Cranfield UNIVERSITY Silsoe

Cranfield University at Silsoe

Institute of Water and Environment

MSc. by Research

2005

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The Impact of the EU Water Framework Directive on Irrigated Agriculture in England.

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January 2005

This thesis is submitted in partial fulfilment of the requirements for the Degree of Master of Science.

ABSTRACT

Irrigation in the England is a small but strategically important sector. It makes a significant contribution to agricultural GDP allowing the production of specialised crops with the ability to maintain and maximise both yield and quality. It is this demand for reliable, quality supplies of produce that drives the demand for irrigation water and is likely to increase in future. In some areas of East Anglia irrigation can account for up to 70% of water abstraction in the region during peak demand. Concerns over environmental quality combined with increasing pressures on scarce water resources have prompted the introduction of new regulation and tighter controls on resource distribution. The introduction of the Water Framework Directive (WFD) into European legislation aims to facilitate better water management and to improve quality of the water environment. Irrigation farming can lead to problems of water quantity and water quality as a result of abstraction and agrochemical discharges.

This study aims to identify the main irrigation farming systems in England; to determine the characteristics and performance of irrigation farming systems; to evaluate the impacts of alternative policy measures on these systems and to determine possible coping strategies that could be adopted. Three case study farms have been used to develop a linear programming (LP) model to enable the assessment of alternative policy measures. Measures aimed at encouraging efficient use of water and reduction in agrochemical discharges have been modelled in the LP and the effect of these policy changes on the sustainability of farms investigated with respect to economic, social and environmental objectives.

The study confirmed the links between irrigated agriculture, WFD and water resource and quality issues. The study indicated that the implementation of policy measure as a result of the WFD are likely to affect the sustainability of irrigated agriculture. The use of abstraction license restrictions and abstraction charge increases faciltated reductions in the use of water. Reduction in water/use availabilty led to reduced areas of irrigated cropping. Reductions in the areas of cropping are closely linked with the returns to water gained for each specific crop. Under water abstraction charge increases, reductions in water use were dependant upon the value of water to the crop,

under high net margins the value of water was high and large areas of irrigated cropping remained in the system. This value could be up to £9.00m^3 for strawberries and in the region of £1.00 -£2.00m^3 for potatoes and vegetables. The inelastic nature of demand for irrigation water leads to a transfer of income from farmers to the regulatory body. General trends showed that the profits to farms could be significantly reduced with the loss of irrigated crops. Labour requirements were also reduced signifiacantly with reductions in the areas of irrigated land. Environmental performance improved under reduced irrigation, confirming the high potential for pollution to occur under the irrigated crops with high levels of agrochemical inputs. Controls on the agrochemical losses impacted upon the areas of land under production. The cropping pattern switched to the most profitable crops with the highest returns per unit of agrochemical loss. Irrigated crops became dominant within the cropping pattern. Areas of land were taken out of production in order to allow the maximisation of areas of irrigated cropping while allowing the farm unit to remain within the limits of agrochemical loss to the environment. Coping strategies were identified namely; the use of winter abstraction combined with a storage reservoir and the use of trickle irrigation as a more efficient method of application, their use was validated under licence restrictions and abstraction charge increases. Trickle irrigation and winter water strorage have been confirmed as being viable options in extending irrigation.

The study identifies priorities for future research, including:-

- Expansion of the examination of coping strategies, (this may include work on deficit irrigation),
- Agrochemical use, and possible yield and quality responses to reduced inputs,
- Development of more complex models including the use of a greater range of cropping options and coping strategies, with the posibility of incorporating reduced input options and agri-environmental land use.

AGNOWLEDGEMENTS

Many people have contributed to this study. Although it is not possible to thank them all individually, I would like to thank you all for your help and assistance.

Thanks are deserved by my supervisor Prof. J. Morris for his assistance guidance and support.

I would like to thank Alistair and William Findlay of Lakes farm, Tim Jolly of Roudham Farm and John Place of Church farm for their help in providing the data for the case study development.

Thanks are also due to Tonny de Vries, for her help with the LP and to Keith Weatherhead, and Jerry Knox for their advice throughout the project. Thanks are also due to Tim Hess, Colin Brown and John Hollis for their help with research models.

Special thanks are due to my girlfriend Laura and to my parents for their support and encouragement throughout the study period. Without the support of my family and friends the thesis would never have been completed.

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CHAPTER ONE. INTRODUCTION

This chapter explains the background of the study, presents the aims and objectives of the study and summarises the structure of the thesis.

1.1 Context.

Irrigation in England is a small but strategically important sector; it commands only a very small proportion of the total-farmed area with an estimated 200,000 ha in a dry year which is just 4% of the cropped area (Twite, *el. al,*. 2001a). Irrigation tends to be concentrated in the Midlands, East Anglia and the Southeast. Though it is a relatively small sector it makes a significant contribution to agricultural GDP (about 7%) allowing the production of more specialised crops with the ability to maintain and maximise both yield and quality (Morris *et al.,* 2003). Irrigation in the UK is used to supplement natural inputs of water and as such varies greatly from year to year (Twite, *et. al.,* 2001a). The main benefits of irrigation in the UK are the increased yields and added value as a result of quality improvements and quality guarantees (Weatherhead, *et. al.,* 1997). It is this demand for quality reliable supplies of produce that drives the demand for irrigation water and is set to further drive the demand for increased supplies of water for irrigation in the future.

Although irrigation uses less than 1.5% of total water abstraction, the majority is concentrated in the driest regions of eastern England. Demand peaks during the summer months when water resources are scarcest (Knox, *et. al.,* 1996). Recent policy has seen a turn towards greater consideration of the environmental consequences of human activities. Reform of the Common Agricultural Policy (CAP) and the introduction of the Water Framework Directive (WFD) will affect the way in which irrigation is undertaken in the future. Water resources have come under increasing pressure from several directions such as public water supply, recreation and power generation. Concerns over environmental quality combined with increasing pressure on the resources have prompted new regulation and tighter controls over resource distribution and abstraction. Increasing pressures from the marketplace to supply high quality guaranteed produce are driving farmers to use irrigation to meet quality and quantity objectives. This pressure to guarantee the quality of produce and maximise production combined with increasing concern over protection and the equitable distribution of water resources will bring the objectives of irrigation farming into conflict with the need to manage the scarce water resources. Policy aimed at protecting and improving the quality and quantity of water will put pressure on the availability of water for use in the irrigation sector. This project aims to identify the links between irrigation and water resource policy, and to identify the impacts that this policy will have on the sustainability of irrigated agriculture.

1.2 Aims and Objectives.

This project was undertaken with the broad aim of identifying the links between irrigated agriculture, water resources and the WFD and investigating the impacts of implementing the objectives of the WFD on irrigated agriculture.

The objectives of the study are to: -

- Identify the key areas of new policy that will have a direct impact on irrigation businesses with particular respect to WFD.

- Identify major irrigation farming systems in England and Wales and select a number of suitable case study farms.

- Determine the demand for water (and the underlying characteristics and performance of irrigation farming systems) under alternative agricultural, water and related environmental policies.

- Determine the impacts on the economic, social and environmental performance of irrigated agriculture under alternative policy measures (such as water pricing, or restrictions on abstraction) that might be used to achieve improved water resource management.

- Determine possible coping strategies that could be adopted by farmers under alternative regimes including cropping options, irrigation technology and management systems.

1.3 Thesis Structure

This chapter gives a brief background to the study, aims and objectives of the study are given

Chapter 2 reviews previous research on the possible relationships between irrigated agriculture and the WFD. The links between irrigated farming practices and water use, issues surrounding the quality and quality of water resources are discussed in relation to irrigation. Discussion of the irrigation techniques, water demand and agronomic water requirements are included. Water quality issues include the identification of quality impacts such as fertiliser and pesticide use. The use of Linear Programming in the study of agricultural planning and policy analysis is confirmed as a suitable technique for use in this project.

Chapter 3 describes the methodology used to meet the study objectives. Descriptions of the case studies used and the data required in the production of LP models are given. Details of the research models used in the development of financial budgets, agronomic water requirements and agrochemical pollution risks are described and explained.

Chapter 4 applies the analytical framework to the case studies. This chapter presents and discusses the impacts of the WFD measures identified in Chapter 2. The impact of the four WFD policy measures are discussed under each of the three case studies, impacts of these measures is discussed in terms of the sustainability of the irrigated agriculture. The main findings on each case study are summarised. Leading on from the assessment of the impacts of WFD measures Chapter 4 discusses the ability of coping strategies to maintain irrigated agriculture under the WFD policy measures. The success of these strategies is discussed in term of the viability of each of the case studies. The overall findings of the chapter are given in a chapter summary.

Chapter 5 provides an overall summary of the study. Conclusions relating to the objectives of the study are outlined. Chapter 5 then goes on to provide recommendations for future research drawing on any deficiencies identified in the present research and areas of study which could not be covered in the scope of this work.

The thesis is supported by Appendices containing research models, LP model structures and results from the LP models.

CHAPTER TWO.

WATER FRAMEWORK DIRECTIVE AND IRRIGATED AGRICULTURE

Chapter 2 reviews the links between the Water Framework Directive (WFD) and irrigated agriculture in England. The issues relating to the WFD and irrigation farming are reviewed and concepts involved in sustainable development discussed. Initially the chapter introduces the implementation of the Water Framework and highlights areas of the Directive that will affect irrigation. Irrigation farming in England is introduced and an overview of the sector's characteristics and methods discussed. The use of linear programming in policy analysis and eco-environmental studies is reviewed. This section confirms the use of linear programming within the context of this study and provides ideas for the development of the linear programming model and a framework for analysis. This chapter reviews possible methods and models which will be used in the development of the LP model.

2.1 Sustainable Agriculture

The concept of sustainable development has emerged over the past 20 years. Broadly it is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). Agriculture plays an important role in the production of food and other products and the provision of these services has been the key role of agriculture, but the concept of sustainability and links between environmental degradation and agricultural systems have led to much interest in agricultural sustainability (Sands and Podmore, 2000). Agricultural sustainability can therefore be defined as the economic activity aimed at producing quality food and other products now and into the future in an environmentally benign, socially acceptable and economically efficient way (Leiva 1997).

In response to this increasing worldwide focus on sustainable development, the UK government has been assessing the current situation and addressing the challenges faced in order to meet the objective of sustainable development. A Strategy for

Sustainable Farming and Food (Defra, 2002) identified serious long-term problems in the economic, social and environmental sustainability of agriculture. The development of the WFD will play a significant role in ensuring the sustainable use of European water resources; this will entail looking at both the quality and quantity of water within aquatic environments. Losses of agrochemicals to both surface and groundwater have caused degradation of the environmental quality with losses in flora and fauna (Defra, 2002). The use of abstracted water for irrigation reduces the water available within surface and ground resources which can lead to environmental degradation through both losses of habitats and the reduction in the ability of the environment to cope with pollution (reductions in the dilution and bioremediation capacity). The WFD will entail increased awareness of water resource management and the provision of greater controls on the use of water and the pollution occurring from agriculture.

2.1.1 Indicators of Sustainability

In order to assess the impacts of the WFD a framework will be needed in order to identify the impacts of irrigated agriculture and what the possible responses to policy changes will be. The review of literature identified three main areas of concern for irrigated agriculture with the objectives of the WFD, namely quantity of water allowed to be abstracted and the timing of this abstraction; the efficient use of water which is available, with reductions in water waste in terms of supply and use; and the quality of the water resources, with respect to the impact which agriculture has upon the water quality in terms of agrochemical inputs and water levels. The Driver, Pressure, State, Impact and Response (DPSIR) framework and variations of it have been used extensively in the appraisal of sustainability and of the sustainability of irrigation farming practices (OECD, 2003). Figure 2.1 shows the DPSIR framework that could be used in the assessment of WDF policy measures on the sustainability of irrigated agriculture.

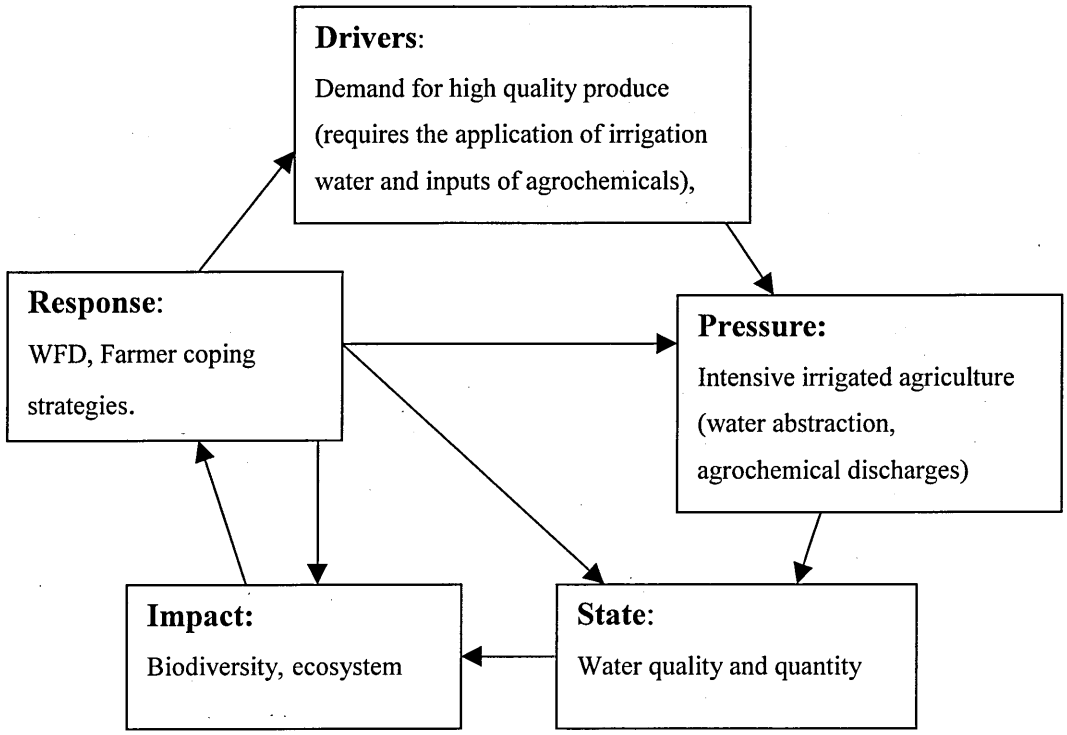

Figure 2.1: DPSIR Framework to assess the impact of WFD policy measures on irrigated agriculture.

One of the key themes consistent within all literature relating to the concept of sustainable development is the use of indicators to measure the changes brought about as a result of changes in practices aimed at promoting sustainability (OECD, 2003; Defra, 2002; MAFF, 2000; Brouwer and Crabtree, 1999).

The use of indicators can help to simplify, communicate and quantify information regarding the identified sustainability criteria for the specific situation (Rigby *et al.*, 2001). The development of indicators for overall government policy often uses sector or regional or national data to consider the impacts and progress of the identified issues on a large scale. Sets of indicators for the assessment of sustainable development have been used by Governments, and large organisations such as the OECD and United Nations (Brouwer and Crabtree, 1999; Rigby *et al.*, 2001). There is no one set of indicators which is applicable to all situations, however Osinski *et al.* (2003) discuss the use of indicator sets and argue that the development of indicators should be specific to individual circumstances and validated for the objectives of the work. The development of indicators for the assessment of sustainability can use techniques such as the DPSIR framework to guide the selection of relevant indicators for a particular situation. This technique has been used by the UK government in their selection of indicators for sustainable agriculture in their document "Towards Sustainable Agriculture, A Pilot Set of Indicators" (MAFF 2000). This identifies 35 indicators which can be used in the assessment of social, economic and environmental performance of the UK agricultural sector.

Table 2.1 gives a summary of the indicator set used by the UK government in the assessment of sustainability of UK agriculture. The use of some of these indicators will be applicable within the assessment of the impact of WFD on irrigated agriculture in England. The highlighted indicators within the table show relevance to irrigated agriculture and will aid in the assessment of the impacts of WFD on irrigated agriculture in this study. Some of the indicators identified in this table are not applicable to the characteristics and impacts of irrigated agriculture and will not be used. The selection of indicators for the assessment of the impacts of WFD on irrigated agriculture must examine the specific links between these two fields. More specifically they must address the impacts of irrigated agriculture on the water environment in terms of water abstraction and diffuse pollution. WFD policy will have an impact of the availability of resources and the level of pollution allowed. Indicators of social and economic performance of irrigated agriculture will also be necessary to assess the impacts of reduced water availability and pollution hazard on the overall sustainability of irrigated agriculture.

Table 2.1: List of indicators used for sustainable agriculture: Source MAFF 2000.

Issue	Area	Indicator
A. Agriculture within the rural economy and society	Structure of the agricultural industry	1. Agricultural assets and liabilities
		2. Age of Farmers
		3. Percentage of holdings that are tenanted
	Farm financial resources	4. E.U. Producer Support Estimates
		5. Payments to farmers for agri-environment purposes
		6. Total income from farming
		7. Average earnings of agricultural workers
	Agricultural productivity	8. Agricultural productivity
	Agricultural employment	9. Agricultural employment
B. Farm management systems	Management	10. Adoption of farm management practices
	Organic farming	11. Area converted to organic farming
	Codes of Practice	12. Knowledge of codes of Good Agricultural Practice
Input use.	Pesticide use	13. Pesticide in rivers
		14. Pesticide in groundwater
		15. Quantity of pesticide active ingredients used
		16. Spray area treated with pesticides
		17. Pesticide residue in food
	Nutrients	18. Nitrate and Phosphorus losses from agriculture
		19. Phosphorus levels of agricultural topsoils
		20. Manure management
		21. Ammonia emissions from agriculture
	Greenhouse gas emissions	22. Emissions of methane and nitrous oxides from agriculture
	Energy	23. Direct energy consumption by farms
		24. Trends in indirect energy inputs to agriculture
Resource use.	Water	25. Use of water for irrigation
	Soil	26. Organic matter content of agricultural topsoils
		27. Accumulation of heavy metals in agricultural topsoils
	Agricultural land	28. Area of agricultural land
		29. Change in land use from agriculture to hard development
	Non-food crops	30. Planting of non-food crops
Conservation value of agricultural land	Environmental conservation	31. Area of agricultural land under commitment to environmental conservation
	Landscape	32. Characteristic features of farmland
	Habitats	33. Area of cereal field margins under environmental management
		34. Area of semi-natural grassland
	Biodiversity	35. Populations of key farmland birds

Foot note: Highlighted text indicates relevance to irrigated agriculture; Source.

2.2 The Water Framework Directive

The European Union's Water Framework Directive is seen as one of the most influential legislative instruments of environmental policy to be introduced for many years (Chave, 2001; Directive 2000/60/EC). The WFD is the culmination of the development of European policy development decisions taken in a series of five Environmental Action Programmes extending over the period 1973-2000 (Chave, 2001). These action programmes identified a number of priority issues that needed to be tackled to reduce water pollution and improve the quality of natural waters. The WFD acts to combine a number of insular directives dealing with specific issues. The WFD aims to provide a framework for member states to develop a common basis for the protection and sustainable use of water (DETR, 2001., Chave 2001).

The WFD sets out new goals for the condition of all water resources in the European Community with an overall goal of "good" and non-deteriorating ecological status for all waters (Kallis & Butler, 2001). Article 1 defines the purpose of the Directive objectives which aim to enable the "sustainable balanced and equitable use of water in the member states" (Chave, 2001): -

- Expand the scope of actions to protect water to all forms of naturally occurring water in the environment, including surface and groundwater;
- Prevent further deterioration, and protect and enhance the status of aquatic ecosystems, and with regards to their water needs, terrestrial ecosystems and wetlands;
- Promote sustainable water use based on long-term protection of available water resources;
- Take specific pollution control measures, by reducing or eliminating discharges and emissions and losses of priority toxic substance, to enhance the protection and improvement of the aquatic environment;
- Reduce pollution of groundwater;
- Contribute to mitigating the effects of floods and droughts;
- Undertake measures that will result in the achievement of 'good water status' for all waters within a predetermined timescale.

The overriding concepts of the directive are that it aims to:

- Manage water as a whole on a river basin basis reflecting the situation in the natural environment;
- Use a combined approach for the control of pollution, setting emission limit values and water quality objectives;
- Ensure that the user bears the costs of providing and using water reflecting its true cost; and
- Involve the public in making decisions on water management

(Mosert, 2003)

As part of the WFD the Member States must manage water as a whole, individual river basins are identified and the competent bodies must develop River Basin Management Plans for each individual river basin district (articles 3, 13). The RBMPs will permit the identification and control of all pressures likely to affect the achievement of good ecological status (RPA, 2003). The purpose of these RMBPs is to enable the implementation of the WFD and to ensure that individual systems are managed with respect to their individual needs and characteristics at their own level. Rather than having one national or community wide implementation plan, the specific issues arising are identified and dealt with in a more holistic and sustainable way with the overriding objectives of the WFD being achieved for each river basin. In addition the management plan itself is required to address issues set out in Annex VII of the directive which includes identification of significant pressures of human activity on the status of surface and ground waters and identification of appropriate measures to alleviate these.

Specific articles in the directive which relate to irrigated agriculture include,

- article 5, which covers the characteristics of the River Basin District reviews of the environmental impact of human activity and economic analysis of water use,
- article 9, the recovery of water cost for water services,
- article 11, programme of measures.

Article 5 covers the impact on the environment and an economic analysis of water use, including the identification of pressures on the state of the water quality with specific identification of diffuse pollution from agriculture, and the identification of water abstraction and the impact of water flow regulation. Irrigated agriculture is a direct and consumptive user of water and as such will be identified under this article. Impacts of irrigated agriculture on the environment come from reduced flows and inputs of diffuse pollution. The links between abstraction and diffuse pollution and possible constraints of water availability and pollution of water resources will require measures to modify the practices of irrigated agriculture to improve environmental performance. Modifications in practices will have a knock on effect on the economic and social performance of irrigated agriculture and this will need to be assessed under the WFD implementation.

Under article 9 the Directive states that the use of water should be sustainable taking into account all users and any costs incurred should be fully recovered by the regulating body. This could include increases in the costs of water to farmers as a result of increased abstraction charges (RPA, 2003).

Article 11 provides details of the "program of measures" which will be used in achieving the objectives of the Directive. Article 11(3) requires the inclusion of measures to promote efficient and sustainable water use, agricultural abstraction for irrigation was identified in the third consultation paper by the UK government as one of the highest sectors in need of additional action to improve the efficiency of water use (Defra, 2003). Some of the measure suggested within article 11 which could be used to encourage increased water use efficiency is rising block tariffs, incentives for on-farm storage the introduction of economic instruments and greater controls on abstraction. Further to these points of abstraction and the associated water quantity issues are the issues of point source and diffuse pollution from agriculture, the identification of diffuse sources of pollution within a river basin specifically identifies agriculture as being a significant source of diffuse pollution.

The specific objectives of the WFD will require the implementation of measures that will improve water quality and water resource management. The implementation of the measures required by the WFD will have a direct impact on the way in which irrigated farms are managed, both in terms of the water available for irrigation and also in the use and loss of agrochemicals to water resources. The analysis of the impact of WFD will need to address the issues involving the implementation of the WFD policy measures and the links with irrigated agriculture.

2.3 Characteristics of UK irrigation farming systems

2.3.1 Irrigated Farming

The area of land irrigated in the UK has undergone major growth in the past 40 years (Weatherhead *et. al.* 1997). The amount of water used for irrigation doubled in the period 1975 to 2000 with an underlying increase of about 3% annually in the eastern region. Initially the increase in irrigation was attributed to the gains in yield achieved as a result of the reduction in water stress to the crops during the growing season. More recent growth in on-farm irrigation has been driven by the demand for high quality, consistent and reliable sources of supply linked to contractual obligations which require the irrigation of crops (Morris *et. al.* 2003).

Irrigation in England is used supplementary to rainfall to allow the production of good quality produce by alleviating moisture stress. Irrigation requirements in England are unlike those of more arid regions of the world where irrigation water is required in order to keep plants alive. Irrigation requirements in England are moderate and the application of irrigation water is necessary only on some soils in areas with low rainfall, such as light soils in East Anglia (Bailey 1990). The majority of irrigation in the UK occurs in the drier eastern regions of England where water deficits are most likely (Morris *et. al.* 2004). Irrigation accounts for just 1.5% of total abstraction in the UK. This is concentrated in the drier regions of the UK with irrigation accounting for up to 70% of total abstraction in the most intensively irrigated areas during the peak periods in the driest months (Knox *et. al.* 1996). Large variations in the area of irrigation occur each year due to the supplementary nature of irrigation and the fact that irrigation is used in rotations along with rainfed cropping. About 1.5% of the total cropped area in England and Wales is irrigated and 7-8% of the total cropped area is involved in an irrigated rotation (Morris *et. al.* 2004).

Irrigation is concentrated around production of high value crops such as potatoes, field scale vegetables and soft fruit. The production of potatoes and vegetables and sugar beet accounted for about 85% of all irrigated area in 2001 (Morris *et. al.* 2004) and 32% of all soft fruit grown was irrigated (Table 2.2).

Table 2.2: Areas of irrigated crops and volume of water applied, England and Wales 2001.

	Area		Water Volume		Irrigation as % of Total Crop Areas
	ha	%	1000 m^3	%	%
Early Potatoes	7,628	5	5,872	4	43
Maincrop Potatoes	70,006	47	70,057	53	47
Sugar beet	9,755	7	4,633	3	13
Orchard fruit	1,578	1	896	1	10
Soft fruit	3,774	3	3,312	2	32
Vegetables	39,164	26	34,114	26	23
Grass	4,104	3	2,470	2	0.2
Cereals	4,615	3	1,471	1	0.5
Other crops	7,272	5	8,841	7	11
Total of Outdoor crops	147,895	100	131,755	100	1.5

Source: Weatherhead and Danert, 2002.

2.3.2 Water abstraction for irrigation

Water abstraction for spray irrigation is regulated by the Environment Agency through means of abstraction licensing. Water supply for irrigation comes from two main sources:- direct abstraction (summer abstractions) and water storage in the form of on-farm reservoirs (winter abstractions). Increasing demand for reliable water sources combined with increasing overall pressure on water resources from industry and environmental uses have led to increases in on-farm water storage which has nearly doubled in the period 1984 and 1995 (Twite *et. al.* 2001,a). This still accounts for a relatively small volume of water in terms of total irrigation water used with over 90% of water used coming from direct summer abstraction (Table 2.3). As reliability of water supply becomes more of an issue it is expected that there will be an increase in on farm investment in technology to ensure water use efficiency and to ensure water availability.

Table 2.3: Sources of irrigation water in England 1995.

Source	Summer (direct abstraction)		Winter (storage reservoir)	
	Volume Mm^3	%	Volume Mm^3	%
River Stream or other water course	66.47	40	10.29	6
Spring Rising on holding	3.86	2	0.67	0
Well	4.04	3	0.11	1
Deep Borehole	52.73	32	0.98	1
Pond or Lake	10.52	6	2.37	1
Gravel or Clay Working	1.66	1	0.11	0
Public mains supply	4.16	2	0.28	0
Other Source	4.93	3	0.96	1
TOTAL ABSTRACTED	148.37	90	15.77	10

Footnote: Mm^3 is $1,000,000m^3$

Source: Weatherhead *et al.*, 1997

Under current licensing regulations all withdrawals from surface and ground water for spray irrigation require an abstraction licence under the Water Resources Act (1991). Under the Water Resources Act the current exemption of trickle irrigation from this requirement will be deleted and all abstraction for irrigation will require an abstraction licence adding further demand to the present licensed volumes. Under the licence to abstract, certain conditions are imposed, these include:

- authorised quantities,
- details of the location,
- period of use (summer or winter),
- abstraction rates (per season, per day, per hour),
- method of measurement and assessment of quantities abstracted,
- special conditions (protection of the environment, and other users).

(EA, 2002).

The abstraction of water is subject to a charge based on the costs of administering the abstraction licensing system. Current abstraction charges for the Anglian region are £0.031m^3 for summer water and £0.0031m^3 for winter water abstraction; this is currently calculated using the following equation:

Annual Charge = Volume x Standard Unit Charge x Season Factor x Loss Factor x Source Factor

Table 2.4 summarises the total cost to the farmer of abstraction. This takes into account the costs of abstracting the water and applying it to the required areas of crop. Typical costs for direct abstraction and hosereel irrigation are in the region of £0.30m^3 the use of winter water adds £0.30m^3 to this cost. Trickle irrigation costs £0.42m^3 under direct abstraction but requires 10% less water applied overall due to better efficiency of application.

Table 2.4: Estimated irrigation costs*(£m^3, 2001 prices) by water source, storage and infield system.

Source **Storage**	**surface** **none**	**surface** **reservoir unlined**	**surface** **none**	**surface** **reservoir unlined**	**g/water** **none**	**g/water** **Reservoi r unlined**	**g/water** **none**	**g/water** **reservoir unlined**
Application method	**hosereel**	**hosereel**	**trickle**	**trickle**	**hosereel**	**Hosereel**	**trickle**	**trickle**
Costs by component £/m^3								
fc	0.07	0.08	0.07	0.08	0.11	0.1	0.11	0.1
vc	0.1	0.06	0.1	0.06	0.12	0.07	0.12	0.07
Total	0.17	0.14	0.17	0.14	0.22	0.17	0.22	0.17
Reservoir								
Fc	0	0.25	0	0.25	0	0.25	0	0.25
Vc	0	0.09	0	0.09	0	0.09	0	0.09
Total	0	0.34	0	0.34	0	0.34	0	0.34
Infield								
Fc	0.09	0.09	0.15	0.15	0.09	0.09	0.15	0.15
Vc	0.04	0.04	0.1	0.1	0.04	0.04	0.1	0.1
Total	0.14	0.14	0.25	0.25	0.14	0.14	0.25	0.25
Total fc	0.16	0.42	0.22	0.48	0.20	0.44	0.26	0.50
Total vc	0.14	0.19	0.20	0.25	0.16	0.20	0.22	0.26
Total	0.30	0.61	0.42	0.73	0.36	0.64	0.48	0.76

Foot note: Costs are per m^3 usefully applied, i.e. net of losses, at an assumed 80% efficiency. Assumes 24 ha irrigated with average annual application of 125mm net of losses. * Including amortisation of initial capital cost over 20 years at 6%.
Adapted from: Morris (*et al*, 2003)

Abstraction licences for irrigation are subject to the conditions described earlier. In deciding upon the issuing of new licences the Environment Agency must assess if additional water is available. Much of the country has been assessed and has been classified as having no additional water. Figure 2.2 shows the availability of water within England. In many regions of England there is evidence of over abstraction and over licensing. This means that new licences will not be available in many regions especially in the drier regions. Increasing demand for water combined with a lack of supply from existing sources will force farmers to look for sources of potable water for high value crops into the future and to maximise the use of current supplies (Knox *et al.,* 2000; EA, 2001; Morris *et al.,* 2003).

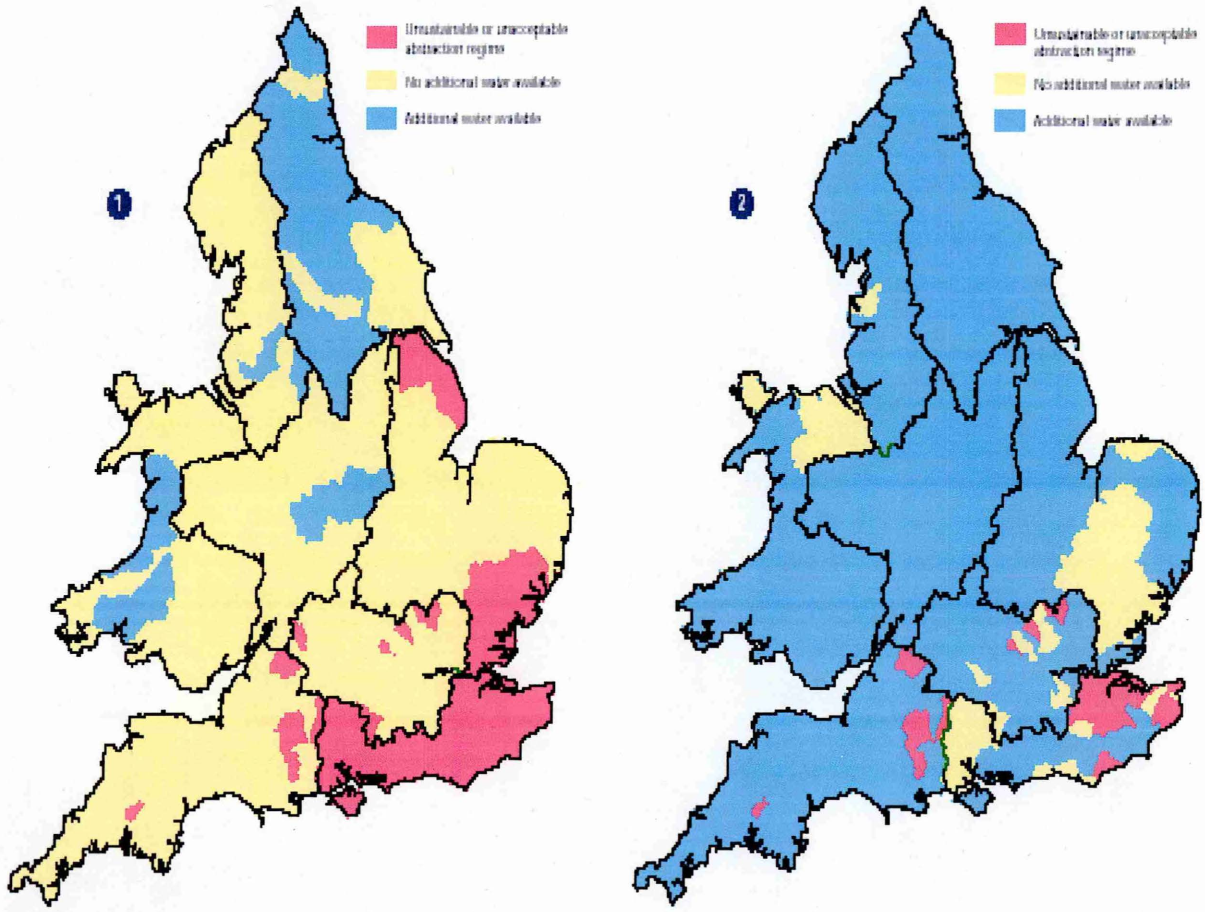

Figure 2.2: Current indicative summer water availability (1, surface; 2 ground). Source: EA, 2001.

2.3.3 Irrigation Technology

The continued trend for increased water demand combined with reduction and restrictions in the availability of water resources is pushing irrigators to seek more efficient ways of utilising the supplies which they have. New technologies looking at improving the utilisation of available water involve improvements in the application methods, better scheduling of applications and ways in which crop demand can be reduced (Weatherhead *et al.* 1997).

Overhead irrigation methods in England include both traditional fixed and set move systems using conventional impact sprinklers and mobile systems such as hosereel, centre pivot and linear move systems.

The majority of irrigation in England is in the form of spray irrigation through the use of mobile rain guns with 97% of irrigation coming from overhead application methods, the majority being from hosereel systems with rainguns or booms. Trickle irrigation accounts for just 3% of current irrigation (Twite *et al.,* 2001b). Reductions in the cost of large moving systems along with increasing costs of labour have led to dominance of mobile overhead systems with high levels of automation. Rainguns account for the majority of overhead irrigation although they are widely recognised as being inaccurate and inefficient in terms of water and energy use. These are popular due to their high versatility, robustness and the ability to fit them into UK mechanised systems. These systems fit well to the demands of highly mobile cropping regimes where irrigation fits into a rotational cropping pattern alongside rainfed cropping. The use of centre pivot and linear move systems is limited in the UK due to difficulties with locating them within the farming system.

The development of irrigation technology has been driven by the need to provide a means of applying water to the crops by the most cost effective method. The fact that most irrigation in England is undertaken using overhead irrigation using rainguns confirms that utilisation of water resources and also of irrigation technology are not designed to optimise the use of water resources (Weatherhead *et. al.* 1997). Recent problems of water restrictions and the increased public awareness of the WFD have led to concerns within irrigator groups and government agencies over the availability of water and developing more efficient working practices or new sustainable sources of water. Possible improvements in the management of the water resources will include greater uptake of winter storage, improvement in irrigation technology and improvements in system management such as better scheduling.

2.4 Abstraction issues for irrigation.

The production of irrigated crops involves the use of abstracted water to meet the plant's water requirements in areas of water deficit. Crops will usually still survive under the moderate water requirements of the UK but irrigation is used to ensure that better quality crops with higher yields and a reliable continuity of supply can be achieved (Bailey, 1990). The abstraction of water for irrigation is essential in enabling farmers to meet the requirements of certain crops in regions of England where there is a water deficit. Restrictions in the available water will have a direct impact on the areas of irrigated crops that can be grown.

Irrigation in the UK has been supplementary to natural inputs of water and is required at times when natural supply is not sufficient to enable the growth of crops to a reasonable quality or quantity (Vasileiou *et al.*, 2003). As such the peak period for abstraction for irrigation water use comes at a time of minimum available supplies and can therefore lead to shortages in this supply and knock on effects to other water users including environmental considerations (DETR, 1998).

The UK already has a system of abstraction licensing first introduced in the 1963. The Environment Agency (EA) controls the management of all abstraction licenses in England and Wales. As part of the implementation of the WFD, revisions to the current licensing system have been proposed and the EA have been working to ensure that the licensing system can be successfully used within the framework set out by the WFD (EA, 2002). As part of this updating of the licensing system the EA has developed a number of initiatives to enable the sustainable management of water resources. One of the most important is the Catchment Abstraction Management Strategy (CAMS). The objectives of the EA in the Catchment Abstraction Management Strategies are to manage water resources in a sustainable and holistic way taking into account all users. The principle of the CAMS is to: -

- make information publicly available on water resources availability and licensing within a catchment;
- provide a consistent and structured approach to local water resources management, recognising both abstractors' reasonable needs for water and environmental needs;
- provide the opportunity of greater public involvement in the process of managing abstraction at a catchment level;
- facilitate licence trading.

