6805	82	192	721	167	138	1671	24670
	Others	1877	155	55	737	164	773	346	304	259	201	4870
	Total	67942	3513	1276	31446	1944	11239	6323	4664	3276	8978	140600
Volume of water applied (Ml)	Potatoes harvested before 31/7	1869	121	25	1067	227	504	198	634	82	203	4930
	Potatoes harvested after 31/7	15184	879	442	8198	320	1433	1155	547	462	4091	32710
	Sugar beet	11211	95	16	4897	2	28	166	186	20	770	17390
	Hops						not available					
	Orchard fruit	1265	0	0	229	8	583	190	83	63	0	2420
	Small fruit	902	47	3	365	40	716	325	57	103	82	2640
	Vegetables for humans	4544	381	43	1568	149	2295	1321	575	282	242	11400
	Grass	3485	480	285	3288	557	1452	1120	755	1476	671	13570
	Cereals	5098	117	42	2251	23	45	174	50	40	421	8260
	Others	1361	149	33	608	135	646	429	237	255	156	4010
	Total volume	44868	2286	899	22476	1442	7687	5115	3145	2808	6654	97380
Volume (Ml) by source	Watercourse	19490	1452	790	13396	734	3586	2092	1545	1854	3183	48120
	Spring	2226	28	2	493	272	296	240	478	179	176	4390
	Well	2618	11	0	191	30	75	246	43	17	9	3240
	Borehole	14242	266	75	5165	108	1231	981	354	281	2288	24990
	Lake	3523	304	6	1788	193	620	542	570	201	781	8530
	Gravel/Clay	694	11	0	264	0	70	145	11	2	73	1270
	Mains	353	158	12	562	64	1675	614	116	201	84	3840
	Other source	1995	78	14	775	29	201	277	21	65	95	3550
	Total volume	45141	2309	901	22633	1430	7754	5137	3137	2800	6690	97930
	Area equipped for Trickle	469	12	10	193	33	540	117	27	39	80	1520
No. of self-propelled irrigators	Boom-type	182	10	10	78	1	42	30	9	148	0	510
	Rain guns	1808	144	37	877	60	403	261	162	103	316	4170
No. of holdings equipped with:	Sprinklers	1168	244	24	653	197	659	396	283	251	185	4060
	Spraylines						included in above figures					
	Rainguns (not self propld)	130	30	1	96	36	66	45	32	63	32	530
	Trickle	145	19	0	71	23	182	82	26	46	16	610
	Other	37	10	0	15	2	26	6	15	19	0	130
Reservoir Capacity (Ml)	Earth or lined earth	17039	678	54	4858	369	3401	2928	1549	659	1086	32620
	Other storage tanks	343	164	0	94	10	163	78	63	44	0	960
Number of reservoirs:	Earth or lined earth	940	144	12	448	108	282	210	268	125	153	2690
Frost protection:	Area equipped (ha)	878	14	2	529	49	294	56	23	90	106	2040
Dry year position:	Area likely to be irrigated (ha)	92466	4599	1748	41157	2729	15124	8862	6123	4656	11867	189330
	Volume likely to be applied (Ml)	80837	8097	1144	34421	2300	11961	8587	4355	4692	9519	166610

