Project 413

Demand for Irrigation Water

Silsoe College

R&D Report 14

NRA

National Rivers Authority

Guardians of the Water Environment

Demand for Irrigation Water

E K Weatherhead, A J Price, J Morris and M Burton*

Research Contractor:
Silsoe College
*University of Manchester

National Rivers Authority
Rivers House
Waterside Drive
Aztec West
Almondsbury
Bristol
BS12 4UD

LONDON: HMSO

R&D Report 14

Publisher:
National Rivers Authority
Rivers House
Waterside Drive
Aztec West
Bristol BS12 4UD
Tel: 0454-624400
Fax: 0454-624409

First Published 1994 **ISBN 0 11 885833 5**

Dissemination status

Internal: Released to Regions
External: Released to Public Domain

Statement of Use

The information contained in this report is for use by NRA staff and others involved in managing and planning for water abstraction for irrigation, and the influence this has on water resources, the environment and other abstractors. The report will also be of general interest to those involved in the agriculture industry.

Research contractor

This document was produced under NRA R&D Project 413 by:

Silsoe College
Cranfield University
Silsoe Campus
Silsoe
Bedfordshire
MK45 4DT
Tel: 0525 860428
Fax: 0525 861527

Project Leader

The NRA's Project Leader for R&D Project 413 was:
Mr David Evans - NRA Anglian Region.

Cover photograph courtesy of K. Weatherhead, Silsoe College.

This document was designed by: Stotts, 14 Frederick Place, Clifton, Bristol;
and printed by T.L. Visuals, Rainbow Court, Armstrong Way, Yate, Bristol.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

GLOSSARY

ACAH	Advisory Council on Agriculture and Horticulture
ADAS	Agricultural Development and Advisory Service
AWC	Available water capacity
CAP	Common Agricultural Policy
CLA	Country Landowners' Association
DM	Dry matter
DoE	Department of the Environment
EC	European Community
GATT	General Agreement on Tariffs and Trade
GIS	Geographical Information System
IACS	Integrated Agricultural Cropping Survey
MAFF	Ministry of Agriculture, Fisheries and Food
NFU	National Farmers' Union
NOP	National Opinion Poll
NRA	National Rivers Authority
PMB	Potato Marketing Board
SWD	Soil water deficit
UKIA	United Kingdom Irrigation Association

NOTATION

ha	hectare
ha mm	hectare-millimetre (volume equivalent to 1 mm depth over 1 ha area. 1 ha mm = 10 m^3)
MJ	Megajoule (10^6 Joules)
Ml	Megalitre (1 Ml = 1000 m^3)
t	tonne

EXECUTIVE SUMMARY

This report predicts future growth in the demand for water for agricultural irrigation in England and Wales, and advises as to how the National Rivers Authority (NRA) should respond. The predictions exclude the possible effects of climate change.

Some previous forecasts of irrigation demand overestimated growth in demand because they were carried out following dry periods; similar bias resulting from the dry years of 1988 to 1991 should be avoided.

The 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 year in the total area irrigated and about 2% per year in the total volume of water used. This was despite an underlying decline in the irrigation of fruit and, particularly, grass.

Current total irrigation costs (at 1993 prices) are typically £4 per ha mm using direct abstraction from rivers or groundwater. Storage to allow winter abstraction adds another £1 to £2 per ha mm. The cost of using a system already installed is typically only £1.2 to £2.3 per ha mm.

Irrigation benefits 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 appears financially attractive at present even if storage is required. Irrigation of sugar beet and some other vegetables is marginal. Irrigation of cereals and grass can only be justified if surplus capacity already exists.

Quality and reliability benefits are substantial and often more important than yield benefits. Quality premiums alone can 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.

The future growth of irrigation will be affected by changes in agricultural policy and by technical, market, and other factors. It is assumed that future agricultural policy will involve partial reform of the European Community's Common Agricultural Policy under a new General Agreement on Tariffs and Trade. 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 premiums exist, resulting in a modest growth in the proportion irrigated. The resulting changes in prices and in cropping patterns were predicted using the Manchester University Agricultural Policy Model.

Changes in irrigation machinery will mainly switch one application method for another, rather than increase the irrigated area. Better systems for irrigation scheduling should increase the efficiency of water use, but as many crops appear to be under-irrigated at present, better scheduling could well lead to increased irrigation.

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 medium term at least. The use of currently set-aside land to produce the same tonnage without irrigation would not give the quality, reliability or continuity benefits of irrigation.

Taking account of all these factors, it is predicted that there will be a relatively minor increase in the area farmers wish to irrigate but a larger increase in the volume of water required. The 'most likely' prediction for growth in volumetric demand is 1.7% per year from 1996 to 2001 and 1% per year from 2001 to 2021 for the 'dry' year. Within these figures, there would be a growth in the irrigation of potatoes, vegetables, and soft fruit and a decline in the irrigation of grass and cereals. The economic case for irrigating sugar beet will remain marginal.

The analysis predicts a large possible range around these 'most likely' values. Growth under the high prediction is two to three times higher. It remains positive but very slow under the low predictions.

The report describes the benefits of irrigation to the nation and to the consumer, and concludes that it is in the national interest to meet future irrigation demands where possible, but subject to adequate protection of the environment and any costs incurred being charged to the beneficiaries. Recommendations for NRA responses are given.

There is widespread support for the formation of an *advisory* National Agricultural Water Resources Forum, including representatives from the NRA, the Ministry of Agriculture, Fisheries and Food, the National Farmers' Union, the Country Landowner's Association and the United Kingdom Irrigation Association.

KEY WORDS

Irrigation, Water demand, Water resources, Predictions, Agriculture.

ACKNOWLEDGEMENTS

The authors wish to thank all those organizations who provided advice and information, including the Ministry of Agriculture, Fisheries and Food, the National Farmers' Union, the United Kingdom Irrigation Association, the Welsh Office, the Country Landowners' Association, the Department of the Environment, 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).

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 which farmers estimate that 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 1976, but since then, the area has approximately doubled again.

A similar surge occurred in the total volumes licensed for irrigation abstraction. Figure 1.2 shows the licensed and abstracted quantities of water for Anglian Water/National Rivers Authority (NRA) Anglian Region and in England and Wales from 1969 to 1991.

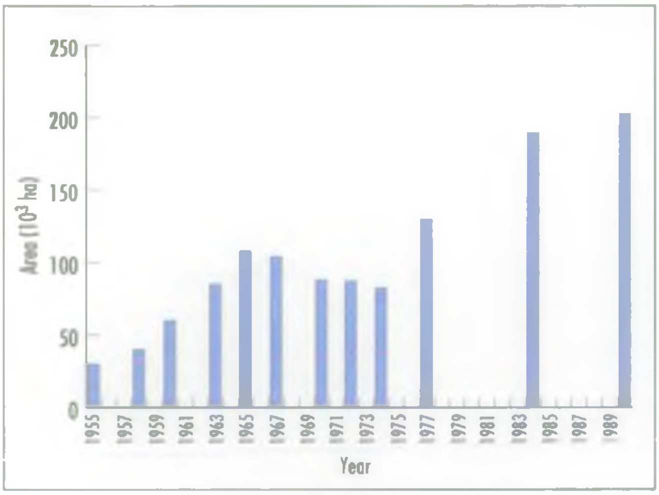

Figure 1.1 Total area likely to be irrigated in a dry year in England and Wales from 1955 to 1990

The actual areas irrigated and depths of water applied varied with the rainfall pattern in each year. As a result of variable climatic conditions in the UK, the average demand for irrigation water may typically only be half the peak requirement, and in a wet year the 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 irrigation survey data are available (Ministry of Agriculture, Fisheries and Food (MAFF) 1991a), was a 'dry' year, and the data for areas irrigated support the dry year estimates; 178 000 ha were reported to have been irrigated. Figure 1.3 shows the distribution of this irrigation between the ten former NRA Regions in terms of area and volume of water. (At the time the study was carried out, England and Wales were divided into ten Regions; subsequently Northumbria and Yorkshire, and South West and Wessex merged resulting in eight Regions.) This clearly shows the uneven geographical distribution of irrigation, with almost a 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.

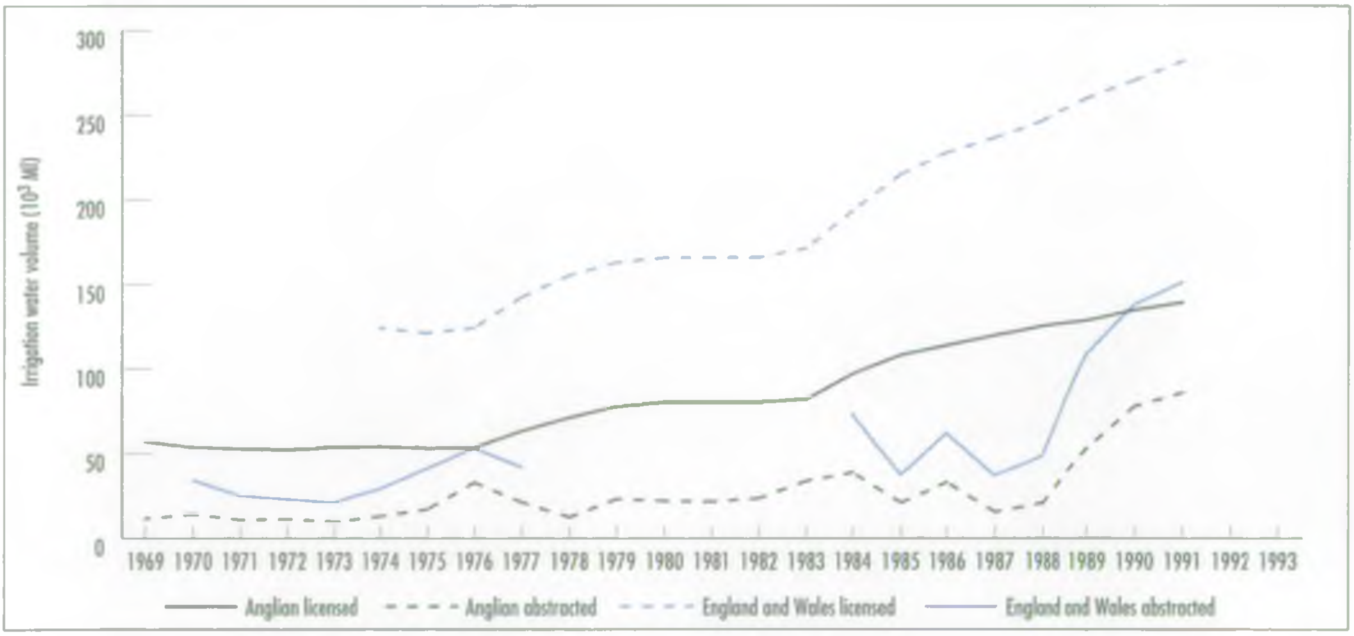

Figure 1.2 Licensed and abstracted volumes of water for irrigation in NRA Anglian Region and in England and Wales