The introduction of CAMS is the Agency's response to WFD and the government's consultation document: Taking Water Responsibly (DETR, 1999). Many of the changes highlighted in the document require new legislation which has been dealt with in the Water Act 2003 (HMSO, 2003) but many of the agency's current powers have been adapted into the CAMS process. In order to fully implement the requirements of the WFD some modification of the legislation was necessary and much of this is relevant to irrigation including:

- removing the exemption of trickle (and other types) irrigation;
- Require new licences to be time limited,
- Allow licences to be transferred by agreement between the parties concerned;
- Reduce the period after which the agency may revoke an abstraction licence for non-use without payment of compensation, from seven to four years;
- Provide additional powers for the agency to require information from abstractors on how water is used.

(EA 2002)

The Agency's role as the competent body will be in the forefront of the implementation of the WFD and the CAMS and will be responsible for the implementation of the revised abstraction licensing regulations. As a result of this new legislation the EA has been given greater powers to enable the sustainable management of water resources in line with the requirements of the WFD. Trickle irrigation is no longer exempt from requiring an abstraction licence and will require an abstraction license. Under the new regulations stricter controls will be placed on water resource use. Restrictions in the volume of water available are likely and the provision of full cost recovery is likely to increase abstraction charges. The reduction in water availability and the requirements of trickle to have an abstraction license will have an impact upon the ability of farmers to irrigate. In areas that are over licensed or over abstracted, trickle irrigators will find it increasingly difficult to gain abstraction licenses. The provision of cost recovery and the likely increases in abstraction charges will act to reduce the profits of irrigated cropping with revenue switching from farmers to the Agency.

2.5 Agrochemicals and Agricultural discharges to waters.

Agricultural policy in the period after the Second World War sought to provide a self-sufficient food production. This trend was continued in the form of the Common Agricultural Policy. With this pressure to produce food the agricultural sector has seen a period of intensification and maximisation of production. As a result of this intensification the inputs of fertilisers and pesticides to the system have seen dramatic increases and resultant increases in the losses to water bodies (DETR, 1998). In their Fourth Report the Environment Food and Rural Affairs Committee stated that "intensive agricultural practices have led to diffuse pollution and it is clear that in order to deal with the problem wholesale changes in such practices will be needed" (HMSO, 2003). Implications on the cost to farming will be two fold in the form of reductions in income due to possible falls in productivity and also in the form of additional costs as a result of the mitigation measures and added costs of modification of practices.

Irrigation may be directly impacted upon as a sector due to its direct use of water. In the production of the RBMP each river system is going to be required to be of good ecological status. A major issue in achieving this status is the effect of the agricultural practices such as nitrogen, phosphorus and pesticides application and sediment and soil losses into the watercourses as a result of the land management techniques used within arable farming.

Production of irrigated crops involves the use of large volumes of fertiliser and pesticide inputs (Bailey, 1990; DETR, 1998; Nix, 2003). The combination of high levels of inputs and the use of irrigation increase the risk of leaching of chemicals into surface and ground waters. Diffuse pollution from agriculture has been highlighted as a major of concern within the WFD. The comparatively high use and high potential losses from irrigated agriculture mean that the link between WFD and irrigated agriculture is potentially significant and control of the losses of agrochemicals to water is likely impact upon irrigated production.

As part of the RBMP appropriate agrochemical limits will be set in order to allow the achievement of "good status". The "program of measures" as set out under article 11 of the directive gives possible "tools" that can be used in the reduction of diffuse pollution. In their report on the indicative costs of agricultural measures RPA (2003) identify measures such as the nitrates directive and the application of best available techniques as being the minimum requirements for achieving the aims of "good ecological status". Other measures identified and relevant to the reduction of pollution from agrochemicals are: -

- Provision of cost recovery for water services;
- Prevention or control of the inputs of pollutants from diffuse sources;
- Eliminate pollution of surface waters from priority substances and to progressively reduce pollution by other substances to achieve the objectives of good status.

Where the implementation of "basic measures" cannot "achieve good status" the use of "supplementary measures" will need to be included in the RBMP to ensure that the objectives of the WFD are met. Possible measure for agrochemicals could include establishment of good codes of practice specific to individual river basin districts, and above the measures provided in the codes of good agricultural practice. Some of these additional measures could include the promotion of measures affecting land management and use (i.e. to restore flow patterns, to establish buffer strips, to recreate and restore wetland areas), requirements to adapt agricultural practices, and to under take research, development, education and training measures (RDA 2003).

RBMPs and the program of measures will be used to meet the objectives of the WFD. Irrigated agriculture will be included in the RBMP and the use of measures will act to control the impacts of irrigated agriculture on water resources. The implementation of these measures will therefore have a direct impact on irrigation techniques and the economic, social and environmental performance of irrigated farming systems. The development of specific RBMPs for each river basin will implement the measure required in order to achieve the goals of the WFD. This site specific design will mean that there is no one set layout for the measures that will be implemented. With respect to the development of this study the impact of a number of these measures most likely to be implemented will be examined and their impact on irrigated farming systems assessed. Not all of the measure will be addressed but they are important in defining the boundary of the study and the interpretation of the results and recommendations for further work.

2.6 Linear Programming

Linear Programming (LP) is a mathematical technique based on the processes of matrix algebra, which given suitably formulated data, is capable of producing optimal mathematical solutions maximising or minimising linear functions subject to linear constraints (Barnard and Nix, 1973). The mathematical form of the model can be presented as follows:

Maximise:

$$Z = \sum_{j=1}^{n} C_j X_j \qquad \text{(objective function)}$$

Subject to: $$\sum_{j=1}^{n} a_{ij} X_j < b_i = 1,2,.....m. \qquad \text{(constraints)}$$

And: $$X_j > 0_j = 1,2,......n, \qquad \text{(non negativities)}$$

Where:

m = number of constraints;

n = number of activities;

Z = total net revenue;

C_j = Value for net revenue per unit of activity $_j$

X_j = Value of the level of activity $_j$

a_{ij} = coefficient of each activity; and,

b_i = constraints.

Linear Programming has been used extensively in farm planning and management helping to determine optimum solutions with respect to a complex set of rules (Barnard and Nix, 1973). LP lends itself to farm planning by determining the combination of enterprises and techniques that maximise the returns within a particular set of resources and constraints thus allowing the design of suitable cropping patterns within the returns and constraints of the scenario (Barnard and Nix, 1973).

2.6.1 LP and water policy analysis

LP has also been extensively used in the research linking agricultural practice with water objectives (Hanley, 1991; Johnson *et al.,* 1991; Moxey and White, 1994 and Moxey *et al.,* 1995). This work has also involved the use of LP to assess the impact of changing prices, land use schemes, taxation systems and agrochemical output and input restrictions through the modification of cropping patterns. The use of LP has been extended to allow policy assessment in respect of possible resource restrictions resulting from environmental protection. Research into the allocation of water resources to maximise returns under conditions of deficit supply used LP in order to define cropping patterns to give maximum returns (Haouari and Azaiez, 2001). This work used LP in order to maximise the returns from systems which have no additional water available. In the context of this study the use of LP can help identify the economic, social and environmental impacts of possible restrictions on the available water in order to achieve environmental objectives. Amir and Fisher (2000) developed a LP model for use as a policy support tool in Israel where water is controlled by the Israel Water Commissioner. Policies aimed at coping with water shortages include tools similar to those proposed in the WFD and include the use of pricing policy and quantity restrictions. They used LP to find the optimum mix of crops that maximises net incomes to an irrigation district. This work includes descriptions of the impacts of water restrictions upon the net revenue and allows analysis of the policy with respect to the economic sustainability of the district, and the effectiveness of the various policies to bring about reductions in the quantity of water used. Pacini *et al* (2003) used a farm planning LP model and developed ecological constraints into the system, using emission and evaluation figures retrieved from external ecological models. The use of LP models applied to farm-level studies are well suited to mixed ecological-economic analysis where consideration of environmental objectives are included in the decision making process (Falconer and Hodge, 2001; De Koeijer *et al.,* 2002; Pacini *et al* 2003). This approach allows the considerations of ecological objectives within the model and allows for ecological constraints in the decision variables constraining the model to certain pre defined environmental precursors. The use of LP can be confirmed as a tool which can successfully be used in the appraisal of impacts of water management and can aid in the development of techniques that allow the maximisation of resources under limited availability.

2.7 Water use for irrigation.

The use of irrigation allows the production of high value crops. The addition of water supplementary to natural precipitation improves both the quality and quantity of crops produced where there is a water deficit present under natural precipitation. If greater restrictions on the volume of water are applied then fundamental benefits of irrigation will be adversely affected (Morris *et. al.,* 1997). In order to understand the impacts of water restrictions under varying rainfall conditions the water requirements of irrigated crops under specific climate and soil conditions need to be understood. The availability of water has a major impact on the quality of crops and is critical in the production of many crops. The importance of irrigation in achieving quality objectives is expressed in the price gained for the specific crops, whether this is in the skin condition, uniformity of size or the overall crop uniformity and supply guarantees (Bailey, 1990). These specific objectives impart the grade of the commodity and as a result the improvements or maximisation of the grade that can be achieved by a particular producer is a key constituent to the farm income (Morris *et al.*, 1997).

2.8 Irrigation water requirements.

The water requirements of plants vary both by the species and as a result of the specific climatic conditions (Çakir, 2004). Evapotranspiration is increased by bright sunshine, high temperatures or strong winds. If sufficient water is present in the soil then transpiration will occur at its optimum level and plant growth will not be limited.

Under conditions of water deficit the increased suction required for the plant to extract water from the soil matrix will reduce the transpiration stream and the plant will become water stressed, under extreme conditions will eventually wilt and will have a net effect of reducing growth rate and lower yields (Bailey, 1990). The addition of irrigation where water deficit is likely to cause stress to plants allows the deficit between precipitation and actual water requirements to be met. This eliminates the potential for drought stress to occur and affect the yield and quality objectives required by the market (Kashyap and Panda, 2003).

Calculation of the water demand of plants is therefore critical in the design and planning of an irrigation system. In order to carry out analysis of the impacts of the WFD on irrigated agriculture in England the irrigation water requirements of each crop will need to be examined under a number of water conditions. The requirements for irrigation water will not remain constant between seasons and will vary depending upon the water inputs into the system and the climatic conditions. Impacts of reduced water availability will differ in connection to these seasonal variations. Table 2.5 gives some typical depths of water applied in areas where water deficits occur.

Table 2.5: Optimum average and dry year irrigation needs for a soil with medium available water capacity in England and Wales.

Crop	Depth	
	Average (mm)	Dry (mm)
Potatoes		
Early	30-55	50-80
Maincrop	90-175	145-235
Carrots	55-120	100-175
Brussel sprouts	75-145	125-200
Lettuce	45-80	75-110
Onions	55-100	90-140
Parsnips	90-175	150-240
Sugar beet	40-95	85-160

Adapted from: Mathieson *et. al.*, (1998)

2.8.1 Modelling water requirements.

With reductions in irrigation water, crop specific water requirements will not be met (The crop water requirements are defined as "the depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in a large field under non constricting soil conditions" (Doorenbos *et. al.*, 1984). Doorenbos and Kassam (1979) identified that the optimum yield will be affected by the water available to the crop throughout the growing season, when the availability of water to the plant is dependant upon the soil water content measured using the soil moisture deficit (SMD). As a plant transpires, it removes water from the soil that can be measured as a depth. Each species of plant will have a critical point at which it can no longer utilise the reserves of water in the soil. This is known as the critical soil moisture deficit (CSMD). Bailey (1990) describes the use of climate data and site-specific soil and plant data in the calculation of yield response to irrigation. Using the CSMD and yield response factors calculated using the methods developed by Doorenbos and Kassam (1979) it is possible to calculate an average yield response per mm of water applied in order to keep the SMD above the critical level. The use of CSMD has been applied in the WaSim model developed by Counsell and Hess (2000) which calculates a daily water balance. Outputs from this model include the relative evapotranspiration rate which can be used in the calculation of yield response. Where relative transpiration is equal to 100% plant water requirements are fully met and yield will not be constrained by water stress. In their work on deficit irrigation Oktem *et al.* (2002) use a similar methodology to investigate the impact of insufficient water on the yield of sweetcorn. This work indicated that maintaining an ET of 100% enabled the elimination of water stress and provided the irrigation water requirements to meet the plants need and not limiting the yield.

Göksoy *et al.* (2004) use the application of water balance models in the calculation of water requirements to maintain full ET. The use of these water balance calculations has the advantage over simple evaporation measurements in that the calculations can be applied to models allowing the calculation of water requirements under theoretical or historical data sets. The irrigation of crops with sub optimum water inputs is referred to as deficit irrigation (Kirda , 1999). Under this system yield benefits are still achieved but associated reductions in yields are also noticed, (Liu *et al.,* 2002; Oketem *et al.,* 2002; Cakir, 2004). The level of this impact will vary according to the level of water stress and the specific crop responses to water stress (Liu *et. al.,* 2002). The use of these models allows the calculation of transpiration. This can be used in assessing the irrigation water requirements through a simple water balance model.

The use of water balance techniques to predict crop water requirements can be used in the modelling of average and dry year water demands. In order to assess the impacts of WFD policy of irrigated farming systems the water demands of the farming and cropping systems will need to be known. The use of water balance models will allow the development of models that can assess the impacts of alternative measures under varying levels of water demand.

2.9 Financial budgeting and revenue models.

The use of farm budgeting models in conjunction with LP has been used extensively in the modelling and planning of farming practices (Barnard and Nix, 1973). More recent research linking agricultural practices and water quality has used LP (Abdelshafae, 1998). Complete financial budgets require the accounting of all costs and revenues for the farm. The profit depends on the costs of producing crops, the output gained from these crops and the ratio of costs to income. Barnard and Nix (1973) discuss the use of whole farm plans taking into account all resources open to the farmer in order to maximise profit. The development of financial budgeting sheets for the calculation of each of the enterprises available to farmers allows the production of individual benefit assessments for each enterprise. Moxey and White, (1994) and Abdelshafae (1998) combined the use of financial benefit assessments in the development of LP for the assessment of agrochemical controls with water quality. Nix (2004) discussing the use of gross margin and net revenue for the planning of enterprises discusses the problems faced with the allocation of fixed costs to specific enterprises. Nix noted that problems with applying fixed costs leads to problems with the interrelationships between the enterprises and the distribution of these costs across each enterprise. Barnard and Nix (1979), Leiva (1997), Witney (1998) and Warren (1982) discuss the use of enterprise budgets with the allocation of costs to the enterprise with which they are concerned. The allocation of "general overheads" such as office expenses or the use of general purpose vehicles can be complicated and arbitrary. The use of full budgets can over complicate the calculation of net margin. Use of enterprise net margin calculation and the allocation of associated fixed costs to each enterprise can lead to better identification of the true performance of each enterprise.

The review of literature has identified that farmers will act to maximise their profits, the production of the LP model will use a maximising function of the total farm net margin to optimise the cropping pattern. The use of financial budgets will be required in this project to allow the production of enterprise net margins for the LP optimisation and also as an output indicator of the farms economic performance.

2.10 Chapter Summary

This chapter has defined the study topic with reference to the issues involving the WFD and irrigated agriculture in England. References to the specific issues within the WFD have been examined and the possible links between WFD and irrigated farming highlighted. Reference to the agricultural practices which will be affected has been made including the impact of water restrictions and impacts upon water quality with respect to the agrochemical inputs to the system. The focus of the WFD will be to improve or maintain the quality of inland waters and to attain good ecological status. The Directive will provide the necessary framework to allow the control of potentially polluting practices. Irrigation farming will be directly affected by this policy through both water quantity and quantity concerns. Summer abstraction and agrochemical usage involved with the production of high value irrigated crops and the key areas which could be directly affected by restrictions implemented as part of the directive. The issues, research models and techniques discussed in this chapter will be combined to formulate an analytical framework and will be used to develop the study methodology described in the next chapter.

CHAPTER THREE. STUDY METHODOLOGY.

This Chapter describes the methods and techniques used to investigate the impact of WFD on irrigated agriculture. The review of literature defines the boundaries for the research and provides confirmation of the study context. A methodology has been developed to enable the testing of various policy measures using the output of economic, social and environmental indicators to communicate the impacts of modifications in the farming system. The selection of the case studies and the characterisation of each case study are given. These case studies have been used to develop LP models representing the current situation. Data requirements for each LP model are identified and collection methods are explained. Research models have been used in the creation of output parameters such as nitrogen and pesticide leaching and energy use and energy output. These are used as indicators in the output from the LP models. An analytical framework is applied to the current situation and to the policy options of the WFD, enabling the analysis of the impacts of policy change on irrigated agriculture.

3.1 Overview

The introduction of the WFD requires greater controls on the management of water resources. Identifying the impacts of WFD on irrigated agriculture requires the investigation of the links between agricultural practices and water resources. These links include the relationship between irrigated crops and water abstraction, agrochemical inputs and risks of agrochemical emissions and the associated economic and technical performance of the farming system.

An analytical framework has been developed to guide the development of the models and ensure that all of the issues are considered within the analysis. Suitable research models identified in Chapter Two are used in the generation of parameters and values for use in the LP models. The LP model connects all input parameters and enables the maximisation of net margin within a number of policy scenarios. Figure 3.1 shows the development of the project and the steps involved in the development of an LP model which can be used to analyse the impacts of WFD.

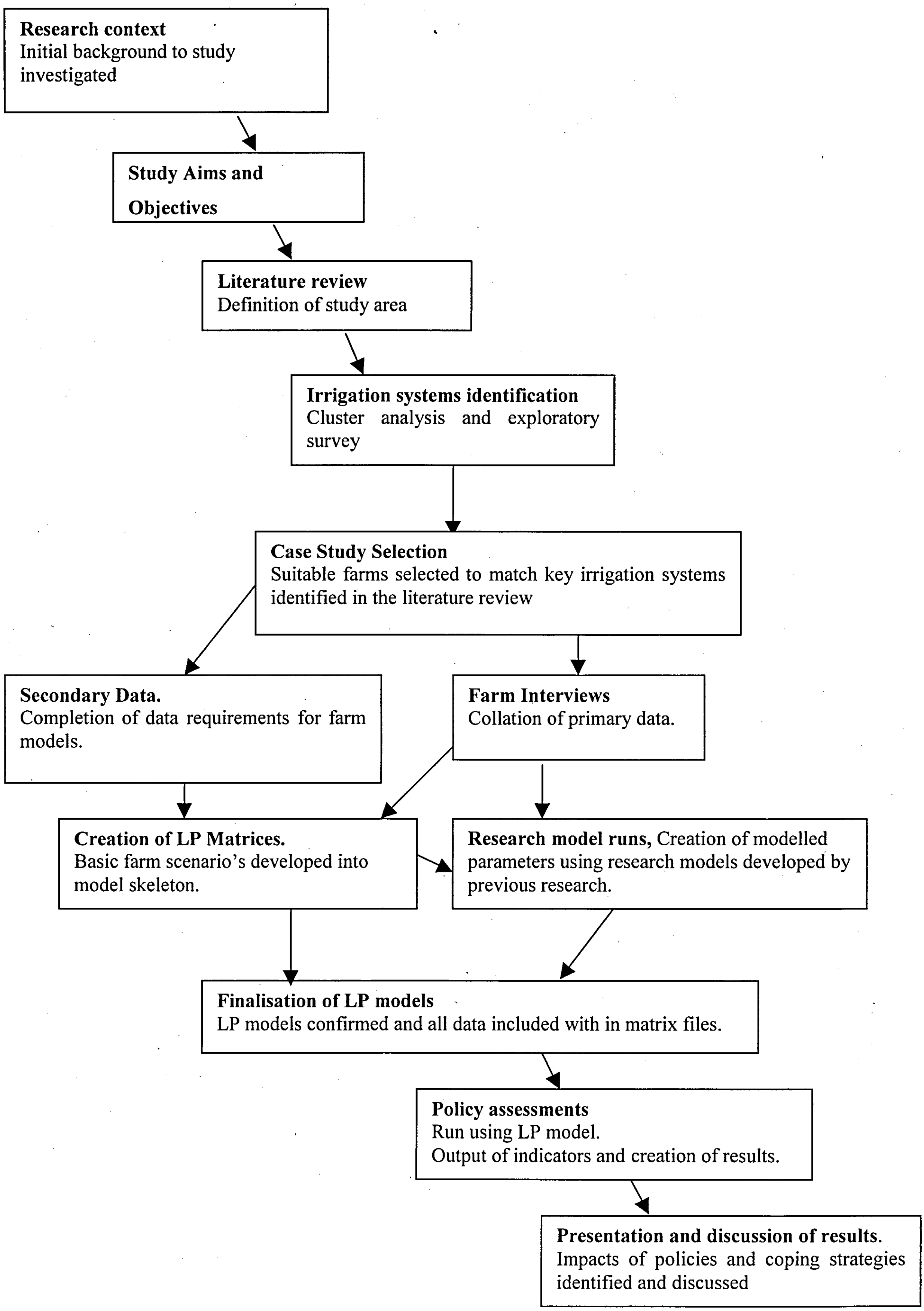

Figure 3.1: Routemap of the research methods.

3.2 Choice of case studies

The use of case studies in conjunction with models to assess the impacts of changes in management practices have been confirmed by a number of studies. Abdelshafae (1998) uses case studies to assess the impact of agro-environmental policy on water quality and agricultural practice. Johnes (1996) uses case studies to develop techniques looking at nutrient losses from agricultural land and Leiva (1997) uses a case study approach to investigate sustainability of agriculture under variations in machinery use.

The use of case studies allows impacts to be assessed and verified against actual scenarios that are representative of particular subgroups within the irrigated agriculture sector. Selection of the case studies required the identification of sub groups within the sector so that representative studies could be selected. Work undertaken by Morris *et al.* (2004) looked at the impacts of changes in European policy on irrigated agriculture in England and Wales. Part of this work included the characterisation of several sub groups within the irrigation sector (Table 3.1).

Table 3.1: Clusters of irrigation farming systems based on all irrigating farms.

	Potato & Sugar Beet	Vege-tables and Potato	Fruit Crops	Grass	Sugar Beet and Cereals	Other Crops	Crops Total Area
Early Potatoes	7%	4%	0%	0%	1%	1%	5%
Maincrop Potatoes	70%	14%	5%	8%	6%	8%	47%
Sugar beet	10%	1%	1%	2%	14%	1%	7%
Orchard fruit	0%	0%	27%	0%	0%	0%	1%
Small fruit	0%	0%	63%	0%	0%	0%	3%
Vegetables	8%	79%	2%	4%	4%	3%	26%
Grass	1%	0%	2%	80%	1%	1%	3%
Cereals	2%	1%	0%	0%	70%	3%	3%
Other crops	2%	1%	2%	4%	4%	83%	5%
Total within group	100%	100%	100%	100%	100%	100%	100%
% of All Groups	61%	27%	4%	3%	2%	4%	100%

Source: Morris *et al.* 2004

Cluster analysis was used to group the farms according to type and area of irrigated crop. Six groups were identified, with two main groups of farmers being dominant. Potato and Sugar Beet farming and Field Scale Vegetables and Potato farming together account for 88% of total irrigated area. Fruit farms were shown to represent just 4% of the total irrigated area but are a specialist group with orchard and soft fruit almost exclusively found in this cluster (Vasileiou, *et al.*, 2003). The specialist nature of this group makes the inclusion of a case study to reflect these cropping options important within the objectives of the study.

A survey was undertaken to confirm the characteristics of the irrigation sector identified in the cluster analysis. Questionnaires were sent to over 25 farmers and irrigator groups. The aim of this survey was to assess the results of the cluster analysis and to confirm that the "typical" farming systems fitted to the actual case. Questions asked in this survey covered the characteristics of the farm in terms of the cropping patterns, total area, irrigation technology and water supply. Questions on the limits of their current water supply were also included and ways in which farmers could adopt in order to cope with any future modification in water availability and supply.

The results from this questionnaire (Appendix 1) show that individual farms have great variation in terms of the areas and mix of crops irrigated. The broad comparison shown in Table 3.1 was however confirmed. Although no single farm exactly fits the average farm for a single cluster the survey confirms the validity of the clusters and supports the selection of typical case studies to assess the impact of WFD policy on irrigated farming.

Selection of the case studies has been limited to the Anglian region. This is the predominant region for irrigation in the UK with 50% of total irrigated area being located within the region and accounting for the largest individual areas of each of the identified clusters (Table 3.2).

Table 3.2: Total Crop Area (ha) Irrigated in 1995 by EA Region.

EA Region	Early Potatoes	Maincrop Potatoes	Sugar Beet	Small Fruit	Vegetables	Total
North East	416	7092	1815	28	754	**11631 (8%)**
North West	304	1351	152	4	934	**3159 (2%)**
Midlands	1674	12107	7181	432	3685	**30947 (22%)**
Anglian	4216	26854	16481	1067	15109	**76271 (53%)**
Thames	210	1127	280	328	1655	**4319 (3%)**
Southern	739	2350	0	966	3653	**9581 (7%)**
South West	576	1086	0	166	649	**3654 (3%)**
Welsh	1021	1023	270	157	864	**3823 (3%)**
Total	**9156**	**52990**	**26179**	**3148**	**27303**	**143385 (100%)**

Source: MAFF 1997

Within the resources available the project was limited to the selection of three case studies selected from the Anglian region. Careful selection of case studies was undertaken with the likelihood of good communication and access to data requirements being essential. Contact was made with a number of farmers who have been involved in previous work undertaken at Cranfield University at Silsoe and a selection of the three most suitable case studies was made. Key characteristics such as the cropping patterns, farm sizes and levels of detail available enabled the selection of representative farms. Morris *et al.* (2004) noted that although the selection of the cluster appears valid there is considerable variation in cropping patterns in the dominant groups. This is especially true of the vegetable and potato group where growers tend to specialise to meet market needs. This suggests that the selection should be presented as representative of the required farm types. Table 3.3 summarises the three case studies chosen, Lakes Farm has been identified as a specialist field scale vegetable grower concentrating on the production of high quality onions, with the production of potatoes alongside. Roudham Farm has a varied cropping pattern concentrating on the production of potatoes and sugar beet with some field scale vegetables, rainfed cropping options are used as gap crops for the rotations required. Church Farm concentrates on the production of soft fruit, with large areas of strawberries and raspberries, some potato and sugar beet is grown as well as cereals for gap rotations.

Table 3.3: Summary of the key characteristics of the three selected case studies.

Characteristic	Lakes Farm	Roudham Farm	Church Farm
Location	Cardington, Bedfordshire	East Harling, Thetford, Norfolk	Tunstead, Norfolk
Farm Area	223 ha tenant, 32 ha rented	408 ha (292.5 ha owned, 115.5 ha rented on yearly rotation	282 ha
Command area	255 ha	408 ha	282 ha
Irrigated area (annual)	64.5 ha	291 ha (including 115.5 ha rented for potatoes and onions)	174.3 ha
Cropping pattern (options)	Rainfed: Winter Wheat, Spring Wheat, Peas. Irrigated: Onions, Maincrop potatoes.	Rainfed: Spring Wheat, Spring Barley, Hemp, Field beans. Irrigated: Potatoes, Sugar beet, Onions, Carrots and parsnips (contract linked).	Rainfed: Spring Barley, Winter Wheat, set-aside. Irrigated: Strawberries, Raspberries, Potatoes, Sugar beet.
Cropping constraints	Rotational for onions and potatoes 1year in 6	Rotations set by potatoes 1year in 6. Vegetables same and sugar beet 1year in 3.	Rotations for fruit five year gap after strawberries and Raspberries. 1year in 4 for pots and sugar beet.
Water supply	290,049 m^3 Storage reservoir with surface water winter abstraction to top up reservoir (Elstow brook).	Four borehole licences total 575,400 m^3. Cessation clause 50% reduction when local SSSI has water shortages.	10 summer abstraction borehole licences 226,000 m^3. Additional water abstracted for irrigation under trickle exclusion.
Irrigation system	Buried main supply network covering whole farm. Hosereel system with 25mm 7 day interval	Buried main supply network connecting all sources, Mixture of hosereel and centre pivot.	Trickle irrigation for fruit with some spray irrigation for potatoes and sugar beet.
Labour and machinery	Regular labour + casual for harvest periods (potatoes). Contract work for combinable crops and all cultivations. Fully mechanised planting and harvest.	4 Regular labourers, with some part time. Casual labour for potato harvest. Fully mechanised system, with latest technology (mechanised grading).	Regular and casual labour employed. Fully mechanised where possible.

3.3 Analytical Framework

An analytical framework has been developed to examine the impacts of the WFD on the various practices involved in irrigated farming. The key data requirements needed in the development of the LP model are summarised in Figure 3.2. Three stages have been identified in the development of this framework. Stage 1 involved the identification of factors linking irrigated agriculture and water resources. A review of literature was used to investigate the sector and to identify the links between irrigated agriculture and water resources with particular reference to the WFD. These factors were required in the production of the LP model in order to assess the impacts in variations in the management of water resources and production activities. Data requirements of the study are outlined in this stage. Stage 2 identified the sources of data, and research models used in the output of parameters that could not be gained from primary sources. Stage 3 involved the collation of all primary and secondary data into the case study models that are used to simulate the farm systems and allow the testing of policy options.

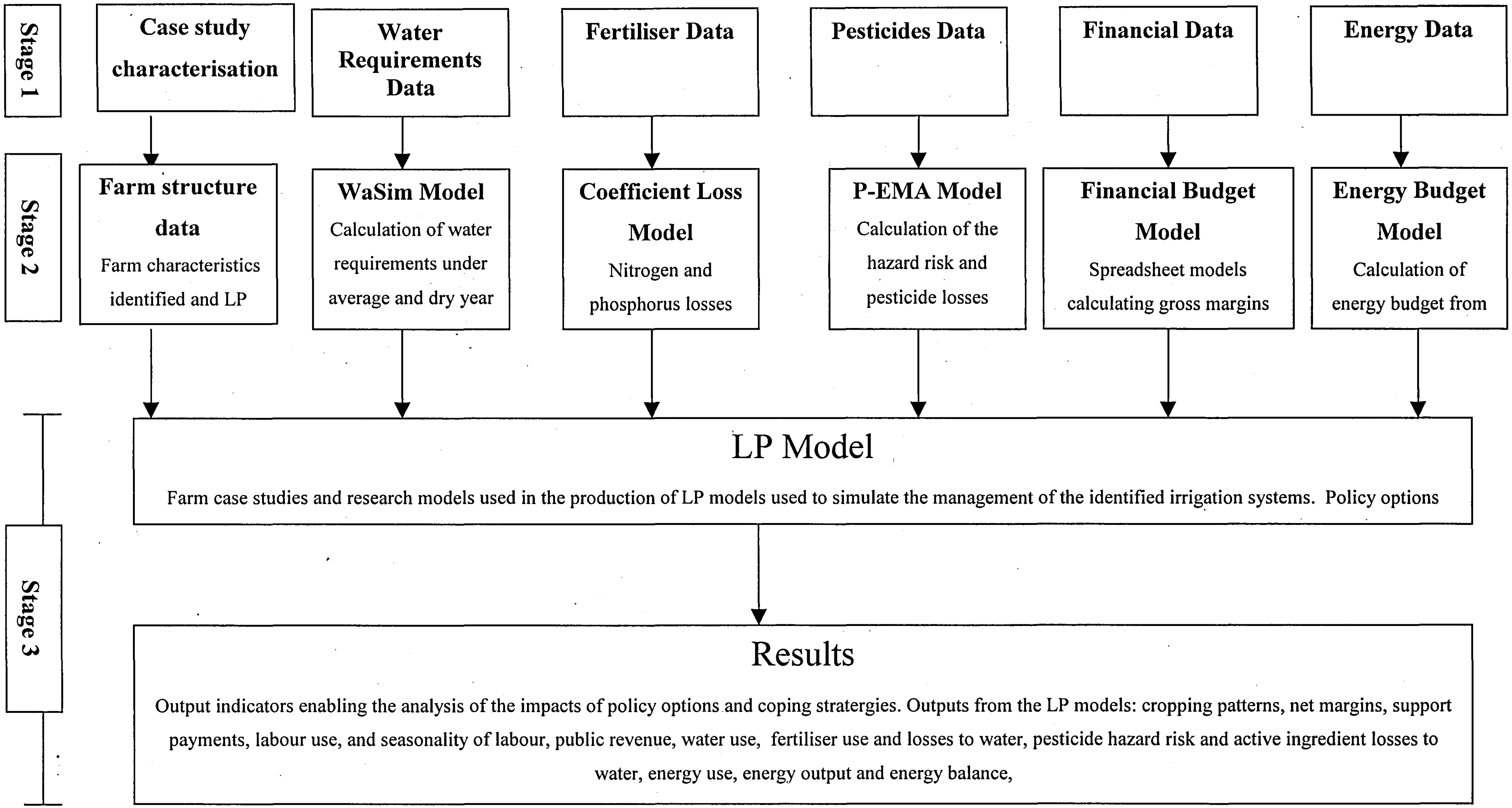

Figure 3.2: Flow chart representing the analytical framework for assessing the impacts of the WFD.

3.4 LP Model

The use of LP lends itself well to farm planning to the determination of enterprises that maximise the returns to a particular set of fixed resources. The development of an LP model requires two basic sets of input data, the matrix and the program. The matrix is basically a two way table which contains the data on the problem to be solved. In this case all the data about each of the case study farms is held within the matrix. The second is the program; this consists of instructions about the manipulations to be performed on the matrix (Barnard and Nix, 1973).

LP has been used to investigate the impact of various policy options and coping strategies on the case study farms. The preparatory models in Stage 2 of the analytical framework, and the general case study characteristics data collected from the farm interview (chapter 3.2) were used to develop a matrix that combined all of the interacting components of the farm case studies. The model aims to optimise the net margin subject to a number of constraints and activity requirements. It uses the results of the preparatory models and determines the optimum levels of each enterprise subject to the available resources and constraints imposed by the selected WFD policy measures.

The assessments of the impact of the WFD policy and the extent to which coping strategies will retain the viability of irrigated agriculture have been investigated using the LP model. The policy measures described in section 3.7 below were used to develop scenarios that impart the restrictions or coping strategies on the case study. The impact of these modifications on the farm was assessed using the indicators outputted from the model. The outputs from each LP model are: total net revenue, cropping pattern, water use, labour use, added value, marginal value product of water, fertiliser use, agrochemical losses/hazard and energy use and output. Details of the LP command and matrix files are given in Appendix 2.

Table 3.4: Summary representation of the LP matrix files.

		ACTIVITIES						
RESOURCES AND CONSTRAINTS		Rainfed Crops	Irrigated Crops	Irrigation systems	Water Supply	Labour Services and costs	Machinery services and costs	Agrochemical discharges
	Maximise Gross Margin	+	+	-	-	-	-	
	Land (owned)	+	+					
	Land (rented)		+					
	Crop Rotations	+/-	+/-	+/-				
	Regular labour	+/-	+/-			-		
	Casual labour	+/-	+/-			-		
	Agrochemical Controls		-					-
	Water		-	-	+			
	Farm Specific area constraints (Contract, trials)	-	-					

Footnote: = or – values denote non zero values, sign denotes direction of relationship

3.5 Data sources and methods of collection

Data has been collected from both primary and secondary sources. Primary sources of data came from the farm interviews for each of the case studies. Careful selection of these case studies ensured that accurate and reliable data could be obtained. All three case study farms were able to supply detailed information regarding the management and characteristics of the system. This aided in the construction of models that were considered reliable and representative of the chosen case studies. Data that could not be obtained from the interviews were collected from secondary sources, mainly academic papers and industry journals such as The Agricultural Budgeting and Costing Book (Agro Business Consultants, 2003) and Farm Management Pocketbook (Nix 2003). Data collected from the interviews, secondary sources and the research models were used in the production of matrix files. Matrix files contain data regarding the characterisation of the farms and allow the interconnection of resources and activities within the LP model.

3.5.1 Case study characterisation

A matrix was constructed for each case study. Standard base data such as the farm area, areas of rented land, crops grown and water sources were required to set up the matrix skeleton. Interviews were carried out with the farmers at each of the case studies in order to gain the required data. Requests for data requirements were sent to each farm prior to the interview so that available data could be collated in time for the interview (Appendix 3). Table 3.5 gives details of the data requirements for farms.

These farm interviews provided the basis for the development of each of the LP models. Where insufficient data were available secondary sources were used to fill any gaps. Specific data for labour requirements were not readily available and were therefore collated using the machinery work rates by operation and labour requirements and secondary sources such as Nix (2003).

Table 3.5: Summary table of data required from the farm case studies.

Data	Requirements	Comments
Baseline farm data	Farm size, Ownership/rental. Soil classification	Basic data required to set up matrix, soils data important in the use of research models
Cropping Data	Cropping options available and historic areas grown. Constraints on area grown e.g. rotations, contracts.	Confirmation that the case study is suitable for the study. Development of the LP requires cropping options and the constraining factors to the areas grown.
Crop specific data	Yields, inputs and output prices. Additional costs such as contract work, marketing	Details used in the production of gross margins and variable cost data and the energy output calculations.
Farming Practices	Details of machinery use, costs, work rate, specialist machinery.	Details for inclusion in the cost models, energy input models and calculation of the labour requirements.
Irrigation details	Irrigated area, total possible command area , delivery systems, Water demand of crops, abstraction licence details, supply of water.	Details on the licences held. Total water availability. Methods of application allow the development of irrigation efficiency in the supply of water.
Labour	Regular labour, costs of labour. Employment of casual labour (which crop and which months) cost of casual labour.	Details of labour use required for the allocation of labour to each crop. Costs of labour and availability of labour are calculated within the LP model.
Agrochemical	Details of fertiliser use, volumes, timing and method of application. Details of pesticide use, specific chemicals used application dates, dosage and reasons for use.	Indicators of environmental performance. Data required for the specific agrochemical inputs for inclusion in the P-EMA and Coefficient models to generate inputs to water resources.