Table B.3 Summary of MAFF irrigation data for the 10 NRA Regions in 1987

		Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Total
Area Irrigated (ha)	Potatoes harvested before 31/7	1966	69	15	1242	206	494	266	933	105	290	5586
	Potatoes harvested after 31/7	14938	383	148	8885	343	1456	2214	847	494	3260	32968
	Sugar beet	6665	45	11	3108	3	0	285	174	18	338	10646
	Hops	na	3	na	na	na	na	na	na	na	na	3
	Orchard fruit	539	16	0	155	4	448	61	58	27	0	1307
	Small fruit	713	314	3	277	32	668	234	55	113	84	2492
	Vegetables for humans	4670	96	13	2064	198	2180	1294	624	189	277	11605
	Grass	1848	62	19	1834	354	590	515	288	828	530	6868
	Cereals	3860	41	16	2957	20	126	274	93	50	335	7772
	Others	1147	1029	13	475	27	336	230	75	117	114	3564
	Total	36345	1029	238	20995	1186	6305	5372	3146	1941	5229	81786
Volume of water applied (Ml)	Potatoes harvested before 31/7	841	30	6	543	119	171	98	449	67	119	2442
	Potatoes harvested after 31/7	6833	174	65	4749	199	791	1067	500	374	1466	16218
	Sugar beet	2064	15	3	1205	1	0	100	90	6	110	3594
	Hops	na	na	na	na	na	na	na	na	na	na	na
	Orchard fruit	206	1	0	48	5	172	29	20	37	0	519
	Small fruit	318	6	1	123	17	297	99	24	51	24	959
	Vegetables for humans	1793	112	4	828	83	928	592	299	98	145	4882
	Grass	820	42	9	846	255	408	193	107	632	219	3530
	Cereals	1130	19	4	812	6	46	58	28	17	85	2206
	Others	601	24	5	248	17	169	122	50	72	44	1352
	Total Volume	14606	424	96	9402	702	2981	2358	1567	1355	2211	35703
Volume by source (Ml)	Watercourse	5857	234	63	5444	343	1386	984	772	849	853	16785
	Spring	936	5	1	182	130	111	88	161	50	20	1684
	Well	1002	12	6	62	6	31	35	19	1	1	1175
	Borehole	4708	79	23	2266	65	662	609	153	154	905	9624
	Lake	1021	25	2	793	92	203	278	285	194	213	3106
	Gravel/Clay	177	7	2	49	1	47	49	2	2	107	443
	Mains	171	27	5	125	32	499	124	22	46	57	1108
	Other source	734	34	1	479	36	45	190	152	61	56	1788
	Total volume	14606	424	96	9402	702	2981	2358	1567	1355	2211	35702
	Area equipped for Trickle	443	17	16	236	19	391	120	44	23	17	1324
No. of self-propelled irrigators:	Boom-type	155	12	9	48	6	43	43	16	28	15	375
	Rain guns	1958	155	30	1060	87	460	371	197	127	351	4796
No. of holdings equipped with:	Sprinklers	878	147	20	532	131	436	269	226	172	137	2948
	Spraylines						included in above figures					
	Rainguns (not self propld)	107	22	4	70	22	31	32	32	33	23	376
	Trickle	139	15	2	76	21	123	52	21	28	15	492
	Other	34	8	2	36	9	16	12	11	12	10	150
Reservoir Capacity (Ml)	Earth or lined earth	19123	788	67	6571	714	2886	4283	2617	784	2233	40066
	Other storage tanks	167	112	2	92	8	56	60	33	12	10	552
Number of reservoirs:	Earth or lined earth	844	102	7	490	97	257	226	293	97	140	2553
Frost protection	Area equipped (ha)	1105	63	1	900	24	419	222	85	76	86	2981
Dry year position:	Area likely to be irrigated (ha)						not available					
	Volume likely to be applied (Ml)						not available					

Table B.4 Summary of MAFF irrigation data for the 10 NRA Regions in 1990

		Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Total
Area Irrigated (ha)	Potatoes harvested before 31/7	3279	318	23	1907	390	1023	440	1121	187	255	8942
	Potatoes harvested after 31/7	22025	955	524	12657	466	2117	2753	1129	531	4795	47951
	Sugar beet	18617	150	40	8378	14	2	1381	386	120	1567	30655
	Hops						not available					
	Orchard fruit	1669	1	0	140	11	1096	216	39	57	0	3229
	Small fruit	1052	60	9	498	68	1039	317	131	154	111	3437
	Vegetables for humans	14437	847	58	4332	362	3284	2740	885	317	686	27949
	Grass	4980	417	202	4374	570	1268	1133	743	1284	1124	16093
	Cereals	15438	241	277	9554	26	277	1484	328	177	2719	30522
	Others	4066	183	84	2077	91	934	783	239	249	543	9250
	Total	85561	3174	1217	43917	1997	11040	11247	4999	3075	11800	178026
Volume of water applied (Ml)	Potatoes harvested before 31/7	3130	212	10	1662	258	536	355	631	149	209	7153
	Potatoes harvested after 31/7	27026	833	472	15342	427	2119	3069	1078	583	4957	55906
	Sugar beet	13525	93	20	6213	9	1	752	258	60	827	21758
	Hops						not available					
	Orchard fruit	1594	172	0	110	11	840	217	32	61	0	3036
	Small fruit	1001	27	5	388	48	1079	289	106	146	70	3160
	Vegetables for humans	10803	386	14	2828	179	2203	1969	643	191	450	19666
	Grass	3886	303	151	3695	517	977	1084	455	1117	913	13098
	Cereals	6401	97	93	4197	8	109	547	128	74	1024	12678
	Others	2648	220	35	1314	98	714	547	184	237	248	6244
	Total Volume	70016	2173	800	35748	1554	8578	8828	3516	2618	8698	142529
Volume by source (Ml)	Watercourse	28717	1212	586	19968	841	4204	4170	2001	1531	3683	66913
	Spring	3440	64	11	582	248	445	306	197	199	258	5750
	Well	2484	26	1	270	5263	123	226	64	17	38	8512
	Borehole	25634	435	119	10231	186	955	1892	463	403	3687	44005
	Lake	4387	232	35	2682	146	661	990	531	213	573	10450
	Gravel/Clay	1125	269	1	464	2	223	196	16	10	214	2520
	Mains	606	126	5	465	86	1825	519	134	161	73	4000
	Other source	3622	50	41	1088	40	143	529	110	81	171	5875
	Total volume	70016	2173	800	35750	1554	8578	8828	3516	2618	8698	142531
	Area equipped for Trickle	514	22	5	109	38	560	101	45	22	5	1421
No of self-propelled irrigators:	Boom-type	145	11	3	45	4	29	40	12	5	15	309
	Rain guns	2339	157	44	274	98	495	452	246	135	378	4618
No of holdings equipped with:	Sprinklers	830	167	26	558	145	472	312	256	177	135	3078
	Spraylines						included in above figures					
	Rainguns (not self propld)	109	22	2	75	32	32	34	38	30	26	400
	Trickle	160	19	4	87	30	154	73	39	28	15	609
	Other	52	12	2	31	11	26	14	16	10	11	185
Reservoir Capacity (Ml)	Earth or lined earth	19487	472	47	6862	990	2789	4185	2275	831	1591	39529
	Other storage tanks	112	9	7	101	9	82	48	12	18	18	416
Number of reservoirs:	Earth or lined earth	898	108	5	555	136	231	250	307	109	134	2733
Frost protection:	Area equipped (ha)	1140	37	1	605	37	195	213	81	102	36	2445
Dry year position:	Area likely to be irrigated (ha)						not available					
	Volume likely to be applied (Ml)						not available					