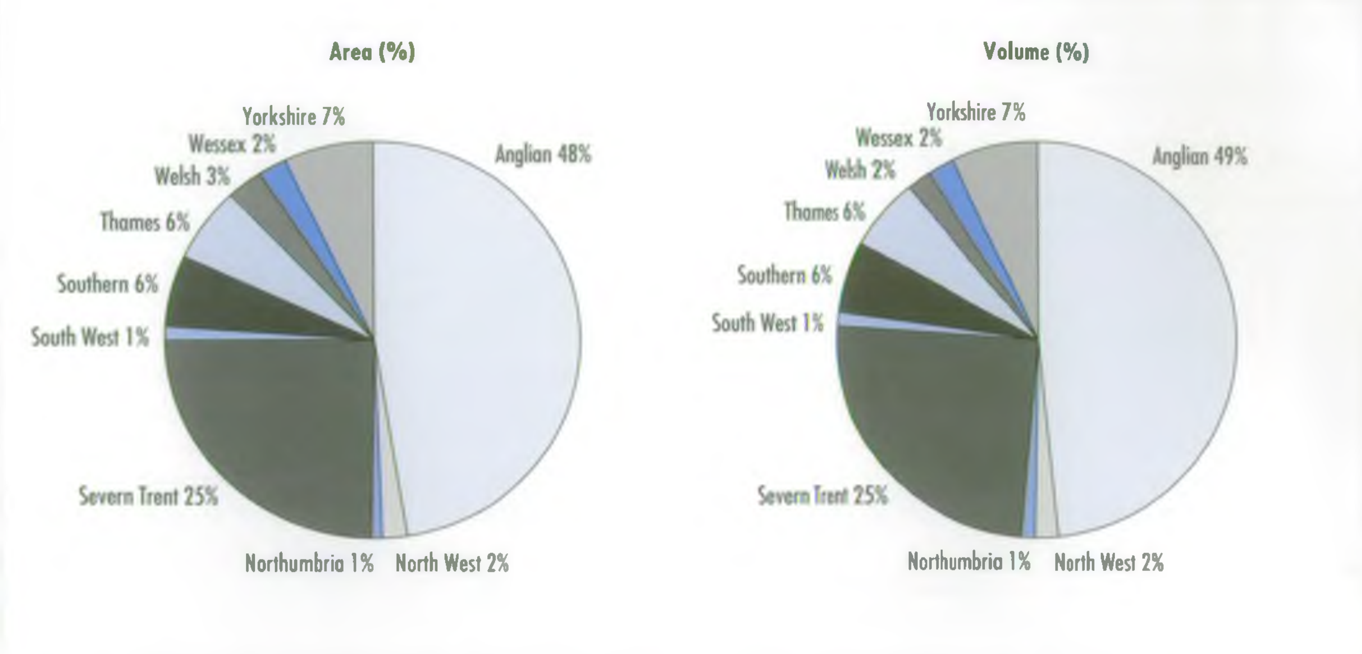

Figure 1.3 The distribution of irrigation between the ten former NRA Regions by area and volume in 1990
After MAFF (1991)a

The partition of irrigation between crops, again both by area and by volume, shows the predominance of a limited number of crops (Figure 1.4). Potatoes and sugar beet together accounted for 50% of the area irrigated and 60% of the water applied. Table 1.1 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 specialized cropping categories. These figures emphasize the difference between crops where irrigation is a major factor and others, particularly grass and cereals, where it is an exception.

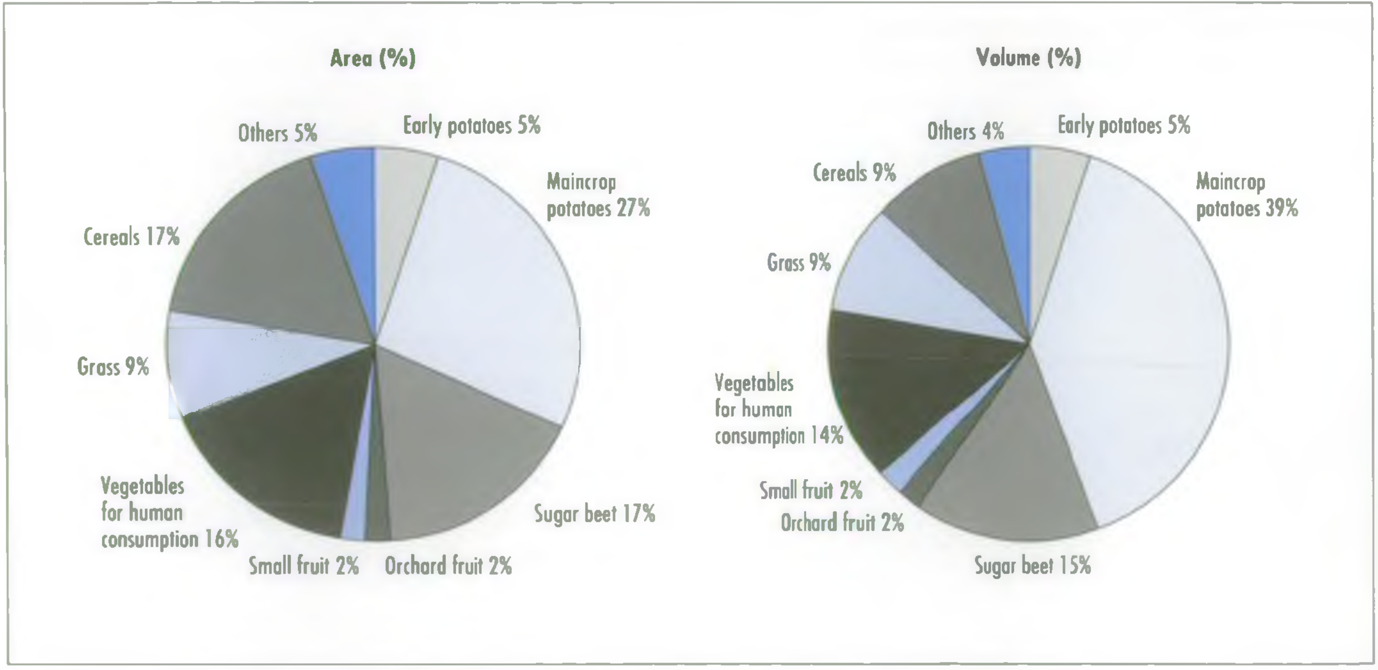

Figure 1.4 The distribution of irrigation between crop category by area and volume in 1990
After MAFF (1991a)

Table 1.1 The proportion of crop areas irrigated for England and Wales in 1990

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

After MAFF (1991a, 1991b)

In the 1950s, a typical irrigator was a horticultural smallholder using portable sprinkler systems. The introduction of mechanized 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 seem to be continuing this trend, but hosereel irrigators remain as the dominant irrigation method for field crops in the UK.

On specialized cropping, in orchards and in glasshouses, there has also been a growth in trickle (drip) and other localized irrigation methods, supported by improvements in technology and latterly in computerized 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 occurred simultaneously in the main reasons why 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 weather in the UK therefore make irrigation a necessity rather than a luxury.

These changes 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 an integral part of an increasingly sophisticated production system. A supply failure not only leaves expensive irrigation equipment 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 been a concurrent growth in both licensed and actual abstraction. Although irrigation remains a relatively small user of water on a national scale, it has the following particular features which affect water supply:

- it is a consumptive user, with all of the effective irrigation lost to increased evapotranspiration;
- most of the demand is concentrated into a relatively short period, typically 8-12 weeks per year;
- it is concentrated in particular catchments, and particularly in the drier South East of the country;
- 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 during dry summers.

The growth in irrigation demand has been accompanied by a growth in demand from 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 are theoretically or actually over-committed, and in large areas additional abstraction licences are unobtainable. This situation was highlighted in the recent drought in 1990, when irrigation was severely restricted in some areas by the NRA.

Demands from farmers for additional and more reliable water supplies, coupled with the desire of the NRA to meet the reasonable needs of abstractors whilst protecting both other users and the environment, has led to pressure for major investment in water resource development.

2. PREVIOUS FORECASTS

2.1 Review

The Advisory Council on Agriculture and Horticulture (ACAH) enquiry and subsequent report 'Water for Agriculture: Future Needs' (ACAH 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. Predictions 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 20. The ACAH figures are now generally considered to have been excessive, because these figures were for a dry year and assumed no limitations on water availability; they should not be compared with actual figures under conditions where abstraction 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 other forecasting work in relation to irrigation demand has been carried out previously by Anglian Water Authority and latterly by NRA Anglian Region. This reflects the large area irrigated and the high proportion of available water supplies used for irrigation within the Region. National Opinion Poll (NOP) 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 Agricultural Development and Advisory Service (ADAS) advice. The forecasts were further downgraded by the NRA Anglian Region (1990) to reflect observations of lower use of licensed quantities and restrictions on the expansion of agricultural production.