3.5.2 Water Requirements.

Water requirements for each of the irrigated crops were modelled using the WaSim water balance model (Counsell and Hess, 2000). Data requirements for this model include crop calendars, climate data soil conditions and irrigation schedules (Table 3.6).

Table 3.6: Data input requirements for the WaSim model.

Data	Units	Sources	Comments
Crop Calendars	Data on the crop growth stage/ crop cover. Dates that each stages is achieved	Some data from farmers, Most gained through literature review	
Climate data	Daily rainfall and evapotranspiration data.	Lakes farm used climate data from the Cranfield university at Silsoe weather station. Data for Roudham farm used climate data from Honington weather station and Church farm used climate data from Coltishall weather station, both of these data sets were gained from the meteorological office	
Soils data	Soil texture classifications	All farms were able to supply the soil textures.	
Irrigation requirements	Historic water requirements. Depths of applications.	Farm records were able to supply the depths applied to each crop. Or the typical depths applied.	This data was used to validate the modelled water requirements

Source: Hess, 2000.

The WaSim model carries out a one dimensional soil water balance aimed at simulating the soil water storage, rates of input (infiltration) output (drainage and evapotranspiration) (Hess *et. al.,* 2000). The calculation of the crop water irrigation requirements uses the model to calculate the crop water requirements for a season and undertakes a water balance. The balance of water inputs and outputs is calculated for a season using weather data from the selected weather stations and years. The calculated water requirements for each crop allow the irrigation need to be calculated. Under conditions where water is not limiting plant growth actual evapotranspiration will be at 100% of the potential. Where rainfall is insufficient, irrigation water is required to meet the total needs of the crops maintaining 100% evapotranspiration. The WaSim model allows the scheduling of irrigation to maintain the soil moisture levels and prevent water stress occurring. An irrigation schedule was defined which would prevent water stress occurring. The level of irrigation at this point is the annual irrigation water requirements.

Crop parameters were added to the database within the model. Crop specific data included crop calendars for each farm and crop. Where these data were not present typical crop calendars were gained from secondary sources. These crop calendars required the planting and harvest dates as well as specific periods during the growing season such as emergence, maximum crop cover date, 20% cover and maximum root depth date. Soil texture data are required in the model to allow for the soil properties with respect to its water holding capacity and drainage. Data on the soil texture were collected from each case study. Soil texture class was selected from a database in the WaSim model. This database contains all of the soil specific characteristics and reduces the level of detail required in the input parameters, avoiding the need for detailed soil analysis.

The WaSim model predicts the agronomic water requirements of each crop. This may not be the same as the actual water requirements per hectare. The application method and irrigation efficiency affects the water required to meet the agronomic needs of the plants. The use of trickle irrigation can reduce the area of land requiring irrigation. In systems where there are large gaps between the cropping rows, total vegetation cover may not be achieved. This is the case with raspberries and strawberries in the fruit farming system. Trickle irrigation can be used to apply the water close to the plants and so does not require the whole area to be irrigated; the agronomic requirements can therefore be met without irrigating the whole field (Knox *et al* 2004). Reduction factors reported in the literature have been applied to water requirements for crops under the trickle irrigation option. Spray irrigation requires the whole field to be irrigated to ensure uniform application of water. This means the agronomic water requirements are the same as the specific field application depths.

Inefficiencies in the application technology can result in water applications being insufficient to meet the agronomic requirements of the crop. These inefficiencies in the application technology have been accounted for in the design of the LP model which assumes efficiencies of 80% and 90% for hosereel and trickle application equipment respectively. Thus application of 25% and 11% more water is required from source to meet the agronomic needs. Storage reservoirs enable the abstraction of winter water for use at a later date; the storage of water will however add a further inefficiency to the system in the form of evaporation losses of up to 10%. Where winter water is used in the case study farms an extra inefficiency factor has been included requiring 10% extra total water to be abstracted to meet the evaporation losses.

3.5.3 Pesticide usage and risks

Pesticide losses have a significant impact upon the quality of water resources (EA, 2004). The identification of annual pesticide losses to water sources and the risk to the environment of each crop have been identified using the P-EMA pesticide risk assessment system (Lewis *et. al.,* 2002). This model uses four main systems incorporated into an overall risk assessment program. These are; data management, simulating environmental fate, assessing risk and risk communication. From this model, potential environmental hazard and losses of pesticides to water resources are calculated for each of the crops in the farming system giving an indication of environmental performance of each of the cropping options.

The model requires input data regarding the application conditions relating to the use of pesticides (Table 3.7). The model has three basic levels of data input, farm level, field level and application specific data. The first is farm general data regarding the total area and location. This allows the program to select climate, soil and water resource data from its own databases, identifying the local environs susceptibility to specific pesticide hazards. The second level allows the input of field information namely: crop types, the number of individual pesticides applied, field drainage, presence of water and characteristic of water (if present). The final stage of data input is the specific field applications of pesticides and requires data on particular chemicals used, application rates, reasons for use, date of application, application methods and crop status are all required. The model uses these input parameters to calculate outputs for the hazard risk of each crop in terms of an index on a scale of 0-100 with 0 being low hazard risk and 100 high hazard risk. These outputs are used in the LP models as indicators of the environmental performance of each farm system.

Table 3.7: Data requirements for the P-EMA model.

Data	Units	Sources	Comments
Farm Location	Post code	Farm Interview	The programme uses databases of climate and water resources held within its own files. These are accessed through postcode identification.
Farm details	Soil Texture, areas of crops. Location of drains, local water resources. Type of field boundaries.	Farm interview and Ordinance Survey maps	Field level characteristics such as the presence of water and the type of field boundary will effect the susceptibility of the local environ's due to their presence or the ease of connection to the potential hazard i.e. hedges will encourage the presence of insects and mammals, the presence of water increases the possibility of pollution form pesticide applications.
Pesticide use	Brand names of chemicals used, including the number of applications of each.	Data direct from farmer records. Secondary sources: The UK Pesticide Guide (BCPC 2004).	Selection of the brand name, where the specific brand name is not present in the P-EMA database alternative brands have been used and were identified from the pesticide manuals.
Date of application	Specific data in dd-mm-yyyy format.	Data from farm records.	Date of application is used in ensuring that applications are mead within the correct boundaries as stated in the label for the pesticides use, some are season specific or have to have a specified date between application and harvest.
Application Rates	Rates of chemical applied per ha. kg/ha or l/ha.	Data from farm records.	
Crop Growth stages	Growth in terms of % crop cover or the growth stage i.e emergence, tillering and flowering.	Data from farm records/ crop growth calendars as used in the WaSim model	

3.5.4 Fertiliser Use/losses

The export coefficient model (Johnes, 1996) was used in the calculation of nitrogen and phosphorus losses per ha of each crop. The total inputs into each cropping system are calculated and a coefficient is applied to this amount to calculate the total losses of fertiliser per ha per annum. Table 3.8 gives an example of the total nitrogen inputs and the coefficients used to derive the total losses of nitrogen per ha for each land use type. The model is simple with the export coefficients calibrated to the specific land uses in the England. The calculation of fertiliser losses uses a modified version of the model described by Johnes (1996).

$$L = \sum_{i=1}^{n} E_i \left[A_i (I_i) \right]$$

Where: L is the loss of nutrients,

E is the export coefficient for nutrient source i,

A is the area of the catchment occupied by land use type i,

I is the input of nutrients to source i.

The export coefficient has been derived by Johnes (1996) from the literature for each of the land use types. In this project calculation of the nutrient losses are required per hectare of land use. The area A in the formula is therefore set at one. Inputs of fertiliser are limited to the inputs to land and include the actual fertiliser applied; these data were collected in the farmer interviews. Data for the nitrogen fixation and the atmospheric nitrogen deposition were taken from Abdelshafae (1998).

Table 3.8: Example of the data required for the export coefficient model for Lakes Farm.

Crop	Nitrogen Fertiliser (kg/ha/yr)	Atmospheric N (kg/ha/yr)	N-Fixation (kg/ha/yr)	Export Coefficient	N-Leaching (kg/ha/yr)
Set aside	196	21.00	10.00	0.02	0.62
Winter wheat	146	21.00	4.00	0.12	28.80
Spring wheat	0	21.00	4.00	0.12	24.00
Peas	192	21.00	50.00	0.20	14.20
Potatoes	110	21.00	10.00	0.20	44.60
Onions	196	21.00	50.00	0.20	36.20

3.5.5 Financial Budget Models

Spreadsheet budget models were developed to calculate the gross outputs, variable costs and gross margins of each enterprise for each farm (Appendix 4). The gross margin for each enterprise has been defined as the gross output less the variable costs (excluding casual labour). Data gained from the farmers included input and output prices and yields. Gross output has been calculated by multiplying the yield and the sale price, where support payments are available these are added to the total income from the sale of the crop. Variable costs are calculated through the allocation of all attributable costs for each enterprise for example seed, fertiliser and pesticide costs. Machinery and casual labour costs are not included in this model but are included in the calculation of final net margin for the farm. Labour costs are allocated per crop enterprise as an activity with negative net revenue. Regular labour (fixed cost allocation) and casual labour were charged per hour with the total labour requirements and cost calculated within the LP model.

Machinery costs are allocated as both fixed and variable costs. Calculation of the machinery costs were based on actual inventories of machines on the case study farms using a spreadsheet based on a model designed by Leiva (1997). In order to calculate the fixed and variable costs for each enterprise on each farm, details of the specific machinery used were required so that they could be entered into the machinery costs model (Table 3.9). Variable and fixed costs for each crop were calculated by summing the costs for each piece of machinery used in production. Costs of investment, shelter, insurance and taxes. Depreciation is calculated using a straight-line method using actual purchase price, resale value and average life of machinery. Where farmers could not provide the data required, estimates were taken from Nix (2003) and Agro Business Consultants (2003). Interest was calculated at 6% for the average investment in the equipment (average of purchase price and resale value). Shelter taxes and insurance costs are assumed to be one percent of the purchase price. Calculation of the variable costs includes repairs and maintenance, fuel and engine oil (Witney, 1988). Annual repairs and maintenance were calculated using factors gained from Agro Business Consultants (2003) according to average annual use. Fuel consumption (l/ha) and unit costs of fuel were used to calculate the costs of fuel, oil costs are assumed to be 15% of fuel costs (Leiva, 1997). Machinery costs combine the tractor charge and the specific implement cost. Where machinery is self propelled the costs do not include tractor charges.

Table 3.9: Example of the budget model for the calculation of gross output, variable costs and gross margin.

SPRING BARLEY GROSS MARGINS		
GROSS OUTPUT		
Barley sale price	£/t	62
Area payment	£/ha	249
Grain Yield	t/ha	5.6
Gross Output	£/ha	596.2
VARIABLE COSTS		
Seeds	£/ha	32.24
Fertilisers	£/ha	14.49
Chemicals	£/ha	67.13
Contractor Harvest	£/ha	63.09
TOTAL V COSTS	£/ha	176.95
GROSS MARGIN	£/ha	419.25

Table 3.10: Example of machinery costs model.

FARM SIZE ha		402			Self prop.
MACHINE TYPE		TRACTOR case5150	PLOUGH	ROLLER	SPRAYER
SIZE/WIDTH kw,m		114	3.5	6	12
POWER RATIO	*		0.8	0.6	0.4
SPEED km/h	*		4	6.4	9
FIELD EFFICENCY	*		0.86	0.85	0.65
PURCHASE PRICE £		36891	18923	6000	36344
RESIDUAL VALUE %P		35	20	20	10
DEPREC.LIFE years		5	6	8	6
ANNUAL USE hours		650	246	150	200
ANNUAL REPAIRS %P		6.8	7.5	2.5	2.5
INTEREST		6	6	6	6
DIESEL £/l		0.17	0.17	0.17	0.17
AREA WORKED %			0.89	0.02	0.96
AREA WORKED HA			357.78	8.04	385.92
ANNUAL FIXED COSTS £					
DEPRECIATION			4796	2523	600
INTEREST		1217	625	198	1199
OTHER		369	189	60	363
TOTAL		6382	3337	858	7014
FIXED COSTS/hour		9.82	13.56	5.72	35.07
TRACTOR fc/h	*		9.82	9.82	9.82
TRACTOR & IMPL fc/h	*		23.38	15.54	44.89
VARIABLE COSTS £/h					
REPAIRS & MAIN.		3.86	5.77	1	4.54
FUEL	*		6.52	5.4	1.45
OIL	*		0.98	0.81	0.22
TRACTOR & IMPL vc/h	*		17.13	12.98	6.21
GRAND TOTAL £/h	*		40.51	28.52	51.1
WORK RATE ha/h	*		1.2	3.26	7.02
GANG SIZE	*		1	1	1
COST SUMMARY £/ha					
FIXED	*		19.42	4.76	5
VARIABLE	*		14.23	3.98	0.88
TOTAL	*		33.65	8.74	5.88

Based on: Leiva, 1997.

3.5.6 Energy Models

Calculation of the energy input, use and balance for each enterprise has been undertaken using a spreadsheet model. Data required for the calculation of the energy balances included the units of energy used in the production of each crop, unit energy values, yields and unit values for energy for each crop (Table 3.11). Data for the inputs of energy carriers was gained from the farm interviews; fuel use was calculated using the machinery costs sheet. The values for energy per unit of carrier were gained from a literature review and Internet searches. Most of these were supplied from work undertaken during the WADI project (Morris *et al.*, 2004). Calculation of the energy inputs uses the summation of all inputs to calculate an overall energy output for all activities involved in production. The energy output is calculated by multiplying crop yield by the energy per unit yield. Energy balance is calculated by subtracting the energy output : the input values.

Table 3.11: Example of the Energy Balance Model.

Crop		Potatoes		
Energy carriers		Units of Energy carrier used	Energy MJ/unit	Energy MJ/ha
Fertilisers kg/ha				
	N	95.8	65	6224
	P	0	15	0
	K	143.6	10	1436
Fertilisers Subtotal				7660
Labour hours/ha		28.5	0.27	8
Fuel lt/ha		430	43.3	18619
Machinery Replacement and Maintenance				1363
Pesticides (Kg of active ingredient)		12.2	97.06	1186
Seeds (tonnes)		1.6	1300	2080
Total ENERGY (MJ/ha)				30915
Output Energy		Yield t/ha	Energy MJ/t	Energy MJ/ha
		49	3223	157927
Energy Balance				127012

3.6 Water Framework Directive Programme of Measures.

The WFD aims to achieve European wide sustainable water resource use. The Directive identified the abstraction and pollution of water resources as being of concern with respect to environmental quality. Irrigated agriculture has a direct affect upon these aspects of water resource management. WFD will attempt to reduce the impact of these operations on the environment through controls on the abstraction of water for irrigation and agricultural discharges to surface and ground waters. The specific agrochemical inputs of common irrigated crops such as potatoes and field scale vegetables are often greater than for typical rainfed crops and the potential for pollution is greater as a result.

The review of literature identified three main links between irrigated agriculture and WFD. The three main areas of irrigated agriculture that the policy will affect are:

a) Quantity and timing of water abstracted
b) Efficient use of water
c) Potential pollution of surface and ground water

In order to assess the impacts of the WFD a series of possible policy options have been developed. Modification on the standard case study (current conditions) will be used to develop matrix files that are subject to the policy options, details of these options are discussed later in this chapter. The policy options are linked to the objectives of the WFD and aim to encourage modifications in water abstraction practice, and improvements in water quality.

The development of the matrix files is intended to represent the true nature of the case study farms supplying all of the potential cropping options available to these farms. The assessment of the case studies under WFD measure may modify the choice of cropping options and the relative proportions of irrigated and rainfed cropping. Under restrictions in the availability of water, farmers may be expected to switch to rainfed cropping options, this is used as a counterfactual in this study against which the performance of irrigation is compared. Under the specific conditions present on all three case studies the farmers stated that they would not be able to produce their high value normally irrigated crops under rainfed conditions. The development of the counterfactual options is therefore restricted to the initial rainfed cropping options of the combined system.

3.6.1 Scenarios for analysis

The three case studies have been used to develop whole farm models. In order to assess the impacts of WFD the current state of the farms has been modelled and assessed in terms of the economic, social and environmental performance. Using the current state as a standard baseline, the impact of each policy measure has been identified using the indicators generated as outputs from the LP model. The indicators are summarised in Table 3.12.

Table 3.12: Indicators used to assess the performance of irrigated farming systems.

	Indicator	Units of measurement
Financial/Economic	Farm income	Net Margins (£/ha), Net Margin reduction (£/ha)
	Support (subsidies)	Area payments, agri-environmental payments (£/ha)
	Value added	Net Revenues less support
	Water use	Sources, season and volume m^3
	Water value	Marginal value of water £/m^3
Social	Farm employment	Regular labour employment, total labour hours (hrs/ha)
	Seasonality of labour	Seasonal variance
Natural resources and environment	Soil cover (erosion risk)	Crop cover index
	Nitrogen balance	Nitrate load and Nitrogen losses (kg/ha)
	Pesticide risk	Pesticide environmental hazard (index), Pesticide active ingredient losses to water (µg/ha)
	Energy use and balance	Energy use (non solar) Energy output, and energy balance (input output balance), MJ/ha

3.6.2 Water Demand

Irrigated farming in England involves the use of additional water supplemental to natural precipitation. As a result the requirements for irrigation water vary annually. The impact of water restrictions and prices will therefore also vary with water demand which varies as a result of rainfall inputs and losses to the systems. Intervention measures controlling the volume of water available for irrigation will impact in differing ways under different levels of water demand. In order to assess how these impacts vary, each of the three systems were analysed under conditions of average rainfall (median year of 20 year data), and under a dry year (5th driest year in 20) when water demands are greater and the impact of water restrictions more influential.

3.6.3 Water quantity policy

Article 11 of the WFD includes measures to promote the efficient and sustainable use of water including rising block tariffs, incentives for on-farm storage and the use of economic instruments. The control of abstraction and impoundment is included within the development of the river basin management plans. Greater controls on abstraction licensing may lead to reductions in the volumes of water licensed for abstraction and to changes in the timing of abstraction. The two main interventions that could be implemented in England are, increases in water prices and greater restrictions on abstraction licenses.

In order to assess the impact of greater controls on the abstraction licensing system restrictions were imposed on the available water. Under current conditions water supply is assumed sufficient to meet the irrigation requirements of the three case study farms in the design year (5^{th} driest year in 20). In order to assess the impact of reduced water supplies for irrigation, restrictions were imposed on the licensed volume. Incremental reductions of 5% were introduced on the licensed volume from full abstraction allowed (100% current volume) to no abstraction. The second measure was to increase the price per m^3 of water charged to farmers in order to encourage reduced water use and/or improved efficiency in water use. Analysis of this policy option has been modelled by increasing the base price of water by five pence increments from no charge to the point where it is no longer economically viable to irrigate.

3.6.4 Water quality policy

The WFD has identified diffuse pollution from agrochemicals as a key constituent in the degradation of water quality. It will attempt to improve upon current situations by facilitating measures that will reduce pollution (Chave, 2001). Measures such as the introduction of modified best practice techniques will be used in order to minimise the potential for pollution to occur. Where basic measures do not alleviate pollution, further restriction on the use of agrochemical inputs will be necessary. Under the analysis of this measure restriction in the losses of agrochemicals from the farm systems have been applied to the model. Constraints in total loss of nitrogen and reductions in the pesticide hazard were placed on the farms.

The two main sources of diffuse pollution from agriculture in England are the use of fertiliser and pesticides. The impact of possible measures to reduce the risk of diffuse pollution was assessed by imposing restrictions on the losses of nitrogen per hectare on each of the systems. The current situation has been used as a standard baseline against which the impact of restrictions will be assessed. Restrictions were been imposed as a falling limit from the current situation to no nitrogen losses. The volume of pesticide lost to water is dependent upon the specific characteristics of each chemical. The hazard of specific chemicals to cause environmental damage is not necessarily connected with the volume lost (Brown *et al.*, 2003) because toxicity depends on the vulnerability of the receiving environment.

The WFD has two classes for the assessment of the chemical status. The first class looks at the chemical quality of the water resource and involves limits on the specific levels of particular pollutants, which are set at EU Community level. The second class is based on an assessment of observed versus target ecological status (DETR, 2001). In order to assess the impact of restrictions in pesticide use to bring about the objectives of the WFD, a hazard index has been used to identify the risk of pollution to surface and ground water. This hazard index includes the risk of both chemical and ecological degradation of the water resources. This index of environmental hazard has been used to restrict the potential for pollution of water resources. Reductions in the hazard risk have been imposed on each of the case studies from the current conditions to zero risk of pollution from pesticides.

3.6.5 Possible Coping Strategies

Implementation of the above measures is likely to encourage farmers to modify their practices in order to remain viable. The measures described above are likely to have impacts upon the commercial viability of irrigated cropping. Modifications in the costs and availability of water may reduce the financial returns from irrigated cropping. Irrigated crops are typically more labour intensive than rainfed crops; reductions in the areas of irrigated crops may reduce labour demand impacting on social participation in agricultural activities.

In order to reduce the impact of the WFD, farmers are likely to adopt strategies which will enable them to meet the objective of the WFD while at the same time maintaining the commercial viability of irrigated cropping. In the questionnaires sent as part of the preliminary case study selection, farmers were asked what strategies they would consider in order to cope with restrictions in water availability.
The main measures that respondents highlighted were:

a) Change of licence from summer abstraction to winter abstraction and construction of a storage reservoir.
b) Improvements in irrigation equipment (efficiency gains).
c) Modified cropping patterns.
d) Deficit irrigation (sub optimal irrigation not meeting total irrigation water requirements) and incurring penalties in terms of yield and quality.

Improvements in the efficiency of irrigation technology are limited due to the nature of current application methods in England. The two case studies which use overhead irrigation methods (Lakes Farm and Roudham Farm) already use advanced scheduling methods and so have relatively efficient levels of water use with little scope for improvements. Trickle irrigation has the potential for greater application efficiency when compared with spray irrigation (Knox *et al.*, 2004). Substitution of trickle irrigation was explored in these case studies to assess the ability of improved water application efficiency to extend the viability of irrigation under licence restrictions and water price increases.

When restrictions are placed on the abstraction of summer water, use of winter water for irrigation enables the continuation of irrigation using a stored water supply. Lakes Farm uses winter abstraction and a storage reservoir to supply its irrigation water, this reservoir was built in response to restrictive water supplies. This case study has already used winter abstraction as a coping strategy to sustain irrigation where summer water is scarce. The Roudham Farm and Church Farm case studies consider the coping strategy of providing winter water for irrigation. Under this policy option charge for water abstraction are reduced by a factor of 10 compared to summer water but the cost of stored water are an additional £0.30-£0.50/m^3. This option was assessed under restrictions in water availability and water price.

3.7 Critique of methods

The study covers a diverse range of topics requiring the selection and use of a number of techniques, and research models which have often been developed for purposes other than those of this study. The approach uses a deterministic approach to assess the farming practices based on average values such as crop yields, output and input prices, agrochemical inputs and losses and water abstraction. In reality the relationships between these factors are uncertain and may vary considerably from year to year. This deterministic approach is characteristic of the LP model. The LP matrix is limited in size; the choice of enterprises available and options for modifying the practices under varying policy and water availability options are limited. These limitations could be overcome through the development of more complicated research methods, and more complex case studies with the ability to incorporate extra choices within the enterprises. This was not possible within the resources available for the current study. With respect to modelling pollution risk, the study derived estimates of potential pollution load but not potential toxicity. The latter would require estimates of total environmental limit values. This was not possible within the constraints of the current study. The case studies used to investigate the impact of WFD policy measures have specific characteristics. The results from the study farms need careful consideration when extrapolating the results to generalise on the impact on the irrigation industry as a whole. This research is explanatory in nature. With this in mind, withstanding criticisms and the limitations of the approach, the findings of the study are considered valid and justifiable. The criticisms of the methods used in the study provide a basis for recommending future research.

3.8 Chapter summary

This chapter describes the methods used to progress with the research, the development of the analytical framework, and the LP models have been described and the selection of case studies explained. The analytical framework identified the data requirements and sources for the project, the structure of the LP model was confirmed and the indicator outputs defined. The WFD policy options were presented and explained. The following chapters present the implementation of the analytical framework to the three case studies. The results are presented and the impacts of the policy options discussed.

CHAPTER FOUR.

RESULTS AND DISCUSSION.

This chapter applies the analytical framework to the case study farms in order to investigate the impacts of the policy measures described in Chapter Three. This Chapter briefly describes the characteristics of each case study in terms of location, land use, soil type and resources available, as well as constraints to the activities undertaken. More detailed data regarding the input parameters used in the production of the LP models are given in Appendix 2.

The results of the LP models for each case and scenario analysis are presented. Coping strategies to maintain irrigation under the influence of WFD policy measures are identified and discussed. A summary of the results and discussion is presented at the end of the chapter.

4.1 Description of measures.

Four measures have been implemented to examine the impacts of the WFD in line with the objectives of the study. The measures that are tested are:-

- Water licensing restrictions; the availability of water was restricted by decreasing increments of 10% of the total licensed volume. Impacts under average and dry conditions were calculated by the WaSim model.
- Water price increase; the current water charge per m^3 was increased by incremental amounts in order to encourage water efficiency increases and water use reduction.
- Nitrogen loss restrictions; limits were placed on the amount of nitrogen lost to water resources.
- Pesticide Hazard restrictions; constraints were placed on the overall hazard index allowed per hectare of farm area.

4.2 Lakes Farm case study.

Lakes Farm is a tenant farm located in Bedfordshire close to the village of Cardington. The farm occupies an area of 255 hectares and has been under the management of the same family for three generations and has a history of irrigated farming prior to the 1970s. The land is made up of sandy loam soils that are relatively coarse in texture. All irrigation water is supplied from winter water abstraction in the form of a 50 million gallon reservoir and a licence to abstract a further 11 million gallons from an old gravel working. The reservoir was installed in the mid 1970s in response to restricted water availability and difficulties in the distribution of the water available. Investments in the irrigation infrastructure allow the whole farm to be irrigated as well as additional land on neighbouring farms. The farm grows onions and potatoes to supply contracts with specific markets and aims for high quality guaranteed produce. Cultivation operations are all undertaken on a contract basis as is spraying and the production of the combinable crops used as gap crops to allow for suitable rotations. Extra land is rented on a yearly basis from neighbouring farms to allow for the extension of total area of onions; this allows the rotational requirements to be met. Casual labour is employed on a seasonal basis mainly for the potato harvest. Regular labour includes the use of some part time labour for tractor driving when required.

4.2.1 Measure 1: Restrictions on licensed abstraction.

The assessment of this policy aims to analyse the sensitivity of the farming system to reductions in available water. To implement this policy option the current licensed volume of water is restricted in increments of 10% restricting the volume of water available for irrigation. The results of the reductions in the volume of water available are compared with the unconstrained scenario (the modelled current situation).

Table 4.1 summarises the results for the water restrictions on the Lakes Farm case study. Changes in water availability affect the cropping patterns as the volume of water available for irrigation decreases the system switches to greater areas of rainfed cropping. During the average year water requirements are less than 75% of the total licensed volume. Reductions in the available water greater than 25% reduce the area of rented land used for onion production. Incremental reductions in the water available lead to reductions in the areas of onions, followed by potatoes in accordance with their relative returns to water.

Figure 4.1 shows the trends in farm performance as the supply of water is reduced. In terms of the economic performance the net margin per ha falls by over 70% due to the switch to rainfed cropping. This switch leads to a 60% increase in the levels of government support. Under unconstrained water supply 38% of the farm is involved in irrigated cropping. In the absence of water for irrigation a switch to rainfed cropping reduces the total land area due to the loss of rented land for onions, and supported crops account for 100% of the farm area. The level of value added to produce falls from £974 per hectare on average to just £66.80 under a rainfed system. Labour shows a large decrease from 2 regular labourers (excluding farm manager) to none due to the contract production for all rainfed crops. Labour hours decrease dramatically from the point of 75% water availability to 0 hour per hectare with the rainfed system at no water available. Total labour requirements show a less drastic fall when there is still some irrigated cropping, at 25% water availability total labour requirements are 7 hours per hectare; a reduction of 35%. As the area of irrigated cropping declines the losses of nitrogen steadily decline with total reductions of just under 40% under the rainfed-cropping regime. Pesticide environmental hazard risk shows a gradual decline in the potential for damage with a total reduction of just over 20% under the rainfed system.

Table 4.1: Summary results for Lakes farm, water restriction measure (average year).

Water Available Cropping pattern (255 ha)	100%	75%	50%	25%	0%
Rainfed Crops					
Winter Wheat	111.5	111.5	111.5	111.5	111.5
Spring Wheat	33.3	33.3	34.3	40.0	40.0
Peas (combined)	0.0	0.0	0.0	19.3	51.2
Set aside	14.5	14.5	14.6	17.1	20.3
Irrigated Crops					
Potatoes	31.9	31.9	31.9	31.9	0.0
Onions	31.9	31.9	30.8	3.3	0.0
Onions (rented)	32.0	26.5	0.0	0.0	0.0
Rainfed land	159.3	159.3	160.3	187.9	223.0
Irrigated land	95.7	90.2	62.7	35.1	0.0
Net margins (£/ha)	1124.41	1106.63	998.07	670.01	316.17
Subsidies (£/ha)	150.03	153.32	172.68	205.83	249.37
Value added (£/ha)	974.38	953.30	825.39	464.17	66.80
Public revenue (£/ha)	2.86	2.74	2.05	1.02	0.00
Net margins reduction (£/ha)	0.00	17.78	126.33	454.40	808.23
Regular labour	2	2	1	1	0
Labour (hrs/ha)	11	11	10	7	0
Seasonality of labour	224	227	243	280	0
Winter water (m^3)	232669	218212	145475	72737	0
Water used (m^3/ha)	2431	2418	2321	2072	0
Water marginal value (£/m^3)	0.00	0.73	0.82	1.02	1.41
N leaching (kg/ha)	30.4	29.6	25.8	23.5	19.3
P leaching (kg/ha)	5.9	5.7	4.8	4.3	4.0
Soil cover index	5.1	5.1	4.9	4.7	4.7
Pesticide Environmental Hazard Index	12.4	12.0	10.3	10.0	9.5
Pesticide active ingredient losses to water (μg/ha)	0.240	0.235	0.211	0.202	0.133
Fert-N (kg/ha)	170.6	172.0	179.6	170.5	138.9
Fert-P (kg/ha)	98.4	97.1	89.0	73.0	45.0
Fert-K (kg/ha)	86.2	86.3	86.9	81.6	44.8
Energy used (MJ/ha)	24768	24581	23463	20589	15251
Energy output (MJ/ha)	102303	102619	104303	99722	82363
Energy balance (MJ/ha)	78631	79088	81623	79524	67113

Total risk of environmental damage is low under this farming system with an initial risk index of 12 falling to just 9.5 under the rainfed cropping regime. The energy balance remains relatively constant, only falling by 15% under the entirely rainfed system and remaining very slightly above the initial balance at the unconstrained water supply.

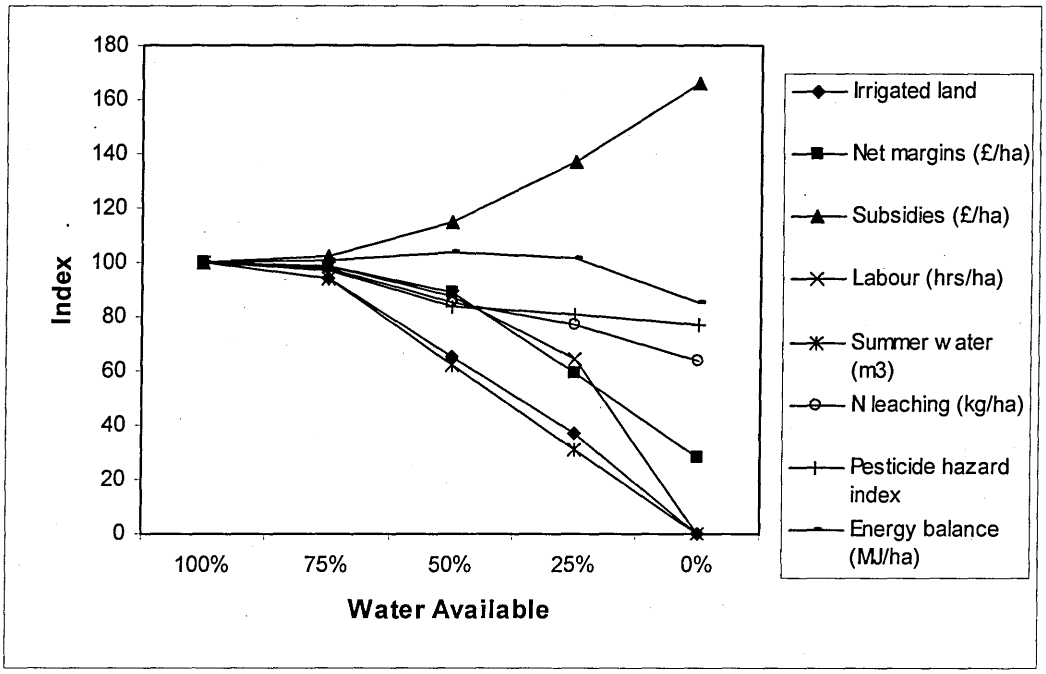

Figure 4.1: Indicators of performance, Lakes Farm, licence restrictions measure (average year).

Dry year scenario, impact of licence restriction.

Table 4.2 gives a summary of the impact of water restrictions under the dry year scenario. Under the full water restrictions with no water available impacts are identical to those for the average year. The current licensed volume is insufficient to supply the total water requirements of the unconstrained cropping pattern. Impacts of the water reductions follow the same trends as identified in the average year scenario. Due to the increased water demand of irrigated crops the impact of water restrictions is felt sooner under the restrictions, for example the area of irrigated land at 50% water restrictions under the average year is 62.7ha and under dry year conditions it is 47 ha. This reduction in the area of irrigated land has associated impacts on the net margins and social and environmental performance of the farm. Greater water requirements in the dry year shift the severity of the impact making any restrictions cause a greater and more immediate effect.

Table 4.2: Summary results for Lakes Farm, Licence restriction measure (dry year).

Water Available	100%	75%	50%	25%	0%
Croppping pattern (246.5 ha)					
Rainfed					
Winter Wheat	111.5	111.5	111.5	111.5	111.5
Spring Wheat	33.3	33.3	40.0	40.0	40.0
Peas (combined)	0.0	0.0	8.5	28.0	51.2
Set aside	14.5	14.5	16.0	18.0	20.3
Irrigated					
Potatoes	31.9	31.9	31.9	25.5	0.0
Onions	31.9	31.9	15.1	0.0	0.0
Onions (rented)	23.4	3.3	0.0	0.0	0.0
Rainfed land	159.3	159.3	176.0	197.5	223.0
Irrigated land	87.2	67.0	47.0	25.5	0.0
Net margins (£/ha)	956.67	906.86	731.93	523.64	309.12
Subsidies (£/ha)	155.20	169.04	191.13	217.69	249.37
Value added (£/ha)	801.46	737.82	540.80	305.95	59.75
Public revenue (£/ha)	3.70	3.02	2.05	1.02	0.00
Net margins reduction (£/ha)	0.00	49.80	224.74	433.02	647.54
Regular labour	2	1	1	1	0
Labour (hrs/ha)	11	10	8	6	0
Seasonality of labour	228	239	260	287	0
Winter water (m^3)	290949	218212	145475	72737	0
Water used (m^3/ha)	3337	3255	3097	2847	0
Water marginal value (£/m^3)	0.42	0.42	0.63	0.66	0.88
N leaching (kg/ha)	29.2	26.3	24.6	22.4	19.3
P leaching (kg/ha)	5.6	5.0	4.5	4.2	4.0
Soil cover index	5.1	5.0	4.8	4.7	4.7
Pesticide Environmental Hazard Index	11.8	10.6	10.1	9.9	9.5
Pesticide Active Ingredient Losses	0.232	0.214	0.206	0.188	0.133
Fert-N (kg/ha)	172.7	178.3	176.3	162.9	138.9
Fert-P (kg/ha)	96.2	90.6	80.1	65.9	45.0
Fert-K (kg/ha)	86.4	87.0	84.0	73.8	44.8
Energy used (MJ/ha)	24904	24056	22161	19370	15251
Energy output (MJ/ha)	102758	104129	102051	95772	82363
Energy balance (MJ/ha)	79322	81272	80702	76807	67113

Figure 4.2 shows the marginal value product (mvp) of water (its contribution (£/m^3) to the net margins) under the two scenarios. This analysis shows that the financial returns to irrigation increase as water becomes more limiting, reflecting the returns to water of the specific enterprises. The dry year has a lower return to water as a result of the increase application depths of water to supply the irrigation needs.