APPENDIX C MAFF CROPPING CENSUS DATA AGGREGATED IN NRA REGIONS

Table C.1 Summary of MAFF cropping data for the 10 NRA Regions in 1982

NRA Region		Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Total
Area cropped (ha)	Early potatoes	7202	1663	154	3271	1808	2747	580	3285	353	1247	22309
	Late potatoes	49148	8801	3564	21069	3580	6048	3717	5305	2190	17935	121358
	Total potatoes	56350	10463	3719	24340	5388	8795	4297	8591	2543	19182	143667
	Sugar beet	147937	1841	553	26955	80	157	1558	2105	304	21371	202860
	Orchard fruit	7721	79	1	4080	591	18867	1564	2589	1390	11	36892
	Small fruit	3927	396	73	2469	329	3333	1028	1143	538	517	13754
	Vegetables for humans	99833	8794	943	13304	3010	12162	7881	3096	1700	17542	168265
	Grass	349064	585044	266233	862754	603157	291704	278290	1004149	462309	350564	5053268
	Cereals	1230870	104870	145652	553638	124434	261112	356147	114226	192921	360129	3443999
	Total	1895703	711487	417174	1487540	736988	596131	650765	1135897	661704	769316	9062706

Table C.2 Summary of MAFF cropping data for the 10 NRA Regions in 1984

NRA Region		Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Total
Area cropped (ha)	Total potatoes	56894	11145	3573	26443	6342	8831	4232	9073	2737	19847	149118
	Sugar beet	145662	1768	509	26664	157	116	1359	2242	481	19726	198684
	Orchard fruit	7082	73	2	3854	569	17710	1486	2398	1455	10	34638
	Small fruit	3407	393	106	2189	322	3271	1034	1008	580	487	12795
	Vegetables for humans	81837	8648	879	10794	2695	10155	5381	2712	1509	13379	137987
	Grass	334278	585631	260993	852343	605466	288395	269790	1020648	456677	341498	5015718
	Cereals	1241164	101079	140336	553997	122173	261642	360297	110438	195679	357520	3444324
	Total	1870323	708737	406397	1476284	737724	590119	643578	1148519	659118	752467	8993264

Table C.3 Summary of MAFF cropping data for the 10 NRA Regions in 1987

NRA Region		Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Total
Area cropped (ha)	Total potatoes	52205	9915	2897	25139	5622	7730	3651	8365	2481	17630	135635
	Sugar beet	147441	1860	522	27402	207	117	1384	2275	475	20361	202043
	Orchard fruit	6661	58	1	3481	577	17242	1404	2234	1421	11	33089
	Small fruit	2875	407	102	1881	325	3237	996	864	585	467	11739
	Vegetables for humans	73457	7501	887	9889	2662	8778	3917	2579	1197	10496	121363
	Grass	313932	586851	259442	828734	594617	272697	253029	1033971	436931	333251	4913455
	Cereals	1181074	102363	142903	544139	126300	250438	343144	111024	199258	356915	3357556
	Total	1777643	708955	406754	1440664	730310	560239	607525	1161310	642348	739132	8774880