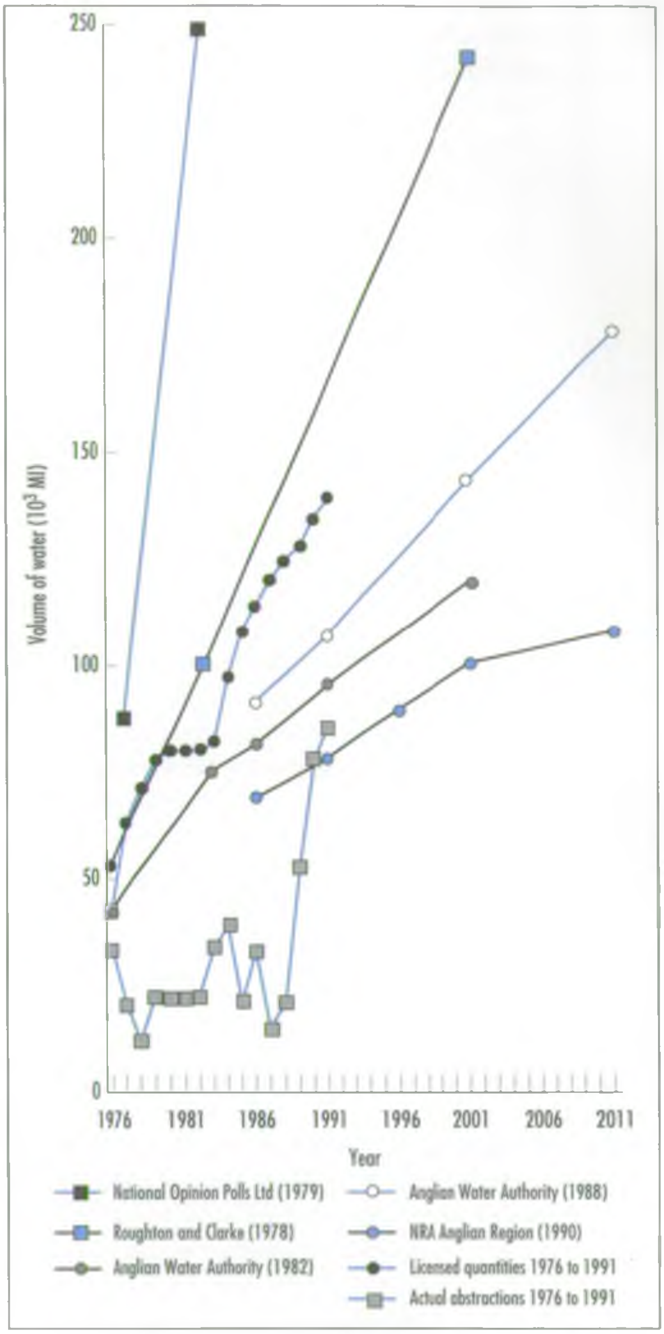

Figure 2.1 Forecasts of the volume of water used in spray irrigation in NRA Anglian Region, together with licensed and abstracted quantities

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.

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 there were fears of a large unsatisfied demand for water in this area, 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, whilst in others growth must be at more than the average national 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 calculated theoretical requirements from the previous study with irrigated areas derived from the 1984 MAFF irrigation survey (MAFF 1985a) to estimate irrigation requirements. Dempsey (1992) identified 1989 and 1986 as representing the driest and fifth driest years respectively in the previous 20 years for the Severn-Trent Region. A comparison of theoretical requirements with actual abstractions showed that actual abstractions were much lower than those theoretically required.

Sir William Halcrow and Partners (1992) carried out a study 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 emphasized that local factors would constrain demand in some catchments.

A comprehensive study of spray irrigation in the former NRA South West Region was undertaken by Sainsbury (1992), who reported that the accuracy of the NRA spray irrigation returns was questionable, citing numerous omissions, errors and inconsistencies. The 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 showing vulnerability to drought 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 requirements; it is also of interest 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 by Weatherhead *et al.* (1993).

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. These are likely to be more important than factors such as changes in water charges. Most growth rate estimates 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. For example, the first part of this methodology was used 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. However, these assumptions 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. A combination of methodologies is however possible, where models are used to help predict trends from a baseline determined from statistical data. Such combination methodology was used in this study.

3. IRRIGATION DATA AND CURRENT TRENDS

3.1 Irrigation Data

3.1.1 MAFF Irrigation Survey data

Background

The most accessible national statistics on agricultural irrigation in England and Wales are those collected through the MAFF 'Irrigation of Outdoor Crops' surveys. 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.

Irrigation surveys have been carried out roughly tri-annually, recently in 1974, 1977, 1982, 1984, 1987, 1990 and 1992. The results of the survey carried out in 1992 (MAFF 1993a) were not available for this report. 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, now giving four sets of directly comparable data (1982, 1984, 1987, 1990).

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.

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 course, landscape and residential irrigation;
- subirrigation by raising water tables (assuming farmers would not consider this as irrigation); and
- irrigation of indoor crops, e.g. glasshouses.

Accuracy

Potential inaccuracies in the MAFF data may arise from:

- 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; and
- data collation errors.

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.

Woodley and Stansfield (1986) state that comparisons at county level between MAFF and NRA data for 1982 gave 'acceptable' correlation for volumes. Attempts to check accuracy for the admittedly limited number of farmers interviewed in the project 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, it is believed that the MAFF national data are broadly correct, particularly in regard to trends, providing that 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

It is recommended that the following requests are made to MAFF:

1. Consider re-wording the trigger question, to 'Did you irrigate/are you able to irrigate if necessary?'

2. Consider separating winter abstraction from summer abstraction in the volume by source question.

3. Produce 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 the NRA Regions.

4. 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 the NRA.

MAFF data for the NRA Regions

For this study, the county level data have been aggregated into the ten former NRA Regions. A difficulty arises because the 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 in proportion to the area in each Region; i.e. assuming that 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 that 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 survey data for 1982, 1984, 1987 and 1990 aggregated by NRA Regions as described above. More comprehensive data showing irrigated areas and volumes for each crop are given by Weatherhead et al. (1993).

Table 3.1 Summary of MAFF irrigation data for the ten NRA Regions for 1982, 1984, 1987 and 1990

	Anglian	North West	Northumbria	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

Table 3.2 Summary of MAFF cropping data for the ten NRA Regions for 1982, 1984, 1987 and 1990

	Anglian	North West	Northumbria	Severn-Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire
					Area' cropped (10^3 ha)					
1982	1896	711	417	1488	737	596	651	1136	662	769
1984	1870	709	406	1476	738	590	644	1149	659	752
1987	1778	709	407	1441	730	560	608	1161	642	739
1990	1725	704	394	1402	716	535	574	1150	625	729

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 survey, 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 survey area data, due to the larger sample sizes.

Data for the NRA Regions

Table 3.2 shows a summary of the MAFF cropping census data for 1982, 1984, 1987 and 1990 aggregated by NRA Regions as described previously. The areas for each of the irrigation survey crop categories are given by Weatherhead *et al.* (1993).

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.

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. It should be noted 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 ran 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 (drip) irrigation;
- subirrigation through pipes or by raising water tables, e.g. in the Fens; and
- 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-1970s but has declined to around 1400 ha. Kay (1992) suggests that this figure has stabilized and no significant growth is expected. 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, an estimated total annual use of 2300 Ml is still relatively small and Kay (1992) 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 the majority of this probably 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 diverted or back-pumped from other water courses; 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, as surface evaporation is avoided and rainfall effectiveness and irrigation efficiency should be very high. However, high water use can occur 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 high, or if water tables have been allowed to fall and are 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 (e.g. see 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); and
- 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. This partly explains the apparent discrepancy between published NRA and DoE data. Records may be further distinguished by use, e.g. potatoes, golf courses.

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, to divide 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. A summary of available NRA data and DoE data for licensed abstractions from 1982 to 1992 is given 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.

Table 3.3 Regional licensed and abstracted volumes for spray irrigation

	Anglian	North West	Northumbria	Severn-Trent	South West	Southern	Thames	Welsh	Wessex	Yorkshire
					Licensed volume per year (Ml)					
1982	80264	-	-	35958	515	-	-	-	-	10101
1983	81870	-	227	37604	549	-	11060	4380	-	10897
1984	96871	-	357	39946	1132	-	11133	-	-	11274
1985	108077	-	439	-	1452	-	11461	-	7373	11791
1986	113734	-	526	48657	1495	-	11534	-	7300	14416
1987	119720	-	544	49463	1622	-	11644	-	7081	15248
1988	125195	-	572	50142	1651	-	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	58953	2015	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 fron DoE) (Ml)					
1982	-	-	-	9490	-	-	-	730	-	-
1983	-	-	-	12410	-	-	-	730	-	-
1984	38836	2117	110	14600	1095	3650	4344	1460	2409	4417
1985	20805	913	73	6570	1095	876	2336	730	1460	2471
1986	33325	913	73	13505	1095	2665	2993	730	2190	4380
1987	15951	475	0	9125	1460	1132	2300	730	2190	3478
1988	20805	548	0	9490	1095	2555	2154	4782	2920	4099
1989	53035	1241	0	26645	1095	8760	4161	2336	4015	7508
1990	77855	1424	182	24820	2190	10585	5183	2409	4380	8818
1991	85775	-	-	-	-	-	-	2519	-	9647
1992	-	-	-	-	-	-	-	5475	-	-

Notes: Data from each of the ten former NRA Regions;
Where no data are presented, these are unavailable or considered unreliable by the Region.

The accuracy of the abstraction data is more doubtful than those from licences. Potential errors include:

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

Opinions vary widely about the accuracy of metered readings, and it is probable that there is the same range of variation 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 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, for example by weed, 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. It is suggested that 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. For abstractors on a two-part tariff, the 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 it is suggested that 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. Indeed, some returns show over-abstraction, indicating commendable honesty.

A summary of available NRA data of abstracted volumes from 1982 to 1992 by NRA Region is also given in Table 3.3. It should be noted that while the NRA and MAFF data are in reasonable agreement at the national level, there are considerable differences at the Regional level (Tables 3.1 and 3.3). Some of the differences in definitions, exclusions and calendar year were discussed above, other errors may also have been introduced by the assumptions made when re-aggregating the MAFF data into NRA Regions.