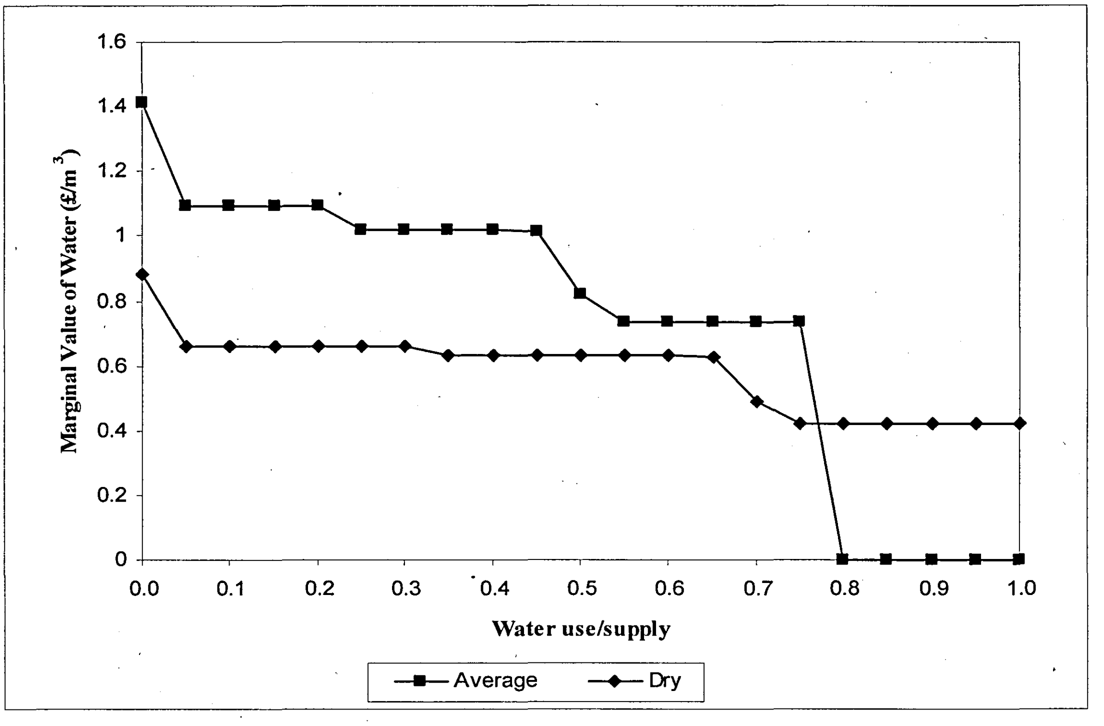

Figure 4.2: Marginal value product of water for Lake Farm under both water scenarios.

The analysis of the dry year scenario suggests that returns to water are lower under increased water requirements. This would not be expected in the market in general, the benefits of irrigation in the dry year above and beyond rainfed cropping would be expected to be far greater due to the reductions in yield and quality of rainfed cropping options under more water stressed conditions. With reduced supply of high quality produce the market would be expected to respond by increasing prices gained for the irrigated produce. The combination of these factors would be overall increases in the net margin return and marginal value product of water in the dry year. These benefits were discussed with William and Alistair Findlay during the production of the Lakes Farm model. They stated that they did not perceive any noticeable increase in the prices received during dry years due to the specific requirements of the contracts with their outlet.

4.2.2 Measure 2: Abstraction charge increases.

The assessment of this measure aims to analyse how increases in abstraction charges may encourage water use efficiency and reduce the pressure on water resources. To examine this policy option the abstraction charge on winter water is increased in increments of £0.05/m^3 up to the point where irrigation is no longer viable. The impact of this policy aims to reduce the total volume of water abstracted; crops with the highest returns to water will remain viable for the longest with the highest charge for water.

Table 4.3: Summary of the results for Lakes Farm, water charge increases policy (average year).

Water Charge (£/m^3)	£0.00	£0.003	£0.74	£0.83	£1.02	£1.03	£1.10
Water Use	79%	79%	50%	48%	44%	22%	0%
Cropping pattern (255ha)							
Rainfed							
Winter Wheat	112	112	112	112	112	112	112
Spring Wheat	33	33	33	36	40	40	40
Peas (combined)	0	0	0	0	0	22	51
Set aside	14	14	14	15	15	17	20
Irrigated							
Potatoes	32	32	32	32	32	32	0
Onions	32	32	32	29	24	0	0
Onions (rented)	32	32	0	0	0	0	0
Rainfed land	159	159	159	162	167	191	223
Irrigated land	96	96	64	61	56	32	0
Net margins (£/ha)	1127.27	1124.41	518.42	458.75	338.55	335.42	316.17
Subsidies (£/ha)	150.03	150.03	171.56	174.37	179.49	209.86	249.37
Value added (£/ha)	977.24	974.38	346.86	284.38	159.06	125.55	66.80
Public revenue (£/ha)	0.00	2.86	491.87	526.01	589.09	296.33	0.00
Net margins reduction (£/ha)	0.00	2.86	608.85	668.52	788.71	791.85	811.09
Regular labour	2	2	1	1	1	1	0
Labour (hrs/ha)	11	11	10	10	9	7	0
Seasonality of labour	224	224	242	244	249	287	0
Winter water (m^3)	232669	232669	148224	141324	128791	64157	0
Water used (m^3/ha)	2431	2431	2326	2313	2286	2014	0
Water marginal value (£/m^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N leaching (kg/ha)	30.4	30.4	25.9	25.7	25.4	23.2	19.3
P leaching (kg/ha)	5.9	5.9	4.9	4.8	4.7	4.2	4.0
Soil cover index	5.1	5.1	4.9	4.9	4.9	4.7	4.7
Pesticide Environmental Hazard Index	12.4	12.4	10.4	10.3	10.2	10.0	9.5
Pesticide Active Ingredient Losses	0.240	0.240	0.212	0.211	0.209	0.201	0.133
Fert-N (kg/ha)	170.6	170.6	179.4	179.9	181.0	168.9	138.9
Fert-P (kg/ha)	98.4	98.4	89.6	88.2	85.6	71.1	45.0
Fert-K (kg/ha)	86.2	86.2	87.1	86.6	85.8	81.0	44.8
Energy used (MJ/ha)	24768	24768	23547	23336	22954	20228	15251
Energy output (MJ/ha)	102303	102303	104370	104201	103894	99084	82363
Energy balance (MJ/ha)	78631	78631	81621	81625	81633	79202	67113

Table 4.3 summarises the results from the Lakes Farm case study. Each major point of change in the volume of water used has been displayed in the summary table, full details of the results can be found in Appendix 5. Current costs of winter water for the Anglian region have been set at £0.003/m^3. Charges shown in the top row of the table reflect the water charge for winter water.

Water charges begin at £0.00/m^3 and increases to the point where irrigation is no longer economically viable. At the point of no charge for irrigation cropping patterns are identical to the current situation, which has a charge £0.003/m^3 of water abstracted. Initial water use under this scenario is 79% of the licensed water available, with 96 ha of irrigated land taken up by 64 ha of onions with 32 ha of potatoes. The level of public revenue at the current charge is £2.86/ha. Reductions in the water usage are not felt until the charge for water increases to £0.70/m^3, at this point the rented onions are lost from the cropping pattern. Water use is reduced to 50% of the licensed volume and the net margin is reduced by £608.85/ha.

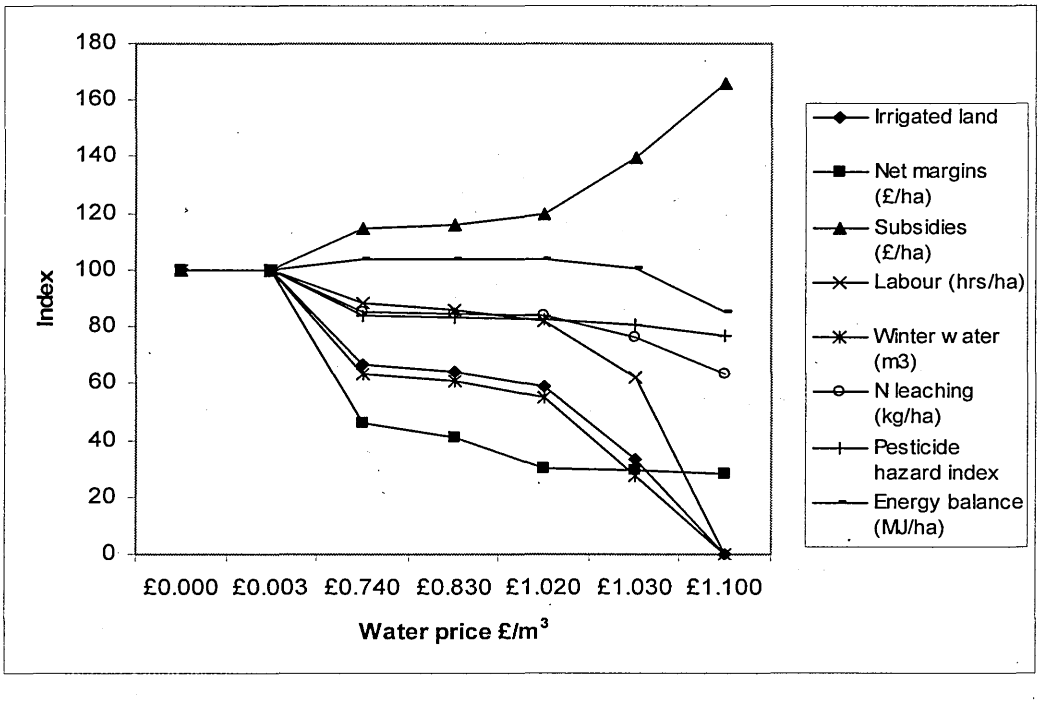

Figure 4.3: Indicators of Performance, Lakes Farm, charge increases (average year).

Further reductions in the volume of water used are at £0.83, £1.02, £1.03 and £1.10/m^3 at which point irrigation is no longer viable. Figure 4.3 shows selected indicators of the impact of price increases. At a charge of £0.74m^3 the use of water is reduced. At this charge for water rented onions are lost from the cropping system. The combination of increased water costs and the loss of high value irrigated crops results in a large decrease in the net margin of approximately 50%. Both the area of irrigated land and water use fall by 30% and reductions of 10% are seen in the labour demand. Pesticide hazard and nitrogen losses to water both decrease by 5%. The energy balance sees a slight increase of 5%. Impacts of price increases at £0.83/m^3 and £1.20/m^3 have less pronounced impacts with irrigated area falling a further 8% for the £0.28/m^3 charge increase with water use falling by just 9%. The net margin falls by a further 16% to £338.55 ha and the level of subsidies increases to a total of £179.49 ha reflecting the switch from irrigated to rainfed cropping options. At a charge of £1.03/m^3 onions are no longer viable within the system. The loss of onions from the system is reflected in the labour requirements of the farm. Little impact on the net margin is seen between a charge of £1.02/m^3 and £1.03/m^3, impacts are reflected in the loss of labour and increases in the area of rainfed cropping and the proportion of the net margin made up by support payments. Water use falls by 27% with slight reductions in pesticide hazard and nitrogen losses. At a charge of £1.10 potatoes are lost from the cropping pattern, irrigation of crops is no longer viable. Associated with this is a total reduction of 72% in the net margin from £1124.41 ha to just £316.17 ha.

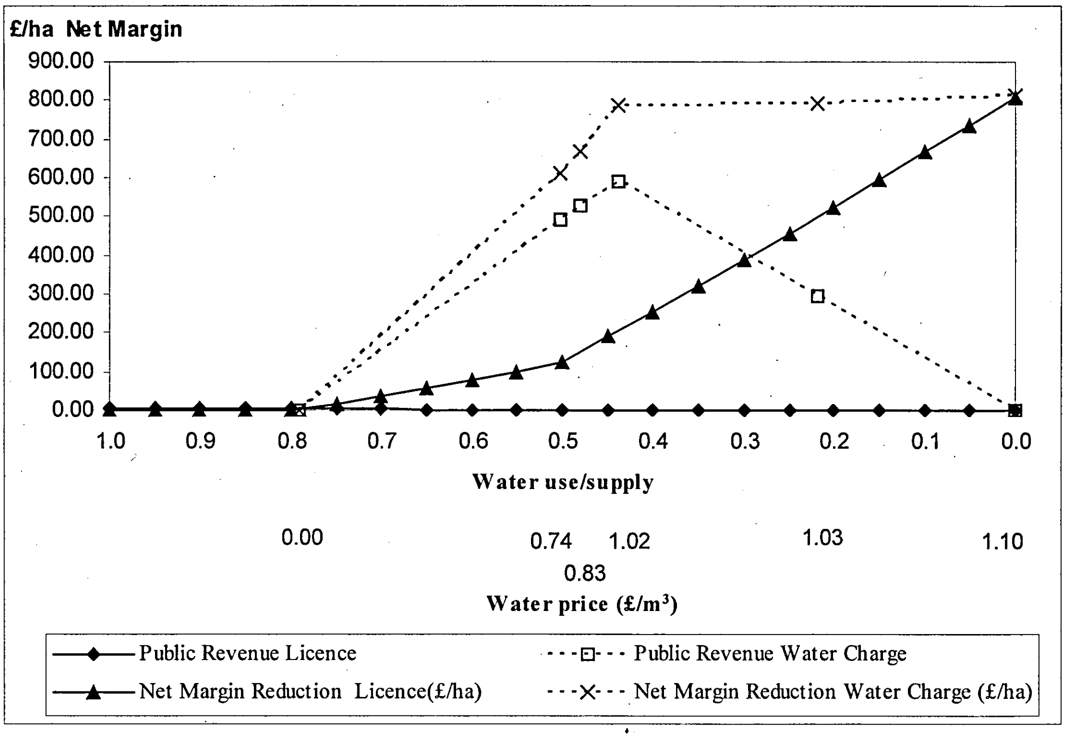

Figure 4.4: Comparison of net margin reduction and water use for Lakes Farm under licence restriction and water charge increases (average year).

Figure 4.4 shows the shift from net margin benefits to the farmer to increased public revenue with little reduction in the use of water. This shifts benefits of irrigation away from the farmer to the water licensing agency. In order to achieve the same level of reduction in water use the impacts upon the farm income are far greater under the water charge measures than under measures which impose quota restrictions on abstractions

4.2.3 Measure 3: Nitrogen restrictions.

Irrigated cropping typically demands the use of greater levels of agrochemical input to ensure maximum yield and quality objectives are met. High levels of fertiliser inputs increase the risk of pollution to water resources. Under this measure restrictions on the average losses of nitrogen per hectare of farm area are imposed, reducing the impact of the farm unit as a whole on the water resources. This measure will enable the maximisation of profit without compromising the ability of the farm to grow high value, high quality irrigated crops. Constraints of nitrogen are imposed in increments of 1 kgN/ha starting at the point of current unconstrained demand.

Table 4.4 gives a summary of the results for the Lakes Farm case study. Initial unconstrained losses are 30.4 kgN/ha. At this point the farm incorporates large areas of irrigated and rainfed cropping. Initial constraints reduce the areas of rainfed crops at a constraint of 30 kgN/ha the area of spring wheat is reduced to 22.9 ha, and maximum areas of irrigated cropping are sustained. The irrigated crops have the highest levels of nitrogen loss but remain in the cropping pattern because they have the highest returns per unit of nitrogen lost and so remain the most profitable crops to retain in the cropping system. With reduction in the area of cereals, peas are introduced into the system. These have a lower level of nitrogen loss and enable maximisation of cropped area and income while irrigated crops are still filling their maximum available area. Restrictions of less than 20 kgN/ha reduce the area of cropped land. Maximisation of profits is achieved through maintaining large areas of irrigated cropping and reducing the area of land in production to enable the nitrogen limits to be met.

Table 4.4 shows that the irrigated areas would be given priority in this cropping pattern. The solution shows a switch out of cereals and into peas reflecting the lower losses of nitrogen associated with this crop. Under current market conditions a switch to peas on this scale is unlikely due to the limited market for this crop. In practice farmers would possibly seek to reduce losses from cereals through reductions on inputs, accepting lower yields and returns. Rather than switch to peas, farmers may choose to simply take land out of production as is the case under more stringent constraints in the model. Table 4.4 indicates this response but a more detailed assessment goes beyond the scope of the current project

Table 4.4: Summary results for Lakes Farm, nitrogen restrictions (average)

Nitrogen limit (kgN/ha)	Unconstrained	30.00	25.00	20.00	15.00	10.00	5.00
Cropping pattern (255 ha)							
Rainfed							
Winter Wheat	111.5	111.5	39.5	0.0	0.0	0.0	0.0
Spring Wheat	33.3	22.9	0.0	0.0	0.0	0.0	0.0
Peas (combined)	0.0	10.4	105.3	123.0	83.2	43.4	3.6
Set aside	14.5	14.5	14.5	12.3	8.3	4.3	0.4
Irrigated							
Potatoes	31.9	31.9	31.9	27.1	18.3	9.6	0.8
Onions	31.9	31.9	31.9	27.1	18.3	9.6	0.8
Onions (rented)	32.0	32.0	32.0	32.0	32.0	32.0	32.0
Rainfed land	159.3	159.3	159.3	135.3	91.6	47.8	4.0
Irrigated land	95.7	95.7	95.7	86.1	68.6	51.1	33.6
Net margins (£/ha)	1124.41	1123.90	1089.94	947.02	718.38	489.73	261.09
Subsidies (£/ha)	150.03	151.66	166.54	146.77	99.29	51.82	4.34
Value added (£/ha)	974.38	972.24	923.40	800.25	619.09	437.92	256.75
Public revenue (£/ha)	2.86	2.86	2.86	2.59	2.09	1.59	1.08
Net margins reduction (£/ha)	0.00	0.51	34.46	177.39	406.03	634.67	863.31
Regular labour	2	2	2	2	1	1	1
Labour (hrs/ha)	11	11	11	10	8	5	3
Seasonality of labour	224	224	224	222	217	210	199
Winter water (m^3)	232669	232669	232669	210378	169642	128906	88170
Water used (m^3/ha)	2431	2431	2431	2442	2472	2522	2624
Water marginal value (£/m^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N leaching (kg/ha)	30.4	30.0	25.0	20.0	15.0	10.0	5.0
P leaching (kg/ha)	5.9	5.8	4.8	3.8	2.9	2.0	1.1
Soil cover index	5.1	5.2	5.2	4.5	3.3	2.1	0.9
Pesticide Environmental Hazard Index	12.4	12.5	14.0	12.7	9.3	5.8	2.3

Pesticide Active Ingredient Losses	0.240	0.241	0.238	0.204	0.148	0.091	0.034
Fert-N (kg/ha)	170.6	163.5	87.1	47.8	36.8	25.8	14.8
Fert-P (kg/ha)	98.4	97.8	88.0	73.8	56.4	39.1	21.7
Fert-K (kg/ha)	86.2	86.0	81.3	68.6	49.7	30.7	11.8
Energy used (MJ/ha)	24768	24460	20712	16792	12711	8630	4549
Energy output (MJ/ha)	102303	100985	79764	60874	44751	28628	12505
Energy balance (MJ/ha)	78631	77620	60147	45072	32838	20604	8371
Nitrogen limit (kg/ha)	30.40	30	25	20	15	10	5

Figure 4.5 presents the indicators of performance for the farm. Indicators of economic performance show that as the losses of nitrogen are restricted to less than 20 kgN/ha the net margin decreases significantly; this corresponds with the drop in land area used for cropping. As the land area decreases there are reductions in both the irrigated area and also in the area of rainfed cropping with a switch in the rainfed cropping to peas with a lower margin but lower nitrogen loss. The proportion of irrigated land in comparison to rainfed land also falls, suggesting that these are the higher polluters and although they remain in the system they can only do so by reducing in area allowing the peas to increase in proportion and maximise the area cropped. This increase in the proportion of the area covered by rainfed crops is reflected in the increase in subsidies received per area of cropped land.

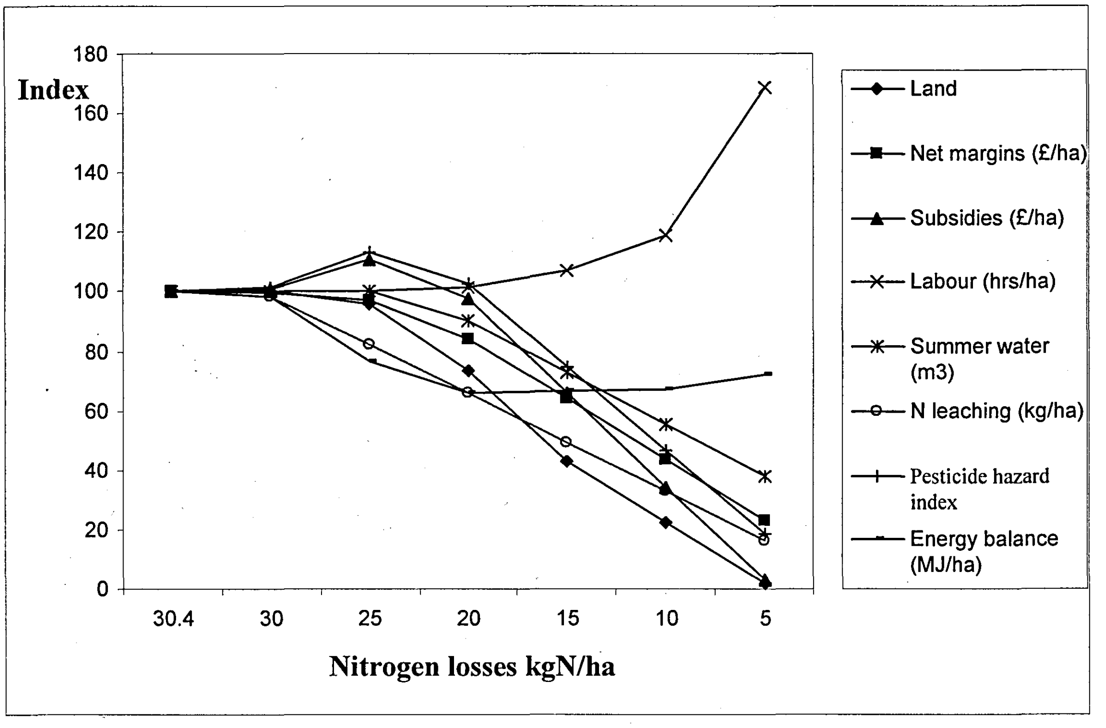

Figure 4.5: Indicators of performance Lakes Farm Nitrogen restrictions (average year)

4.2.4 Measure 4: Constraints on pesticide hazard risk.

This measure aims to identify the impact of restrictions in the levels of hazard risk imposed on the local environment. This measure aims to assess the impact of restricting pesticide hazard on the whole farm without constricting the specific requirements of individual crops. Pesticide hazard risk is constrained in falling increments of 1. The response in terms of the cropping pattern will reflect the most profitable use of the resources available under the constraints of limiting the pollution risk.

In this system the pesticide hazard risk is greater in the irrigated crops (Table 4.5) with specific index values of 17 for potatoes and 16 for onions. The pesticide hazard risk of cereals is slightly lower than the irrigated crops with an index of 11. These values have been calculated using standardised field conditions and actual application data collected from the farm interviews.

Table 4.5: Specific individual crop contributions to farm hazard risk and active ingredient losses to water resources.

Crop	Pesticide Hazard Risk	Active ingredient losses to water (μg/l/y)
Winter Wheat	11	0.179
Spring Wheat	11	0.143
Peas	15	0.163
Set aside	0	0.000
Potatoes	17	0.690
Onions	16	0.227
Onions (rented land)	16	0.227

Table 4.6 summarises the results of the impact of restricted hazard index on Lakes Farm. Initial unconstrained pesticide environmental hazard is 12.4 which is classed as good practice on the P-EMA scale hazard index scale. Assessments of the impacts of pesticide hazard restrictions have been imposed by constraining the whole farm weighted average hazard index. Restrictions on the pesticide hazard have been imposed at decreasing levels of 2 to the point where current farming practices can no longer sustain a viable farm business. The assessment assumes the continuation of current pesticide application practices. It is recognised that current input levels could be varied with consequences for crop yields and returns. Allowance for this goes beyond the scope of the study.

Under restrictions in the whole farm pesticide hazard risk, modifications in the cropping pattern are required to enable the restrictions to be met. Initial modifications in the cropping pattern are general reductions in the area of land involved in cropping. All crops receive slight reductions in the area grown apart from the rented land. As the hazard risk index is constrained further, reductions in the area of cropped land continue. The balance of irrigated cropping increases in proportion to rainfed cropping, demonstrating the greater importance of irrigated cropping to the net margin. The area of rented onions remain high in comparison with all the other crops due to the lack of alternative cropping option on this land type and the need to maximise the total farm area for the calculation of the average hazard index.

Table 4.6: Summary results for Lakes farm, pesticide hazard restrictions (average year)

Pesticide Hazard Index	12.4	12.0	10.0	8.0	6.0	4.0	2.0
Rainfed							
Winter Wheat	111.5	107.4	85.9	64.4	42.9	21.4	0.0
Spring Wheat	33.3	32.1	25.7	19.2	12.8	6.4	0.0
Peas (combined)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Set aside	14.5	14.0	11.2	8.4	5.6	2.8	0.0
Irrigated							
Potatoes	31.9	30.7	24.6	18.4	12.3	6.1	0.0
Onions	31.9	30.7	24.6	18.4	12.3	6.1	0.0
Onions (rented)	32.0	32.0	32.0	32.0	32.0	32.0	31.9
Rainfed land	159.3	153.5	122.8	92.0	61.3	30.6	0.0
Irrigated land	95.7	93.4	81.1	68.8	56.5	44.2	31.9
Land Used	255	247	204	161	118	75	32
Net margins (£/ha)	1124.41	1092.35	921.89	751.29	580.70	410.11	239.24
Subsidies (£/ha)	150.03	144.57	115.64	86.70	57.76	28.82	0.00
Value added (£/ha)	974.38	947.77	806.25	664.59	522.94	381.28	239.24
Public revenue (£/ha)	2.86	2.80	2.44	2.09	1.74	1.39	1.03
Net margins reduction (£/ha)	0.00	32.06	202.52	373.11	543.71	714.30	885.16
Regular labour	2	2	2	1	1	1	1
Labour (hrs/ha)	11	11	9	8	6	4	3
Seasonality of labour	224	224	221	217	212	205	199
Water abstracted (m^3)	232669	227279	198690	170100	141511	112922	84115
Water used (m^3/ha)	2431	2433	2450	2472	2503	2552	2639
Water marginal value (£/m^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N leaching (kg/ha)	30.4	29.5	24.5	19.5	14.5	9.5	4.5
P leaching (kg/ha)	5.9	5.7	4.7	3.8	2.9	1.9	1.0
Soil cover index	5.1	5.0	4.1	3.3	2.5	1.6	0.8
Pesticide Environmental Hazard Index	12.4	12.0	10.0	8.0	6.0	4.0	2.0
Pesticide Active Ingredient Losses	0.240	0.232	0.192	0.151	0.110	0.069	0.028
Fert-N (kg/ha)	170.6	164.9	134.7	104.4	74.2	43.9	13.8
Fert-P (kg/ha)	98.4	95.6	80.5	65.3	50.2	35.1	20.0
Fert-K (kg/ha)	86.2	83.4	68.7	54.0	39.4	24.7	10.0
Energy used (MJ/ha)	24768	24019	20047	16075	12104	8132	4160
Energy output (MJ/ha)	102303	98984	81380	63775	46171	28566	10988
Energy balance (MJ/ha)	78631	76035	62268	48500	34733	20965	7224

Figure 4.6 displays a selection of the indicators of performance under constrained pesticide hazard. As the allowable pesticide hazard decreases all indicators of

performance decrease. Immediate impact on the net margin is seen with a linear relationship of a 15% reduction in net margin per 2 point fall in the hazard index. All indicators of performance see linear reductions, related to the reductions in the pesticide hazard risk.

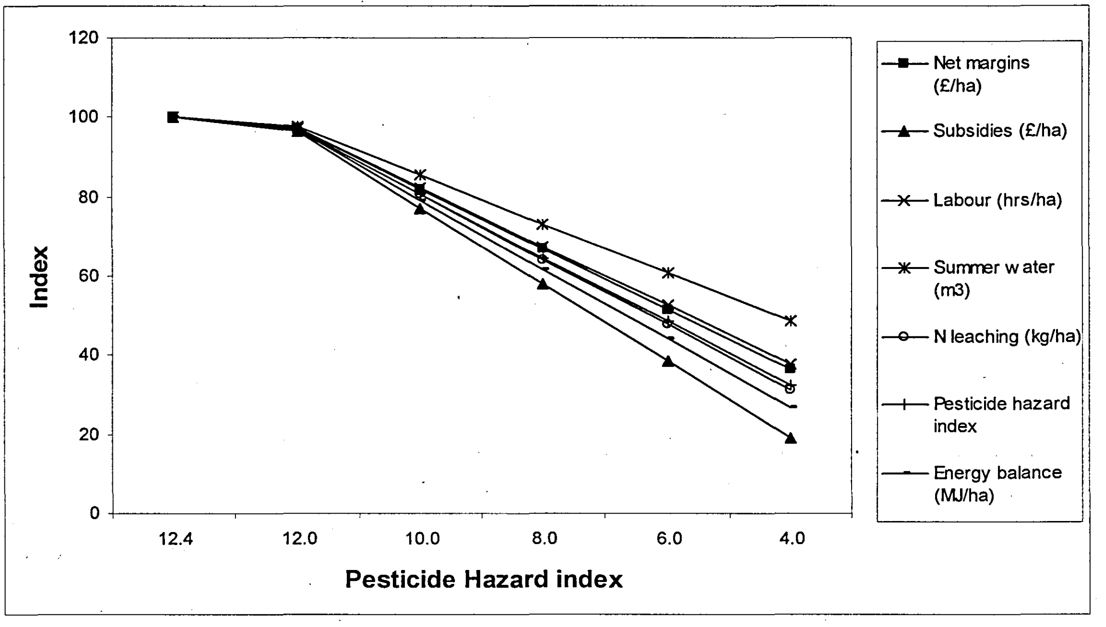

Figure 4.6: Indicators of performance Lakes Farm, pesticide restriction (average year).

4.2.5 Summary of Lakes Farm.

The analysis of the Lakes Farm case study fulfilled the aims of the study. Impacts of the WFD policy measures showed that impacts of water and abstraction charges could lead to reductions in the use of water with associated improvements in the environmental performance of the farm. Impact upon the economic and social performance of the farm could be considerable however. Reductions in the areas of irrigated cropping are closely linked to the availability and use of water. These high value crops are labour intensive and required large amounts of both regular and casual labour. Losses in the area of irrigated land under all policy measure resulted in significant reductions in farm profitability and the social inputs in terms of jobs for the local workforce. The dominance of cereal and protein cropping under rainfed conditions increases the farm's reliance on government support.

Under nitrogen and pesticide constraints irrigated cropping becomes the dominant cropping system. In order to accommodate the constraints imposed by the restrictions land is removed from production.

4.3 Roudham Farm Case Study.

Roudham Farm was selected primarily as a potato and sugar beet grower. This case study is located on the eastern boundary of Thetford Forest. The farm concentrates predominantly on potato production with irrigated sugar beet, onions and field scale vegetables linked to contract limited areas. Soil and climatic conditions restrict the production to irrigated cropping only. Water deficits in this region would not allow the production of crops which would give a sufficient yield and quality return to make their production viable without irrigation.

4.3.1 Measure 1: Restrictions on licensed abstraction

Table 4.7 summarises the performance of Roudham Farm. This farm has been used to assess the impact of WFD policy on potato and sugar beet farming. Initial cropping patterns under unconstrained conditions are dominated by irrigated cropping with over 70% of the total farm area involved in irrigated cropping. 118 hectares of this irrigated land is rented land for irrigation, which is restricted to potato and onion cropping. To allow for maximised irrigated cropping this rented land is rotated on a yearly basis to allow rotational gaps. On the land owned by the farm areas, of irrigated crops (potatoes, onions, and carrots) are all approximately 30 hectares. Initial water usage is 86% of the licensed volume in an average year.

Reductions in the water available for irrigation cause a change in the cropping pattern; at 75% water availability the area of irrigation is reduced to 240 hectares from 288 hectares, the area of sugar beet has been reduced and has the lowest return to water per unit applied. As water availability is constrained further the area of sugar beet is reduced and cropping switches to rainfed options. At 50% water availability sugar beet and potatoes are no longer grown on the owned land and the area of rented potatoes begins to decline again due to lower returns to water. Cropping switches to cereals, with spring wheat being the dominant rainfed crop. Under 25% water availability the irrigated cropping falls to 26% of the land still in use, total farm area has fallen to 301 hectares reflected in the loss of rented land for irrigation. At 25% water availability, only 8.5 hectares of land is rented for onions and all irrigation is involved in the production of vegetables (onions, carrots and parsnips) due to their higher returns to water. Rainfed cropping also includes field beans at this point.

Figure 4.7 shows selected indicators of performance for the Roudham Farm case study under water restrictions. Economics indicators show reductions in the gross margin from £732.47 ha in the unconstrained situation to £201.29 ha under the rainfed cropping system, added value is reduced from £659.19 ha to -£55.51 ha. Under a totally rainfed system this farm would not be profitable without government support. Decreases in the net margin do not drop steadily with reductions in the irrigated area but remain within 10% of the initial net margin under unconstrained water availability until no water is available. This is a result of the high returns to water received by the field scale vegetable crops and the marginal profit of both sugar beet and potatoes under this system. Subsidies received per hectare increases gradually in the area of rainfed cropping rising to an increase of over 350% from £73.28 ha on average to £256.8 ha. With the change in cropping patterns the labour required on the farm reduces by 65% to just 2 regular labourers and an average of 6 hours of labour required per hectare.

Table 4.7: Summary results Roudham Farm, water restriction (average year).

Water availability	100%	75%	50%	25%	0%
Cropping pattern (408.2 ha)					
Rainfed					
Spring Barley	21.7	17.3	78.6	63.6	75.2
Spring Wheat	78.4	126.4	110.5	111.0	123.3
Hemp	10.0	10.0	10.0	10.0	10.0
Field Beans	0.0	0.0	0.0	18.1	58.5
Set aside	10.0	14.4	18.9	19.3	25.7
Irrigated					
Parsnips	15.0	15.0	15.0	15.0	0.0
Potatoes	30.0	30.0	0.0	0.0	0.0
Potatoes (rented)	107.0	107.0	73.5	0.0	0.0
Sugar beet	68.0	20.0	0.0	0.0	0.0
Onions	29.7	29.7	29.7	25.7	0.0
Onions (rented)	8.5	8.5	8.5	8.5	0.0
Carrots	30.0	30.0	30.0	30.0	0.0

Rainfed land	120.0	168.0	218.0	222.0	292.7
Irrigated land	288.2	240.2	156.7	79.2	0.0
Net margins (£/ha)	732.47	728.10	657.13	493.35	144.33
Subsidies (£/ha)	73.28	102.61	133.13	137.25	184.14
Value added (£/ha)	659.19	625.49	524.01	356.10	-39.81
Public revenue (£/ha)	38.04	33.15	22.10	11.05	0.00
Net margins reduction (£/ha)	0.00	4.37	75.34	239.12	588.14
Regular labour	6	5	3	2	2
Labour (hrs/ha)	18	18	15	13	6
Seasonality of labour	49	59	56	67	130
Summer water (m^3)	495188	431550	287700	143850	0
Water used (m^3/ha)	1718	1797	1835	1817	0
Water marginal value (£/m^3)	0.00	0.03	0.29	0.61	2.02
N leaching (kg/ha)	16.4	14.1	9.5	5.3	4.6
P leaching (kg/ha)	0.2	0.2	0.2	0.2	0.0
Soil cover index	4.5	4.4	4.2	4.1	3.5
Pesticide Environmental Hazard Index	6.1	5.8	4.7	3.6	2.7
Pesticide Active Ingredient Losses	0.056	0.057	0.039	0.017	0.011
Fert-N (kg/ha)	51.2	41.4	24.7	7.0	6.4
Fert-P (kg/ha)	0.0	0.0	0.0	1.8	6.0
Fert-K (kg/ha)	91.4	79.3	56.5	35.8	8.0
Energy used (MJ/ha)	23003	23190	18605	14699	10822
Energy output (MJ/ha)	117836	116287	105037	90818	77327
Energy balance (MJ/ha)	96677	94703	87599	76845	66505

Environmental performance of the farm shows improvements, pesticide hazard risk falls by 55% from 6.1 to 2.7. Nitrogen leaching is already relatively low in comparison to the Lakes Farm case study (Table 4.1) at 16.4kgha leached to water each year. This reduces by over 70% under the rainfed system with the biggest reductions caused by the reductions in the area of potatoes grown. As the area of rainfed crops increases, the energy balance decreases gradually to about 70% of the initial balance.

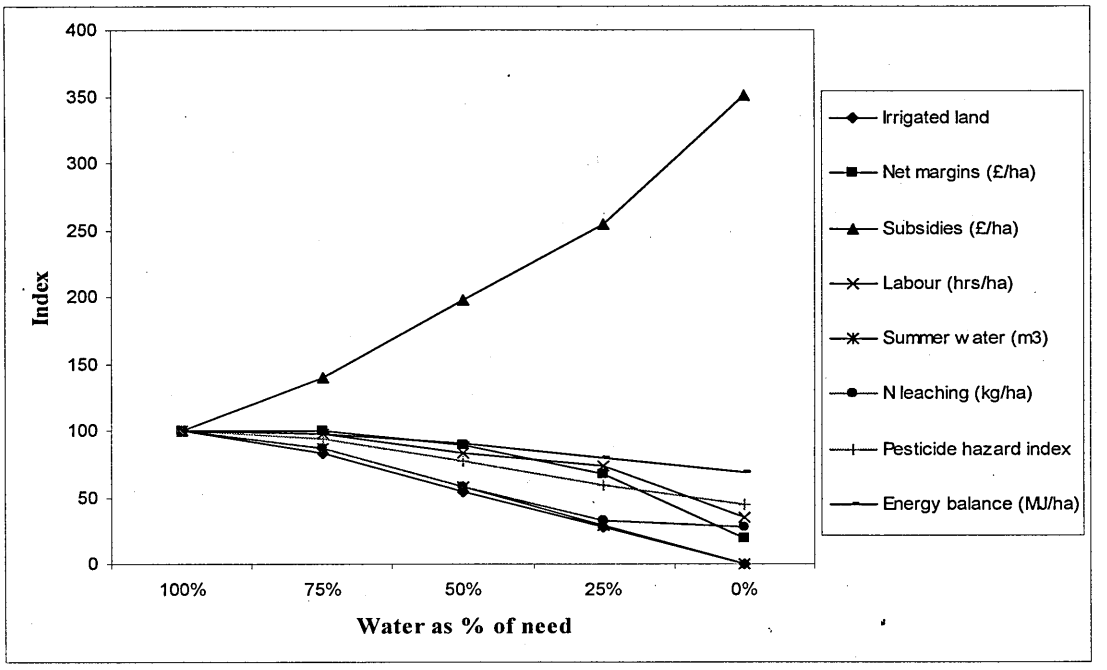

Figure 4.7: Indicators of Performance, Roudham Farm (average year).