Table C.4 Summary of MAFF cropping data for the 10 NRA Regions in 1990

NRA Region		Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Total
Area cropped (ha)	Total potatoes	54218	9618	2585	27106	5877	6899	3299	8229	2461	18400	138692
	Sugar beet	141139	1783	499	26632	162	79	1423	2234	526	19620	194097
	Orchard fruit	5872	46	2	3291	584	15931	1241	2166	1266	9	30408
	Small fruit	2897	341	124	1837	314	3454	972	845	633	408	11824
	Vegetables for humans	80303	7381	731	10589	2424	8355	3481	2446	1314	12100	129123
	Grass	317247	594322	253830	828564	597724	270628	252549	1037671	434166	335449	4922151
	Cereals	1123027	90447	136443	503738	109414	230043	310642	96302	184294	343492	3127842
	Total	1724703	703939	394215	1401756	716498	535390	573606	1149892	624661	729477	8554137

APPENDIX D NRA REGIONAL IRRIGATION DATA

a) Anglian

Anglian Region are currently putting archive data on a computer system. Previously divided into five areas, these have been merged into three: Northern, Central, and Eastern. Licensed volumes (Ml per annum and m^3 per day) are recorded against each grid reference of each licence number. 'Site name', licence holder, start date and, when appropriate, end date are included. Year ends 31st December. Current total number of licences and annual licensed totals on a catchment basis can be retrieved from the database. Licensed daily quantities cannot be totalled.

Total spray irrigation licensed and abstracted quantities (Ml per day, averaged over 365 days) for 1969 to 1990 were made available. Post-1975 abstraction data included assessments for abstractors who failed to make returns. It was noted that the computer database, when complete, will perform the function of determining abstractions by an assessed percentage of licensed quantity rather than an audit of all 'returns'.

Annual return forms are dispatched end October for return by 14th November. Readings for each month are required.

b) North West

Licensed quantities per annum and per day are recorded in "mega gallons" on computer. Licence grid reference, start date and end date are held on the data-base (for 1982 to date), but licensed quantities per annum and per day could be provided for current year only. Regional totals only are available.

Abstraction data are held on micro-fiche and paper. Abstracted quantities per annum were made available for 1978 to 1990, totalled for the Region.

c) Northumbrian

Computer records in this Region hold only current year licensed quantities. Licensed quantities per annum and per day are recorded in cubic metres, for each application of each licence number. The data-base contains codes for abstraction type, purpose, hydrometric area, hydrometric sub-area, and source type. Application number, licence number, grid reference, source name and licence holder are also given. Year of issue for each licence is not recorded on the data base, thus total licensed quantities for previous years had to be calculated by hand. The abstraction type code and purpose code used apparently included agricultural and non-agricultural spray irrigation uses.

Abstraction data are held on paper (Section 201 forms). Abstracted quantities per annum were made available for 1983 to 1991, totalled for the five catchment areas and sub-regions of 0 to 6.

d) South West

A summary of technical details for all licensed water abstractions is held on a data base - the South West NRA Licensing System - operated and maintained by South West Water Services Ltd for the NRA South West Region under an agency agreement. The abstraction licensing section of NRA South West is responsible for updating licence details. Codes are used to distinguish: *Purpose:* Spray Irrigation Agriculture from Spray Irrigation Other; *Sub code:* Summer abstraction from Winter abstraction; *Source:* Groundwater (Borehole, Well, Spring, Adit, Groundwater-fed reservoir, Shaft), Surface (River/stream/brook, Leat, Reservoir pond), or Tidal.

Details on licensed quantities are recorded for the years 1965 to date. Actual abstracted quantities are also recorded but, following a recent appraisal, are recognised as being far from complete due to unreturned or dubious annual 'return' forms.. Totals on a catchment basis can be extracted.

e) Severn Trent

The computer data-base in this Region is currently being updated. Post 1988 records have been entered, pre 1988 data are held on micro-fiche only. Licensed quantities in cubic metres per annum and per day, and abstracted quantities per annum, for each licence number are stored. No reading for abstracted quantity in the data-base implies either no abstraction was made or the form was not returned. Totals are not available from the data-base.

The data-base contains codes for licence type, use, and source. Licence number, grid reference, and meter number are also given. Start and end dates as month number from one to twelve are given.

Authorised volumes for licences and number of licences for spray irrigation as at June 1992, and for the years December 1982 to '84 and 1985 to 1988 (millions of cubic meters) were given separated into surface and ground supplies for 'Severn', 'Trent', and 'total'. Frost protection licences were itemised separately.