Recommendations for improvement

The following recommendations are made:

1. The national abstraction and licensing database should be introduced, and consideration given to using a GIS-based system to allow aggregation of data by catchment and aquifer.
2. The 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. Work should continue 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. A pilot study should be carried out to estimate the accuracy of metering and establish a correction factor. If appropriate, the NRA should then consider helping establish a non-site recalibration service.
5. Consider should be given to making both licence and abstraction data available to interested parties. The volume abstracted by one abstractor from the national resource is of legitimate interest to other water-users. It is believed that this move would also improve the quality of the abstraction 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

After PMB (1992)

3.1.4 Potato Marketing Board data

Detailed statistics on potato production are available from the Potato Marketing Board (PMB) for Great Britain (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 summarizes the areas planted and irrigation applied from 1987 to 1991. The total areas planted in England and Wales are also shown. The totals agree reasonably well with the MAFF crop census data described in Section 3.1.1.

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 figures derived from MAFF data for 1982 and 1984 (Section 3.2). 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, 1990, Dunham and Clarke 1992).

Table 3.5 Other crops irrigated in conjunction with sugar beet

	1984-1985
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

After 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. 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 or 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 on use for this study, the combination of remote sensing and GIS promises to be a valuable technology in the future.

3.1.7 IACS data

Detailed cropping information is also being collected under the Integrated Agricultural Cropping Survey (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 which they have dealt with.

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 United Kingdom Irrigation Association (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.

Co-operatives, merchants and customers also hold much data on irrigation practices although these are generally commercially confidential. For example, one group of potato processors holds records of the soils, irrigation applied and yield field by field for each of its growers.

3.2 Derived Data

Weatherhead *et al.* (1993) derive the average depths applied to each crop category and the percentage of each crop category irrigated in each NRA Region for 1982, 1984, 1987 and 1990 respectively from MAFF data.

3.3 Current Trends

Since 1982 the MAFF irrigation survey 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

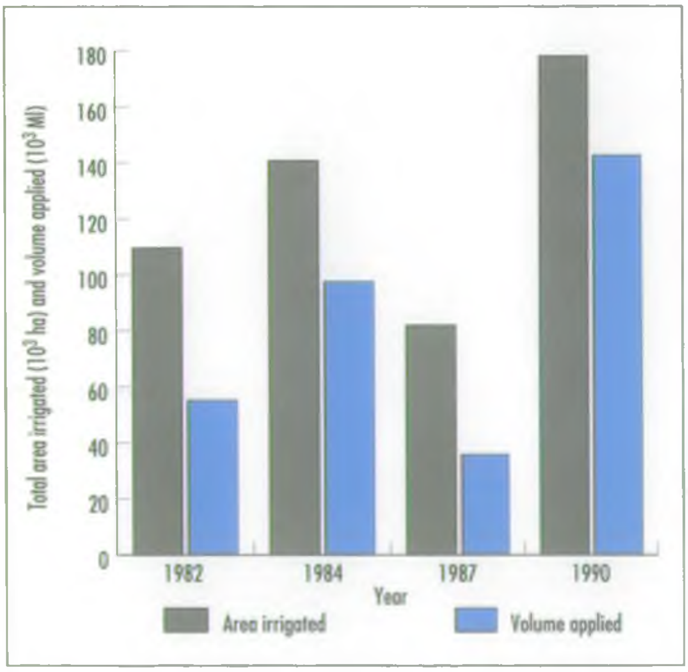

Figure 3.1 Total area irrigated and total volume of water applied in England and Wales, 1982 to 1990

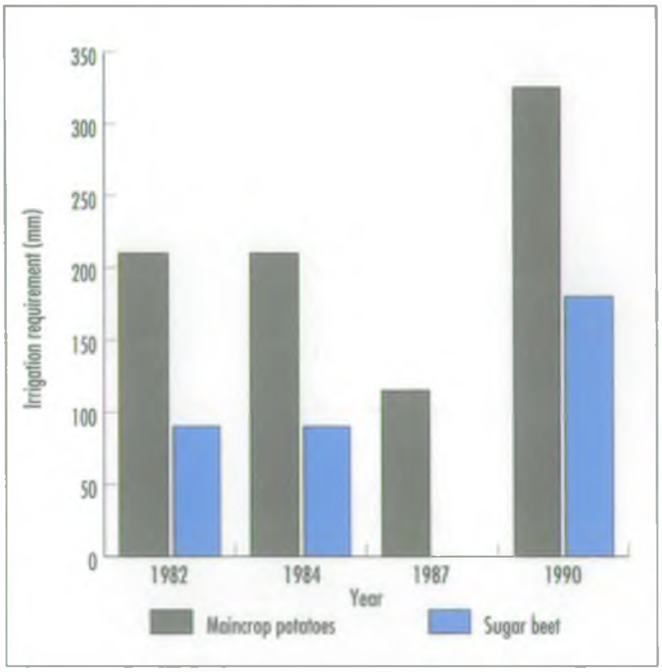

Figure 3.2 Theoretical crop irrigation requirement for maincrop potatoes and sugar beet grown on a medium AWC soil in East Anglia, 1982 to 1990

Table 3.6 Underlying growth rates in the area, volume and depth of irrigation, 1982 to 1990

	% 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	+2
Other	+2	+4	+1
Overall	+1	+2	+2

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).

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. 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 period 1982 to 1990.

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, as 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 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 practices. Changes in these practices would alter the potential theoretical demand.

4.2 Methodology

A computer model developed 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 were used. These were 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 used to provide the daily weather records. Ultimately four stations were used, with data being generated for one zone and irrigation not being required in the zone with least SWD (Table 4.1).

Table 4.1 Climatic zones and representative weather stations

Climatic zone	Mean value of maximum soil water deficit (mm)	Representative weather station
A	0-25	Irrigation 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

Three soils were chosen to represent soil types with low, medium and high AWC 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 4.2 Characteristics of representative soils of 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

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 20 years, are given in Table 4.4. It is emphasized that these are theoretical demands under the assumptions stated, net of any losses; they cannot be used to assess demand on any particular farm.

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
Maincrop 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 25	n/a

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

Climatic zone	Soil type (AWC)	Irrigation requirement (mm) Early potatoes	Maincrop potatoes	Sugar beet	Vegetables (carrots)	Permanent grass
B	Low	30	170	65	125	125
	Medium	24	170	55	80	125
	High	25	170	0	n/a	125
C	Low	35	190	70	130	160
	Medium	30	185	65	80	160
	High	30	185	0	n/a	160
D	Low	45	215	80	140	190
	Medium	40	200	75	80	190
	High	40	200	0	n/a	190
E	Low	50	250	125	175	210
	Medium	45	235	115	140	210
	High	45	225	50	n/a	210
F	Low	60	275	140	175	210
	Medium	50	260	125	160	210
	High	50	260	55	n/a	210

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 of the former ten NRA Regions as derived from MAFF irrigation survey data (Section 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 soil values used throughout. The results are given in Table 4.5. The theoretical requirements calculated for 1990 have also been multiplied by the 1990 irrigated crop areas, derived as above to give the theoretical irrigation requirements by NRA Region (Table 4.6).

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 (1989), who allowed much larger soil water deficits to develop before irrigation. This emphasizes the sensitivity of these theoretical values to the assumptions made. The volumes calculated in Table 4.6 can be compared with the actual volumes applied in 1990 (see Weatherhead *et al.* (1993)). As might be expected, there are a few anomalies (the apparent over-irrigation of early potatoes is due to a

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	1905	56120	22787	22405	10438
North West	90	11432	79	549	541
Northumbria[a]	7	832	21	42	254
Severn-Trent	792	25794	6975	4228	8000
South West[b]	138	856	9	290	891
Southern	555	5197	2	4874	2663
Thames	242	6734	1591	3923	2348
Welsh	280	1470	177	496	834
Wessex[b]	88	1159	115	356	2559
Yorkshire[a]	87	8136	941	499	1654
Total	4184	117730	32697	37662	30182

[a] Now part of Northumbria & Yorkshire Region

[b] Now part of South Western Region

Table 4.6 Theoretical irrigation requirements by NRA Regions for selected crops - 1990

	Theoretical irrigation water requirement (Ml)				
NRA Region	Early potatoes	Main crop potatoes	Sugar beet	Vegetables (carrots)	Permanent grass
Anglian	2046	69553	31835	27718	13446
North West	129	1703	122	686	676
Northumbria[a]	9	902	32	49	343
Severn-Trent	1063	32078	10507	5562	9744
South West[b]	191	999	14	365	1135
Southern	703	6266	3	5806	3303
Thames	282	8312	2196	4866	2957
Welsh	398	1760	276	629	1049
Wessex[b]	126	1413	154	446	3046
Yorkshire[a]	118	9656	1506	653	2085
Total	5065	132642	46645	46780	37784

[a] Now part of Northumbria & Yorkshire Region

[b] Now part of South Western Region

difference in definition), but the overall results support previous studies suggesting that between 40% and 60% of the potential theoretical demand is actually being applied. This discrepancy between theoretical demand and actual applications is not surprising. The theoretical demand assumes that the full crop water requirements will always be met, but for a variety of agronomic, economic and resource limitation factors, it is often sensible or necessary to apply less; for example:

1. 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 irrigate the whole crop partially rather than irrigate part of it fully.

2. 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 financial breakeven point 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.

3. Portable systems can be used to irrigate partially adjacent lower priority cropping at times of spare capacity. These crops enter the statistics as having been under-irrigated, biasing the average depths down.

However, no allowance has been made in the theoretical calculation for losses, poor scheduling, extra irrigation to compensate for non-uniformity, and other inefficiencies. For these and other reasons, demand predictions 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 the UK. 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 not otherwise be feasible. 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 so that generalization 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; and
- 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 by Weatherhead *et al.* (1993).

The capital or initial investment costs without storage are typically £2000 - £2500 per hectare (at 1993 prices), 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 per ha mm applied (1 ha mm = 0.01 Ml). Using a groundwater source increases costs to £4.1 per 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 to £6 per ha mm for storage based systems, although cost savings are evident for large reservoirs.

