Environment Agency

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Climate change impacts on water for irrigated horticulture in the Vale of Evesham

Final Report

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Executive Summary

This project has undertaken a scoping review and assessment of the impacts of climate change on irrigated horticulture in the Vale of Evesham, an area of intense irrigated production located within the Environment Agency's Warwickshire Avon CAMS Catchment. The research was based on a combination of methodologies including desk-based review of published and grey literature, computer agroclimatic and water balance modelling, GIS mapping, meetings with key informants and a stakeholder workshop.

Future climate datasets were derived from the latest UK Climate Impacts Programme (UKICIP02) climatology, using selected emission scenarios for the 2020s, 2050s and 2080s. These scenarios were then used to model and map the future agroclimatic conditions under which agriculture might operate and the consequent impacts on irrigation need (depths of water applied) and volumetric demand. This was complimented by a postal survey to abstractors and a stakeholder workshop, to identify, review and assess farmer adaptation options and responses. The key findings arising from the research, implications for water resource management and recommendations for further work are summarised below.

Using a geographical information system (GIS), a series of agroclimate maps have been produced, for the baseline and selected UKCIP02 scenario. The maps show major changes in agroclimate within the catchment over the next 50 years. The driest agroclimate zones are currently located around Worcester, Evesham, Tewkesbury and Gloucester, corresponding to areas where horticultural production and irrigation demand are most concentrated. By the 2020s, all agroclimate zones are predicted to increase in aridity. By the 2050s the entire catchment is predicted to have a drier agroclimate than is currently experienced anywhere in the driest parts of the catchment. This will have major impacts on the pattern of land use and irrigation water demand.

Using an irrigation scheduling computer model the impacts of these climate changes on the depths of irrigation applied and on volumetric water demand have been simulated. The analysis suggests that climate change would increase 'dry' year water demand for the existing irrigated crops in the Vale of Evesham by around 13-20% by the 2020s, 25-50% for the 2050s and 38-84% by the 2080s. The crop sectors most impacted will be potatoes, field-scale vegetables and small fruit production.

These estimates exclude the impacts of any increases in the areas grown due to changes for example in socio-economic policy.. The impacts of elevated atmospheric CO_2 concentration on fertilisation and hence water use and crop productivity have not been investigated. The changing climate is also likely to result in new crops being grown and some crops that are currently un-irrigated requiring irrigation. This will inevitably impact on the water demand-supply balance, with more frequent restrictions on irrigation water abstraction.

With climate change, farmers will need to implement coping strategies to respond to changing water availability. Farmer adaptation options and responses will depend to a large extent on their perception of the risks and/or opportunities. A postal survey confirmed that most farmers consider climate change to present a major threat to their business, but they are uncertain over the time-scales over which the impacts will take effect. Most farmers questioned believed that in the near future (5 to 10 years) there will be less water available for irrigation and that crop yields and farm incomes will be reduced. Many farmers believed that climate change is already beginning to have a discernable effect on agronomic practices, with longer growing seasons and some new crops being grown.

Farmers were also asked whether they had already started adapting to water shortages, through for example, responses to changes in water regulation or drought. To obtain more water, the preferred choices for farmers are to convert to mains water, harvest rainwater from land and farm buildings, and/or to re-use waste water. Many believed there was scope to improve irrigation efficiency through better equipment and scheduling. Whilst building a winter storage reservoir remains a viable option,

most farmers are reluctant to invest in long-term strategic developments given the short-term economic uncertainty surrounding agricultural production and the changing reliability of local water resources.

Finally, a workshop was held in the catchment to outline the findings and to obtain feedback from a broad range of stakeholders, including representatives from academia and research, government and local authority, industry and consulting and specialist interest groups. The workshop provided a useful opportunity for stakeholders to raise their awareness of the key issues, and to explain and compare their attitudes and perceptions to climate change.

This scoping study has highlighted some of the potential impacts that climate change may have on irrigated horticultural production in the Vale of Evesham, focusing on water demand and farmer adaptation. However, due to its limited geographical focus and scale of enquiry, there remain a number of fundamental gaps in knowledge. These clearly need to be addressed if a more integrated assessment of the impacts of climate change in the rural sector in this region is to be achieved. The key areas that warrant further research include:

- Investigating farmer costs associated with adapting to climate change. Better information is needed to help both growers and the regulatory agencies assess the relative costs and benefits of various adaptation options;
- Working with local agribusinesses, to test the UKICIP "climate adaptation: risk, uncertainty and decision-making framework" tool. This could help farmers, the regulatory authority and stakeholders assess the local risks posed by climate change, and work out how best to respond. The tool has been used in other vulnerable sectors to judge the significance of the climate change risk, compared to other risks, so that the appropriate adaptation measures can be implemented. It would involve undertaking case study farm assessments, comparing the different adaptation options and their financial and environmental impacts. It would also provide information to help avoid mal-adaptations that might be unbeneficial at the catchment level (in terms of water resources management) or at individual farm level (such as investments in additional water storage);
- Extending the methodologies developed across a wider geographical focus (e.g. Warwickshire Avon CAMS). This would also enable new climate change scenarios from 'UKCIPnext' to be applied;
- To investigate the impacts on UK irrigators of climate change elsewhere, particularly in countries where horticultural exports are in competition with local agribusiness;
- To assess which new crops which might be grown in the region, and how those that are currently un-irrigated might impact on water demand if irrigation becomes necessary;
- Addressing, with the regulator, how a potential reduction in water resources due to climate change would be allocated between existing abstractors and environmental river flow objectives. This would be useful for assessing farmer adaptations options in response to changes in the magnitude of summer and winter river flows, and could be tested using a hydrological modelling approach in a local catchment (e.g. Badsey Brook). This could provide useful information on climate change impacts in support of the CAMS process.