Estimates of spray irrigation (assumed to be agricultural and non-agricultural) abstraction data (Ml/d) as made to the DoE were given for 1982 to 1991 (excluding 1984). These are presented as surface (tidal and non-tidal), ground, and total water abstractions

Since 1991, abstraction return cards have requested daily meter readings, as they had done prior to 1985. (From 1985 to 1991, monthly readings were requested). The Severn Trent Region year runs as the financial year from April to March.

f) Southern

Availability of data for the Southern Region is limited, much of it having been lost in the change over to the NRA Region from the old Water Authority.

Current year totals for licensed quantities (m^3 per annum and m^3 per day) and 1990/91 and 1991/92 totals of abstracted quantities were given. The 'year' runs from October to September.

g) Thames

Archive data for the years 1983 to 1991 on spray irrigation licensed and abstracted quantities have been put onto a computer database. 1963 to 1983 data are held on microfiche.

The database records licence number, grid reference, 'aquifer code', and 'purpose code'.

Totals of licensed and abstracted volumes for the Region were given for the years 1983 to 1990 in Ml/d (assumed to be averaged over 365 days). Separated figures were given for spray irrigation 'agriculture' and spray irrigation 'non-agriculture'.

h) Welsh

Licensed quantities are held on computer for the current year only, for licensing catchments in hydrometric areas. Abstraction data are stored as annual totals only. These, together with some licensed data, were given for 1980 to 1991 in Ml per day, as calculated from annual figures over 365 days. Licence grid reference, start date and end date are recorded on the data-base.

i) Wessex

Wessex Region are currently developing a new database for licensed and actual abstraction data. To date, actual returns have never been archived. Grid reference, licensed quantities per day and per annum, start date and end date are recorded.

Summary data of licensed and actual abstractions (Ml per day, assumed to be averaged over 365 days) in each of three areas in the Region were given for the years 1985 to 1192. These areas are 'Bristol Avon', 'Avon and Dorset' and 'Somerset'.

j) Yorkshire

Licensed quantities per annum and per day and abstracted quantities per annum are held on computer for the current year only. Totals cannot be generated. Licence grid reference, start date and end date are recorded on the data-base. Total licensed quantities (Ml per annum), for each of 34 sub-catchment areas were hand-calculated for 1974 to 1991.

Abstraction data (Ml per day) as provided to the DoE were given for 1981 to 1991.

Table D.1 Regional licensed and abstracted volumes for spray irrigation

	Anglian	North West	Northumbrian	South West	Severn Trent	Southern	Thames	Welsh	Wessex	Yorkshire
Licensed volume per year (Ml)										
1982	80264	-	-	515	35958	-	-	-	-	10101
1983	81870	-	227	549	37604	-	11060	4380	-	10897
1984	96871	-	357	1132	39946	-	11133	-	-	11274
1985	108077	-	439	1452	-	-	11461	-	7373	11791
1986	113734	-	526	1495	48657	-	11534	-	7300	14416
1987	119720	-	544	1622	49463	-	11644	-	7081	15248
1988	125195	-	572	1651	50142	-	11206	-	7227	17756
1989	128480	-	572	1663	-	-	10987	6205	12629	18370
1990	134685	-	857	1701	-	-	10658	-	12410	18933
1991	139065	-	857	1793	-	-	-	7446	13578	20380
1992	-	5517	865	2015	58953	25894	-	-	-	-
Abstracted volume per year (data direct from NRA Regions) (Ml)										
1982	23433	1058	-	-	9490	-	-	730	-	-
1983	33690	1314	64	-	12410	-	3066	730	-	2263
1984	38727	2117	91	-	-	-	3504	1460	-	-
1985	20842	913	42	-	6570	-	1679	730	1460	2482
1986	32923	913	135	-	13505	-	2409	730	2190	4380
1987	15367	474	17	-	9125	-	1971	730	2190	3468
1988	20805	547	35	-	9490	-	1880	4782	2993	4088
1989	53035	1241	162	-	26645	-	3176	2336	3796	7519
1990	77855	1431	166	-	24820	-	3796	2409	4453	8833
1991	85775	-	118	-	-	2931	-	2519	2774	9636
1992	-	-	-	-	-	2838	-	5475	-	-
Abstracted volume per year (data from DoE) (Ml)										
1982	-	-	-	-	9490	-	-	730	-	-
1983	-	-	-	-	12410	-	-	730	-	-
1984	38836	2117	110	1095	14600	3650	4344	1460	2409	4417
1985	20805	913	73	1095	6570	876	2336	730	1460	2471
1986	33325	913	73	1095	13505	2665	2993	730	2190	4380
1987	15951	475	0	1460	9125	1132	2300	730	2190	3478
1988	20805	548	0	1095	9490	2555	2154	4782	2920	4099
1989	53035	1241	0	1095	26645	8760	4161	2336	4015	7508
1990	77855	1424	183	2190	24820	10585	5183	2409	4380	8818
1991	85775	-	-	-	-	-	-	2519	-	9647
1992	-	-	-	-	-	-	-	5475	-	-

Notes: Source: NRA Regions.
Where no data are presented, these are unavailable or are considered unreliable by the region.