Trickle tape systems cost about £5.1 per ha mm assuming the infield tape can be used a second time. Centre pivots offer economies of scale with average costs of about £4.0 per ha mm to £3.4 per 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 per ha mm to £1.4 per ha mm for mobile and automated trickle systems. For sprinkler sets they are about £2.3 per 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

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	

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 unreliable. 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 Varvarigos and Hinton (1990) in the mid-1980s confirmed the great variation in system size, water use, crops irrigated and costs. At 1993 prices, capital costs varied from £500 to almost £3000 per hectare, and average total costs were typically about £8.5 per 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.

5.2.2 Sensitivity analysis

Table 5.2 shows the percentage 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, an increase or decrease of 10% 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.

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.

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

* 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).

5.3 Irrigation Benefits

The main purpose of irrigation is to increase the level and reliability of 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 among 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 premiums 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. 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. 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 maincrop potatoes generates a yield benefit of £5.44 per 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.

In areas of irrigation need, the average response in dry matter (DM) yield in grassland is equivalent to an extra

Table 5.3 Average yield response of crops to irrigation and related financial benefits (1993 prices)

	Crop price (£/t)	Extra crop costs (£/t)	Extra net margin (£/t)	Yield response (t/ha mm)	Financial benefit (£/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	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
Brussels 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 - grazed	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
combinable 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).

25% of yield without irrigation (Garwood 1979). This is equivalent to about 0.025 tonne DM per ha mm. Irrigation can also stabilize the growth of grass during the season and lengthen the grazing period. 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 per tonne DM (11400 MJ/tDM x 80% utilization factor x £.01/MJ). This is not very different from the value of cereals, which in turn are not very responsive to irrigation.

Carr *et al.* (1991) analyzed data from a number of sources on irrigation yield benefits in the UK.

Table 5.4 Crop response to irrigation 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	0.00	40	30	20	3.38	2.10	0.00
Winter barley	6.00	1.50	0.70	0.00	40	30	20	3.27	2.04	0.00
Spring barley	5.00	1.50	0.70	0.00	40	30	20	3.27	2.04	0.00
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 - grazed	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

*Closely correlated with dry, medium and wet summers
After Bailey (1990)

Drawing on these and other sources, Table 5.4 summarizes 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 (however the definition of the adequacy of rainfall varies between crops). Irrigation gives greatest yield response and related yield benefits in dry years.

Actual seasonal weather records over a 24-year period were used to model 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 Varvarigos and Hinton (1990) who solicited the 'considered opinions' of farmers regarding crop yield response.

Table 5.5 Average response and value added from irrigation due to yield increase alone

	Average potential yield (t/ha)	Yield without irrigation (%)	Irrigation water applied (mm)	Extra yield due to irrigation (t/ha)	Yield benefit (£/ha)	(£/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	1158	11.8	103	9.0
Grass	6	77	183	1.4	128	0.8
Runner beans	21	88	48	2.5	730	8.3

Notes: Derived from Silsoe College's Irrigation Water Requirements scheduling model using 24 years weather data on medium AWC soils in dry area. Based on average yields assuming adequate water.

Table 5.6 Crop quality benefits

	Potential yields	Average price	Mean irrigation water applied	Benefit due to irrigation by quality price		
				Premium		
				10%	20%	30%
	(t/ha)	(£/t)	(mm)		(£/ha mm)	
Maincrop potatoes	40	80	117	2.73[1]	5.46	8.19
Early potatoes	25	125	68	4.62	9.24	13.86
Sugar beet	42	35	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
Carots	37	80	79	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 - grazed	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	16.70	25.07
Raspberries	4	1240	50	10.00	20.00	30.06
Blackcurrants	6	550	50	6.67	13.30	20.00
Dessert apples	11	350	79	4.86	9.72	14.58

[1] For example, 40 t/ha x £80/t x 10% premium divided by 117 mm/ha = £2.73/ha mm

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.

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.

Irrigation also plays a 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 premiums 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.

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 per ha mm in order to recover average total costs - £5.9 per ha mm where PVC-lined reservoirs are required. Once installed, however, irrigation is relatively cheap to use: operating

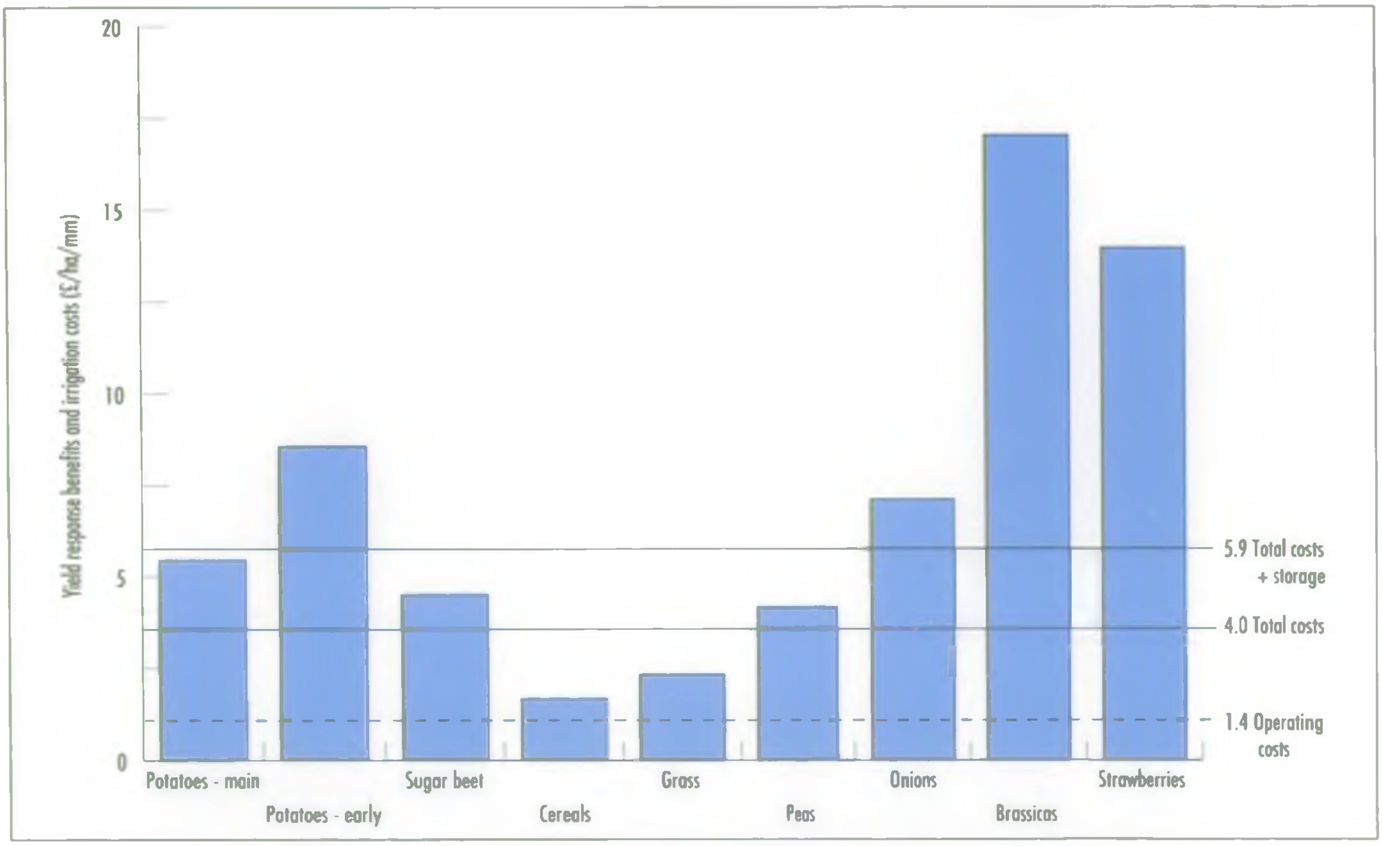

Figure 5.1 Comparison of yield response benefits (shown as histograms) and irrigation costs

Notes: Yield response benefits = Extra net margin due to yield response
Total costs = Average total costs for direct abstraction (hosereels)
Total costs + storage = Average total costs for direct abstraction and water storage systems (hosereels)
Operating costs = Repairs, fuel, labour, water charges.

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

	Crop price (£/t)	Extra net margin (£/t)	Crop response (t/ha mm)	Percentage change in variable to break even: 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 - grazed	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

Notes:

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

costs at about £1.4 per 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. 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 of 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.

With respect to quality benefits, the same pattern emerges. Quality premiums 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 percentage change in a variable necessary to meet the financial break even point for irrigation. For example, for a direct abstraction hosereel system on maincrop potatoes, average costs are £3.98 per ha mm and average benefits from yield increase alone are £5.44 per ha mm (Table 5.3), giving a value-added after irrigation costs of £1.46 per 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. This 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 premiums 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 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 liberalization 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 quotas 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.

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). 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 (e.g. pre-CAP reforms) to complete trade liberalization (e.g. post-General Agreement on Tariffs and Trade (GATT)). These policy scenarios are described in terms of likely changes in producer prices, yields and areas up to 2021. The implication of these changes for the irrigation sector and water demand was assessed.

5.6.1 Scenario I: pre-reform status

This scenario describes that which prevailed in 1992 prior to the CAP reform. Support prices are kept high by protectionist measures and intervention purchasing.

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 (mostly 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 the 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 vegetables	1.072	1.089	1.067	1.038	1.005	0.968
Brassicas	1.002	0.981	0.952	0.920	0.887	0.854
Protected vegetables	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
Oilseed 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
Oilseed 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 vegetables	0.928	0.877	0.853	0.836	0.824	0.817
Protected vegetables	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
Oilseed rape	0.927	0.840	0.818	0.802	0.782	0.750
Total horticulture	0.952	0.912	0.891	0.874	0.863	0.855

Table 5.9 Estimated changes in producer prices, yields and area under the liberalization 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 vegetables	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 vegetables	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
Oilseed 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
Oilseed 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 vegetables	0.965	1.057	1.034	1.012	0.996	0.984
Protected vegetables	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
Oilseed rape	0.831	1.291	1.826	2.438	3.160	3.937
Total horticulture	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 vegetables	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 vegetables	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
Oilseed 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
Oilseed 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 potaotes	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 vegetables	0.947	0.967	0.944	0.924	0.910	0.900
Protected vegetables	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
Oilseed rape	0.879	1.065	1.322	1.620	1.971	2.343
Total horticulture	0.969	0.997	0.975	0.958	0.944	0.934

5.6.2 Scenario II: complete liberalization and free trade

Scenario II implies the implementation of the GATT proposals for trade in agricultural commodities: complete liberalization and free trade.