Keywords: abstraction; adaptation; climate change; horticulture; impact; irrigation; water.

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1 Introduction

Rural water resources are under pressure. The demand for water for irrigation in England and Wales is currently growing at 2 to 3% per annum (Weatherhead and Danert, 2002). Anthropogenic climate change threatens to exacerbate the situation. Abstraction of water for irrigation is considered by many to be one of the sectors that will be most influenced by climate change. Climate change will impact on irrigation water use by affecting plant physiology, soil water balances, cropping patterns, the areas irrigated and the methods used. Simultaneously, there are likely to be reductions in water availability particularly in dry summers.

The Vale of Evesham constitutes one of the most important regions for irrigated horticultural production in England, providing a focus for intensive production of vegetables, salad crops and soft fruit. These high value crops are increasingly dependant on supplemental irrigation to meet the exacting, high quality standards for produce being demanded by the major multiples and processors. As in other parts of England where irrigated production is concentrated, the underlying demand for irrigation in this region is growing steadily. In Worcestershire, these rising abstractions for irrigation, particularly in dry years, are impacting on local surface and groundwater resources, such as the Badsey Brook and Offenham gravels. Indeed, the Warwickshire Avon CAMS Report (EA, 2006) highlights that over the last decade restrictions at the Offenham control point have been applied every year for between 54-246 days to protect the environment from over-abstraction. Climate change will worsen the situation, with higher summer temperatures, less summer rainfall and more evaporation being predicted (Hulme *et al.*, 2002). Climate change could therefore result in a reduction in summer water available for abstraction, and an increase in irrigation water demand.

In response to climate change, it is apparent that growers will need to increase their efficiency of water use and consider coping strategies to adapt to changing water availability. In particular, they will need to know the extent to which water resources (summer and winter) may become less reliable. Similarly, water resource planners will need to develop strategies to meet the rising demands for water for horticulture whilst ensuring that the environment (and other abstractors) is adequately protected. In order to develop appropriate strategies, there is a need to know the likely magnitude of change and to assess the range of adaptation options available for irrigated horticulture.

This project commenced in January 2006 and was completed in November 2006. Using selected scenarios of climate change provided by the latest UK Climate Impacts Programme (UKCIP02), the project has modelled and mapped the impacts of climate change on local agroclimate, assessed the likely impacts on irrigation water demand (volumetric) and reviewed farmer adaptation options and their likely responses. This report provides a summary of the research objectives, the methodological approaches and the key outputs. The implications of the research for managing and allocating water resources for horticultural irrigation in the Vale of Evesham under conditions of climate change, together with recommendations for further work, are provided.

1.1 Aim and Objectives

The overall aim of this project was to conduct a scoping study to review and assess the impacts of climate change on water for irrigated horticultural production in the Vale of Evesham.

The specific objectives were:

1. To model and map the impacts of climate change on local summer agroclimate in the catchment;

2. To assess the impacts of climate change on the irrigation water requirements and water demand for selected horticultural crops grown in the catchment;

3. To identify and review a range of adaptation options available to farmers in response to changing water availability, and;

4. To organise a stakeholder workshop to elicit feedback on the options and responses to climate change.

The project relied on a combination of research methodologies including extensive desk-based studies, review of published and grey literature, water balance modelling, GIS mapping, interviews with key informants and a stakeholder workshop. The research approaches and methodologies were developed and applied within a catchment case study, the Warwickshire Avon catchment, located within the Environment Agency Midlands Region. This is known as CAMS (Catchment Abstraction Management Strategy) 40.

1.2 UKCIP Climate change scenarios

The scenarios used in this study were based on the most recent UKCIP climate change data (Hulme *et al*., 2002). The UKCIP02 provides climate change data for three time slices (2020s, 2050s, and 2080s) and for four core emissions scenarios (low, medium-low, medium-high, and high). For this study, four scenarios were selected for modelling, namely, the 2020s low and medium-high emissions scenario (2020L and 2020MH) and the 2050s medium-high and high emissions scenario (2050MH and 2050H). The data are for averages across 30-year time slices centred on 2025 (i.e. 2010 to 2040) and 2055 (i.e. 2040 to 2070), rather than for specific years. The uncertainty inherent in all climate change forecast scenarios, and those added in the use of UKCIP scenarios, is discussed by Downing *et al* (2003), particularly in relation to water resource issues, where changes in extreme events may be as important as gradual changes. The results of this study must therefore be interpreted in the context of remaining uncertainty.