APPENDIX E DERIVED DATA FROM MAFF IRRIGATION AND CROPPING CENSUSES, AGGREGATED IN NRA REGIONS

Table E.1 Average actual depth of water applied to each crop category in each NRA Region, 1982

	Depth of water applied (mm)										
	Anglian	North West	Northumbian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Overall
Potatoes harvested before 31/7	64	61	86	62	59	45	60	50	60	59	58
Potatoes harvested after 31/7	72	55	57	68	61	64	87	57	87	66	70
Sugar beet	52	41	36	55	0	100	57	49	11	41	52
Orchard fruit	67	100	na	77	67	71	66	92	66	na	69
Small fruit	44	40	50	51	86	57	53	48	63	53	51
Vegetables for humans	41	47	18	55	65	48	44	58	56	38	46
Grass	61	61	52	60	65	65	57	58	59	67	61
Cereals	34	17	25	36	33	27	23	28	26	35	34
Others	33	0	0	25	2	21	19	17	13	13	24
Overall	51	49	43	56	60	49	29	54	58	55	50

Table E.2 Average actual depth of water applied to each crop category in each NRA Region, 1984

	Depth of water applied (mm)										
	Anglian	North West	Northumbian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Overall
Potatoes harvested before 31/7	67	57	98	72	71	47	66	56	63	82	64
Potatoes harvested after 31/7	91	87	134	103	86	71	98	83	103	105	95
Sugar beet	67	52	51	76	7	49	61	80	53	55	68
Orchard fruit	80	na	na	67	120	66	87	58	115	na	75
Small fruit	81	54	24	73	72	70	85	67	68	60	74
Vegetables for humans	61	53	34	70	51	64	88	72	81	63	65
Grass	67	60	61	67	88	92	80	66	87	64	72
Cereals	35	34	28	33	28	23	24	30	29	25	33
Others	73	97	60	82	82	84	124	78	98	78	82
Overall	66	65	70	71	74	68	81	67	86	74	69

Table E.3 Average actual depth of water applied to each crop category in each NRA Region, 1987

	Depth of water applied (mm)										
	Anglian	North West	Northumbian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Overall
Potatoes harvested before 31/7	43	44	39	44	58	35	37	48	64	41	44
Potatoes harvested after 31/7	46	45	44	53	58	54	48	59	76	45	49
Sugar beet	31	34	32	39	34	na	35	52	36	32	34
Orchard fruit	38	8	na	31	148	38	48	34	139	na	40
Small fruit	45	2	19	44	53	44	42	44	45	28	44
Vegetables for humans	38	117	31	40	42	43	46	48	52	52	41
Grass	44	67	47	46	72	69	37	37	76	41	51
Cereals	29	45	27	27	28	37	21	30	34	25	28
Others	52	2	36	52	64	50	53	66	62	38	52
Overall	40	41	41	45	59	47	44	50	70	42	44

Table E.4 Average actual depth of water applied to each crop category in each NRA Region, 1990

	Depth of water applied (mm)										
	Anglian	North West	Northumbian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Overall
Potatoes harvested before 31/7	95	67	44	87	66	52	81	56	80	82	80
Potatoes harvested after 31/7	123	87	90	121	92	100	111	96	110	103	117
Sugar beet	73	62	50	74	64	51	54	67	49	53	71
Orchard fruit	96	0	na	78	96	77	100	81	107	0	89
Small fruit	95	44	56	78	70	104	91	81	95	63	92
Vegetables for humans	75	46	24	65	50	67	72	73	60	66	70
Grass	78	73	75	84	91	77	96	61	87	81	81
Cereals	41	40	34	44	30	39	37	39	42	38	42
Others	65	120	41	63	107	76	70	77	95	46	68
Overall	82	68	66	81	78	78	78	70	85	74	80

Table E.5 Percentage of crops irrigated in 1982 based on MAFF Irrigation and Cropping data, for the 10 NRA Regions

	Percentage of crop irrigated (%)										
	Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Overall
Potatoes harvested before 31/7	41	10	9	50	13	45	51	36	33	18	36
Potatoes harvested after 31/7	19	6	8	28	4	25	26	10	15	12	18
Total potatoes	22	7	8	31	7	31	29	20	17	12	21
Sugar beet	7	4	3	15	2	6	16	8	4	3	8
Orchard fruit	22	1	0	6	1	4	15	2	2	0	8
Small fruit	27	32	2	31	10	26	35	16	30	14	26
Vegetables for humans	6	6	7	13	6	24	23	25	22	2	9
Grass	not available										
Cereals	1	0	0	1	0	0	0	0	0	0	0