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. The 40% reduction in sugar beet prices would render irrigation unfeasible. 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 perhaps 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. It is this third scenario that is expected, and therefore used for the irrigation demand predictions. This scenario relates to the current policy regime introduced in 1992/93 which involves a reform of CAP under a new 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 livestock 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.

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 liberalization and removal of support to agriculture.

- The absolute profitability of irrigation will be similarly affected; benefits will increase less than costs. Crops currently 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 premiums. 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 robust, versatile, labour-efficient and fit in well on the typical highly-mechanized 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 northern Europe and north eastern United States.

From the water use point of view, the main problem with hosereel irrigators is non-uniformity of application, particularly in windy weather. While farmers under-irrigate, this leads to non-uniform cropping rather than waste of water, but it would lead to low efficiency of water use if higher levels of irrigation adequacy were sought, e.g. on high value crops.

Although conventional portable sprinkler systems are versatile, high labour costs in the UK meant that 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 irrigation survey data are now only used as back-up or for odd corners. Scope for further water savings is limited.

Mechanized laterals, mostly centre pivots, grew in popularity 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 and Bliesner (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 1991 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.

6.2 Distribution and Storage

Almost all distribution systems in the UK use pressurized pipes. Unlike most European countries, there is no potential for water-saving by reducing canal losses from evaporation and seepage. No data on irrigation pipe leakage have been found, but it is probably small. Irrigation mains are generally newer than water supply mains and only pressurized 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. 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 takes place 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. Better scheduling should increase the efficiency of water use, but paradoxically if it confirms that farmers are under-irrigating, it may actually result in increased 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 any 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.

Much research has been carried out on these and similar techniques, but mostly for optimizing production rather than water conservation. 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. No major breakthrough in this area was identified. 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 for 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 of 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 under way are important for short and even medium-term predictions. These changes appear to suggest a trend towards greater seasonal application depths.

7. PREDICTIONS

7.1 Introduction

This chapter aims to produce 'most likely', 'high' and 'low' irrigation demand forecasts. The forecasts are for a design 'dry' year such as 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.

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 predictions midway between Scenario I (pre-reform status) and Scenario II (liberalization and free trade). The national 'most likely' predictions 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 census data (MAFF 1993b) 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' predictions 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), and expert opinion.

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 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' predictions 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 for fruit and some vegetables.

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 predictions into the long term suggest modest increases to 197 000 ha by the year 2011 and 202 000 ha by the 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 the year 2021 is 237 000 Ml. The low and high estimates are about +/- 20% either side of the most likely prediction for the year 2001, but this gap widens to about +/- 40% for the year 2021.

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		
Prediction:	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) predictions 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
Prediction	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

7.3.2 National predictions for Scenarios I and II

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

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 the year 2001, rising to an extra 25% and 12% respectively by the 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 the year 2001. By the 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 'most likely' predictions for Scenarios I and II all fall between the high and low estimates for the expected Scenario III.

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

	Predicted irrigated area (ha)					
	1996	2001	2006	2011	2016	2021
SCENARIO III ML						
Early potatoes	9951	10377	10706	10956	11152	11290
Main potatoes	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
Vegetables for human consumption	19300	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	174991	191241	194528	197267	199839	202252
SCENARIO III H						
Early potatoes	10816	11622	12135	12440	12611	12677
Main potaotes	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
Vegetables for human consumption	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	206235	226554	241178	253216	263425	271786
SCENARIO III L						
Early potatoes	8950	8950	8950	8950	8950	8950
Main potaotes	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
Vegetables for human consumption	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	167016	164686	165008	167054	170191	173994

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

	Predicted irrigated area (Ml)					
	1996	2001	2006	2011	2016	2021
SCENARIO III ML						
Early potatoes	9269	10087	10820	11475	12069	12594
Main potaotes	78148	86053	91526	95411	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
Vegetables for human consumption	22526	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	175611	194358	206697	217735	227994	237406
SCENARIO III H						
Early potatoes	10604	12265	13627	14730	15631	16346
Main potaotes	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
Vegetables for human consumption	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	242832	272720	298633	321343	341035
SCENARIO III L						
Early potatoes	7876	7876	7876	7876	7876	7876
Main potaotes	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
Vegetables for human consumption	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	162839	167899

Table 7.5 Predicted irrigated areas 1996 to 2021 under Scenarios I and II

	Predicted irrigated area (ha)					
	1996	2001	2006	2011	2016	2021
SCENARIO I ML						
Early potatoes	10400	11046	11499	11807	12015	12135
Main potatoes	59830	63317	65071	65411	64941	63852
Sugar beet	34747	37991	40751	43656	46506	49304
Orchard fruit	3344	3341	3322	3300	3283	3272
Small fruit	4852	6125	6964	7654	8216	8663
Vegetables for human consumption	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	212576	224437	234729	243898	251900
SCENARIO II ML						
Early potatoes	9469	9868	10240	10586	10909	11209
Main potatoes	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
Vegetables for human consumption	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	172733	173949	177280	181894	187236	192944

7.3.3 Regional predictions

The analysis has been repeated for each of the former ten NRA Regions, 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 predictions (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.

An equivalent prediction using the NRA 1990 abstraction data for the baseline can be obtained by substituting these values for the 1990 MAFF-based data and adjusting all the predicted values by the same ratios. The result is shown in Table 7.8. A 10% allowance has again been made for drought restrictions in force in 1990.

Table 7.6 Predicted irrigation water volumes 1996 to 2021 under Scenarios I and II

	Predicted irrigation water volumes (Ml)					
	1996	2001	2006	2011	2016	2021
SCENARIO I ML						
Early potatoes	9687	10737	11622	12366	13003	13536
Main potatoes	81221	89703	99849	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
Vegetables for human consumption	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	187814	207335	228634	239604	252952	264811
SCENARIO II ML						
Early potatoes	8819	9592	10349	11088	11806	12503
Main potatoes	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
Vegetables for human consumption	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	168525	182620	198028	214165	230631	247136

7.4 Conclusions

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.

Table 7.7 Predicted irrigation water volumes for each NRA Region, 1996 to 2021, for the 'most likely' predictions under Scenario III, based on 1990 MAFF data (+10%)

	Predicted 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
Northumbria[a]	880	994	1055	1106	1153	1197	1238
Severn-Trent	39324	45020	48000	50096	51783	53214	54410
South West[b]	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[b]	2880	2938	3065	3175	3299	3433	3572
Yorkshire[a]	9568	11327	12253	13013	13693	14322	14889
Total	156970	178351	194357	206697	217765	227995	237407

[a] Now part of Northumbria & Yorkshire Region
[b] Now part of South Western Region

Table 7.8 Predicted irrigation water volumes for each NRA Region, 1996 to 2021, for the 'most likely' (ML) predictions under Scenario III, based on 1990 NRA data (+10%)

	Predicted irrigation water volumes (Ml)						
	(1990)	1996	2001	2006	2011	2016	2021
Anglian	85641	99375	109267	117058	124088	130619	136681
North West	1566	1789	1984	2154	2322	2490	2656
Northumbria[a]	201	227	241	253	264	274	283
Severn-Trent	27302	31257	33326	34781	35952	36946	37776
South West[b]	2409	2650	2848	3028	3216	3413	3615
Southern	11644	12834	14902	16512	18028	19445	20759
Thames	5701	5314	5536	5639	5735	5829	5923
Welsh	2650	3034	3379	3670	3949	4219	4477
Wessex[b]	4818	4915	5127	5312	5520	5744	5977
Yorkshire[a]	9700	11484	12422	13193	13882	14520	15095
Total	151632	172879	189032	201600	212956	223499	233242

[a] Now part of Northumbria & Yorkshire Region
[b] Now part of South Western Region

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 142 000 Ml were applied in total. Of this, 73 000 Ml were abstracted from springs and watercourses over the year, 52 000 Ml came from groundwater sources, and the remainder came from old gravel/clay pits, mains and other sources. Because total on-farm storage capacity was only 40 000 Ml (not all of which would have been used), at least 33 000 ML, and probably over 40 000 Ml, came from direct summer abstraction from springs and watercourses. Groundwater use would also have been mostly summer abstraction.

The most likely prediction foresees an additional 37 000 Ml demand by 2001 and another 43 000 Ml by 2021. Much of this extra demand will be in areas already short of water. Clearly a period of conflict will 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.

The benefits of irrigation to farmers were discussed in Chapter 5. Benefits to the consumer include high quality produce, potentially more stable prices through elimination of weather variables, and potentially lower prices from resulting cost-savings in production, storage and processing. There are also substantial import substitution benefits to the nation, and potential for increased exports, supporting the balance of payments and UK employment levels. 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 for water resources would then be a good indication of the national interest.

The present water market, however, is far from perfect. On one side, optimum cropping is distorted by subsidies, quota systems and other restrictions. On the other side, the cost recovery constraint on charges means that it is impossible to adopt a long-run marginal costing approach; environmental costs cannot be fully incorporated and abstraction charges are too low to have any significant incentive effect.

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 which irrigators are aiming for, are already outside price support systems. The quotas on potato production are likely to be loosened or 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 liberalization 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 inflating the total demand for water.

It is recognized 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 to the environment of abstraction. Conserving the general water-related environment is clearly also very much in the national interest. Placing a financial value on environmental changes is extremely difficult, although attempts are made, for example in connection with conservation schemes, and detailed analysis is beyond the scope of this study.

Generally, the problem areas are summer abstractions from watercourses during periods of low flow and excessive abstractions from unconfined aquifers (hence affecting springlines). The problems are often site-specific and need to be addressed at catchment/aquifer scale (e.g. within the context of the relevant NRA catchment management plan) or even on individual sites. Whilst in some cases environmental constraints may exclude additional abstraction, in others, problems may be minimal or can be avoided or compensated for by improvements elsewhere. The costs incurred in such work can be fairly accurately assessed.