Dry Year case: Impact of licence restriction.

Under the dry year scenario the water requirements are increased to 97% of the total licensed available water. The impacts of the increased water restrictions follow the same trends as with the average year. The impacts are earlier in the restrictions as a result of the increased demand using greater volumes of water per ha of irrigated land. With the increased water requirements as a result of higher evapotranspiration an increase in production costs has caused sugar beet to fall from the system in the initial unconstrained cropping pattern. The loss of sugar beet and the increase in production costs have cut the initial net margin by 20% to £588.17 ha without constraints.

Table 4.8: Summary results Roudham Farm, licence restriction measure. (Dry year).

Water availability	100%	75%	50%	25%	0%
Cropping pattern (408.2 ha)					
Rainfed					
Spring Barley	15.5	58.1	83.3	54.9	75.2
Spring Wheat	146.4	131.0	107.8	95.4	123.3
Hemp	10.0	10.0	10.0	10.0	10.0
Field Beans	0.0	0.0	0.0	58.5	58.5
Set aside	16.2	18.9	19.1	20.9	25.7
Irrigated					
Parsnips	15.0	15.0	15.0	15.0	0.0
Potatoes	30.0	0.0	0.0	0.0	0.0
Potatoes (rented)	107.0	88.4	36.7	0.0	0.0

Sugar beet	0.0	0.0	0.0	0.0	0.0
Onions	29.7	29.7	27.5	22.6	0.0
Onions (rented)	8.5	8.5	8.5	8.5	0.0
Carrots	30.0	30.0	30.0	15.4	0.0
Rainfed land	188.0	218.0	220.2	239.7	292.7
Irrigated land	220.2	171.6	117.7	61.5	0.0
Net margins (£/ha)	588.17	573.85	513.85	416.14	144.33
Subsidies (£/ha)	114.81	133.13	134.49	151.74	184.14
Value added (£/ha)	473.37	440.72	379.36	264.40	-39.81
Public revenue (£/ha)	43.15	33.15	22.10	11.05	0.00
Net margins reduction (£/ha)	0.00	14.33	74.33	172.03	443.84
Regular labour	5	3	2	2	2
Labour (hrs/ha)	18	16	14	12	6
Seasonality of labour	65	59	57	64	130
Summer water (m^3)	561640	431550	287700	143850	0
Water used (m^3/ha)	2551	2515	2445	2337	0
Water marginal value (£/m^3)	0.00	0.09	0.22	0.41	1.89
N leaching (kg/ha)	13.2	10.4	7.1	6.1	4.6
P leaching (kg/ha)	0.2	0.2	0.2	0.3	0.0
Soil cover index	4.4	4.2	4.1	4.0	3.5
Pesticide Environmental Hazard Index	5.6	5.0	4.0	4.0	2.7
Pesticide Active Ingredient Losses	0.057	0.044	0.028	0.018	0.011
Fert-N (kg/ha)	37.3	27.4	16.9	6.6	6.4
Fert-P (kg/ha)	0.0	0.0	0.0	5.8	6.0
Fert-K (kg/ha)	74.3	59.8	46.1	30.8	8.0
Energy used (MJ/ha)	23851.4	20392.0	16976.0	13600.5	10822.4
Energy output (MJ/ha)	115642.8	107409.8	99095.3	85149.2	77327.2
Energy balance (MJ/ha)	93882.6	88701.5	83413.4	72274.5	66504.8

Figure 4.8 provides a summary of the farm indicators under the dry year scenario. Economic and social performance of the farm follow similar patterns with steadily declining margins and labour requirements as the availability of water and area of irrigated cropping falls. Net support does not increase as significantly under this scenario when compared with the average year due to the higher initial level of support from the increased area of wheat grown to replace sugar beet. The environmental performance of the farm shows reductions in nitrogen losses as the area of irrigated crops falls in line with the reduction in irrigated cropping, with its associated high use and loss of nitrogen. Pesticide hazard risk falls but stabilises between 50% restrictions and 25% restrictions. The introduction of field beans to the cropping pattern at this point causes the pesticide risk to stabilise as a result of the specific chemicals used.

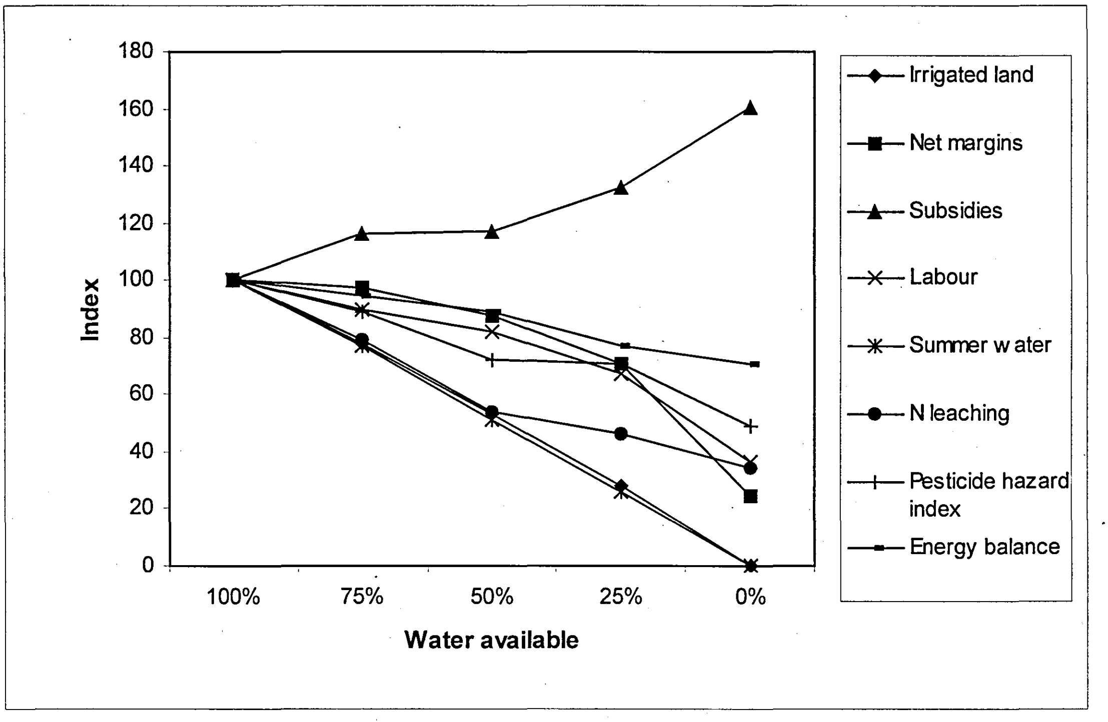

Figure 4.8: Indicators of farm performance, Roudham Farm (dry year).

Figure 4.9 shows the marginal value product of water under the two scenarios. The increased requirements for water in the dry year have led to a reduction in the marginal value product of water, the greater volumes of water required to achieve the same returns in terms of yields and sale revenue have resulted in a lower return per unit of water used. This is not in line with the expected trend in the industry as a whole. Under dry years irrigated crops would be expected to receive a premium, the yield gap between rainfed and irrigated crops will also be greater and expected returns to water would be higher. This is not the case in this scenario however due to the farmer being unsure of any obvious price benefits in the drier years, due to this uncertainty the case study has been modelled assuming both price and yields remain constant. Further research examining the impacts of premium prices in dry years, and the relative benefits of water in these years but this is not possible within the scope of this study.

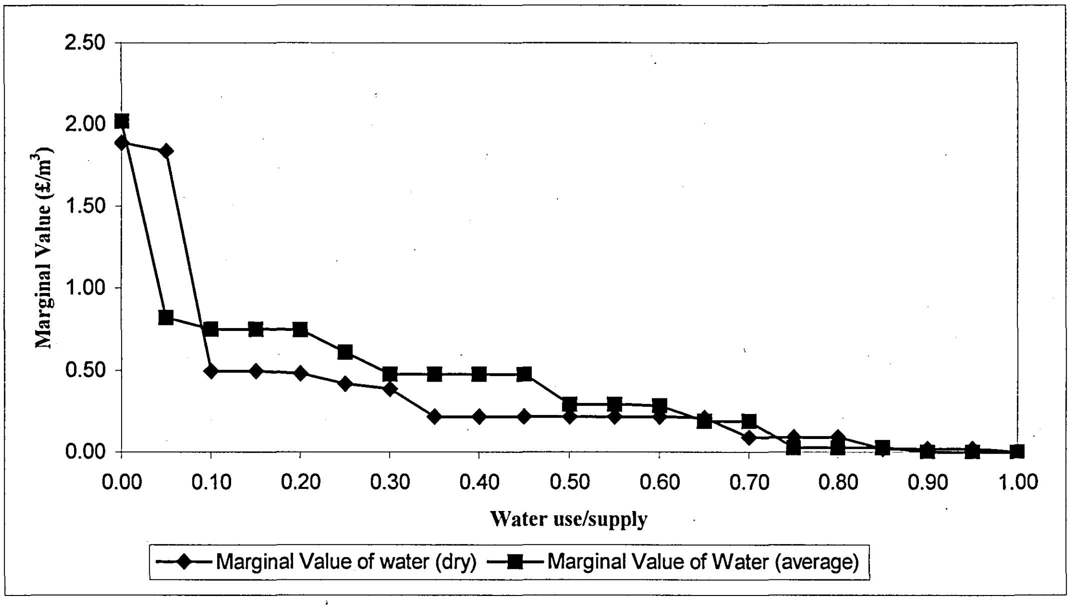

Figure 4.9: Marginal value product of water for Roudham Farm under the two water scenarios.

4.3.2 Measure 2: Abstraction charge increases

Water supply on this farm comes solely from direct abstraction from ground water sources. All water is abstracted during the summer as it is required to supply the irrigation need. Currently the abstraction of water is subject to a charge £0.031/m^3 from the environment agency. The analysis of this measure applied charges starting at £0.00m^3 increasing in increments of £0.05/m^3 until the point where water costs become too high to allow the production of irrigated crops. Table 4.9 presents the results of increased water charges. Unconstrained licensed supply allows unconstrained water supply, with 86% of the licensed volume used in the average year. The results displayed show the points of change in the water used along with the corresponding water charge. Impacts of increased water charges affect the cropping pattern on the farm as the price of water increases the area of irrigated land is reduced as the production of each irrigated crop becomes uneconomical. Water charge increases have a relatively quick impact upon this system with an increase to just £0.10/m^3 forcing sugar beet from the cropping pattern. This would be expected under the current trends in sugar beet production; Morris *et al* (2004) found that slight increases in the costs of applying water whether in increased charges or application costs render sugar beet irrigation unfeasible. Incremental increases in the charge for water cause a switch to rainfed cropping. Crops with the lowest returns to water are lost from the system first. Initial areas of potatoes grown on the owned land are lost from the system at a price of £0.25/m^3. This is far lower than the point at which potatoes are lost from the Lakes Farm case study and reflects the poor prices received by this farm for potatoes (£70/t Roudham, £114/t Lakes). The area of rented land falls next but is not entirely lost from the system, the costs of regular labour make up the major cost of potato cropping, the loss of some areas of potatoes correspond with reductions in the total regular labour. An increase in water charge to £0.50/m^3 causes potatoes to be lost from the system. Onions, carrots and parsnips remain in the system, an increase to £0.65/m^3 reduces the water use to 23% of the licensed quantity, at this point the area of onions grown begins to fall, and this is again in line with a reduction in the regular labour required. Rented onions remain viable in the system up to a charge of £0.85m^3 this reflects the benefits of rented land which is restricted to the production of onions or potatoes. The margin of onion production at this charge makes the production of onions less attractive than rainfed cropping where this option is available.

Table 4.9: Summary results Roudham Farm, abstraction charge increases (average year).

Price (£/m^3)	£0.00	£0.10	£0.25	£0.35	£0.50	£0.65	£0.80	£0.85	£2.05	£2.10
Water Use (m^3/ha)	86%	70%	61%	49%	46%	23%	8%	5%	2%	0%
Cropping pattern (408.2 ha)										
Rainfed										
Spring Barley	21.7	15.5	42.7	82.4	95.1	55.1	76.0	80.4	77.9	75.2
Spring Wheat	78.4	146.4	146.4	106.7	96.5	84.2	107.2	103.0	113.8	123.3
Hemp	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Field Beans	0.0	0.0	0.0	0.0	0.0	58.5	58.5	58.5	58.5	58.5
Set aside	10.0	16.2	18.9	18.9	19.2	19.8	24.2	24.2	25.0	25.7
Irrigated										
Parsnips	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	7.5	0.0
Potatoes	30.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Potatoes (rented)	107.0	107.0	107.0	70.8	63.7	0.0	0.0	0.0	0.0	0.0
Sugar beet	68.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Onions	29.7	29.7	29.7	29.7	26.9	20.1	0.0	0.0	0.0	0.0
Onions (rented)	8.5	8.5	8.5	8.5	8.5	8.5	8.5	0.0	0.0	0.0
Carrots	30.0	30.0	30.0	30.0	30.0	30.0	1.8	1.6	0.0	0.0
Rainfed land	120.0	188.0	218.0	218.0	220.8	227.6	275.9	276.1	285.2	292.7
Irrigated land	288.2	220.2	190.2	154.0	144.2	73.6	25.3	16.6	7.5	0.0
Net margins (£/ha)	770.52	658.12	513.47	432.93	331.44	275.66	231.03	226.45	144.40	144.33
Subsidies (£/ha)	73.28	114.81	133.13	146.08	150.79	195.68	235.63	242.69	250.43	256.80
Value added (£/ha)	697.23	543.32	380.34	328.97	219.93	177.91	77.48	73.11	-49.04	-55.51
Public revenue (£/ha)	0.00	99.24	214.10	265.91	361.99	287.09	127.35	90.18	99.55	0.00
Net margins reduction	0.00	112.39	257.04	337.59	439.08	494.86	539.48	544.07	626.11	626.18

(£/ha)										
Regular labour	6	5	4	3	3	2	2	2	2	2
Labour (hrs/ha)	18	18	16	15	15	13	9	8	7	6
Seasonality of labour	49	65	61	56	55	73	78	90	104	130
Summer water (m^3)	495188	405088	349588	282629	264217	133031	47949	31054	14214	0
Water used (m^3/ha)	1718	1840	1838	1835	1832	1808	1894	1875	1900	0
Water marginal value (£/m^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N leaching (kg/ha)	16.4	13.2	11.6	9.3	8.8	6.2	5.3	5.0	4.8	4.6
P leaching (kg/ha)	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.1	0.0
Soil cover index	4.5	4.4	4.3	4.2	4.2	4.1	3.7	3.6	3.6	3.5
Pesticide Environmental Hazard Index	6.1	5.6	5.3	4.7	4.5	4.2	3.4	3.2	3.0	2.7
Pesticide Active Ingredient Losses	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fert-N (kg/ha)	51.2	37.3	30.6	24.2	22.8	6.3	6.3	6.2	6.3	6.4
Fert-P (kg/ha)	0.0	0.0	0.0	0.0	0.0	5.8	5.8	6.0	6.0	6.0
Fert-K (kg/ha)	91.4	74.3	63.7	55.9	53.2	38.8	12.6	9.0	8.0	8.0
Energy used (MJ/ha)	23003	23268	21108	18347	17431	13212	11356	10508	10666	10822
Energy output (MJ/ha)	117836	115643	109973	104577	103220	87478	81538	80897	78972	77327
Energy balance	96677	93883	90167	87385	86890	74937	70424	70550	68380	66505

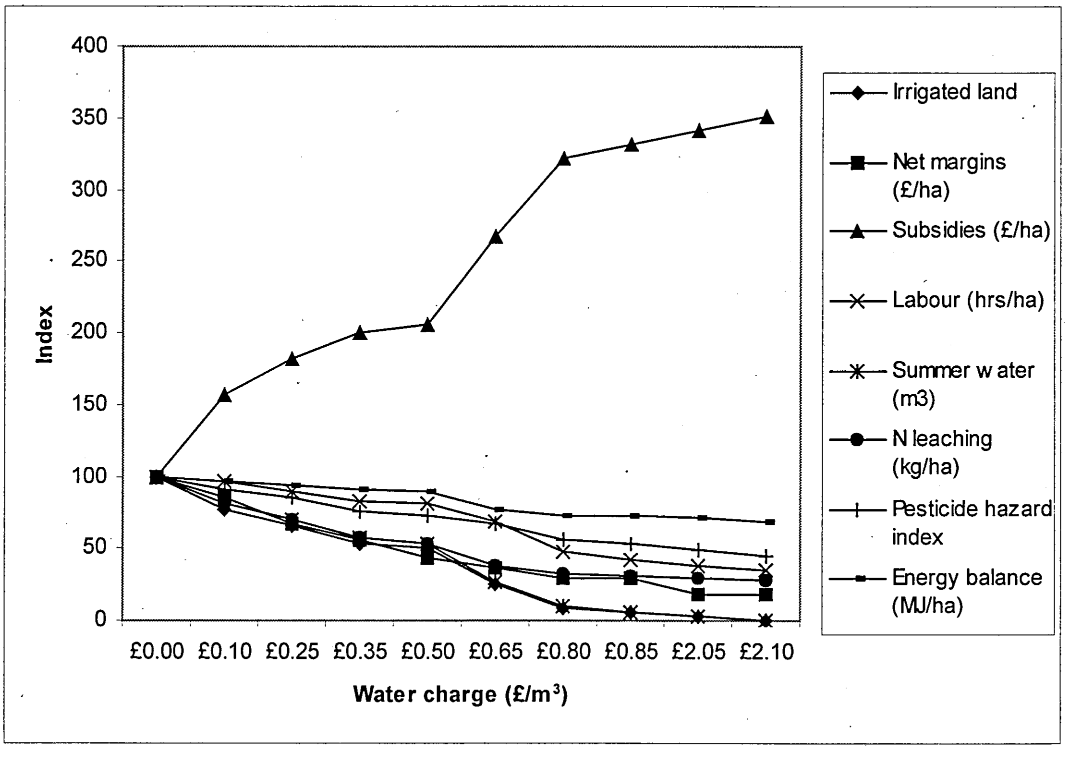

Figure 4.10: Indicators of farm performance, Roudham Farm (average year).

Figure 4.10 displays the indicators of farm performance under increases in the charge for water. As the farming system moves to a rainfed dominated system the economic performance of the farm declines, a gradual reduction in the net margin is seen with the total reduction in net margin of 86% to just £144.07 ha. Without the extra income from government support this farm would not be able to survive under a rainfed cropping system, as added value falls to –£55.51 ha. Labour declines gradually with an initial fall in total labour required of 16% up to a charge of £0.50/m^3. At the point of a charge of £0.65m^3 potatoes are completely lost from the system causing a steeper decline in the labour, net margin and irrigated area. Indicators of environmental performance improve as the area of irrigated land declines. Both nitrogen leaching and pesticide hazard risk decline as the area of irrigated cropping is reduced, highlighting the high demand for agrochemical inputs associated with the higher value irrigated crops.

4.3.3 Measure 3: Restrictions to nitrogen losses.

Table 4.10 summarises the results for the modelled nitrogen losses measure on Roudham Farm. Initial unconstrained nitrogen losses from the farm are low in comparison with the other case studies, almost half the initial level for the Lakes Farm case study. The inputs of fertiliser to this farm are far lower than national averages and the other case studies (Nix 2004, Agricultural budgeting and costing, 2004). Initial cropping is dominated by the irrigated crops with 288ha of irrigated cropping and just 120ha of rainfed cropping. The initial nitrogen lost from the farm is just 16.41kgN/ha, the measure used in the assessment of impact of reducing nitrogen losses to water restricts the allowable losses of nitrogen from the farm area. Allowable losses are decreased in increments of 1 down to 1 kgN/ha allowable losses. At the point of 0 losses of nitrogen it becomes impossible to produce any crops, and in reality natural deposition and nitrogen fixing will allow a residual level of nitrogen loss, so this has not been modelled.

In reality farmers will attempt to reduce the losses of nitrogen associated with the cropping options either through reducing losses from the land through best practice or through reduced inputs. In the case of lower inputs they will accept lower returns as a result of reduced yields. The dominance of irrigated cropping will be retained with maximised production, with the penalties being accepted in the rainfed cropping options.

Reductions in the nitrogen lost from the farm as a whole impact upon the optimum cropping patterns. At the first point of cropping change a reduction in the area of sugar beet is seen. The total area of land used remains constant with a switch to rainfed cropping in the form of spring wheat. Further constraints on the nitrogen losses cause a reduction in the area of land used for production the extra land no longer in production is used as loss neutral ground and allows the average losses from the farm to remain within the constraints. Under the specific production returns and margins this farm switches from irrigated cropping to a rainfed dominated system. The total area of cropping remains high until constraints become less than 5kgN/ha, the proportion of rainfed cropping increases to 218 ha.

Table 4.10: Summary results Roudham Farm, nitrogen loss restriction measure (average year).

Nitrogen losses (kg/ha)	16.41 (unconstrained)	15	10	5	1
Rainfed					
Spring Barley	21.7	18.9	61.6	75.5	27.4
Spring Wheat	78.4	108.3	136.5	122.6	17.1
Hemp	10.0	10.0	0.0	0.0	0.0
Field Beans	0.0	0.0	0.0	0.0	0.0
Set aside	10.0	12.7	19.8	19.8	4.5
Irrigated					
Parsnips	15.0	15.0	15.0	15.0	12.2
Potatoes	30.0	30.0	0.0	0.0	0.0
Potatoes (rented)	107.0	107.0	92.9	12.5	0.0
Sugar beet	68.0	38.0	0.0	0.0	0.0
Onions	29.7	29.7	29.7	29.7	0.0
Onions (rented)	8.5	8.5	8.5	8.5	0.0
Carrots	30.0	30.0	30.0	30.0	12.2
Rainfed land	120.0	150.0	218.0	218.0	49.0
Irrigated land	288.2	258.2	176.1	95.7	24.5
land used	408.2	408.2	394.1	313.7	73.4
Net margins (£/ha)	732.47	729.79	675.76	522.69	182.11
Subsidies (£/ha)	73.28	91.58	133.13	133.13	29.90
Value added (£/ha)	659.19	638.21	542.63	389.56	152.21
Public revenue (£/ha)	38.04	34.99	24.85	13.43	3.33
Net margins reduction (£/ha)	0.00	2.69	56.71	209.78	550.36
Regular labour	6	5	4	2	1
Labour (hrs/ha)	18	18	16	11	3
Seasonality of labour	49	55	59	60	101

Summer water (m^3)	495188	455495	323447	174792	43297
Water used (m^3/ha)	1718	1764	1837	1826	1769
Water marginal value (£/m^3)	0.00	0.00	0.00	0.00	0.00
N leaching (kg/ha)	16.4	15.0	10.0	5.0	1.0
P leaching (kg/ha)	0.2	0.2	0.2	0.2	0.2
Soil cover index	4.5	4.5	4.2	4.1	4.1
Pesticide Environmental Hazard Index	6.1	5.9	5.1	3.7	1.0
Pesticide Active Ingredient Losses	0.056	0.057	0.046	0.021	0.009
Fert-N (kg/ha)	51.2	45.1	25.6	7.6	2.5
Fert-P (kg/ha)	0.0	0.0	0.0	0.0	0.0
Fert-K (kg/ha)	91.4	83.9	58.7	30.4	5.7
Energy used (MJ/ha)	23003	23120	20336	16268	11564
Energy output (MJ/ha)	117836	116870	110133	97588	103975
Energy balance (MJ/ha)	96677	95446	91045	82166	93307

Figure 4.11 illustrates indicators of the farm's performance under constraints on the nitrogen lost from the whole farm. Economic performance of the farm in terms of the net margin, value added and subsidies are all affected by increasing constraints on the nitrogen losses. With increasing constraints on nitrogen the net margin is compromised, cropping switches away from an irrigation dominated system to a progressively rainfed dominated cropping pattern reflecting the higher fertiliser use and losses involved with the irrigated cropping. Net margin falls progressively as the proportion of irrigated area declines, initial reductions are relatively small with an initial reduction of 10% for the reduction between unconstrained cropping and a limit of 15 kgN/ha. The fall between the first two even reductions in nitrogen is 21% this increases as the nitrogen loss limit decreases further falling by an additional 46% between 5kgN/ha and 1kgN/ha losses. The level of government support received by the farm initially increases up to 180% as the proportion of rainfed land increases, this levels out between 10kgN/ha lost and 5kgN/ha lost followed by a dramatic decrease in the subsidies to just 41% of the initial level. This dramatic reduction in the level of subsidies is connected to the massive drop in land used for cropping and a switch to cropping dominated by irrigation. Total cropped land accounts for just 73 ha of the potential 408.2 ha available at this point of restriction. As the level of nitrogen losses falls below 5kgN/ha the cropping switches to carrots and parsnips, these two crops dominate the cropping pattern due to the very high value returns and high returns to the nitrogen losses.

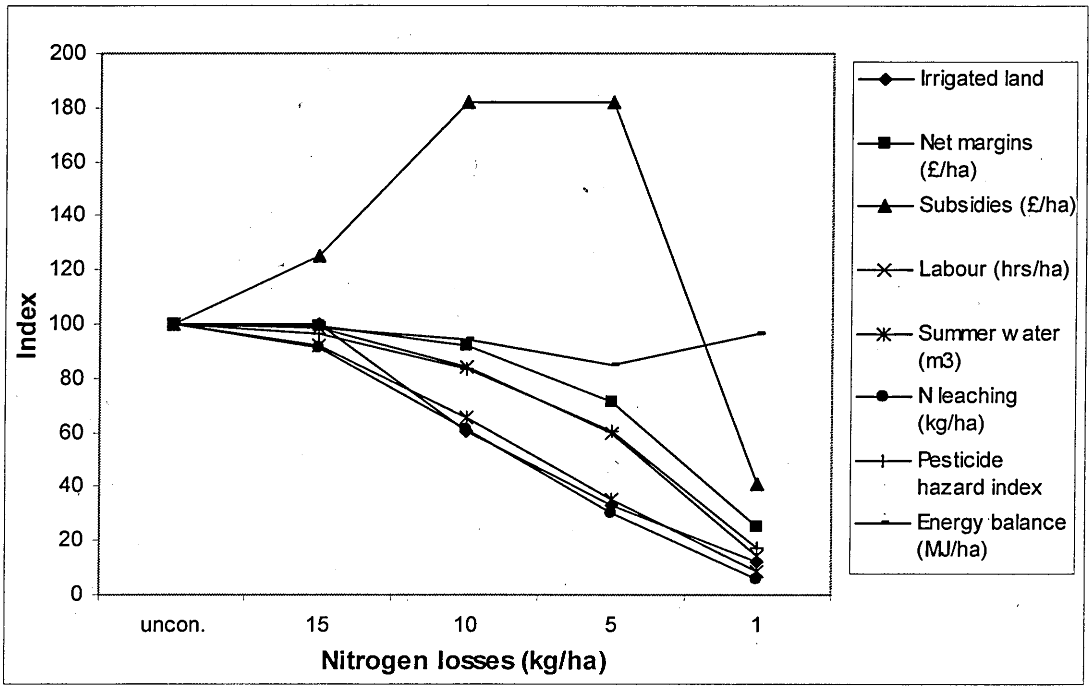

Figure 4.11: Indicators of farm performance Roudham Farm, nitrogen restrictions (average year)

Labour requirements are impacted severely by the restriction in nitrogen losses, total reductions in labour fall from 18 hours per hectare to just 3. Reductions in the labour required decline gradually at first with reductions increasing by greater increments as nitrogen constraints are increased. Environmental performance of the farm improves over the range of constraints, with nitrogen losses falling in line with the prescribed constraints. Improvements in the pesticide hazard are seen due to the reduction in the irrigated crops and the associated higher risks involved as a result of the specific chemicals used. Energy balance remains relatively stable with fluctuations between 85% and 97% over the range of cropping patterns.

4.3.4 Measure 4: Constraints on pesticide hazard risk.

This measure is designed to restrict the potential for agricultural practice to case harm to the surrounding environments. The hazard index is designed to calculate a risk of environmental damage/pollution occurring under specific chemicals, application techniques and environmental conditions. This measure acts to constrain the pesticide hazard risk permissible for the whole farm area as an average of the crops produced. Reductions in the hazard will impact upon the specific mix of crops depending upon their contribution to the overall hazard risk of the farm. Table 4.11 shows the crop specific contribution to the hazard risk and total active ingredient losses to water for each of the cropping options available.

Table 4.11: Crop contribution to pesticide hazard risk and active ingredient loss.

Crop	Pesticide losses	Pesticide hazard index
Spring Barley	0.017	3
Spring Wheat	0.017	3
Hemp	0.000	0
Field Beans	0.02	9
Set aside	0.000	0
Parsnips	0.247	15
Potatoes	0.123	7
Potatoes (rented)	0.123	7
Sugar beet	0.008	6
Onions	0.002	9
Onions (rented)	0.002	9
Carrots	0.000	9

Table 4.12 show a summary of the results for the pesticide hazard restriction measure, outlining the impact of this option on the performance of the farm. The specific environmental conditions present at Roudham Farm combined with the chemicals used have led to low hazard risk when compared with the risks present on the Lakes Farm case study. Initial unconstrained hazard risk is 6.14 under the standard conditions. The cropping pattern is dominated by irrigated crop at 70% of the initial area, including 155.5 ha of rented land that is rotated to new land on a yearly basis. At the first point of effect the hazard index is constrained to an index of 6, cropping is affected by reducing the total area of land used in production, the area of cereal crops is reduced by 54 ha reducing the total cropped area to 355.7 ha. The loss of a large area of cereals produces a relatively minor reduction in the whole farm pesticide hazard, this is due to the relatively low specific hazard of these crops. The cropping pattern favours a reduction in the area of cereals due to the low returns from these crops when compared with the high value irrigated crops. Further reductions in the hazard index continue to reduce the area of land used for cropping. Irrigated cropping remains the dominant choice maintaining smaller areas of high value crops which have greater returns to the pesticide risk.

Table 4.12: Summary of Roudham farm, pesticide restriction measure (average year).

Pesticide hazard risk index	6.14 (uncon.)	6.00	5.00	4.00	3.00	2.00	1.00
Rainfed							
Spring Barley	21.7	0.0	0.0	16.7	5.6	0.0	0.0
Spring Wheat	78.4	45.9	18.5	0.0	0.0	0.0	0.0
Hemp	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Field Beans	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Set aside	10.0	4.6	1.8	1.7	0.6	0.0	0.0
Irrigated							
Parsnips	15.0	15.0	15.0	15.0	15.0	15.0	9.0
Potatoes	30.0	30.0	30.0	28.9	20.8	15.0	9.0
Potatoes (rented)	107.0	107.0	84.7	33.1	25.1	9.1	0.0
Sugar beet	68.0	55.1	45.0	43.4	31.2	20.0	8.0
Onions	29.7	29.7	29.7	28.9	20.8	15.0	9.0
Onions (rented)	8.5	8.5	8.5	8.5	8.5	3.6	0.0
Carrots	30.0	30.0	30.0	28.9	20.8	15.0	9.0
Rainfed land	119.4	60.5	30.3	28.4	16.2	10.0	10.0
Irrigated land	288.2	275.3	242.9	186.7	142.3	92.7	44.0
Land used	408.2	335.7	273.2	215.0	158.5	102.7	54.0
Net margins (£/ha)	732.47	679.21	621.56	545.09	441.84	334.43	185.88
Subsidies (£/ha)	73.28	36.92	18.50	17.32	9.90	6.11	6.11
Value added (£/ha)	659.19	642.29	603.06	527.77	431.94	328.33	179.78
Public revenue (£/ha)	38.04	36.72	32.53	24.62	18.88	12.31	5.88
Net margins reduction (£/ha)	0.00	53.26	110.91	187.39	290.63	398.04	546.59
Regular labour	6	6	5	3	2	2	1
Labour (hrs/ha)	18	17	15	12	9	6	3
Seasonality of labour	49	53	54	46	44	44	51
Summer water (m3)	495188	478032	423489	320447	245740	160264	76563
Water used (m3/ha)	1718	1737	1743	1717	1727	1728	1739
Water marginal value (£/m3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N leaching (kg/ha)	16.4	15.2	13.0	9.6	7.4	4.9	2.6
P leaching (kg/ha)	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Soil cover index	4.5	3.9	3.3	2.6	1.9	1.3	0.6
Pesticide Environmental Hazard Index	6.1	6.0	5.0	4.0	3.0	2.0	1.0
Pesticide Active Ingredient Losses	0.056	0.054	0.045	0.029	0.024	0.017	0.008
Fert-N (kg/ha)	51.2	58.3	60.2	52.2	53.6	51.6	50.2
Fert-P (kg/ha)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fert-K (kg/ha)	91.4	107.2	116.2	110.1	110.7	104.8	92.2
Energy used (MJ/ha)	23003	25150	25601	22653	23200	22182	19516
Energy output (MJ/ha)	117836	124402	126662	119067	119594	117060	106194
Energy balance (MJ/ha)	96677	101416	103417	98678	98751	97248	88831

Figure 4.12 demonstrates the impact of pesticide hazard restrictions on the Roudham Farm case study. With constrictions in the pesticide hazard the economic performance of the farm suffers. As the acceptable hazard risk is decreased the net margin falls by a total of 75% to just £179.79/ha. Initial changes in the cropping pattern reduced the area of rainfed cropping with a fall in the area of rainfed cropping of 75% from the first 2 units of pesticide hazard risk reduction the area of irrigated land falls more gradually with a 16 % reduction in the area of irrigated land for the same fall in pollution risk. The rapid fall in the area of rainfed cropping causes the total subsidies received per hectare to fall in line with the reduction in rainfed cropping. Reductions in the area of irrigated cropping cause a decline in the total labour required, total labour falls from 18 hours per hectare to just 3 under a limit of 1. The environmental performance of the farm sees improvements under all of the indicators. Reduction in nitrogen loss are seen due to the reduction in the area of land used for production and not as a result of reductions in the proportion of total cropped converting to rainfed cropping with lower values of nitrogen use and loss as seen under the water use measures.

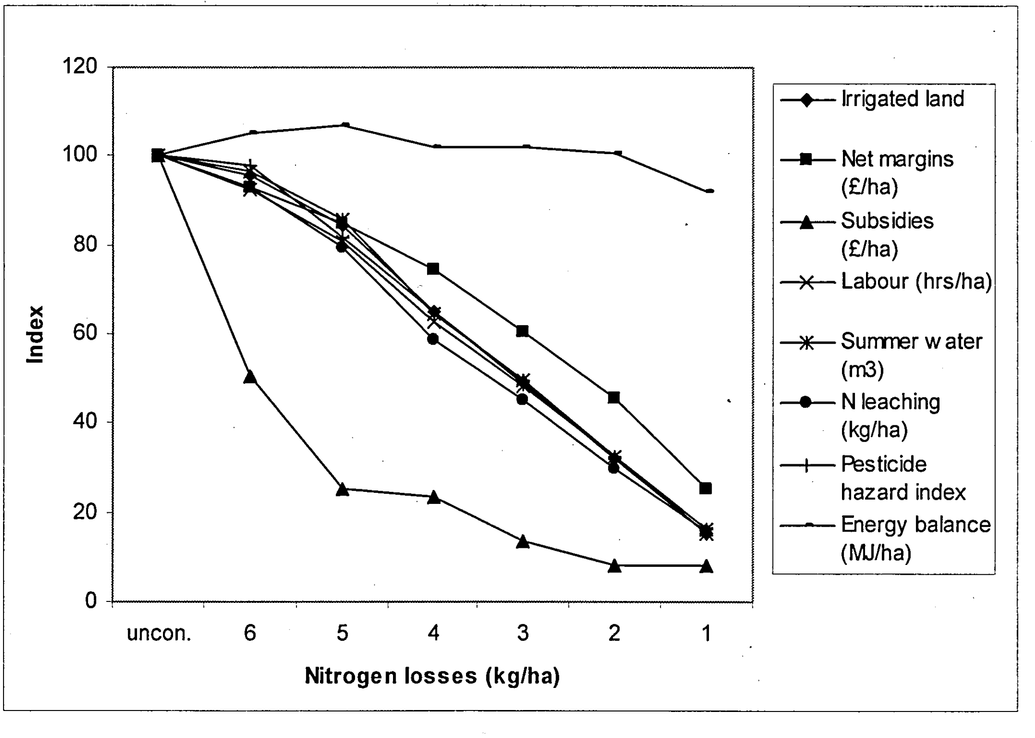

Figure 4.12: Indicators of farm performance Roudham Farm, pesticide hazard risk (average year).

4.3.5 Roudham Farm summary.

The analysis of Roudham Farm confirmed that the introduction of the measures identified in the WFD will have an impact upon the performance of this irrigated farming system. Both the abstraction license restriction and abstraction charge increase measures can ultimately provide reductions in water use. The abstraction charge increase requires large increases from the current charge before significant reductions in the use of water occur. This acts to reduce the revenue to the farmer as a result of increased costs with transfer of income from the farmer to the licensing agency. Under both measures the reduction in water acts to reduce the area of irrigated cropping. Associated with this reduction is the loss of income, and social impacts of reduced labour requirements, cropping switches to rainfed options with increases in the reliance on government support

4.4 Church Farm Case Study.

Church Farm is a predominantly soft fruit farm located to the north of Norwich. The farm grows irrigated strawberries, raspberries and potatoes. Rainfed cropping is used to allow for the rotational constraints associated with the irrigated cropping. Potatoes, winter wheat and spring barley are all treated as secondary crops with the majority of resources being associated with the production of fruit crops. Problems with disease and incompatibility between potatoes and fruit have led to the consideration of removing them from the cropping pattern. The production of the current irrigated crops under rainfed conditions in not viable on this farm due to the specific climatic and soil conditions and the soil moisture deficits occurring as a result of these conditions. Initial water available was uncertain due to the volume of unlicensed abstraction for trickle irrigation currently allowed. Several abstraction licences are held and along with the current unlicensed abstraction total water availability is in the region of 354000 m^3 per year.