Table E.6 Percentage of crops irrigated in 1984 based on MAFF Irrigation and Cropping data, for the 10 NRA Regions

	Percentage of crop irrigated (%)										
	Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Overall
Total potatoes	34	11	10	36	11	35	35	20	21	21	28
Sugar beet	12	10	6	24	15	49	20	10	8	7	13
Orchard fruit	22	0	0	9	1	5	15	6	4	0	9
Small fruit	33	22	13	23	17	31	37	8	26	28	28
Vegetables for humans	9	8	14	21	11	36	28	29	23	3	13
Grass	2	0	0	1	0	1	1	0	0	0	0
Cereals	1	0	0	1	0	0	0	0	0	0	1

Table E.7 Percentage of crops irrigated in 1987 based on MAFF Irrigation and Cropping data, for the 10 NRA Regions

	Percentage of crop irrigated (%)										
	Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Overall
Total potatoes	32	5	6	40	10	25	68	21	24	20	28
Sugar beet	5	2	2	11	1	0	21	8	4	2	5
Orchard fruit	8	27	0	4	1	3	4	3	2	0	4
Small fruit	25	77	3	15	10	21	23	6	19	18	21
Vegetables for humans	6	1	2	21	7	25	33	24	16	3	10
Grass	1	0	0	0	0	0	0	0	0	0	0
Cereals	0	0	0	1	0	0	0	0	0	0	0

Table E.8 Percentage of crops irrigated in 1990 based on MAFF Irrigation and Cropping data, for the 10 NRA Regions

	Percentage of crop irrigated (%)										
	Anglian	North West	Northumbrian	Severn Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire	Overall
Total potatoes	47	13	21	54	15	46	97	27	29	27	41
Sugar beet	13	8	8	31	9	2	97	17	23	8	16
Orchard fruit	28	2	0	4	2	7	17	2	5	2	11
Small fruit	36	18	7	27	22	30	33	15	24	27	29
Vegetables for humans	18	11	8	41	15	39	79	36	24	6	22
Grass	2	0	0	1	0	0	0	0	0	0	0
Cereals	1	0	0	2	0	0	0	0	0	1	1

APPENDIX F IRRIGATION COSTS

Costs can be assessed under the main categories of water supply, delivery, and in-field application. Costs can be analysed in terms of capital and annual costs, the latter distinguished into fixed and variable elements.

Irrigation costs have been estimated for four infield application systems (hosereels, sprinklers, trickle and centre pivots) over relevant irrigated areas, and for alternative water supply situations (surface or borehole sources abstracting directly or involving reservoirs, either clay or PVC lined).

Most components in a water supply system are site specific. Table F.1 contains broad estimates of capital costs in 1993 prices.

Table F.1 Capital costs of irrigation components (1993 prices)

			£
Pumps	diesel	(per unit)	3000 - 8000
	electric		2000 - 8000
	controls		1500 - 7000
	civil works		500 - 2500
Boreholes	drill and test	(per unit)	10 000 - 15 000
	submersible pump & pipework		3000 - 8000
Reservoirs	clay	(per Ml)	440 - 880
	PVC		550 -1160
Main Supply	150 mm pipe	(per m)	13 - 15
	hydrants	(per unit)	180 - 300
	mains complete system	(per ha)	700 - 1100
Infield	sprinkler	(per ha)	400 - 500
	hosereel		900 - 1000
	trickle (including mains)		1800 - 2000
	gantry/pivot		650 - 1000

Source works

These comprise the source, pumping and, where relevant, the storage of water. The selection of pumps depends on required flow rates, head lift, required operating pressure and power source. These in turn determine capital and operating costs.

Reservoir costs are similarly difficult to generalise, particularly given the sizeable economies of scale in earth moving and construction (Hawes, 1982). Contractors are currently quoting about £880/Ml for a 25 Ml clay lined reservoir to £440/Ml for a 250 Ml reservoir (Hawes, personal communication, 1993).

Reservoir size is determined by peak irrigation requirement: usually accommodating the fifth driest year in twenty, plus 10% for storage losses (20% for unlined reservoirs). Over the range of 12 to 36 irrigated hectares, for example, storage costs per irrigated hectare vary from about

£2250 to £1500. PVC lining increases these costs by about one third. Most reservoirs would be filled by electric pumps, which add about a further £200/ha

Delivery

The requirement for mains pipeline depends on scheme design characteristics, infield application methods, the size and configuration of the command area, and, particularly, the distance between the latter and the water source.