There appears to be general agreement that there can actually be environmental benefits from on-farm storage if the reservoirs are designed and operated in an environmentally-sensitive manner, so that conflict is not inevitable. Any argument may therefore be more between direct abstraction and storage, rather than whether to supply water at all. Similarly there are suggestions that, although irrigated farming uses higher fertiliser inputs per unit area, the combination of higher yields, lower post-harvest losses, improved control of fertiliser application and improved fertiliser availability to the crop could together result in reduced nitrate leaching for a given volume of produce.

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, it is suggested that (increased) irrigation of most irrigated crops can be 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.

8.3 NRA Options for Response

A number of specific possible NRA responses, as suggested by the NRA and others were discussed with the Project Consultative Panel, farmers and other interested parties. Key suggestions are presented and 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 utilized, 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. This is not as simple as it sounds, as cropping patterns change.

(b) As (a) but constrained by some overriding national food production objective.

The prospect of the NRA prioritizing crops on licences was almost universally disfavoured. It was thought impractical given the complexity of scheduling and prioritization, 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 to control nationally the production of subsidized 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.

It is recommended that 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 and encouraging proper water use. 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 that winter abstraction and on-farm storage will have to play an increasing role if extra demand is to be met. This is seen by both the farming community and environmental bodies such as English Nature as potentially environmentally beneficial if reservoirs are well designed, and could hence avoid much of the controversy surrounding the use of water for irrigation. From the farmers' viewpoint, such water is reliable, i.e. not subject to restrictions, and hence allows more conservative scheduling. Farmers' readiness to improve on the reliability of supply is illustrated by the investments that many have already made in water storage facilities. 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 is disagreement over who should pay for on-farm storage. It is generally agreed that costs should fall fairly and equitably on the beneficiaries. This is usually initially the abstractor and ultimately the consumer. However, in some instances the beneficiary is other water users (e.g. where reservoirs replace existing summer abstraction) or the nation (e.g. through increased employment, balance of payments, environmental gain).

Many parties particularly stressed that work correcting previous over-licensing and alleviating environmental problems caused by past policies should be funded by the community as a whole.

The National Farmers' Union (NFU) consider that the most effective means of encouraging on-farm storage would be through construction grants, possibly linked to the exchange of summer abstraction for winter abstraction licences. This scheme would be consistent with the principle that grants are appropriate to encourage action that will alleviate environmental problems (NFU 1993).

An alternative view favours water-price and availability incentives to encourage on-farm storage. In this context, an increased differential between summer and winter abstraction charges is favoured. Indeed, there is support for recommendations to the NRA by Rees *et al.* (1993) to reduce the 'volume abstracted' element of the winter abstraction charges to zero. This would then allow simpler metering and reporting requirements, giving further small but useful cost savings. At current charge levels these changes alone would be insufficient to persuade farmers to invest in on-farm storage.

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

This option was generally less favoured except where economies-of-scale, or incorporation in a multi-use scheme, 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 how the cost is split is a major concern, as all abstractors would gain reliability of supplies. Farmers generally are to pay more for reliable supplies, but the level is likely to be a subject for controversy. Depending on crop and sales contract liabilities etc., different farmers value reliability of supplies very differently.

(e) Other

A number of other options were discussed. Most had practical limitations, but would be worth considering where conditions allow.

Any support from the NRA for promoting technical and management improvement in irrigation would be welcomed by the industry. Current practice ranges from the highly efficient to the poor, and advances in equipment and scheduling offer further improvements to water use efficiency. Some of the potential areas for improvement are discussed in Section 6.

The re-use of effluent could have implications for public relations if not real health risks. It is also likely to be expensive. There may however be local opportunities for the use of low-quality water, e.g. with high nitrate levels or slight salinity, and water used in cooling towers and food processing.

The NFU (1993) suggest that more use might be made of any periods of high river flows occurring during the summer abstraction period, perhaps by redefining 'summer' in terms of river flow rather than calendar date. Generally however, high flows do not occur during drought years.

Promoting the conjunctive use of surface water and groundwater with (limited) reservoir storage, where feasible, would increase the reliability of supply. Surface water and groundwater droughts often occur separately. Surface water is more available in the early summer, allowing reservoir supplies and groundwater to be reserved for later in the year. Confined aquifers which recharge slowly could be reserved for emergency use in drought years only. Conjunctive use is already widely practised by public water suppliers, but is rare at farm level, partly because of cost and partly because there is limited incentive within the current licensing scheme. The ability to trade water and water rights between local farmers, and/or to pool existing rights within an 'irrigation water company' owned jointly by the farmers, would have many attractions and should lead to an economically more efficient use of the available water. At least one group of farmers is currently considering the latter option. Possible benefits include increased flexibility and reliability of supplies, reduced costs, joint investment in winter storage or NRA augmentation works, and greater opportunities for conjunctive use.

The view was put forward that this is likely to lead to the reactivation of some currently under-used licences, and hence lead to a higher proportion of licensed quantities being abstracted. There is also a question as to whether the windfall profits should benefit only existing licence holders.

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. MAFF is responsible for securing food production, but is increasingly concerned with protection of the agricultural environment. 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.

Regular bilateral meetings between the NRA and organizations including the County Landowners' Association (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 management plans, Regional water resource plans and now a national water resource plan, are providing a more rational framework within which to negotiate.

The National Agricultural Water Resource Forum will be central to discussions on irrigation issues. This includes representatives of the NRA, MAFF, CLA, NFU and UKIA. The forum enables general policy guidelines, any necessary revision to legislation, research requirements and future developments to be discussed.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The predictions for the growth in demand for water for agricultural irrigation in England and Wales are summarized in Table 9.1. It is emphasized that these are demands and actual usage will be reduced by any restrictions on water availability.

It is believed that it is in the national interest to meet these demands where possible, subject however to adequate protection of the environment and full costs being charged to the beneficiaries.

9.2 Recommendations

9.2.1 Improvements to irrigation data

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

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

3. The NRA should ask MAFF to continue producing irrigation survey 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 the NRA Regions.

4. The NRA should ask MAFF to consider recompiling irrigation survey 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 is quite feasible. Catchment and aquifer-based totals would be much more useful to the NRA.

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

6. The 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.

7. The 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.

Table 9.1 Predictions of 'dry' year volumetric demand for irrigation water in England and Wales, 1996 to 2021

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

Notes: 1990 values (for comparison) are actual abstractions based on MAFF data plus 10% to allow for restrictions then in force.

8. The 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 assisting the establishment of an on-site recalibration service.

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

9.2.2 Response to the predicted growth in irrigation water demand

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

11. The NRA should license any remaining summer water, although not necessarily on a first-come first-served basis.

12. The NRA should help encourage and promote technical and managerial improvements in the use of irrigation water.

13. The 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 and encouraging proper water use. Once water is allocated, each farmer should decide how best to use it.

14. The NRA should encourage additional on-farm storage where feasible. Water price and availability incentives could be used, possibly reducing to zero the 'volume abstracted' element of the winter abstraction charges and relaxing the metering requirements for winter abstraction. The NRA could provide (or encourage others to provide) free advice to existing summer abstractors on the feasibility, cost and benefits of switching to winter storage.

15. The NRA should undertake augmentation works, at the beneficiaries' expense, where technical factors give such works a clear advantage over on-farm storage.

16. The NRA should seek amendments to the Water Resources Act 1991 to bring trickle irrigation and abstractions for subirrigation within the licensing requirements.

9.2.3 Improved liaison between the NRA, Government and the farming industry

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

18. This forum should discuss general policy guidelines, any necessary revision to legislation, research requirements and future developments. The forum should try to produce agreed responses to the forecast increase in demand for irrigation water. Recommendations produced would be purely advisory for all parties, but would form a strong basis for action.

19. The NRA should use this forum to promote a full public debate into issues raised by the possibility of tradeable permits, pooling licences into 'irrigation water companies' and changes in licensing legislation.

9.2.4 Updates to the irrigation demand forecasts

20. The NRA should update the calculations of underlying growth rates, utilising the 1992 MAFF Irrigation Survey data.

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

9.2.5 Additional research

22. The NRA should support, and encourage MAFF to support, further research into the environmental impacts of irrigated agriculture.

23. The NRA should help identify possible sources of available low quality (secondary) water and support research into its usability for irrigation.

REFERENCES

Advisory Council for Agriculture and Horticulture in England and Wales (1980) *Water for Irrigation: Future needs.* Her Majesty's Stationery Office: London.

Agricultural Development and Advisory Service (1977) *The economics of irrigation,* Report of the Working Party of the Agricultural Development Advisory Service. Ministry of Agriculture, Fisheries and Food.

Anglian Water Authority (1982) *Anglian Water forecasts of demand for direct water use and for in-river needs.* Anglian Water Authority.

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

Bailey, R.J. (1990) *Irrigated Crops and their Management.* Farming Press Books,: Ipswich.

Bailey, R.J. and Minhinick, R.(1989) The agricultural requirements for water with particular reference to irrigation, *Irrigation News,* **15,** 19-30.

Burton, M.P. (1992) *An Agricultural Policy Model for the UK.* Avebury.

Carr, M.K.V., Wright, E. and Hamer, P.J.C. (1991) *Irrigation of field vegetable and arable crops,* Report to the Ministry of Agriculture, Fisheries and Food. Department of Agricultural Water Management, Silsoe College, Cranfield Institute of Technology, Silsoe, UK.

Cowton, M.I. (1981) *A technique for the assessment of irrigation needs: case study for potatoes in Kent.* MSc Thesis, Volumes 1 and 2. National College of Agricultural Engineering, Silsoe, UK.

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] National Rivers Authority.

Doyle, C. and Elliot, J.G. (1983) Putting an economic value on increases in grass production, *Grass and Forage Sciences,* **38,** 169-177.

Dunham, R.J. (1988) Irrigation of sugar beet: the main effects, *British Sugar Beet Review,* **56,** No.3, 34-37.

Dunham, R.J. (1990) Irrigation of sugar beet: the benefits in 1989, *British Sugar Beet Review,* **58,** No.2, 15-18.

Dunham, R.J. and Clarke, N. (1992) Coping with stress, *British Sugar Beet Review,* **60,** No.1, 10-13.