4.4.1 Measure 1: Restrictions on licensed abstraction.

Under unconstrained water supply, cropping consists of irrigated strawberries, raspberries and potatoes. Initial cropping contains roughly equal areas of irrigated and rainfed at 142 ha and 140.4 ha respectively. The majority of irrigated land is involved in the production of soft fruit with 74 ha of strawberries and 46 ha of raspberries. Just 22 ha of potatoes are grown as a result of rotational constraints within the no fruit area. Initial water usage is 70% of the total licensed water available, at 50% restriction the irrigated cropping is restricted to 93 ha of land; potatoes have the lowest return to water and are lost from this scenario, and the area of raspberries is also reduced to 19.3 ha, with strawberries remaining at 74 hectares. Cropping switches from the irrigated cropping to winter barley that covers 141.2 ha spring barley is introduced to the cropping due to rotational constraints of winter wheat. Under 75% water restrictions the area of irrigated cropping is limited to just 44 ha and cropping is dominated by cereals.

As the cropping pattern changes with the restrictions in water availability, the economic performance of the farm causes a reduction in the net margin of 95% from the unconstrained scenario to the rainfed cropping option. At 50% water availability the net margin is reduced by 8% and falls to a 50% under a 75% water restriction. As the area of rainfed cropping increases the level of support increases steadily from £122.80 ha on average to £247.00 ha under a rainfed system. Under the standard case the added value is £4907.68 ha this falls to -£19.41 under rainfed cropping at which point cropping would make a loss without the addition of government support. Labour requirements fall as the area of irrigated cropping decreases. At 50% water availability the total labour required per hectare falls by 25% to 399 hours per hectare. At 75% water availability labour falls to 34% of the unconstrained demand. The number of regular labourers required falls from 12 to just 3 under this level of restriction. Environmental performance of the farm shows improvements in both the pesticide and nitrogen losses with reductions of 60% in the pesticide hazard index from 25% restrictions to 100% restrictions in water.

Table 4.13: Summary results for Church Farm, water restriction measure (average year)

Water availability	100%	75%	50%	25%	0%
Cropping pattern (282.4 ha)					
Rainfed					
Winter Wheat	127.6	127.6	141.2	141.2	141.2
Spring Barley	0.0	0.0	30.7	75.4	115.5
Set aside	12.8	12.8	17.2	21.7	25.7
Irrigated					
Strawberries	74.0	74.0	74.0	44.1	0.0
Raspberries	46.0	46.0	19.3	0.0	0.0
Potatoes	22.0	22.0	0.0	0.0	0.0
Rainfed land	140.4	140.4	189.1	238.3	282.4
Irrigated land	142.0	142.0	93.3	44.1	0.0
Net margins (£/ha)	5030.48	5030.48	4626.07	2732.35	227.59
Subsidies (£/ha)	122.80	122.80	165.42	208.40	247.00
Value added (£/ha)	4907.68	4907.68	4460.66	2523.94	-19.41
Public revenue (£/ha)	27.86	27.86	19.66	9.83	0.00
Net margins reduction (£/ha)	0.00	0.00	404.41	2298.14	4802.89
Regular labour	12	12	7	3	2
Labour (hrs/ha)	539	539	399	181	9
Seasonality of labour	188	188	198	206	138
Summer water (m^3)	250867	250867	177000	88500	0
Water used (m^3/ha)	1767	1767	1898	2006	0
Water marginal value (£/m^3)	0.00	0.00	2.03	7.96	9.92
N leaching (kg/ha)	28.4	28.4	24.5	22.1	20.3
P leaching (kg/ha)	6.1	6.1	4.8	4.8	4.9
Soil cover index	7.3	7.3	6.9	6.0	5.1
Pesticide Environmental Hazard Index	8.0	8.0	6.7	4.8	3.2
Pesticide Active Ingredient Losses	0.132	0.132	0.131	0.085	0.020
Fert-N (kg/ha)	141.3	141.3	137.1	140.7	146.4
Fert-P (kg/ha)	60.5	60.5	48.1	48.3	48.4
Fert-K (kg/ha)	102.0	102.0	71.1	53.5	39.8
Energy used (MJ/ha)	20691.9	20691.9	19220.7	18827.4	18625.6
Energy output (MJ/ha)	72945.7	72945.7	75140.8	88446.9	100355.1
Energy balance (MJ/ha)	53470.0	53470.0	56778.2	70048.5	81729.6

This decrease is in line with the reductions in irrigated area and the presence of the fruit cropping. Reductions in nitrogen losses fall from 28.4 kgN/ha to 20.3 kgN/ha under the rainfed cropping system. The reduction in nitrogen losses falls gradually with a 14% reduction at 50% water restrictions and a 22% reduction in nitrogen losses at 75% water restrictions. The energy balance shows improvements with a greater output of energy in relation to the energy inputs under the rainfed cropping. High labour requirements for the fruit cropping give a net negative energy balance for these crops. As the level of fruit decreases the energy balance rises to 53% under the rainfed cropping system.

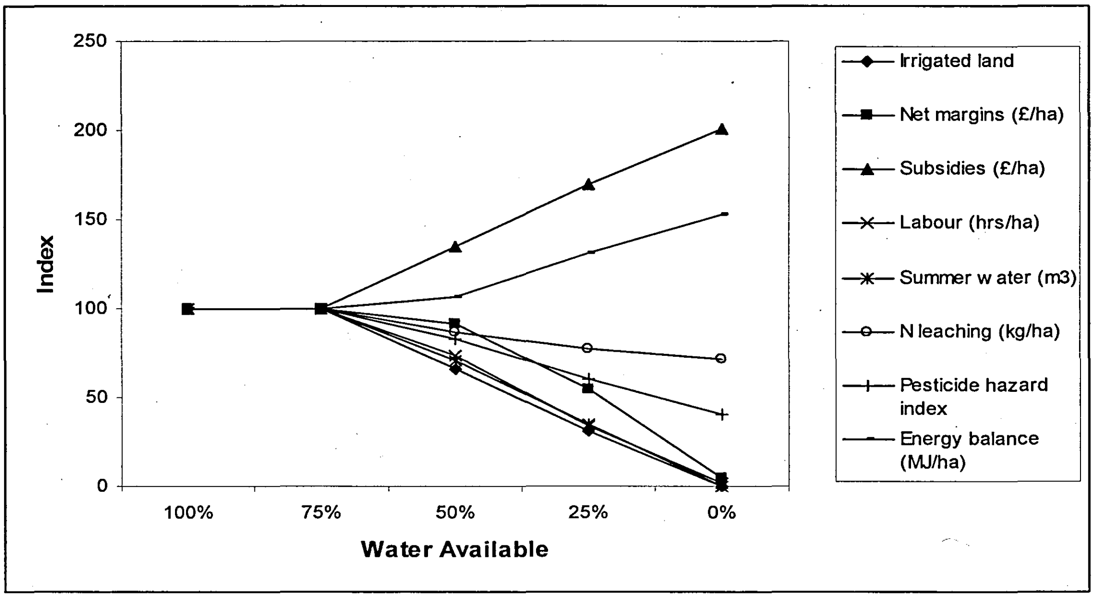

Figure 4.13: Indicators of farm performance Church Farm, licence restriction measure (average year).

Dry year scenario: Licence restriction measure.

Under dry year conditions the initial cropping pattern on the farm is identical to the average year. Water requirement are however increased to 95% of the licensed volume, the extra costs involved in the supply and application of this additional water reduced the net margin by £132.13 ha. Water restrictions impact upon the system earlier than under average year conditions, once the threshold of 95% licensed water availability has been passed the area of irrigated land that can be sustained is reduced due to insufficient water to supply the requirements of all of the irrigated crops. Under this system the first reduction in cropping is the loss of potatoes from the system. At 25% water restrictions there is no longer sufficient water to sustain the production of potatoes and they are completely lost from the system. The area of raspberries is also reduced and at 50% water restrictions is lost entirely. The area of strawberries remains at its maximum available area in line with the high returns to strawberries. At 25% restrictions there is only sufficient water to produce 34 ha of strawberries. The reduction in the irrigated cropping causes a switch to rainfed cropping options.

Table 4.14: Summary results Church Farm, licence restriction measure (dry year).

Water availability	100%	75%	50%	25%	0%
Cropping pattern (282.4 ha)					
Rainfed					
Winter Wheat	127.6	141.2	141.2	141.2	141.2
Spring Barley	0.0	14.2	53.3	84.4	115.5
Set aside	12.8	15.5	19.5	22.6	25.7
Irrigated					
Strawberries	74.0	74.0	68.4	34.2	0.0
Raspberries	46.0	37.5	0.0	0.0	0.0
Potatoes	22.0	0.0	0.0	0.0	0.0
Rainfed land	140.4	170.9	214.0	248.2	282.4
Irrigated land	142.0	111.5	68.4	34.2	0.0
Net margins (£/ha)	4898.35	4724.21	4043.85	2141.50	227.59
Subsidies (£/ha)	122.80	149.49	187.14	217.07	247.00
Value added (£/ha)	4775.55	4574.71	3856.71	1924.44	-19.41
Public revenue (£/ha)	37.22	29.48	19.66	9.83	0.00
Net margins reduction (£/ha)	0.00	174.14	854.50	2756.84	4670.76
Regular labour	12	10	4	3	2
Labour (hrs/ha)	539	493	276	143	9
Seasonality of labour	188	192	214	200	138
Summer water (m^3)	335150	265500	177000	88500	0
Water used (m^3/ha)	2360	2382	2586	2586	0
Water marginal value (£/m^3)	0.00	1.41	6.07	6.07	7.60
N leaching (kg/ha)	28.4	25.8	23.0	21.7	20.3
P leaching (kg/ha)	6.1	4.8	4.8	4.9	4.9
Soil cover index	7.3	7.2	6.5	5.8	5.1
Pesticide Environmental Hazard Index	8.0	7.4	5.7	4.5	3.2
Pesticide Active Ingredient Losses	0.132	0.133	0.120	0.070	0.020
Fert-N (kg/ha)	141.3	137.3	137.6	142.0	146.4
Fert-P (kg/ha)	60.5	48.1	48.2	48.3	48.4
Fert-K (kg/ha)	102.0	79.0	61.0	50.4	39.8
Energy used (MJ/ha)	21101	19761	19131	18878	18626
Energy output (MJ/ha)	72946	70186	81885	91120	100355
Energy balance (MJ/ha)	53470	51712	63612	72671	81730

Figure 4.14 summarises the farm performance indicators under the licence restrictions in the dry year. All impacts are effective earlier in the licence restriction than under average year conditions. The degree of impact is greater at each stage of the water reductions as a result of the greater requirements for water to achieve the production

requirements. Impacts follow the same trends as identified in the average year scenario but the impacts are shifted to the left of the chart with the severity of the impact greater earlier in the license restrictions.

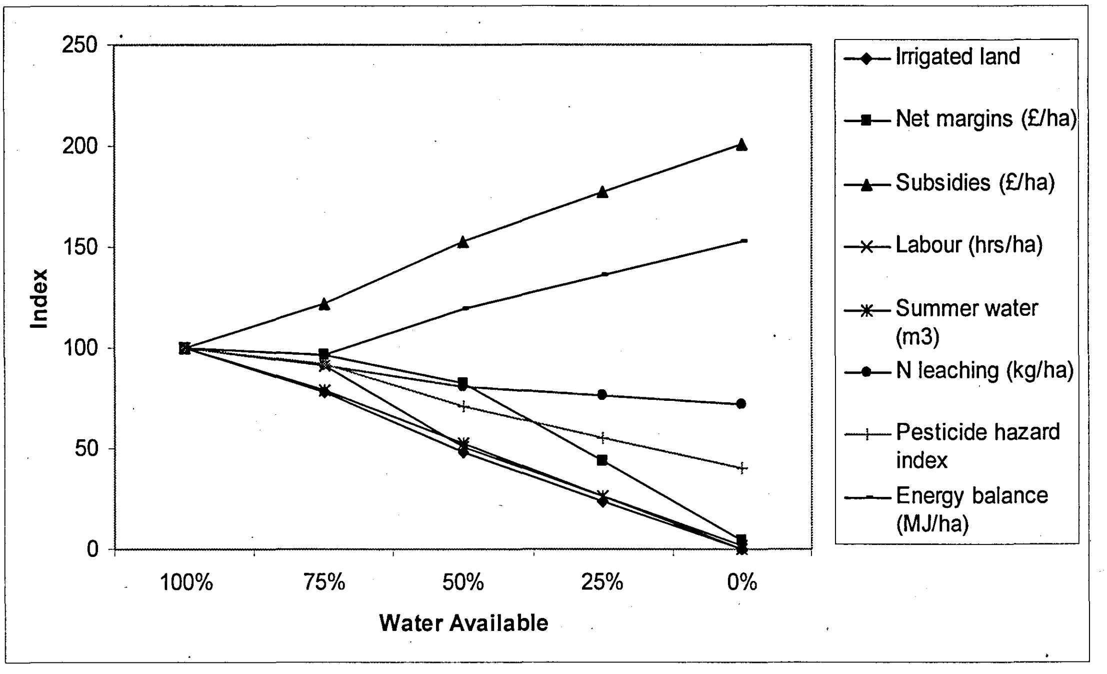

Figure 4.14: Indicators of farm performance Church Farm, Licence restrictions (dry year).

Figure 4.15 presents the marginal value product of water under both water scenarios. As water availability increasingly restricts the area of irrigated cropping available the marginal value product of water increases. Under the two water scenarios, the marginal value product of water is greater for the average year reflecting the greater returns per unit of water applied. Impacts of the dry year on water requirement cause a shift to the right in the incremental jumps in marginal value product. Under the dry year the impacts of water restrictions are seen earlier in the license restriction as a result of the higher water requirements of the crops. Returns to water are lower in the dry year scenario due to the increased water required and the lack of premium prices which will increase the benefits to irrigation. The dry year scenario would be expected to perform better in the dry year with increased net margins for the irrigated crops due to premium prices in the dry year. Marginal value product of the irrigated crops would also be expected to be higher due to the extra gap in the benefit gained between rainfed and irrigated production of the same crops in the dry year.

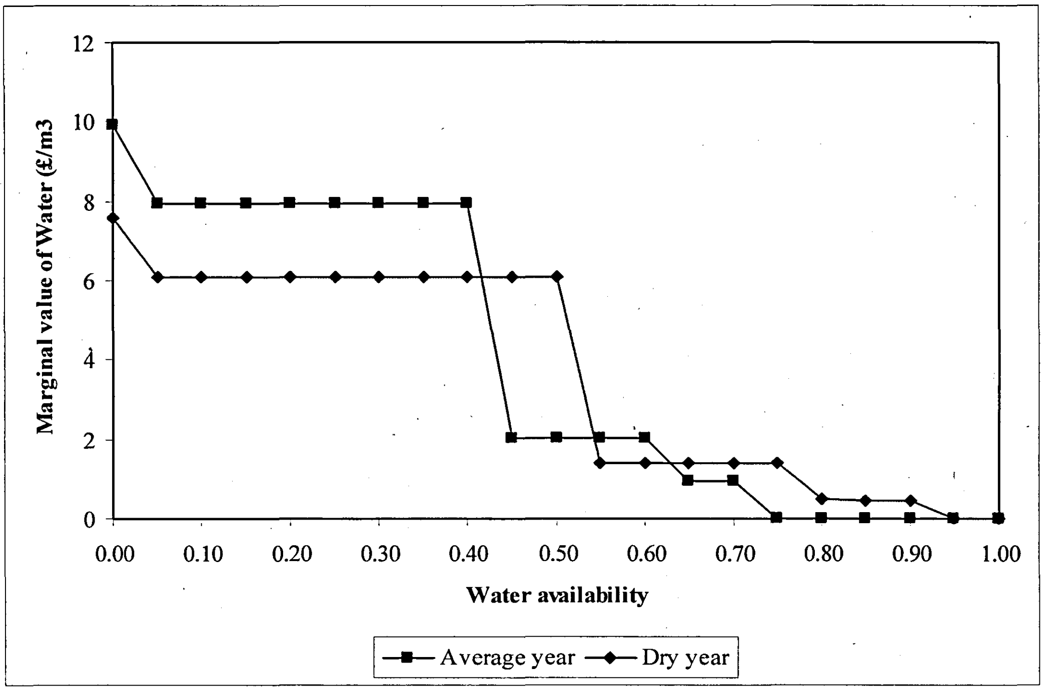

Figure 4.15: Marginal value product of water on Church Farm for both water scenarios

Yield and quality targets may not be met under the rainfed cropping even in areas which are able to produce high quality high yielding crops in the average year giving the irrigated crops an added advantage above that gained in the average year. Under the analysis of Church Farm this trend is not shown in the dry year due to the specific characteristics of the farm. In the interview conducted with John Place the issue of dry year premium prices was discussed. He could not be certain of any specific price premiums in the dry year, the outlets for all produce of this farm go direct to supermarkets and all produce is packed and processed on the farm. John Place reported that there were yearly variations in the prices but stated that he did not think that dry years significantly affected the prices they received. As a result of this the dry year assumes the same yield and price data as the average year with increased costs of water and identical net margin returns leading to the findings discussed.

4.4.2 Measure 2: Price Increases.

Water supply for this farm comes from direct abstraction from both surface and ground water sources. Summer abstraction is currently subjected to an abstraction charge of £0.31/m^3. This measure imposes increases on the charge for water abstraction with the aim of reducing the volume of water used through economic incentives to save water. Incremental increases of £0.05/m^3 have been imposed on the system until the point where irrigation is no longer economically viable.

Table 4.15 summarises the results of increases in water charges; the results displayed show the point of change in water use as a result of increased water costs. Water abstraction at the point of no water charge utilises 70% of the licensed volume available. Increases in the abstraction charge result in reductions in the irrigated cropping; with increasing costs of abstraction the net revenue for each crop is reduced until the point where irrigation of each crop becomes less attractive than an alternative rainfed crop.

Table 4.15: Summary results Church Farm, charge increase measure (average year).

Water Charge	£0.00	£1.00	£1.10	£2.10	£8.00	£9.95
Water Use	71%	64%	61%	42%	1%	0%
Cropping pattern (282.4 ha)						
Rainfed						
Winter Wheat	127.6	141.2	141.2	141.2	141.2	141.2
Spring Barley	0.0	0.0	6.4	48.3	114.7	115.5
Set aside	12.8	14.1	14.8	18.9	25.6	25.7
Irrigated						
Strawberries	74.0	74.0	74.0	74.0	0.9	0.0
Raspberries	46.0	46.0	46.0	0.0	0.0	0.0
Potatoes	22.0	7.1	0.0	0.0	0.0	0.0
Rainfed land	140.4	155.3	162.4	208.4	281.5	282.4
Irrigated land	142.0	127.1	120.0	74.0	0.9	0.0
Net margins (£/ha)	5058.34	4171.29	4091.83	3333.00	239.08	227.59
Subsidies (£/ha)	122.80	135.85	142.04	182.28	246.23	247.00
Value added (£/ha)	4935.54	4035.44	3949.79	3150.72	-7.15	-19.41
Public revenue (£/ha)	0.00	806.15	843.87	1103.62	50.32	0.00
Net margins reduction (£/ha)	0.00	887.06	966.51	1725.34	4819.26	4830.75
Regular labour	12	11	11	4	2	2
Labour (hrs/ha)	539	538	538	298	12	9
Seasonality of labour	188	189	190	215	83	138
Summer water (m^3)	250867	227658	216644	148411	1776	0
Water used (m^3/ha)	1767	1791	1805	2006	2006	0
Water marginal value (£/m^3)	0.00	0.00	0.00	0.00	0.00	0.00
N leaching (kg/ha)	28.4	27.2	26.3	23.2	20.4	20.3
P leaching (kg/ha)	6.1	5.2	4.8	4.8	4.9	4.9
Soil cover index	7.3	7.4	7.4	6.6	5.1	5.1
Pesticide Environmental Hazard Index	8.0	7.9	7.8	5.9	3.3	3.2

Pesticide Active Ingredient Losses	0.132	0.133	0.134	0.128	0.021	0.020
Fert-N (kg/ha)	141.3	140.5	137.4	136.8	146.2	146.4
Fert-P (kg/ha)	60.5	52.3	48.0	48.2	48.4	48.4
Fert-K (kg/ha)	102.0	89.3	82.8	62.8	40.0	39.8
Energy used (MJ/ha)	20692	19984	19577	18964	18630	18626
Energy output (MJ/ha)	72946	69899	67868	80385	100116	100355
Energy balance (MJ/ha)	53470	51019	49342	62141	81495	81730

Initial cropping on this farm is concentrated around the production of soft fruits namely strawberries and raspberries. These are very high value, labour intensive crops which demand high prices but require quality guarantees in order to achieve the best prices. Without careful irrigation the quality of these crops could not be guaranteed and it would be difficult to gain the outlets for fresh fruit (Place, personal communication). Net margins on these crops have been calculated using actual data sets from the farm interviews, and include both fresh sales and processed sales that gain a reduced price due to the lower quality and market requirements. Initial irrigated cropping contains 74 ha of strawberries, 46 ha of raspberries and 22 ha of potatoes. These account for almost half of the total farm area, rainfed cropping includes winter wheat, winter barley and set-aside. Losses of irrigated crops begin with the loss of potatoes, followed by raspberries and finally strawberries. An abstraction charge of £1.00/m^3 reduces the area of potatoes to just 7.1 ha, this is associated with the loss of 1 regular labourer. A further increase of £0.10/m^3 forces potatoes from the system completely. The loss of potatoes from the system reduces the total water use by just 10% to 216644m^3 per year with a loss of £966.51 ha in net margin. At a charge of £2.10/m^3 raspberries are lost from the system, with an extra reduction of an additional 20% in the water use. An increase in the abstraction charge to £8.00/m^3 causes a reduction in the area of strawberries, the total area of strawberries is reduced to just 0.9 ha. Remaining production utilises the extra labour available from the two regular labourers once all labour has been assigned to the rainfed cropping. Water use is reduced by an additional 41% to just 1% of the total licensed volume. An increase of £1.95/m^3 in the charge for water makes the production of strawberries economically unsustainable and therefore they are lost from the system.

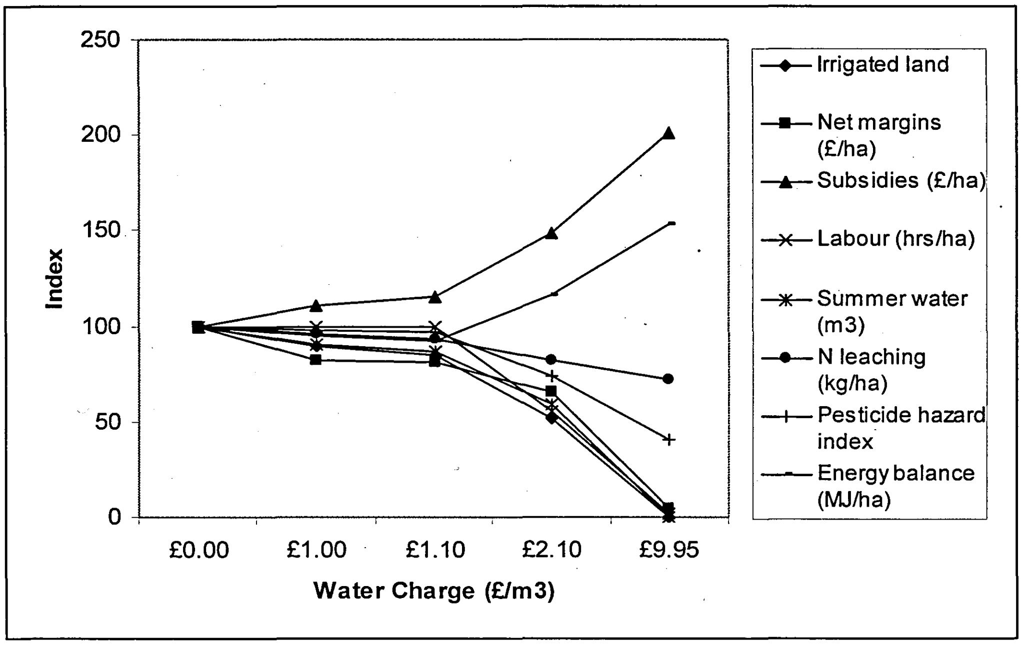

Figure 4.16: Indicators of farm performance, Church Farm water charge increase measure (average year).

Figure 4.16 summarises the indictors of performance for Church Farm under abstraction charge increases. Increases in the abstraction charge have encouraged reductions in the water use on the farm through the reduction in irrigated cropping as a result of increased costs making the crops less profitable. With the increases in water charges the net revenue for each of the irrigated crops is reduced, initial charge increases of up to £1.10/m^3 have the impact of reducing the water use by just 10% and the net margin by 20% to £966.51 ha. Once the abstraction charge reaches £2.10/m^3 the gross margin declines by a further 15% to £3333.00 ha with the loss of raspberries from the system altogether. Strawberries remain in the system at maximum cropped area the total net margin is reduced by over 40% for a reduction of 40% in water use. The high value of strawberries requires an increase in the abstraction charge to £9.95/m^3 before water use is totally stopped, water use remains at 60% of the initial usage until this point. Reductions in the labour requirements for Church Farm are closely linked with the areas of fruit grown. With the loss of potatoes from the system there is a reduction of 1 hour per hectare of labour required. At a charge of £2.10m^3 the production of raspberries is no longer viable which causes labour requirements to fall sharply by almost 50% to just 298hrs/ha and 4 regular labourers. The loss of raspberries and potatoes from the cropping pattern reduces the environmental impact of the farm with reduction in the pesticide hazard risk and the nitrogen losses. The energy balance of the soft fruits is poor. High manual labour requirements cause a negative net balance for these crops, as the rainfed cropping options become more important within the overall cropping pattern the energy balance increases reflecting the higher outputs of energy achieved under the rainfed system.

Figure 4.17 displays the effectiveness of the water reduction measures. Both measures act to reduce the total volume of water used. The impact on the economic performance of the farm varies considerably between the two measures. Under charge increases the impact on net margins is greater for a comparative reduction in the water use than the water restriction measure. The use of the abstraction charge measure will deliver the required water use reduction but abstraction charges will have to increase by up to £1.00m^3 before water use reductions occur. The effect of this inelastic response to water use will be a transfer of income from the farmer to the licensing agency. The abstraction license restrictions deliver the same level of water control without this transfer of revenue from the farm.

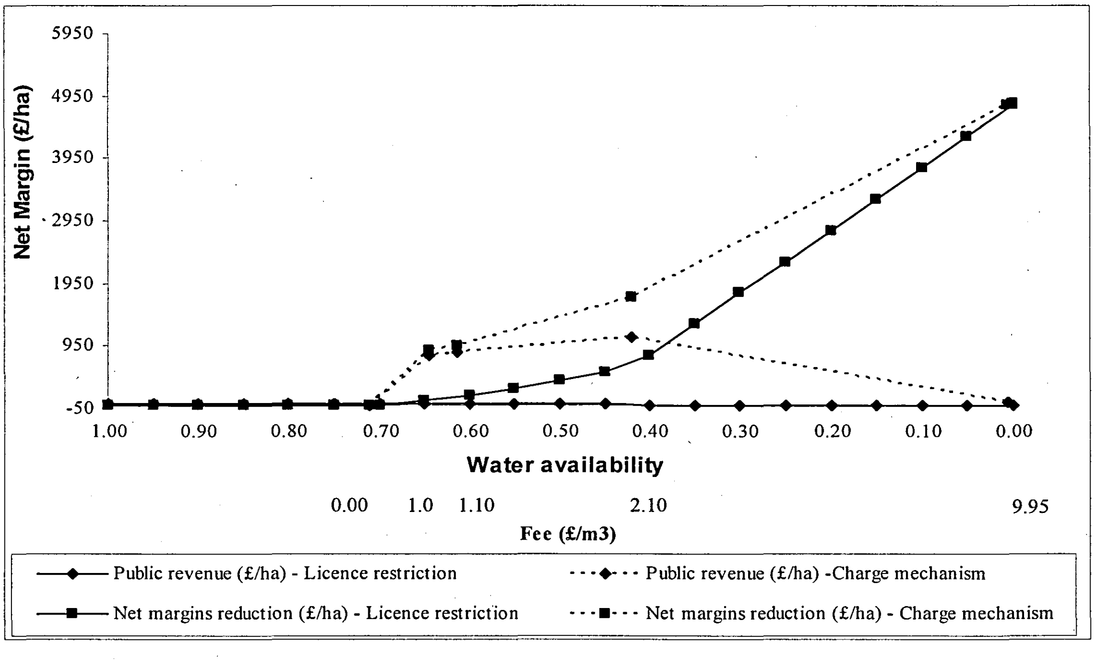

Figure 4.17: Comparison of water use reduction between licence and charge measures on Church Farm.

4.4.3 Measure 3: Constraints on nitrogen losses.

Table 4.16 presents a summary of the results for the nitrogen constraints measure on the Church Farm case study. Initial unconstrained nitrogen losses from the farm are 28.4 kgN/ha. Initial cropping on this farm concentrates on the production of strawberries and raspberries with a small area of irrigated potatoes and the total irrigated area accounts for 142 ha, just over half of the area available. Rainfed cropping accounts for the other half of the cropped area and includes winter wheat and spring barley. Initial constraints to the system cause a switch in the rainfed cropping pattern. The area of winter wheat is reduced and switches to spring barley, which has a lower level of nitrogen loss. The farm is able to retain maximum net margin while maintaining the cropped area until the nitrogen loss is limited to 18kgN/ha. Once this threshold has been reached the cropping pattern is unable to maintain cropping on the whole farm and reduces the area of cropped land. The optimum cropping pattern tries to maintain the maximum area of high value crops, as the nitrogen limit decreases the area of rainfed land falls leaving the irrigated cropping with high returns to nitrogen losses.

Table 4.16: Summary results Church Farm, pesticide hazard constraints (average year).

Nitrogen Limit Cropping pattern (282.4 ha)	28.4	26	22	18	14	10	6	2
Rainfed								
Winter Wheat	127.6	80.8	2.4	0.0	0.0	0.0	0.0	0.0
Spring Barley	0.0	46.8	125.2	51.9	0.0	0.0	0.0	0.0
Set aside	12.8	12.8	12.8	5.2	0.0	0.0	0.0	0.0
Irrigated								
Strawberries	74.0	74.0	74.0	74.0	74.0	74.0	70.0	23.3
Raspberries	46.0	46.0	46.0	46.0	46.0	32.0	0.0	0.0
Potatoes	22.0	22.0	22.0	22.0	14.1	0.0	0.0	0.0
Rainfed land	140.4	140.4	140.4	57.1	0.0	0.0	0.0	0.0
Irrigated land	142.0	142.0	142.0	142.0	134.1	106.0	70.0	23.3
Land used	282.4	282.4	282.4	199.1	134.1	106.0	70.0	23.3
Net margins (£/ha)	5030.48	5006.15	4965.37	4915.23	4832.12	4586.08	3997.03	1332.34
Subsidies (£/ha)	122.80	122.80	122.80	49.95	0.00	0.00	0.00	0.00
Value added (£/ha)	4907.68	4883.35	4842.57	4865.30	4832.12	4586.08	3997.03	1332.34
Public revenue (£/ha)	27.86	27.86	27.86	27.86	26.50	21.77	15.59	5.20
Net margins reduction (£/ha)	0.0	24.3	65.1	115.3	198.4	444.4	1033.5	3698.1

Regular labour	12	12	13	12	11	8	3	1
Labour (hrs/ha)	539	539	539	536	534	460	276	92
Seasonality of labour	188	188	189	190	192	198	225	225
Summer water (m3)	250867	250867	250867	250866	238641	196007	140422	46807
Water used (m3/ha)	1767	1767	1767	1767	1779	1849	2006	2006
Water marginal value (£/m3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N leaching (kg/ha)	28.4	26.0	22.0	18.0	14.0	10.0	6.0	2.0
P leaching (kg/ha)	6.1	5.8	5.4	4.2	2.8	1.5	1.0	0.3
Soil cover index	7.3	7.3	7.3	8.3	9.8	10.6	11.0	11.0
Pesticide Environmental Hazard Index	8.0	7.9	7.6	6.8	6.0	5.0	3.2	1.1
Pesticide Active Ingredient Losses	0.132	0.130	0.126	0.122	0.119	0.117	0.106	0.035
Fert-N (kg/ha)	141.3	121.4	88.1	87.4	80.6	62.1	50.0	50.0
Fert-P (kg/ha)	60.5	58.0	53.8	59.0	57.9	40.0	40.0	40.0
Fert-K (kg/ha)	102.0	97.9	90.9	117.3	145.5	125.7	115.0	115.0
Energy used (MJ/ha)	20692	20170	19294	20195	20766	19103	18341	18341
Energy output (MJ/ha)	72946	68690	61556	5039	27661	11122	11305	11305
Energy balance (MJ/ha)	53470	49737	43478	31918	9331	-5450	-4290	-4290

Winter wheat is lost from the system first at a constraint of 18kgN/ha. Spring barley follows at a constraint of 14kgN/ha. At this point the level of irrigated land can no longer be maintained and the area of potatoes is reduced reflecting the relatively low returns of potatoes in relation to the soft fruit cropping. Further restrictions lead to the reduction in the area of raspberries and finally a reduction in the area of strawberries grown.

Figure 4.18 summarises the indicators of farm performance under nitrogen restrictions. Initial constraints have little impact on the net margin of the farm. The margin gained from the soft fruit production is so good that reductions in the areas of rainfed cropping have little impact on the net margin per hectare. The net margin remains above 90% of the unconstrained level until nitrogen is constrained to less than 6kgN/ha, when the area of soft fruit is reduced by the loss of raspberries. Labour follows a similar pattern to the net margin again associated with the reduction in the area of soft fruit production falling rapidly as the area of fruit is reduced. A switch to irrigated cropping causes the level of support to fall to 0 reflecting the loss of rainfed cropping from the system. The dominance of the soft fruit production also causes a sharp decline in the energy balance due to the high labour requirements of soft fruit production and the energy that this uses. Pesticide hazard risk fall in line with the reduction of irrigated area, initially the hazard risk falls relatively slowly as the area of rainfed cropping is reduced. These have relatively low pesticide hazard risks when compared with the irrigated crops and so the loss of these from the system has a small impact of the over all farm hazard risk.

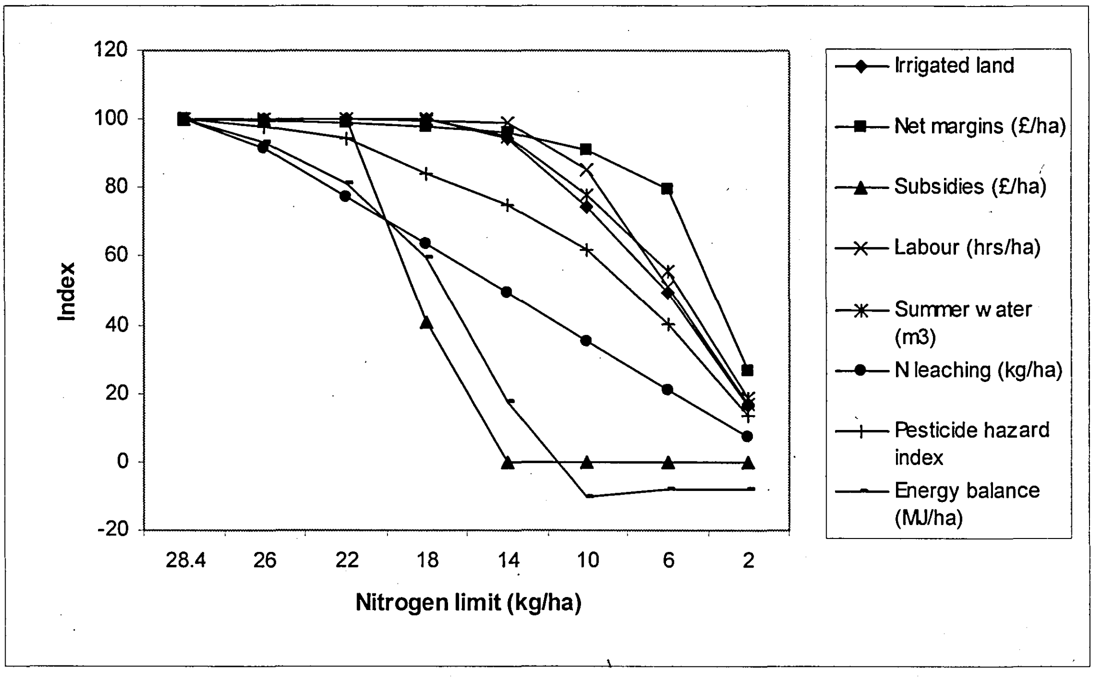

Figure 4.18: Indicators of farm performance, Church Farm nitrogen restrictions (average year).

4.4.4 Measure 4: Reductions in pesticide hazard risk.

This measure acts to assess the impact that increased restrictions on the use of pesticides will have on irrigated farming. The hazard index is designed to calculate a risk of damage occurring under specific chemicals, application techniques and environmental conditions. This measure acts to constrain the hazard risk permissible for the whole farm area. Table 4.17 shows the crop specific contribution to the hazard risk and total active ingredient losses to water for each of the cropping options available. The irrigated crops have greater risk of causing environmental damage and therefore contribute more to the overall hazard index of the farm.