Infield application systems

A wide range of equipment and systems are available which differ in terms of capital cost, labour requirements, fuel consumption, and convenience and flexibility in use. The main infield systems for spray irrigation are self-travelling hosereels and sprinklers. There are only about 30 centre pivot and lateral move systems in Britain.

Assumptions regarding irrigation cycle length (days and working day length) are critical for the determination of infield system capacity and capital costs. It is common to design for an eight day cycle applying 25 mm/cycle. For the hosereel systems a 16 hour (or 2 x 8 hour) operating day and for the sprinkler system a 12 hour day (e.g. 3 x 4 hour) are reasonable assumptions.

With respect to infield costs (irrigator plus portable mains), portable sprinkler systems involve the lowest capital expenditure at about £410/ha, compared to hosereels at between £650/ha and £1250/ha depending on area. The capital costs per hectare of centre pivots and gantries are significantly higher than for hosereels up to about 80 ha capacity, after which they are about £650/ha.

Trickle and drip systems are used for protected cropping and selected outdoor applications. For trickle systems, pumping is typically by low pressure pumps, delivering through 50 mm to 75 mm mains, sub-main laterals, and finally plastic tapes. A network of filters are placed throughout the delivery and distribution system. Valves are often electronically controlled. Total capital costs of a typical trickle tape system are about £2300/ha, of which the trickle tapes are £500/ha. New materials and placement systems allow much of the tape to be re-used, at least for one further application.

Comparative capital costs

Table F.2 compares the estimated capital costs of selected irrigation systems (comprising water source and applicator options) for given irrigated areas. For the assumptions made, conventional sprinklers are least expensive to install. Water storage in the form of a reservoir increases capital costs by at least 50% compared to that of direct abstraction systems. Trickle systems appear to demonstrate similar initial capital costs to hosereel systems, but the annual cost of replacing trickle tape is likely to be at least £500/ha. In practice, for a given irrigated area, capital costs vary according to the need for water storage and the distance between source and field.

Table F.2 also shows the breakdown of capital cost by component, namely: source works, distribution and infield application. These data confirm that the composition of capital costs is influenced particularly by water source and storage options.

Table F.2 Capital costs of irrigation systems

Water source[a]:	Surface	Borehole	Reservoir	Surface	Surface	Borehole
Applicator:	Hosereel	Hosereel	Hosereel	Sprinkler	Trickle	C. Pivot
Area (ha):	24	24	24	24	24	100
Capital Cost £/ha	2291	2670	4060	1780	2278	2119
% Capital Cost by						
- Source	14	27	52	17	18	26
- Distribution	46	40	26	60	60	45
- Application	39	33	22	23	22	29
Subtotal	100	100	100	100	100	100
% Capital Cost by						
- Civils	1	17	47	1	4	17
- Pumps	11	7	4	17	19	7
- Mains & Fittings[b]	48	42	27	59	59	47
- Portable pipes	7	6	4	[c]23	[d]22	5
- Irrigator	33	28	18	-	-	24
Subtotal	100	100	100	100	100	100

Notes: [a]direct abstraction except for reservoir option; [b]2000 m buried mains for all systems except trickle; [c]including sprinkler heads [d]trickle tapes.

Annual fixed and variable costs

Annual costs comprise fixed and variable costs. Fixed costs include the amortisation of capital costs over asset life, and insurance. Variable costs are made up of repairs and maintenance, fuel and energy, labour and water charges. Table F.3 contains the rates used for estimating fixed and variable costs.

Table F.3 Assumptions for estimating fixed and variable costs of irrigation

	Life (years)	Remaining value (% of capital cost)	Repair costs per year (% of capital cost)
Components			
Pumps			
- Diesel	7	10	8
- Electric	7	10	3
Main pipes and fittings	15	0	3
Portable pipes and fittings	7	10	5
Irrigators	7	10	3
Civils	15	0	1.5
Trickle tape	2	0	10

Insurance per year (% of capital cost)	0.25
Real interest rate per year (%)	6
Fuel Price	
- Diesel (£/1)	0.15
- Electricity (£/Kwh)	0.07
Fuel Costs (£/ha mm)	
- Direct hosereel	0.32
- Direct sprinkler	0.15
- Extra for:	
groundwater	0.06
reservoir storage	0.03
Labour Rate (£/h)	4
Water Price (£/Ml)	12 000
Reservoir	
cost: unlined	£20 000 for 25 Ml plus £360 per additional 1 Ml
cost: lined	£26 600 for 25 Ml plus £480 per additional 1 Ml