Dunham, R.J., Messem, A.B. and Turner, R. (1987) Irrigation of sugar beet - a survey, *British Sugar Beet Review,* **55,** No.2, 30-34.

Dutta, Sunil C. H. (1989) *Irrigation demand forecasting: A methodology and case studies in eastern England.* PhD Thesis, Silsoe College, Cranfield Institute of Technology, Silsoe, UK.

Ejikeme, E. (1989) *Spray irrigation requirements in Severn basin.* MSc Thesis, University of Birmingham, UK.

Gallagher, R. A. (1984) *Water for irrigation in the UK: demand, availability, and the growth of on-farm storage.* MSc Thesis, Silsoe College, Cranfield Institute of Technology, Silsoe, UK.

Garwood, E.A. (1979) Water control and grassland productivity. In *British Grassland Society Water Meeting* (1979).

Halcrow, Sir William, and Partners (1992) *Water Resources Development Strategy.* [South West Region]. National Rivers Authority.

Hawes, S.M. (1982) The relative costs of water storage projects for irrigation, *Irrigation News,* **3,** 21-24.

Hinton, L. and Housden, W.C. (1991) *Economic results from horticulture 1989 harvest year.* Agricultural Economics Unit, Department of Land Economy, University of Cambridge.

Hinton, L. and Housden, W.C. (1992) *Economic results from horticulture 1990 harvest year.* Agricultural Economics Unit, Department of Land Economy, University of Cambridge.

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, Silsoe, UK.

Keller, J. and Bliesner, R.D. (1990) *Sprinkle and Trickle Irrigation.* Van Nostrand Reinhold: New York.

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,* 7 (5) (in press).

Ministry of Agriculture, Fisheries and Food (1983a) *Agricultural and Horticultural Returns -Final Results of the June 1982 Census in England and Wales.* Ministry of Agriculture, Fisheries and Food: Guildford.

Ministry of Agriculture, Fisheries and Food (1983b) *Irrigation of outdoor crops - Enquiry 1983 - England and Wales Area of Crops Irrigated in 1982.* Ministry of Agriculture, Fisheries and Food Guildford.

Ministry of Agriculture, Fisheries and Food (1984) *Irrigation - why and when,* Booklet 2067. Agricultural Development and Advisory Service, Ministry of Agriculture, Fisheries and Food.

Ministry of Agriculture, Fisheries and Food (1985a) *Irrigation of outdoor crops - Enquiry 1985 - England and Wales Area of Crops Irrigated in 1984.* Ministry of Agriculture, Fisheries and Food: Guildford.

Ministry of Agriculture, Fisheries and Food (1985b) *Agricultural and Horticultural Returns -Final Results of the June 1984 Census in England and Wales.* Ministry of Agriculture, Fisheries and Food: Guildford.

Ministry of Agriculture, Fisheries and Food (1988a) *Agricultural and Horticultural Returns -Final Results of the June 1987 Census in England and Wales.* Ministry of Agriculture, Fisheries and Food: Guildford.

Ministry of Agriculture, Fisheries and Food (1988b) *Irrigation of outdoor crops - Enquiry 1988 - England and Wales Area of Crops Irrigated in 1987.* Ministry of Agriculture, Fisheries and Food: Guildford.

Ministry of Agriculture, Fisheries and Food (1991a) *Irrigation of outdoor crops - Enquiry 1991 - England and Wales Area of Crops Irrigated in 1990.* Ministry of Agriculture, Fisheries and Food: Guildford.

Ministry of Agriculture, Fisheries and Food (1991b) *Final Results of the June 1990 Agricultural and Horticultural Census: England and Wales, Regions and Counties.* Ministry of Agriculture, Fisheries and Food: Guildford.

Ministry of Agriculture, Fisheries and Food (1993a) *Survey of Irrigation of outdoor crops in 1992, England and Wales.* Ministry of Agriculture, Fisheries and Food: Guildford.

Ministry of Agriculture, Fisheries and Food (1993b) *Final Results of the June 1992 Agricultural and Horticultural Census: England and Wales, Regions and Counties.* Ministry of Agriculture, Fisheries and Food: Guildford.

Morris, J. (1983) UK irrigation costs, benefits and feasibility, *Irrigation News,* **5**, 64-75.

Morris, J. (1993) The economics of irrigation for potatoes in Britain. In *Irrigating Potatoes,* UK Irrigation Association Technical Monograph 4 edited by R.J. Bailey. Cranfield Press: Cranfield.

Morris, J. and Day, R. (1985) The costs, benefits and feasibility of UK irrigation: getting it right. In *Proceedings of the Royal Agricultural Society Conference,* Stoneleigh 1985.

Morris, J. and Sutherland, D.C. (1991) Changes in the economics of irrigated crop production: irrigation in the 1990s, *Irrigation News,* **18**, 27-35.

National Farmers' Union (1993) *Better Use of Water - The NFU's Proposals. A discussion document.* National Farmers' Union.

National Opinion Poll Market Research Ltd. (1979) Survey of demand for irrigation water. Anglian Water Authority.

National Rivers Authority (1990) *Forecasts of abstraction demands for water, 1990 series, public water supply and direct abstraction.* [Anglian Region] National Rivers Authority.

Nix, J.S. (1992) *Farm management pocketbook* (23rd Edition). Wye College, University of London.

Potato Marketing Board (1992) *Potato statistics in Great Britain 1987-91.* Potato Marketing Board: Oxford.

Rees, J.A., Williams, S., Atkins, J.P., Hammond, C.J., Trotter, S.D. (1993) *Economics of water resource management.* National Rivers Authority Research and Development Note 128. National Rivers Authority: Bristol (Restricted).

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

Sainsbury, R. (1992) *Non mains agricultural demand, Stage 1: Regional geographic overview of agricultural and non agricultural demand for spray irrigation.* [South Western Region] National Rivers Authority.

Smith, L.P. (1984) *The agricultural climate of England and Wales,* Ministry of Agriculture, Fisheries and Food/Agricultural Development and Advisory Service Reference book 435. Her Majesty's Stationery Office: London.

University of Newcastle-upon-Tyne (1990) *Water resources and demands in the Middle Level.* [Anglian Region] National Rivers Authority.

Varvarigos, P. and Hinton, L. (1990) An economic assessment of irrigation in East Anglia, *Irrigation News,* **16**, 13-26.

Weatherhead, E.K.,Place, A.J., Morris, J. and Burton, M. (1993) *Demand for Irrigation Water.* National Rivers Authority Research and Development Project Record 413/3/A. National Rivers Authority: Bristol.

Vaughan, R.L. and Crane, R.T. (1991) *Horticultural business data.* Department of Agricultural Economics and Management, University of Reading.

Woodley, R. and Stansfield, C. B. (1986) The Ministry of Agriculture, Fisheries and Food 1985 irrigation survey, *Irrigation News,* **9**, 44-47.

HEAD OFFICE
Rivers House
Waterside Drive
Aztec West
Almondsbury
Bristol
BS12 4UD
Tel: (0454) 624400
Fax: (0454) 624409

LONDON OFFICE
Eastbury House
30-34 Albert Embankment
London SE1 7TL
Tel: (071) 820 0101
Fax: (071) 820 1603

ANGLIAN
Kingfisher House
Goldhay Way
Orton Goldhay
Peterborough PE2 5ZR
Tel: (0733) 371811
Fax: (0733) 231840

NORTHUMBRIA & YORKSHIRE
21 Park Square South
Leeds LS1 2QG
Tel: (0532) 440191
Fax: (0532) 461889
Gosforth Office
Eldon House
Regent Centre
Gosforth
Newcastle Upon Tyne
NE3 3UD
Tel: (091) 213 0266
Fax: (091) 284 5069

NORTH WEST
Richard Fairclough House
Knutsford Road
Warrington WA4 1HG
Tel: (0925) 653999
Fax: (0925) 415961

SEVERN-TRENT
Sapphire East
550 Streetsbrook Road
Solihull B91 1QT
Tel: (021) 711 2324
Fax: (021) 711 5824

SOUTHERN
Guildbourne House
Chatsworth Road
Worthing
West Sussex BN11 1LD
Tel: (0903) 820692
Fax: (0903) 821832

SOUTH WESTERN
Manley House
Kestrel Way
Exeter EX2 7LQ
Tel: (0392) 444000
Fax: (0392) 444238
Bridgwater Office
Rivers House
East Quay
Bridgwater
Somerset TA6 4YS
Tel: (0278) 457333
Fax: (0278) 452985

THAMES
Kings Meadow House
Kings Meadow Road
Reading RG1 8DQ
Tel: (0734) 535000
Fax: (0734) 500388

WELSH
Rivers House/Plas-yr-Afon
St Mellons Business Park
St Mellons
Cardiff CF3 0LT
Tel: (0222) 770088
Fax: (0222) 798555

The NRA is committed to the principles of stewardship and sustainability. In addition to pursuing its statutory responsibilities as Guardians of the Water Environment, the NRA will aim to establish and demonstrate wise environmental practice throughout all its functions.

HMSO

HMSO publications are available from:

HMSO Publications Centre
(Mail, fax and telephone orders only)
PO Box 276, London, SW8 5DT
Telephone orders 071-873 9090
General enquiries 071-873 0011
(queuing system in operation for both numbers)
Fax orders 071-873 8200

HMSO Bookshops
49 High Holborn, London, WC1V 6HB
(counter service only)
071-873 0011 Fax 071-873 8200
258 Broad Street, Birmingham, B1 2HE
021-643 3740 Fax 021-643 6510
33 Wine Street, Bristol, BS1 2BQ
0272 264306 Fax 0272 294515
9–21 Princess Street, Manchester, M60 8AS
061-834 7201 Fax 061-833 0634
16 Arthur Street, Belfast, BT1 4GD
0232 238451 Fax 0232 235401
71 Lothian Road, Edinburgh, EH3 9AZ
031-228 4181 Fax 031-229 2734

HMSO's Accredited Agents
(see Yellow Pages)

and through good booksellers

£9.95 net

Publication Code: HO-7/94-1K-C-AKKM

ISBN 0-11-885833-5

9 780118 858335