Table 4.17: Crop contributions to pesticide hazard risk and active ingredient loss on Church Farm.

Crop	Active ingredient losses (μ/ha)	Pesticide hazard risk
Winter Wheat	0.028	4
Spring Barley	0.015	3
Set aside	0.000	0
Strawberries	0.427	13
Raspberries	0.046	14
Potatoes	0.000	7

Table 4.18 summarises the impacts of pesticide hazard restrictions for Church Farm. Initial hazard risk of the unconstrained farm is a pollution hazard index rating of 8. As the hazard rating is restricted the cropping pattern alters in response to maximise the net margin returns while meeting the required constraints. Initial reductions in the hazard index cause a reduction in the area of rainfed cropping. Although the rainfed cropping options have lower hazard risks associated with their production the very high returns linked with the irrigated crops make it more profitable to take land out of production in order to maximise the area of irrigated cropping. The reduction of rainfed cropping allows the system to maintain maximum areas of irrigated cropping until a hazard risk of 5 is reached. At this point the rainfed cropping is removed from the system completely and a reduction in the area of raspberries is seen. From this point the area of irrigated land falls more steeply with reductions in the area of raspberries halved and a slight decrease in the area of potatoes.

Table 4.18: Summary results for Church Farm, pesticide hazard risk restrictions (average year).

Pesticide Hazard Index	8	7	6	5	4	3	2	1
Cropping pattern (282.4 ha)								
Rainfed								
Winter Wheat	127.6	124.8	54.2	0.0	0.0	0.0	0.0	0.0
Spring Barley	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Set aside	12.8	12.5	5.4	0.0	0.0	0.0	0.0	0.0
Irrigated								
Strawberries	74.0	74.0	74.0	74.0	74.0	74.0	65.2	43.4
Raspberries	46.0	46.0	46.0	41.3	22.5	4.2	0.0	0.0
Potatoes	22.0	22.0	22.0	22.0	19.3	15.6	0.0	0.0
Rainfed land	140.4	137.3	59.6	0.0	0.0	0.0	0.0	0.0
Irrigated land	142.0	142.0	142.0	137.3	115.8	93.8	65.2	43.4
Land Used	282.4	279.3	201.6	137.3	115.8	93.8	65.2	43.4
Net margins (£/ha)	5030.48	5027.18	4944.90	4828.90	4599.72	4369.87	3720.29	2480.19
Subsidies (£/ha)	122.80	120.07	52.15	0.00	0.00	0.00	0.00	0.00
Value added (£/ha)	4907.68	4907.11	4892.74	4828.90	4599.72	4369.87	3720.29	2480.19
Public revenue (£/ha)	27.86	27.86	27.86	27.09	23.52	19.87	14.51	9.68
Net margins reduction (£/ha)	0.00	3.31	85.58	201.59	430.77	660.62	1310.19	2550.29
Regular labour	12	12	11	11	7	4	3	2
Labour (hrs/ha)	539	539	537	510	411	315	257	171
Seasonality of labour	188	188	190	193	200	217	225	225
Summer water (m3)	250867	250867	250866	243916	211796	178891	130701	87134
Water used (m3/ha)	1767	1767	1767	1776	1829	1907	2006	2006
Water marginal value (£/m3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N leaching (kg/ha)	28.4	28.1	20.9	14.8	12.2	9.5	5.6	3.7
P leaching (kg/ha)	6.1	6.0	4.5	3.3	2.8	2.3	0.9	0.6
Soil cover index	7.3	7.4	8.2	9.6	9.7	9.9	11.0	10.9
Pesticide Environmental Hazard Index	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0
Pesticide Active Ingredient Losses	0.132	0.132	0.125	0.119	0.116	0.113	0.099	0.066
Fert-N (kg/ha)	141.3	139.1	85.4	42.6	34.6	26.1	11.5	7.7
Fert-P (kg/ha)	60.5	59.9	44.9	32.7	28.0	22.7	9.2	6.2
Fert-K (kg/ha)	102.0	101.5	87.7	74.7	61.9	48.4	26.5	17.7
Energy used (MJ/ha)	20692	20701	21003	21482	21315	20945	18341	18341
Energy output (MJ/ha)	72946	72522	57754	36303	37385	37480	11305	11305
Energy balance (MJ/ha)	53470	53051	38455	17253	18574	19146	-4290	-4290

The net margin returns of potatoes are lower than those of raspberries, but the lower hazard risk means that the area of potatoes can be maintained at a higher level giving a greater net income. The high value of the strawberries gives very high returns to the pesticide hazard. Production of strawberries remains the most profitable enterprise up to the point where production can no longer exist under current practice. Figure 4.19

summarises the performance indicators for Church Farm under increasing constraints on the pesticide hazard risk. Impacts on the net margin are initially relatively small as the high value crops are retained in the cropping pattern and act to keep the net margin high. The loss of rainfed cropping options reduces the net margin per hectare by less than 10%. The net margin remains within 10% of the initial level until a hazard risk of 4 is introduced.

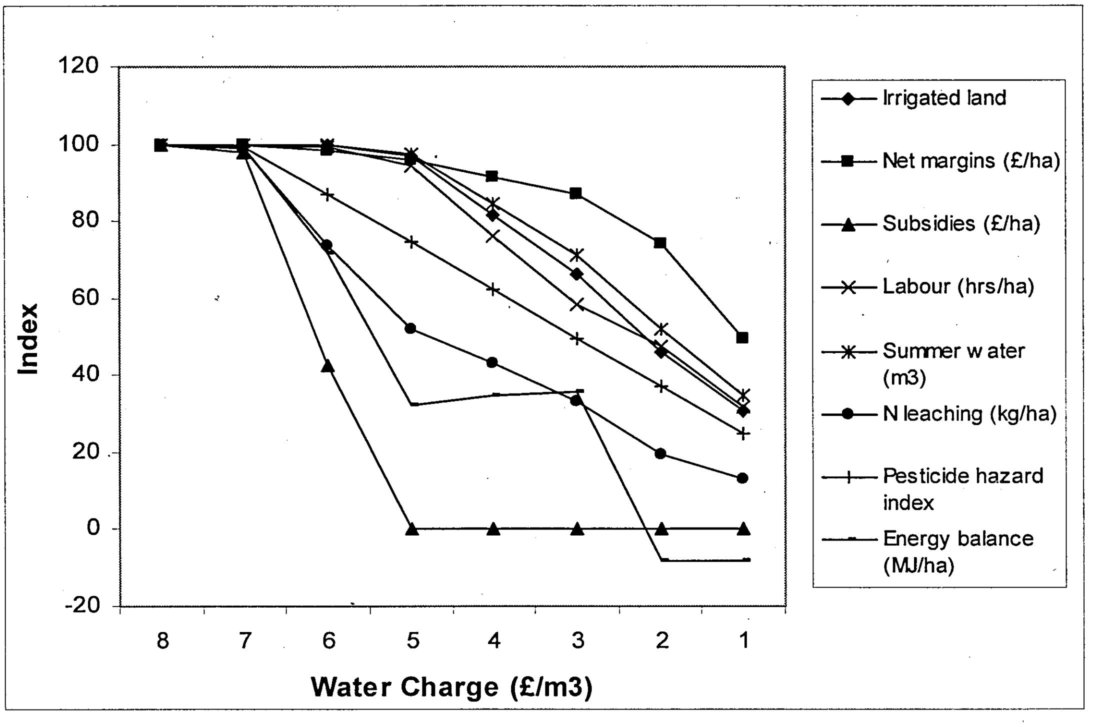

Figure 4.19: Indicators of farm performance Church Farm, pesticide hazard restrictions measure (average year).

At this point the reductions in the area of raspberries and potatoes lead to larger reductions in the net margin. Past this point increasing restrictions have a greater effect on the net margin as the high value fruit cropping is lost from the system. Labour requirements follow the same trend as the net margin indicating the importance of irrigation in the labour requirements. Rainfed cropping is lost from the system at a limit of 5, the level of support drops to 0 with the loss of the rainfed cropping. The fruit crops have lower energy balance values than either the rainfed cropping or potato cropping options, with the loss of rainfed cropping from the system the energy balance falls to 32% of the unconstrained level. The reduction in the area of raspberries in the cropping pattern stabilises the balance due to the presence of potatoes in the cropping pattern but falls again to -8% when cropping consists solely of strawberries. The nitrogen losses from the farm reduce with the reduction in cropped area. Little impact in the nitrogen losses are seen under a pesticide hazard restriction of 7. Constraints greater than this act to reduce the level of nitrogen lost from the system.

4.5.5 Church Farm Summary.

The analysis of Lakes Farm confirmed that the WFD measures identified can act to reduce the impact of irrigated agriculture on water resources by reducing abstraction and though limiting the diffuse pollution to water resources. In applying these restrictions to the farming system there are impacts upon the economic and social sustainability of the farm. Environmental indicators show improvements in the farm's performance under all measures, with abstraction license constraints and abstraction charge increases acting to reduce the irrigated area and the agrochemical constraints acting to reduce the total losses from the system. Associated with these restrictions however significant impacts upon the social and economic performance of the farm. The high revenue and labour employment are closely linked to the irrigated crops, as these are constrained and lost from the system there are considerable penalties in terms of the economic and social performance of the farm.

4.5 Coping Strategies.

An exploratory survey of irrigators showed that farmers would cope with restrictions on abstraction and/or higher abstraction charges by adopting strategies which would enable them to continue irrigating. Two strategies dominated the responses and farmers stated these were:

a) Changing licences from summer abstraction to winter abstraction and a storage reservoir.
b) Improving irrigation equipment (efficiency gains).

The ability of these coping strategies to enable the continuation of irrigated cropping has been investigated by substituting these methods into the case study systems in the form of winter storage reservoirs and the modification of irrigation methods to trickle irrigation.

4.5.1 Use of coping strategies on Lakes Farm.

Lakes Farm already uses winter abstraction with a storage reservoir to supply all of its irrigation water. Assessment of the ability of the coping strategies is limited to substituting trickle irrigation into the system in order to improve the efficiency of the water available. Fiugure 4.20 shows the impacts of switching to trickle irrigation and its ability to sustain irrigated farming if water becomes a limiting factor. This confirms that the use of trickle irrigation is viable within the system allowing the production of irrigated area to be sustained. The use of trickle irrigation reduces the use of water by 11% of the total available under the current license in the average year.

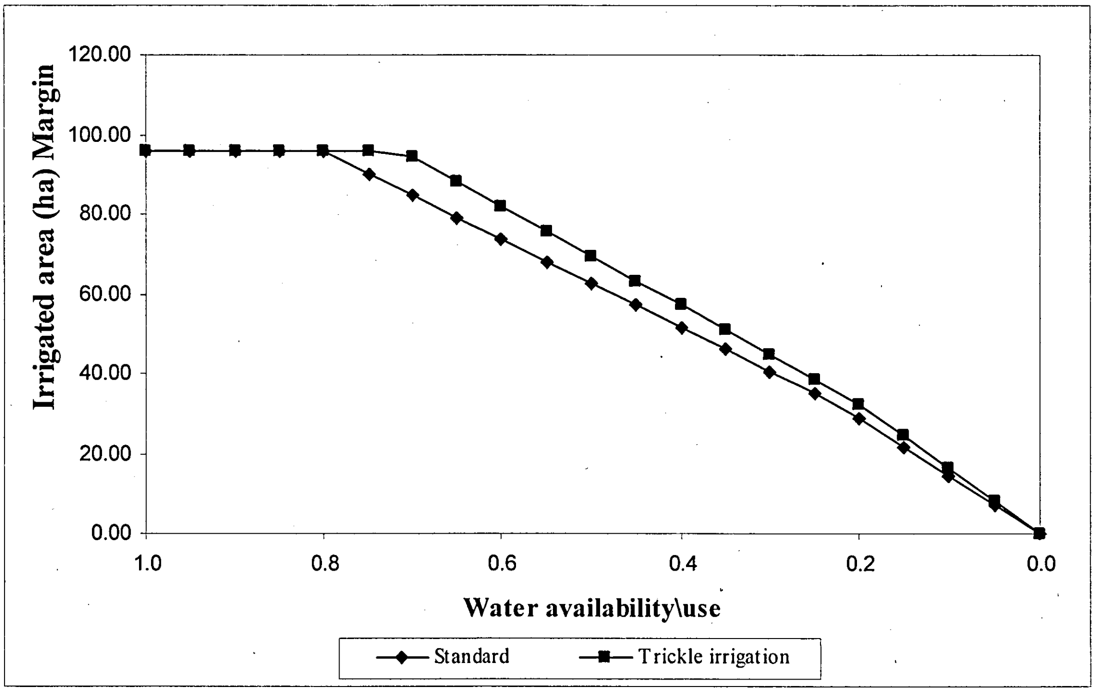

Figure 4.20: Area of irrigated land under limited water availability at Lakes Farm.

Figure 4.20 shows the potential for trickle irrigation to maintain the area of land which can be irrigated as licensed abstraction is reduced. The extra cost of trickle irrigation affects the net margin gained under unconstrained water availability. Although trickle irrigation is a viable option and enables all irrigated crops to be produced the loss of net margin means that it is an unattractive option where water supply is not limiting.

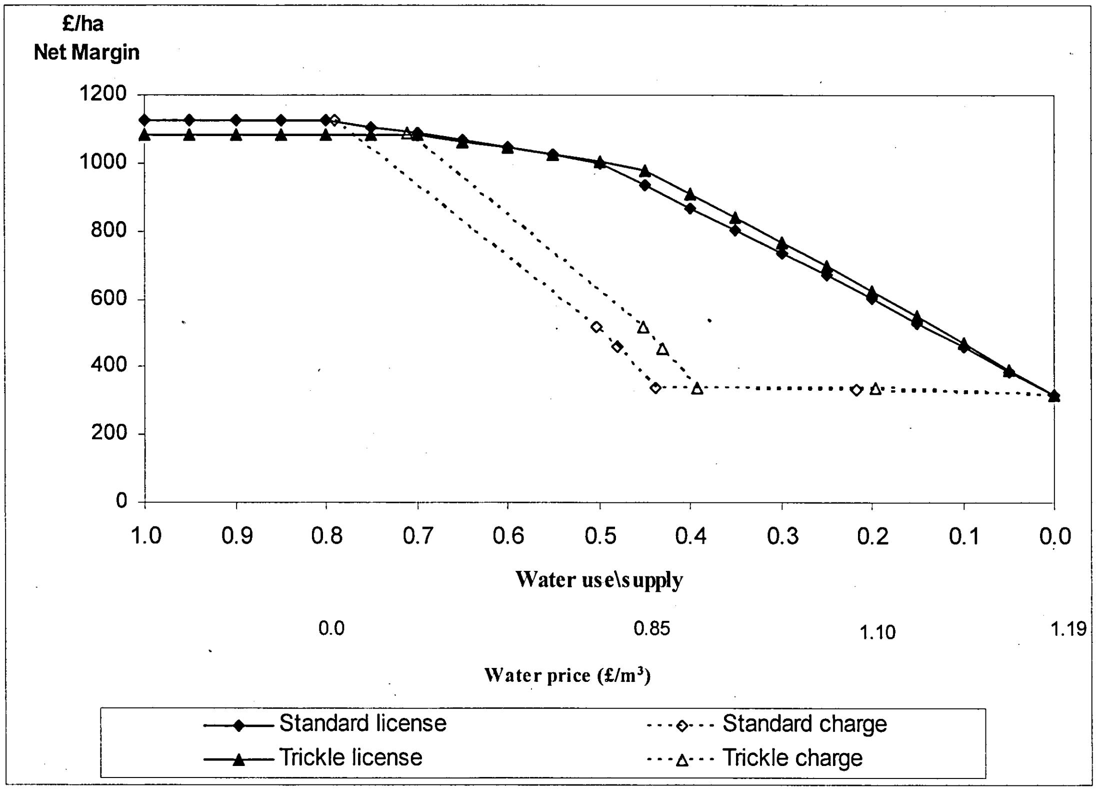

Figure 4.21: Ability of trickle irrigation to extend the benefits of irrigation farming.

Figure 4.21 shows the ability of trickle irrigation to maximise the returns to irrigation water under restricted availability. At a point of 50% reduction in water availability the benefits of water savings under trickle irrigation become great enough to sustain higher costs under the trickle system. If water availability was reduced to 50% of the current licensed volume then the introduction of trickle irrigation to this system would enable the net margin to be sustained at a higher level than the hose reel system. The lower use of water per hectare of cropped land compensates for the higher cost of irrigation application under the abstraction charge increases.

4.5.2 Use of coping strategies on Roudham Farm

Water abstracted during the winter period when supply is not limiting can be held in a storage reservoir for use in the summer months. Additional costs involved in the storage of winter water increase the overall base cost of irrigation by about £0.30/m^3. Winter charges are currently 10% of summer water rates per m^3. Current water supply to Roudham Farm is from direct abstraction from ground water resources. The introduction of the WFD is likely to restrict the availability of water on this farm. Figure 4.22 confirms the use of trickle irrigation as viable coping strategies enabling the retention of irrigation within the cropping system. Increases in the cost of water supply under the trickle (£0.47 trickle compared with £0.36 summer ground water using hose reel irrigation) forces sugar beet from the cropping pattern, confirming the marginal irrigation benefit to sugar beet production. A switch to trickle irrigation reduces the initial water requirements by 28% from the standard farm, increased efficiency enable greater returns per unit of water applied and reduces the overall water requirements. Figure 4.22 demonstrates the ability of trickle to sustain the area of irrigated land under reduced water availability, maximum irrigated cropping can be sustained up to the point where available water is reduced by 30-35%.

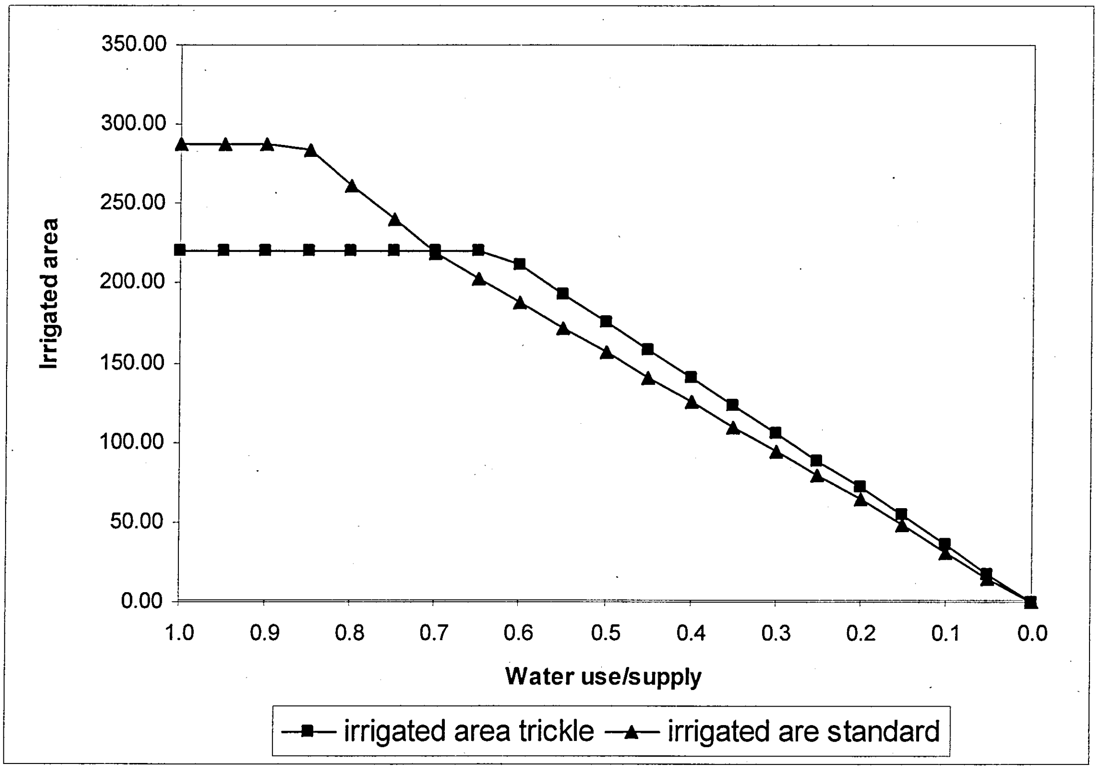

Figure 4.22: Irrigated areas under limited water availability at Roudham Farm.

The added costs of trickle irrigation reduces the net margin. Trickle allows larger areas of irrigation to be maintained in the system under greater restrictions in water availability. This demonstrates the water savings available using trickle on this system. Figure 4.23 displays the net margin benefits under the two coping strategies. The increased costs of trickle irrigation reduced the net margin in this system the benefit gained by maintaining larger areas of irrigation are not sufficient to improve the financial performance of the irrigated cropping. Under the current conditions switching to trickle irrigation does not give any benefits in terms of maintaining profit, this farm performs better by accepting reductions in income under overhead irrigation techniques.

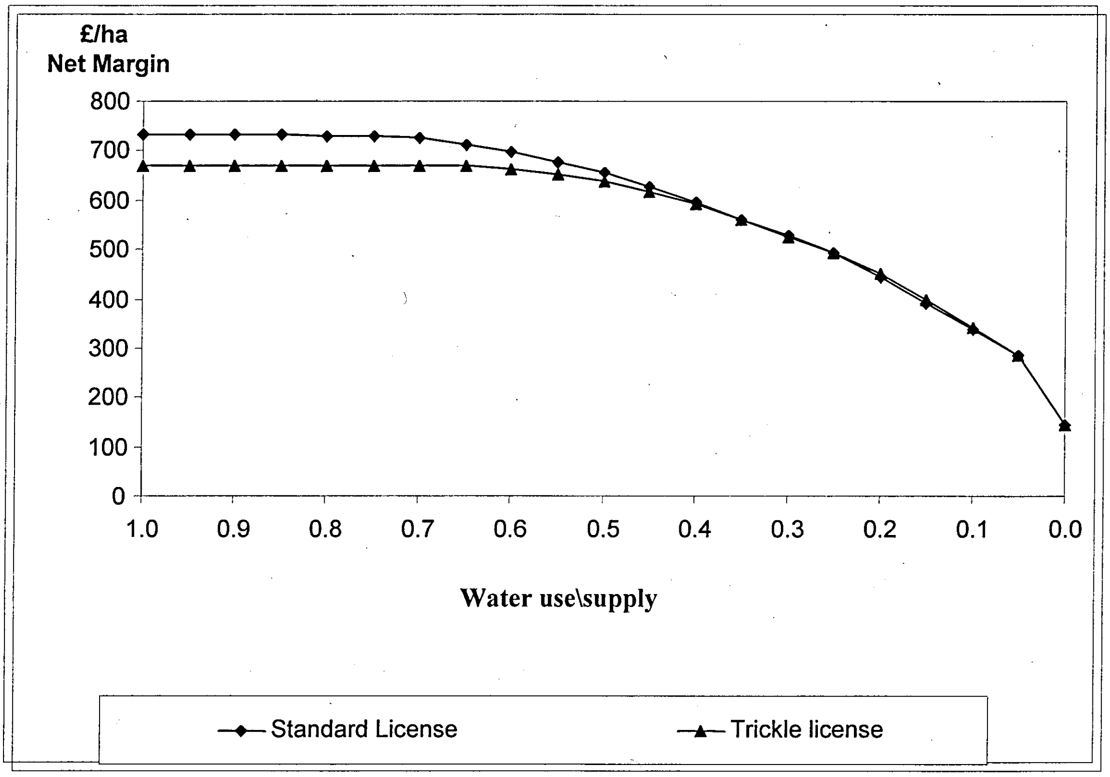

Figure 4.23: Ability of trickle irrigation to extend the benefits of irrigation farming under licence restrictions.

Under the charge increase mechanism trickle reduces the water applied. With increasing abstraction charges per m^3 of water the importance of reduced inputs becomes more important. The saving in water applied under trickle under this system brings about benefits in the net margin as water charge constrains the area of irrigated cropping. Figure 4.24 shows that the net margin can be maintained at a higher level. The use of trickle irrigation under this policy measure is a viable option on this system and will allow higher profits to be gained under trickle irrigation than hosereel systems.

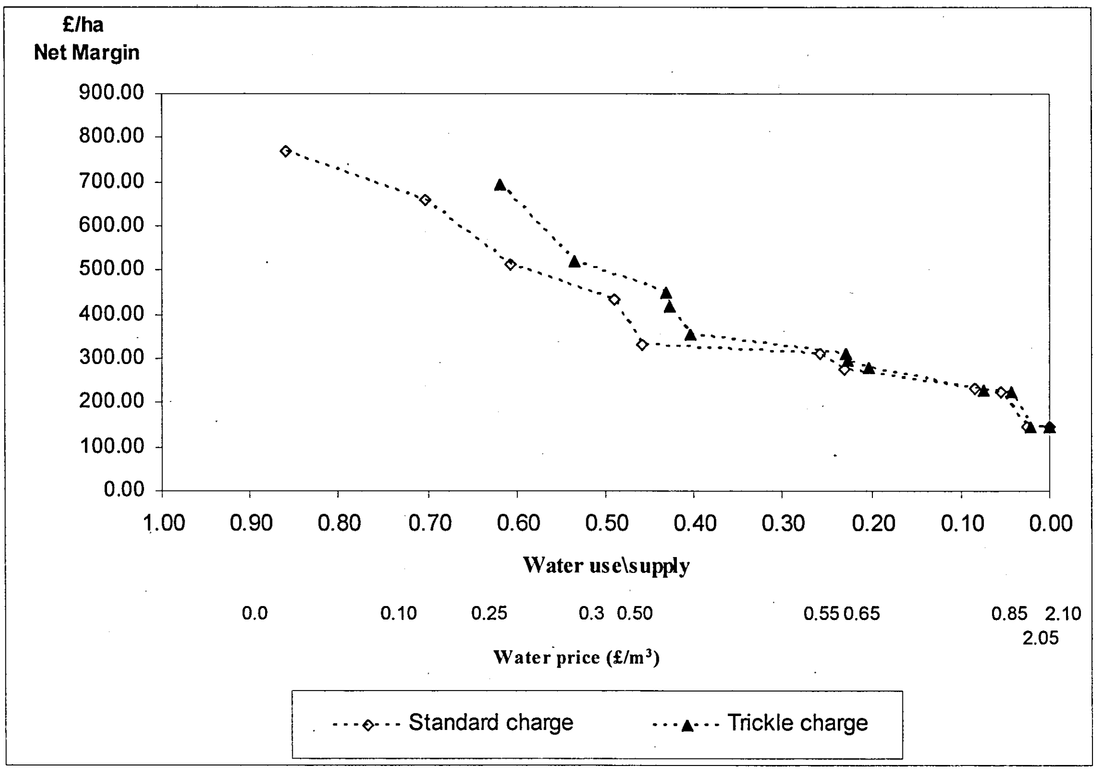

Figure 4.24: Ability of trickle irrigation to extend the benefits of irrigation farming under abstraction charge increases.

It is assumed that the use of winter water will not be affected by restrictions in licenses and will allow irrigation to continue with impacts upon the net margin as a result of increased water costs (£0.46m^3 winter water compared with £0.36m^3 for summer ground water).

4.5.3 Impact of winter abstraction on Church Farm.

Church Farm is dominated by the production of soft fruit; the specific requirements of these crops lend themselves to trickle irrigation. Fruit plants are cropped for several years in succession and the application of the trickle infrastructure at the time of establishment can save labour in future years. Strawberries are susceptible to quality problems associated with excess moisture at the surface, therefore the use of spray irrigation is unsuitable for strawberry production. Due to the specific requirements of soft fruits Church Farm has adopted trickle irrigation for all of the irrigated crops. Assessments of coping strategies have been undertaken looking at the ability of winter water to sustain irrigation on this case study. Table 4.19 confirms that using winter water allows the continuation of irrigation if availability of summer water is restricted or lost. Impacts on the system are limited to a reduction in the net margin and increased water abstraction. A switch to winter water reduces the net margin by 2.5% and 2.3% respectively for the winter water under license restrictions and winter water under the charge measure. Water costs are increased from £0.17/m^3 to £0.29/m^3 for the surface water and from £0.22/m^3 to £0.32m^3 for the ground water increasing the cost of water of irrigation and cutting the net margin fractionally. Under winter abstraction the total volume of water abstracted needs to be greater to meet the crop water demand in the summer months. Extra water needs to be abstracted to allow for losses through evaporation and seepage from the storage reservoir, the cost of this additional abstraction also reduces the net margin further.

Table 4.19: Summary of the impact of switch to winter water on Church Farm.

	Standard	Winter license	Winter charge
Net margins (£/ha)	5030.48	4901.99	4905.08
Value added (£/ha)	4907.68	4779.19	4782.28
Public revenue (£/ha)	27.86	3.10	0.00
Net margins reduction (£/ha)	0.00	128.49	125.40
Summer water (m3)	250867	278741	278741
Water used (m3/ha)	1767	1963	1963

4.4.4 Summary of coping strategies.

The analysis of the possible coping strategies likely to be used as identified in the survey confirmed that both the use of trickle irrigation to improve water use efficiency and switching to winter abstraction can both be used in order to maintain irrigation under license restrictions and abstraction charge increases. The ability of trickle to maintain profitable irrigation is confirmed under both the Lakes Farm and Roudham Farm case studies under abstraction charge increases. Under license restrictions however the increase in cost of water application make the use of trickle less profitable than hose reel irrigation on Roudham Farm. Lakes Farm confirms that the use of trickle could be justified under restrictions greater than 40% of the current licensed volume. The ability of trickle irrigation to maintain the profitability of irrigated cropping is sensitive to the increase in water costs and to the marginal value product of water. The use of winter water is confirmed as being a suitable coping strategy for maintaining irrigation.

4.6 Chapter Summary.

This chapter has presented the results and discussion of the three case study farm identified as being representative of the major irrigated systems in England. It includes descriptions of each of the case studies used in the project and describes the measures used to assess the impact of WFD. The results of the LP models used to examine the impact of WFD are presented in the chapter and discussion of these results is included within the analysis. Results of the LP models for the ability of coping strategies to sustain irrigation under reduced water availability are presented at the end of the chapter and suitability of these strategies is discussed.

The key finding from the analysis of the three case studies can be summarised as follows:-

- Reductions in water availability through license restrictions of abstraction charge increases directly affect the areas of irrigated cropping.
- Both measures are capable of bringing about reduced water use.
- The loss of irrigated cropping causes significant reductions in the economic and social performance of the farming systems.
- Reductions in the area of irrigated cropping leads to improvements in the environmental performance of the farms.
- The use of constraints on agrochemical losses leads to a dominance of high value irrigated crops.
- In order to maximise the profit of the system areas of rainfed crops are reduced and land is taken out of production to enable large areas of irrigated cropping to remain viable.

The results of these case studies will be used in the final chapter to examine the study objectives and to draw conclusions on the impact of WFD on irrigated agriculture and to identify areas for further research in the subject area.

CHAPTER FIVE. CONCLUSIONS AND RECOMMENDATIONS.

Following an overview of the aim and approach of the study, this chapter contains the conclusions and recommendations arising from the research.

5.1 Summary of the study.

This project was undertaken with the broad aim of identifying the links between irrigated agriculture, water resources and the WFD and to investigate the impacts of implementing the policy measures of the WFD on irrigated agriculture.

In order to structure the research, a number of objectives for the study were drawn up. These were:-

1. Identify the key areas of new policy that will have a direct impact on irrigation businesses with particular respect to WFD.

2. Identify major irrigation farming systems in England and Wales and select a number of suitable case study farms.

3. Determine the demand for water and the underlying characteristics and performance of irrigation farming systems.

4. Determine the impacts on the economic, social and environmental performance of irrigated agriculture under alternative policy measures (such as water pricing, or restrictions on abstraction) that might be used to achieve improved water resource management.

5. Identify whether these policy changes will affect the sustainability of the farming systems. Determine possible coping strategies that could be adopted by farmers under alternative regimes, this will include cropping options, irrigation technology and management systems.

Following the development of the aims and objectives a review of the WFD and irrigated agriculture was undertaken. This review confirmed the relevance of the study. A study 'framework was developed which enabled the evaluation of the impacts of WFD on the economic, social and environmental performance of the farms. The review of literature identified the links between irrigated agriculture and the WFD. The review identified possible measures that could be used to implement the changes required in order to meet the objectives of the WFD namely:-

a, Restrictions in licensed abstractions,
b, Increases in abstraction charges,
c, Restrictions in nitrogen losses,
d, Restrictions in pesticide hazards.

Cluster analysis of irrigated farming in England and Wales undertaken as part of the EU WADI project (Morris *et* al., 2004) identified three major irrigated farming systems; potatoes and sugar beet farming, field scale vegetables with potatoes and soft fruit farming. Case study farms were selected which represented each of these systems and were used to assess the impact of WFD. Linear programming models were used to develop farm plan models and included outputs of the economic, social and environmental performance of the case study farms. Primary data collected through farm interviews combined with research models were used to produce indicative farm planning models, which enabled the impacts of modified water and agrochemical regimes to be tested in accordance with the aims of the study. One of the aims of the study was the discussion of possible coping strategies which could be adopted by farmers to extend the use of irrigation under constricting WFD measures. The LP farm models were used in the testing of the viability of irrigation under two coping strategies (winter abstraction, and trickle) identified by farmers as being the most likely to be adopted under water restrictions or increased abstraction charges.

5.2 Conclusions.

Conclusion relating to the research topic covered in this study can be summarised as follows.

5.2.1 Objective 1: Links between irrigated agriculture and the WFD.

The study has shown that irrigated agriculture has an impact on the quality and quantity of water resources. The WFD addresses the issue of water quantity and quality issues and provides measures to facilitate the control of water resource use and pollution. The study confirms that the production of irrigated crops can have an impact on both the quantity and quality of water resources and confirms the link between WFD and irrigated agriculture. The results confirmed this through the use of indicators and research models predicting the levels of water use and diffuse pollution. Production of irrigated crops requires large volumes of water in order to meet the requirements of the cropping. The production of irrigated crops requires large amounts of agrochemical inputs, these large inputs are associated with high potential losses leading to diffuse pollution. Indicators of environmental performance outputted from the LP models confirmed the high water requirements of irrigated cropping and the high levels of agrochemical pollutions resulting from irrigated production.

5.2.2 Objective 2: Major irrigated farming systems in England.

The study used cluster analysis developed under the WADI project (Morris *et al.*, 2004) and a questionnaire sent to irrigated user groups to identify the major irrigated farming systems in England. The cluster analysis was used to identify the major irrigated crops produced and the mixes of these crops within individual farming system. The survey was used in support of the cluster analysis to confirm that real case farms matched the clusters identified through analysis of national data sets.

From this work the major irrigated farming systems were identified as potato and sugar beet farms, potato and field scale vegetable farms and fruit farms. Together the potato and sugar beet and the potato and field scale vegetable growers make up 88% of the total irrigated area. Fruit farmers account for only 4% of the total irrigated area but were found to be a very specialist group, and the inclusion of this cluster was therefore important within the objectives of the study.

Although the surveyed farming systems did not exactly match the clusters identified and large variation was found in the characteristics of irrigated farming systems, the patterns of cropping were found to be valid. The farms surveyed responded with general cropping patterns that were similar in overall characteristics to those identified with in the cluster analysis. The production of field scale vegetable was found to be more specialised than the cluster analysis suggested with farms concentrating on the production of larger areas of individual vegetable gaining specialist knowledge and investing in equipment and labour to produce high quality produce.

5.2.3 Objective 3: Demand for water and the underlying characteristics of irrigated farming system.

The demand for water on each of the farms was calculated through the LP model. Total demand is dependant upon the individual climatic, soil and crops characteristics. The total farm water demand has been calculated as a sum of the total water requirements of each of the crops within the system. Water demands for each crop were calculated using the WaSim model and predictions of water requirements in the average (median year of 20 years climate date) and dry (fifth driest year of 20 years climate data). Table 5.1 gives the underlying water requirements of the irrigated crops on the three case study farms.

Table 5.1: Water requirements of the three farms (m^3/ha)

Crop	Lakes Farm		Roudham Farm		Church Farm	
	average	dry	Average	dry	average	dry
Potatoes	1450	2050	1480	2140	1400	2160
Onions	1900	2610	1550	2010	-	-
Sugar beet	-	-	1060	1630	-	-
Carrots	-	-	1310	1840	-	-
Parsnips	-	-	1520	1610	-	-
Strawberries	-	-	-	-	1850	2328
Raspberries	-	-	-	-	1335	1780

Using the cluster analysis and irrigated farming survey three farm case studies were selected which could be used as templates for the production of farm plan models. All three farms were selected from the Anglian region which accounts for over 50% of the total irrigated area of England. In order to assess the impacts of the WFD policy measures on these case studies research models were use alongside primary data from farm interviews to compile the farm characteristics. Table 5.2 gives the overall characteristic of the three case study farms

Table 5.2: Characteristics of the three case study farms used in the study.

Characteristic	Lakes Farm	Roudham Farm	Church Farm
Location	Cardington, Bedfordshire	East Harling, Thetford, Norfolk	Tunstead, Norfolk
Farm Area	223 ha tenant, 32 ha rented	408 ha (292.5 ha owned, 115.5 ha rented on yearly rotation	282 ha
Command area	255 ha	408 ha	282 ha
Irrigated area (annual)	64.5 ha	291 ha (including 115.5 ha rented for potatoes and onions)	174.3 ha
Cropping pattern (options)	Rainfed: Winter Wheat, Spring Wheat, Peas. Irrigated: Onions, Maincrop potatoes.	Rainfed: Spring Wheat, Spring Barley, Hemp, Field beans. Irrigated: Potatoes, Sugar beet, Onions, Carrots and parsnips (contract linked).	Rainfed: Spring Barley, Winter Wheat, set-aside. Irrigated: Strawberries, Raspberries, Potatoes.
Cropping constraints	Rotational for onions and potatoes 1year in 6	Rotations set by potatoes 1year in 6. Vegetables same and sugar beet 1year in 3.	Rotations for fruit five year gap after strawberries and Raspberries. 1year in 4 for pots.
Water supply	290,049 m^3 Storage reservoir with surface water winter abstraction to top up reservoir (Elstow brook).	Four borehole licences total 575,400 m^3. Cessation clause 50% reduction when local SSSI has water shortages.	10 summer abstraction borehole licences 226,000 m^3. Additional water abstracted for irrigation under trickle exclusion.
Irrigation system	Buried main supply network covering whole farm. Hosereel system with 25mm 7 day interval	Buried main supply network connecting all sources, Mixture of hosereel and centre pivot.	Trickle irrigation for fruit with some spray irrigation for potatoes and sugar beet.
Labour and machinery	Regular labour + casual for harvest periods (potatoes). Contract work for combinable crops and all cultivations. Fully mechanised planting and harvest.	4 Regular labours, with some part time. Casual labour for potato harvest. Fully mechanised system, with latest technology (mechanised grading).	Regular and casual labour employed. Fully mechanised where possible.

5.2.4 Objective 4: Impacts of alternative policy measures on the economic, social and environmental performance of irrigated agriculture.

The introduction on the WFD will promote good water quality status through the use of regulatory, economic and other measures. The directive states that a number of "basic measures" be required in the production of River Basin Management Plans, a number of these will directly affect irrigated agriculture and include:-

a. Abstraction and impoundment controls.
b. Cost recovery for water services.
c. Controlling the impacts of water pollutants.

The requirements for WFD basic measures to include abstraction and impoundment controls will require modifications to the basic legislation, requiring that all abstraction for irrigation be included (inclusion of trickle irrigation). Licenses will be required to be time limited and renewed at intervals with justification against economic need. The introduction of Catchment Abstraction Management Strategies will facilitate this review process under English law. Where environmental water quality is at risk, limits will be placed on direct abstraction during the summer months. The analysis of this measure shows the reductions in water availability will have direct impacts on the areas of irrigated cropping. Associated with this, farm incomes will fall. The level of impact is related to the reduction in water availability with any reductions in irrigated area causing a switch to rainfed cropping. Water use concentrates on the production of the crops with the highest returns to water, which can be as high as £9.92/m^3 for strawberries but is generally in the region of £0.62/m^3-£2.00/m^3 for potatoes and field scale vegetable on the case study farms.

Full cost recovery will include the costs of environmental protection and mitigation. The analysis of water charge increases showed that all three irrigated systems tested using the LP models demonstrated price inelastic demand for water. Increases in the charge for abstraction would need to be in the region of £0.10/m^3 under the Roudham Farm case before production of sugar beet ceased, a significant increase from the current cost of £0.031/m^3 for summer water in the Anglian region. Increases in the order of 30-40% on currents levels will not act to reduce abstraction of water for use in irrigation under the case studies involved with this project. The returns to water reflect the willingness of the farms to pay for water, the range being from £0.10/m^3 for the irrigation of sugar beet in the average year on Roudham Farm to £9.95/m^3 for the irrigation of strawberries at Church Farm in the average year. The use of abstraction charges seems unlikely to be used as the regulating measure in England. A strong willingness to pay over and above the current charges to secure supplies of water has been identified through the analysis of this measure. In order to secure significant reductions in water use the increases in the charge for water abstraction would have to be considerable and would have very significant impacts on the income of farmers.

Controls on diffuse pollution to waters have been assessed through setting limits on whole farm average losses and risks of environmental hazard for the nitrogen and pesticide use. Constraining diffuse pollution affects all farming practice where the use of agrochemicals is involved. Irrigated farming is particularly susceptible to these restrictions due to the high inputs of both fertilisers and pesticides in the production of irrigated crops in comparison with the adjacent rainfed cropping. Under constrained losses of agrochemicals, farmers respond by reducing the land area cropped. Irrigation remains the dominant cropping system due to high returns per unit of agrochemical loss associated with their production. The loss of cropped area again impacts upon the farm income with the most dramatic reductions coming as the areas of irrigated land are reduced. The analysis showed that maintaining the income of the farming systems favoured concentrating the production of crops with the highest returns to the agrochemical use and associated loss. Some research suggests that the production of high risk crops (such as irrigated cropping) should be restricted. This research suggests that controls on the environmental impact of the land area should be treated as a land unit. Limiting agrochemical losses in this way allows the production of high value, high risk crops without exceeding the environmental limits set for the area. The total environmental impact will remain the same for the area taking land out of production in order to maximise the returns to land and agrochemical loss. Farmers may seek to reduce the inputs of agrochemicals to the lower value crops, accepting reductions in the yields and net margins as a result but enabling the production of crops to continue with in the boundaries of the agrochemical limits.

Under all four measures the imposition of controls on the water used and pollution hazard, had the ultimate impact of reducing the area of irrigated land. The economic and social performances of all farms investigated in the product were closely linked with the presence of irrigated crops. High returns and high labour requirements of the irrigated cropping sustained net margins well in excess of rainfed cropping options. As the viability of irrigated cropping is reduced, the impacts on the economic and social sustainability of the farms are severe. The reliance of government support increases with two of the three farms having negative added value under a purely rainfed cropping system. The environmental performance of the farms generally improved with reductions in the irrigated areas. Water use was reduced with the requirement of the assessments, pollution from diffuse sources also declined under both the water management measures and the agrochemical restriction measures.

The WFD measures are likely to impose increasing controls to meet water resource and quality objectives, these measures will have an impact on irrigated agriculture. Economic and social indicators suggest that reductions in the irrigated area will have a negative impact on the economic and social performance of the farming systems with significant reductions in the farm income as well as reductions in labour requirements, both in terms of regular skilled and casual unskilled labour.

5.2.5 Objective 5: Use of coping strategies to extend the use of irrigation under measures to reduce water use.

The implementation of the WFD may encourage the adoption of strategies by farmers that will allow them to sustain irrigation without excessive reductions in net margins such as use of winter abstraction and storage reservoirs, and switching to trickle irrigation to improve water use efficiency.

The use of winter abstraction can allow the supply of full water requirements without the worry of restrictions on summer water abstraction. A slight increase in the overall water required is seen due to losses from the storage systems. The use of winter storage was confirmed under all of the case study farms with Lakes Farm having adopted this strategy in the 1970s in response to limited water availability in the summer months. Some reductions in the net margin are seen as a result of the use of winter water due to the costs associated with the provision and maintenance of the reservoir and the extra cost of double pumping the water. All crops remained viable in the three case studies with the exception of sugar beet which was confirmed as having a marginal net benefit from irrigation. Investment in winter abstraction and storage has been confirmed as a viable coping strategy which could be used on all of the case studies involved.

The second coping strategy which has been assessed is the replacement of hosereel irrigation with trickle irrigation, which can offer up to 10% improved water use efficiency under some circumstances. The specific crop characteristics on Church Farm lend themselves to the use of trickle irrigation. This method is therefore already used on this case study for reasons other than water use efficiency. The switching of hose reel to trickle irrigation has been assessed under the two remaining case studies. The models confirmed that irrigation under trickle was a viable option for both systems. Initial unconstrained production under trickle had identical cropping patterns under the Lakes Farm case study. The slight increase in application costs negated the benefit of irrigation on sugar beet on the Roudham Farm case study and this was lost from the initial cropping pattern.

Reductions in the net margins as a result of increased cost of water application offset any benefits of reduced water consumption. The use of trickle is therefore not a reasonable option under unrestricted water use. Figure 5.1 shows the net margins under restricted water availability/use under the two measures for Lakes Farm and Roudham Farm. Under both cases studied the use of trickle irrigation under increased abstraction charges allows the continuation of irrigation at the same levels of abstraction but with improved net margins i.e. trickle costs are compensated by savings in the abstraction charge costs. This indicates that trickle is a viable technique in maximising the farm income under increased abstraction charges. Under the license restriction measure the use of trickle irrigation does not show any benefits in sustaining the income of Roudham Farm. Reductions in the net margin as a result of increased costs are not compensated for by the reduced water requirements, the use of trickle remains less financially productive than hose reel irrigation across the entire range of water restrictions. The use of trickle on the Lakes Farm does not initially give any benefit in terms of the farm income. Under this case study however as the water availability reduces to about 60% of the initial licensed volume, the use of trickle enables a higher income which confirms that under the specific conditions of this farm trickle irrigation could be used to maximise the returns under limiting water availability.

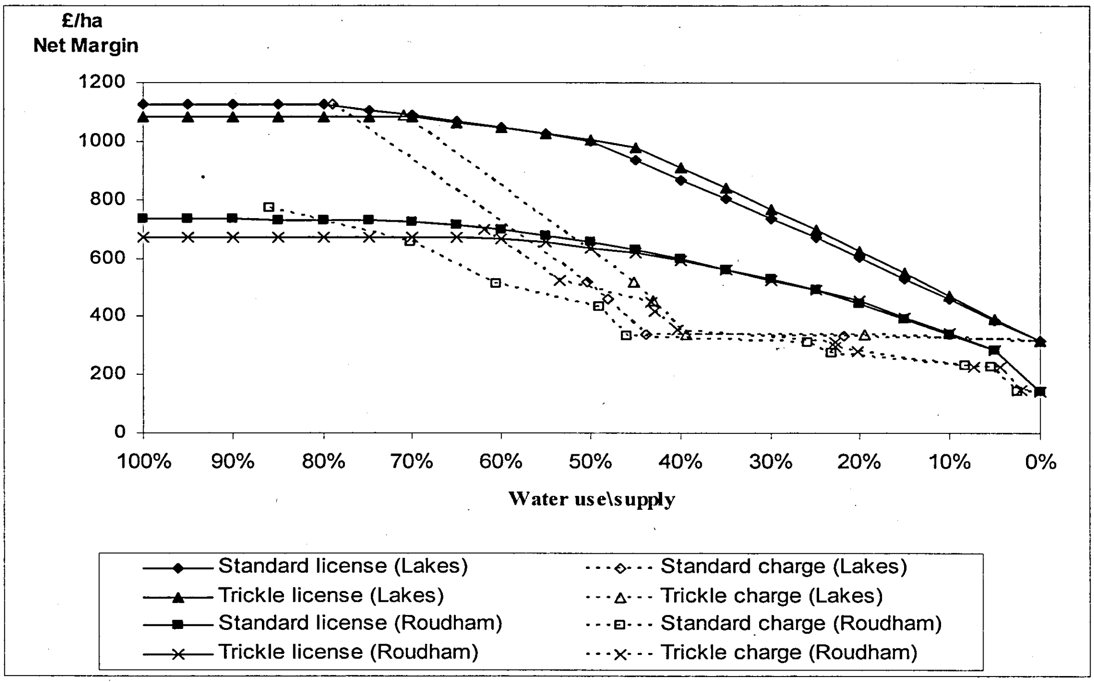

Figure 5.1: Comparison of trickle and standard irrigation benefits on Lakes and Roudham Farms.

5.3 Recommendations.

Following the conclusions this section presents the recommendations emerging from the study:

The study framework developed to examine the impact of WFD on irrigated agriculture and the viability of coping strategies which could be adopted to extend the use of irrigation was confirmed to be adequate for this study and offers potential for future research.

The work on coping strategies was limited to strategies that maintain irrigation under water limitation measures. Further research needs to look at the possibility of more varied coping strategies such as deficit irrigation and to investigate the links between water demand/supply yield and quality, and the impacts that these factors will have on prices and net revenues.

The work on agrochemical use and restrictions is limited to simple output restrictions and the impact of restrictions assuming that no reductions to inputs are made. Research needs to be undertaken which examines the reduction in losses through alternative measures such as reduced inputs, improvements in technology and better management practices. Where reductions in the levels of inputs are examined the interactions of crop loss and crop response need to be examined to take into account changes in net revenue as a result of reduced cost and impact upon crop quality and yields.

Further research could explore some of the limitations of the LP model used in this study. The number of decision variables available within the model was restricted to the current farm characteristics. A larger more integrated model allowing the selection of a greater variety of options would allow a more integrated approach. Options such as the inclusion of the coping strategies, varied levels of agrochemical inputs and deficit irrigation would enable the optimum farm cropping pattern to be selected while including techniques that reduce water use and water pollution. Use of these options will have an impact on farm revenue due to reductions in yield or quality of produce but may allow the overall margin to be retained at a higher level due to the ability to keep larger areas in high value production. The assessment of agrochemical losses led to the removal of land from production. The inclusion of agri-environmental options within the matrix alongside rainfed and irrigated cropping options would allow the LP to determine the optimum mix of agricultural and environmental practices.

5.4 Closing Statement.

This study has identified the links between irrigated agriculture, water resources and the WFD and the framework enabled the assessment of measures highlighted in the WFD on irrigated agriculture. The viability of coping strategies to manage limited water supplies under possible regulation was confirmed. As a consequence the study has been able to identify areas which require future research.

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Appendix 1

Example of the questionnaire sent to irrigation farmers to validate the cluster analysis

Irrigated Farming Systems

Please answer the following questions with respect to the farm which is run as a business unit and on which irrigation is practised. If there is more than one farm business unit with irrigation, please provide information for each unit separately.

1. Baseline Farm Data

Total Farm Area (ha)	
Total Irrigated Area (ha)	
Total number of full time staff	

2. What is the total command area (i.e. total area which **can** be supplied with irrigation water)

3. What are the main soil types present on the farm?
   a) main irrigated soil type.
   b) main rainfed soil type.

a) main irrigated soil type.	
b) main rainfed soil type.	

4. Cropping pattern on the farm in a typical year.

Crop type (including setaside)	Cropped area (ha)	Is the crop irrigated (please tick if yes)	Irrigated area (ha)

5. What is your total licensed water quantity (m^3)?

6. What sources of water for irrigation do you have?

Source	Yes/No	% of total quantity
Direct from surface water (e.g.river or stream)		
Direct from ground water (e.g. well, bore hole, spring)		
Indirect from surface water (e.g. via on-farm reservoir)		
Indirect from groundwater (e.g. via on farm reservoir)		
Reuse of water from other purposes (e.g. vegetable washing		
Direct from mains supply		

Other Please Specify		
Total		100

7. Do you have a reservoir, yes/no If yes:

Type of storage	Total capacity (m^3)
Unlined or clay-lined reservoirs	
Reservoirs with synthetic lining (e.g. butyl rubber)	

8. What type of infield irrigation system do you use?

Equipment	% of irrigated area
Hose reels (boom)	
Hose reels (raingun)	
Sprinklers and spray lines	
Trickle	
Centre Pivot	
Linear Move	
Total	100%

9. a) In what circumstances do you regard the availability of water for irrigation to be a major constraint? Please tick the most appropriate box.

Water supply is not an issue	
In some years	
In the dry years	
In most years	

b) If water availability is an issue, in what ways does it affect your farming? Please tick.

Reduction in the irrigated area	
Inability to meet quality guarantees	
Inability to secure contracts	
Other	

c) What action have you taken to reduce the impact of limited water availability for irrigation and what is your most likely next move? Please mark T or N.

Water storage	
Modified cropping pattern	
Substitution of different crop varieties	
Water harvesting	
Public mains	
License trading	
Application for new license	
Improvements in technology (e.g. more efficient application)	
Improvements in scheduling	
Other	

Appendix 2

Example of the command file for the LP model as used on all farms. Details of the LP matrix files used are given on the attached cd rom.

```
model Lakes Farm
uses "mmodbc", "mmxprs"

parameters
CSTR='DSN=MyExcel; DBQ=U:\@ Thesis folder\Findlay\Findlay matrix
average.xls'

end-parameters

declarations
Crop: set of string
end-declarations

SQLconnect(CSTR)
SQLexecute("select Crop from Crops",Crop)
finalise(Crop)



declarations
MaxAvailable,
Constrained    ,
SUBSIDIES   ,
VARCOST     ,
GRMRGN      ,
LANDOWN     ,
LANDRENT    ,
IRRIGATION,
SAS    ,
WWHRES      ,
POTROT      ,
SUGROT      ,
ONIROT      ,
PARROT      ,
CARROT      ,
FERTN       ,
FERTP       ,
FERTK       ,
REGLABJAN,
REGLABFEB,
REGLABMAR        ,
REGLABAPR,
REGLABMAY        ,
REGLABJUN,
REGLABJUL ,
REGLABAUG        ,
REGLABSEP ,
REGLABOCT        ,
REGLABNOV        ,
```

```
REGLABDEC        ,
MECVAR    ,
MECFIX    ,
WATERDEM ,
WATDELV   ,
SURGRNPROP       ,
NLEACH    ,
PLEACH    ,
PESTLEACH,
ENERGYUSED       ,
ENERGYOUTPUT    ,
ENERGYBALANCE ,
SOILCOVER ,
PESTLCHINDEX : array (Crop) of real
OwnLand: real
RentedLand:real
MaxIrrigation: real
MaxWater: real
SummerPrice: real
WinterPrice: real
MaxPesticide: real
MaxNitrogen: real
Z: real
Answer: array(Crop) of real
end-declarations

SQLexecute("select Crop,    MaxAvailable from Crops",   MaxAvailable )
SQLexecute("select Crop,    Constrained         from Crops",   Constrained )
SQLexecute("select Crop,    SUBSIDIES           from Crops",   SUBSIDIES   )
SQLexecute("select Crop,    VARCOST                   from Crops",
        VARCOST    )
SQLexecute("select Crop,    GRMRGN                    from Crops",   GRMRGN
        )
SQLexecute("select Crop,    LANDOWN                   from Crops",
        LANDOWN  )
SQLexecute("select Crop,    LANDRENT            from Crops",   LANDRENT  )
SQLexecute("select Crop,    IRRIGATION          from Crops",   IRRIGATION )
SQLexecute("select Crop,    SAS                       from Crops",   SAS    )
SQLexecute("select Crop,    WWHRES                    from Crops",   WWHRES
        )
SQLexecute("select Crop,    POTROT                    from Crops",   POTROT
        )
SQLexecute("select Crop,    SUGROT                    from Crops",   SUGROT
        )
SQLexecute("select Crop,    ONIROT                    from Crops",   ONIROT
        )
SQLexecute("select Crop,    PARROT                    from Crops",   PARROT
        )
```

```
SQLexecute("select Crop,    CARROT            from Crops",   CARROT
        )
SQLexecute("select Crop,    FERTN             from Crops",   FERTN
        )
SQLexecute("select Crop,    FERTP             from Crops",   FERTP
        )
SQLexecute("select Crop,    FERTK             from Crops",   FERTK
        )
SQLexecute("select Crop,    REGLABJAN      from Crops",   REGLABJAN )
SQLexecute("select Crop,    REGLABFEB      from Crops",   REGLABFEB )
SQLexecute("select Crop,    REGLABMAR         from Crops",
        REGLABMAR           )
SQLexecute("select Crop,    REGLABAPR      from Crops",   REGLABAPR)
SQLexecute("select Crop,    REGLABMAY         from Crops",
        REGLABMAY           )
SQLexecute("select Crop,    REGLABJUN      from Crops",   REGLABJUN )
SQLexecute("select Crop,    REGLABJUL      from Crops",   REGLABJUL )
SQLexecute("select Crop,    REGLABAUG         from Crops",
        REGLABAUG           )
SQLexecute("select Crop,    REGLABSEP      from Crops",   REGLABSEP )
SQLexecute("select Crop,    REGLABOCT         from Crops",
        REGLABOCT           )
SQLexecute("select Crop,    REGLABNOV         from Crops",
        REGLABNOV           )
SQLexecute("select Crop,    REGLABDEC         from Crops",
        REGLABDEC           )
SQLexecute("select Crop,    MECVAR            from Crops",   MECVAR
        )
SQLexecute("select Crop,    MECFIX            from Crops",   MECFIX
        )
SQLexecute("select Crop,    WATERDEM       from Crops",   WATERDEM )
SQLexecute("select Crop,    WATDELV           from Crops",
        WATDELV    )
SQLexecute("select Crop,    SURGRNPROP        from Crops",
        SURGRNPROP          )
SQLexecute("select Crop,    NLEACH            from Crops",   NLEACH
        )
SQLexecute("select Crop,    PLEACH            from Crops",   PLEACH
        )
SQLexecute("select Crop,    PESTLEACH      from Crops",   PESTLEACH )
SQLexecute("select Crop,    ENERGYUSED        from Crops",
        ENERGYUSED          )
SQLexecute("select Crop,    ENERGYOUTPUT   from Crops",
        ENERGYOUTPUT        )
SQLexecute("select Crop,    ENERGYBALANCE from Crops",
        ENERGYBALANCE )
SQLexecute("select Crop,    SOILCOVER      from Crops",   SOILCOVER )
SQLexecute("select Crop,    PESTLCHINDEX   from Crops",   PESTLCHINDEX
        )
```

```
OwnLand:=             SQLreadreal("select OwnLand from OwnLand")
RentedLand:= SQLreadreal("select RentedLand from RentedLand")
MaxIrrigation:= SQLreadreal("select MaxIrrigation from MaxIrrigation")
MaxWater:=            SQLreadreal("select MaxWater from MaxWater")
WinterPrice:= SQLreadreal("select WinterPrice from WinterPrice")
SummerPrice:=         SQLreadreal("select SummerPrice from SummerPrice")
MaxPesticide:=        SQLreadreal("select MaxPesticide from MaxPesticide")
MaxNitrogen:=         SQLreadreal("select MaxNitrogen from MaxNitrogen")
SQLdisconnect

declarations
x: array (Crop) of  mpvar
end-declarations


!OBBJECTIVE FUNCTION: TotalGRMRGN
TotalGRMRGN:=     sum(i in Crop)x(i)*GRMRGN (i)


!General constraints
forall(i in Crop) x(i) * Constrained(i) <= MaxAvailable(i)


!LAND CONSTRAINTS
LandOwned:= sum(i in Crop) x(i)*LANDOWN(i) <= OwnLand
LandRented:= x("OniRNT")
TotalLand:= LandOwned + LandRented

!CROP ROTATIONS AND SET ASIDE
TotalSAS:=            sum(i in Crop) x(i)*SAS(i)=0
TotalWWHRES:=         sum(i in Crop) x(i)*WWHRES(i)>=0
TotalPOTROT:=         sum(i in Crop) x(i)*POTROT(i)>=0
TotalONIROT:=         sum(i in Crop) x(i)*ONIROT(i)>=0
TotalRented:=         sum(i in Crop) x(i)*LANDRENT(i) <=0
!OSRRatio:= x("ROSR") = x("RFBN")

!IRRIGATION
TotalIRRIGATION:= sum(i in Crop) x(i)*IRRIGATION(i)<= MaxIrrigation
TotalWATERDEM:=          sum(i in Crop) x(i)*WATERDEM(i)=0
TotalWATDELV:=           sum(i in Crop) x(i)*WATDELV(i)=0
SURGRNPROPOR:=           sum(i in Crop) x(i)*SURGRNPROP(i) >=0
TotalWater:=          x("SURWIN") <= MaxWater


! SUBSIDIES
TotalSUBSIDIES       := sum(i in Crop)x(i)*SUBSIDIES(i)

!ADDED VALUE
```

```
ADDEDVALUE := TotalGRMRGN - TotalSUBSIDIES

!Variable Costs
TotVARCOST:= sum(i in Crop)x(i)*VARCOST(i)

!LABOUR DEMAND AND COST
RegLABJAN:=    sum(i in Crop)x(i)*   REGLABJAN(i) <=0
RegLABFEB:=    sum(i in Crop)x(i)*   REGLABFEB(i) <=0
RegLABMAR:=    sum(i in Crop)x(i)*   REGLABMAR(i) <=0
RegLABAPR:=    sum(i in Crop)x(i)*   REGLABAPR(i) <=0
RegLABMAY:=    sum(i in Crop)x(i)*   REGLABMAY(i) <=0
RegLABJUN:=    sum(i in Crop)x(i)*   REGLABJUN(i) <=0
RegLABJUL:=    sum(i in Crop)x(i)*   REGLABJUL(i) <=0
RegLABAUG:=    sum(i in Crop)x(i)*   REGLABAUG(i) <=0
RegLABSEP:=    sum(i in Crop)x(i)*   REGLABSEP(i) <=0
RegLABOCT:=    sum(i in Crop)x(i)*   REGLABOCT(i) <=0
RegLABNOV:=    sum(i in Crop)x(i)*   REGLABNOV(i) <=0
RegLABDEC:=    sum(i in Crop)x(i)*   REGLABDEC(i) <=0

LABJAN:=   sum(i in Crop)x(i)*   REGLABJAN(i) -
x("REGLAB")*REGLABJAN("REGLAB")
LABFEB:=   sum(i in Crop)x(i)*   REGLABFEB(i) -
x("REGLAB")*REGLABFEB("REGLAB")
LABMAR:=   sum(i in Crop)x(i)*   REGLABMAR(i) -
x("REGLAB")*REGLABMAR("REGLAB")! + x("CasLabMar")
LABAPR:=   sum(i in Crop)x(i)*   REGLABAPR(i) -
x("REGLAB")*REGLABAPR("REGLAB")! + x("CasLabApr")
LABMAY:=   sum(i in Crop)x(i)*   REGLABMAY(i) -
x("REGLAB")*REGLABMAY("REGLAB")! + x("CasLabMay")
LABJUN:=   sum(i in Crop)x(i)*   REGLABJUN(i) -
x("REGLAB")*REGLABJUN("REGLAB")! + x("CasLabJun")
LABJUL:=   sum(i in Crop)x(i)*   REGLABJUL(i) -
x("REGLAB")*REGLABJUL("REGLAB")! + x("CasLabJul")
LABAUG:=   sum(i in Crop)x(i)*   REGLABAUG(i) -
x("REGLAB")*REGLABAUG("REGLAB") + x("CasLabAug")
LABSEP:=   sum(i in Crop)x(i)*   REGLABSEP(i) -
x("REGLAB")*REGLABSEP("REGLAB") + x("CasLabSep")
LABOCT:=   sum(i in Crop)x(i)*   REGLABOCT(i) -
x("REGLAB")*REGLABOCT("REGLAB") + x("CasLabOct")
LABNOV:=   sum(i in Crop)x(i)*   REGLABNOV(i) -
x("REGLAB")*REGLABNOV("REGLAB") + x("CasLabNov")
LABDEC:=   sum(i in Crop)x(i)*   REGLABDEC(i) -
x("REGLAB")*REGLABDEC("REGLAB")


TotalLabour:= LABJAN + LABFEB + LABMAR + LABAPR +
        LABMAY + LABJUN + LABJUL + LABAUG +
        LABSEP + LABOCT + LABNOV + LABDEC
```

```
!AGROCHEMICALS APPLICATIONS AND LEACHING
TotalFERTN:=        sum(i in Crop)x(i)*    FERTN(i)
TotalFERTK:=        sum(i in Crop)x(i)*    FERTK(i)
TotalFERTP:=sum(i in Crop)x(i)*    FERTP(i)
TotalPESTLCHINDEX:=     sum(i in Crop)(x(i)* PESTLCHINDEX(i))/(OwnLand +
RentedLand)<=MaxPesticide
TotalPESTLEACH:= sum(i in Crop)(x(i)* PESTLEACH(i))/(OwnLand +
RentedLand)
TotalNLEACH:=       sum(i in Crop)(x(i)* NLEACH(i))/(OwnLand +
RentedLand)<=MaxNitrogen
TotalPLEACH:=       sum(i in Crop)(x(i)* PLEACH(i))/(OwnLand + RentedLand)
!Dave Freeman: added constraint for pesticideleaching index (env. hazard index)
index calculates a weighted average and can be constrained to an index.
!also added a active ingridient loss per/ha for farm again calculated with a weighted
average.

!ENERGY USE
TotalENERGYUSED:=             sum(i in Crop)x(i)*    ENERGYUSED(i)
TotalENERGYOUTPUT:=           sum(i in Crop)x(i)*    ENERGYOUTPUT(i)
TotalENERGYBALANCE:= sum(i in Crop)x(i)*    ENERGYBALANCE(i)

!Soil Cover
TotalSOILINDEX:=  sum(i in Crop)x(i)*    SOILCOVER(i)

!MACHINERY COSTS
TotalMECVAR         := sum(i in Crop)x(i)*MECVAR(i) =0
TotalMECFIX:= sum(i in Crop)x(i)*MECFIX(i) =0

!OBBJECTIVE FUNCTION: Profit seeking behaviour
maximize(TotalGRMRGN)


!SOLUTION TO SCREEN
forall(i in Crop) writeln("",i," = ",      getsol (x(i)))
writeln("LABJAN is ", getact(LABJAN))
writeln("LABFEB is ", getact(LABFEB))
writeln("LABMAR is ", getact(LABMAR))
writeln("LABAPR is ", getact(LABAPR))
writeln("LABMAY is ", getact(LABMAY))
writeln("LABJUN is ", getact(LABJUN))
writeln("LABJUL is ", getact(LABJUL))
writeln("LABAUG is ", getact(LABAUG))
writeln("LABSEP is ", getact(LABSEP))
writeln("LABOCT is ", getact(LABOCT))
writeln("LABNOV is ", getact(LABNOV))
writeln("LABDEC is ", getact(LABDEC))
writeln("TotalLabour is ", getact(TotalLabour))
writeln("Landused is ",         getact(TotalLand))
writeln("WaterUsed is ",        getact(TotalWater))
writeln("GrossMargin is ",      getact(TotalGRMRGN))
```

```
writeln("SUBSIDIES is ",     getact(TotalSUBSIDIES))
writeln("VALUEADDED is ",         getact(ADDEDVALUE))
writeln("VariableCosts is ",    getact(TotVARCOST))
writeln("EnergyUSED is ",    getact(TotalENERGYUSED))
writeln("EnergyOUTPUT is ",          getact(TotalENERGYOUTPUT))
writeln("EnergyBALANCE is ",       getact(TotalENERGYBALANCE))
writeln("FERTN is ",  getact(TotalFERTN))
writeln("FERTK is ",  getact(TotalFERTK))
writeln("FERTP is ",  getact(TotalFERTP))
writeln("NLEACHING is ",    getact(TotalNLEACH))
writeln("PLEACHING is ",    getact(TotalPLEACH))
writeln("PESTICIDEHAZARDINDEX is ",  getact(TotalPESTLCHINDEX))
writeln("PESTICIDELEACHING is ",        getact(TotalPESTLEACH))
writeln("SoilCover is ",         getact(TotalSOILINDEX))

!SOLUTION TO EXCEL FILE
forall(i in Crop) Answer(i):= getsol(x(i))
SQLconnect('DSN=MyExcel; DBQ=U:\@ Thesis folder\Findlay\Findlay results
average.xls' )
SQLexecute("create table Results (Solution real)")
SQLexecute("insert into Results (Solution) values(?)", Answer)
Z:=getact(TotalGRMRGN)
SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getact(TotalSUBSIDIES)
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SQLexecute("insert into Results (Solution) values(?)", [Z])
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SQLexecute("insert into Results (Solution) values(?)", [Z])
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SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getact(LABJAN)
SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getact(LABFEB)
SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getact(LABMAR)
SQLexecute("insert into Results (Solution) values(?)", [Z])
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SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getact(LABSEP)
SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getact(LABOCT)
```

```
SQLexecute("insert into Results (Solution) values(?)", [Z])
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SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getact(LABDEC)
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Z:= getact(TotalSOILINDEX)
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Z:=getact(TotalENERGYUSED)
SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getact(TotalENERGYOUTPUT)
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Z:=getact(TotalENERGYBALANCE)
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SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getact(TotalFERTK)
SQLexecute("insert into Results (Solution) values(?)", [Z])
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SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getact(TotalPESTLCHINDEX)
SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getact(TotalPESTLEACH)
SQLexecute("insert into Results (Solution) values(?)", [Z])
Z:=getdual(TotalWater)
SQLexecute("insert into Results (Solution) values(?)", [Z])
SQLexecute("insert into Results (Solution) values(?)", [SummerPrice])
SQLexecute("insert into Results (Solution) values(?)", [WinterPrice])
SQLexecute("insert into Results (Solution) values(99999999)")
SQLdisconnect

end-model


!land constraints added to allow for rented land, requires the addition of a second
!land type in the matrix file Land Rent in the columns and the addition of two new
!rows for the rented in and rented out land these will contribute to the max land and
!will need writing into the command file.  Onions and potatoes only are grown on this
!land and will not be constrained by any rotational constraints
```

Appendix 3

Data request forms sent to farmers prior to the interviews.

1. General Farm Data

Total farm size (ha)

Land owned

Land rented

Predominant soil type	Irrigated Non-Irrigated

2. Cropping Data

List of all possible crops grown and if possible a typical cropping pattern for each year.

Any maximum areas of crops e.g limits on area of each specific crop and reason for this limit

Yields of all crops achieved on farm.

Prices gained (if possible for last 5 years)

Cost of seeds/plants

Marketing/ packaging costs

Rotational constraints of any crops

Costs of additional contractors and detail of work undertaken (e.g harvest)

3. Agrochemicals.

Details of fertiliser application to crops, application rates, manufacturer, timings for each crop type.

Details of the pesticides used for each crop, pesticide brand, active ingredient, dosage rates and number of applications.

Also any information regarding any limitations imposed on the use of any agrochemical and reasons

4. Farming Practices

Details of equipment used (make model cost).

Details of equipment use i.e what crops it is used for, how often, size of tractor required. What machinery use is for each separate crop and what is the work rate (how long to cover a ha or field).

Fuel costs, if know fuel consumption of machinery and cost of Base fuel

5. Irrigation Data

Area of farm irrigated (ha)

Total possible command area (ha)

Delivery systems and area of crops each system is used for.

Water demand of crops (if known)

Costs of irrigation equipment

Abstraction licence details (volume and any specific restrictions such as day allowance)

Details of water supply (direct supply from surface water or borehole.) Use of reservoir

Possible future supplies or modifications in system.

6. Labour Employment

Total employment of regular labour and costs

Employment of casual labour (which months and for which crops)

Costs of casual labour

Source of casual labour

For each month and crop details of the labour used in hours per crop per ha and defined between casual and regular labour

Appendix 4.

Example of the Financial Budget sheets for crop enterprises on Lakes Farm.

WINTER WHEAT GROSS MARGINS

milling wheat £/t		80	
Area payment £/ha		249.28	
GRAIN YIELD	t/ha	8	
GROSS OUTPUTS	£/ha	640	
VARIABLE COSTS			
seeds	kg/ha		
	£/ha	26.6	
nitrogen	kg/ha	196	
	£/ha	74.48	
phosphate	kg/ha	20	
	£/ha	6	
potash	kg/ha	54	
	£/ha	11.88	
chemicals	£/ha	120	
other	£/ha	14	
Contractor charges	£/ha	260	all operations are contract so no mech costs or labour costs
TOTAL V COSTS	£/ha	512.96	
GROSS MARGIN	£/ha	376.32	

SPRING WHEAT GROSS MARGINS			
milling wheat		80	
	£/ha		
area payment		249.28	
GRAIN YIELD	t/ha	5.7	
GROSS OUTPUTS			
	£/ha		
milling wheat		456	
VARIABLE COSTS			
seeds			
	£/ha	26.6	
nitrogen	kg/ha	146	
	£/ha	55.48	
phosphate	kg/ha	19	
	£/ha	5.7	
potash	kg/ha	43	
	£/ha	9.46	
chemicals	£/ha	65	
other	£/ha	11	
Contractor charges	£/ha	260	same as for wheat
TOTAL V COSTS	£/ha	433.24	
GROSS MARGIN	£/ha	272.04	

PEAS GROSS MARGINS				
Peas	£/t	91		
	£/ha			
Area payment	287			
YIELD	t/ha		3.6	
GROSS OUTPUTS	£/ha		327.6	
VARIABLE COSTS				
seeds	kg/ha			
	£/ha		34	
nitrogen	kg/ha		0	
	£/ha		0	
phosphate	kg/ha		14	
	£/ha		4.2	
potash	kg/ha		32	
	£/ha		7.04	
chemicals	£/ha		102	
other	£/ha		8	
Contractor charges	£/ha		200	no mech or labour charges required
TOTAL V COSTS	£/ha		355.24	
GROSS MARGIN	£/ha		259.36	

POTATOES (MAINCROP) GROSS MARGINS				
potatoes	£/t	114		
YIELD	t/ha		50	
GROSS OUTPUTS	£/ha		5700	
VARIABLE COSTS				
seeds	£/ha		290	
nitrogen	kg/ha		192	
	£/ha		72.96	
phosphate	kg/ha		50	
	£/ha		15	
potash	kg/ha		253	
	£/ha		55.66	
chemicals	£/ha		390	
bags	£/ha		350	
BPC levy incuding sundries	£/ha	Nix 33 ed	39	
contractor charges	£/ha		265	contract spraying fert and land prep
TOTAL V COSTS	£/ha		1477.62	
GROSS MARGIN	£/ha		4222.38	

DRY BULB ONIONS GROSS MARGINS			
PRICE	£/t	160	
YIELD	t/ha	50	
GROSS OUTPUTS	£/ha	8000	
VARIABLE COSTS			
seeds	kg/ha		
	£/ha	560	
nitrogen	kg/ha	110	
	£/ha	41.8	
phosphate	kg/ha	80	
	£/ha	24	
potash	kg/ha	130	
	£/ha	28.6	
chemicals	£/ha	370	
Drying (plus storage, fuel costs)	£/tn	30	
	£/ha	1500	
Nets	£/tn	9	
	£/ha	450	
Contract	£/ha	470	(spraying, fert ground prep.
TOTAL V COSTS	£/ha	3444.4	
GROSS MARGIN	£/ha	4555.6	

Appendix 5.

Appendix 5 gives the details of the results for all of the case studies under the various measures and coping strategies. Full results from the LP are given as well as the summary tables. This data is held on the attached cd-rom due to the number of files required.