For irrigation modelling, the main variables of interest were rainfall and the variables required to derive reference evapotranspiration (temperature, humidity, radiation and wind). The predicted impacts of climate change on selected variables are shown in Table 1.

Table 1 summarises future predicted changes in temperature and precipitation based on the UKCIP02 scenarios for the West Midlands and Southwest England; these areas represent 77% and 14% of the case study catchment, respectively (the remaining 9% of the catchment forms part of the East Midlands and Southeast England). In both areas, a progressive increase in mean annual temperature is predicted for all scenarios up to the 2080s (ranging from +0.5 to 4.5 degrees); in contrast, there is expected to be a significant decrease in summer precipitation (-10 to -50%) but compensated for by an increase in winter rainfall (+10 to +30%). The range in values reflects the low and high greenhouse gas emissions associated with each scenario and time-series. According to UKCIP (2002), in the near future, the Midlands region, which includes the case study catchment, is expected to get warmer and wetter with more droughts in the summer. This will intensify competition for water resources between public water demand, industrial use, agricultural consumption and environmental protection.

Table 1 Predicted changes in temperature and precipitation for West Midlands and Southwest England, for selected UKCIP02 scenarios.

UKCIP 02 scenario	**West Midlands**		**Southwest England**	
	Mean annual temp (°C)	*Mean annual precipitation (%)*	*Mean annual temp (°C)*	*Mean annual precipitation (%)*
2020s	+ 0.5 to +1.5	+ 0 to +10 (Winter) - 0 to -20 (Summer)	+ 0.5 to +1.5	+ 0 to +15 (Winter) - 0 to -15 (Summer)
2050s	+1.0 to +2.5	+ 0 to +20 (Winter) -10 to -30 (Summer)	+1.0 to +2.5	+ 5 to +15 (Winter) - 15 to – 30 (Summer)
2080s	+1.5 to +4.5	+ 0 to +30 (Winter) -20 to -50 (Summer)	+1.5 to +4.5	+10 to +30 (Winter) - 25 to -50 (Summer)

Derived from Anderson *et. al* (2003) and Metcalf *et. al* (2003).

1.3 Perturbed weather data

For the irrigation need modelling, a long-term historical weather dataset was perturbed using scaling factors derived from the 50 km x 50 km UKCIP02 baseline and scenario climatology. Daily long-term climate data representative of the catchment were obtained from Pershore, a weather station located in the catchment (Latitude 52:06:36N; Longitude: 2:04:29W). For this station, historical long-term 20-year (1979-98) daily weather data for rainfall and reference evapotranspiration (ETo), the climatic variables that influence irrigation, were available.

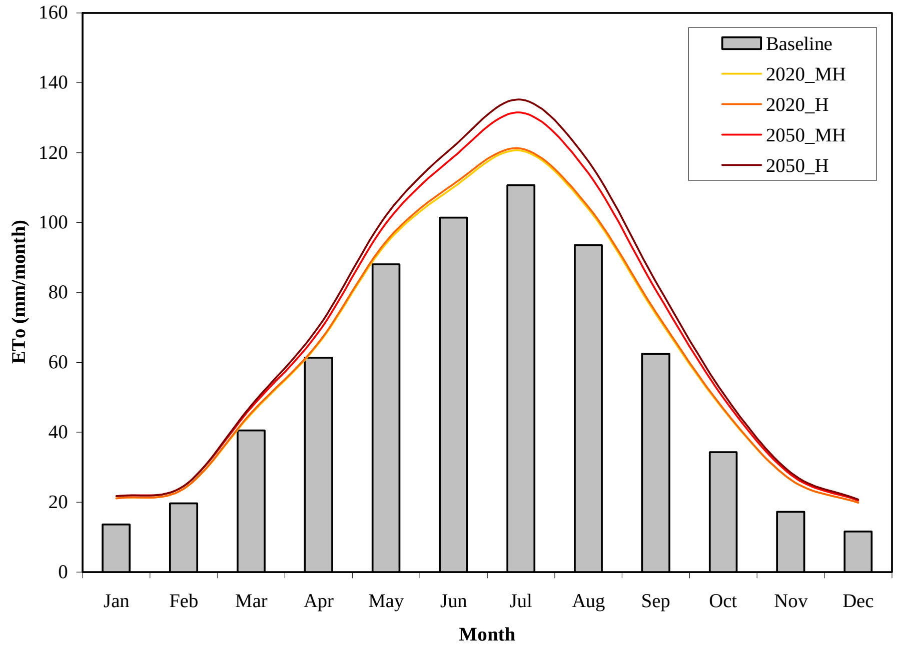
Using a procedure developed by Knox *et al* (2006), a series of future 20-year daily-perturbed datasets for rainfall and reference evapotranspiration (ETo) for each defined UKCIP02 scenario were derived. The procedure used assumed that the relative variability in climate from day to day and year to year (i.e. the shape of the frequency distribution) remained constant. This approach has the virtue of simplicity whilst maintaining a realistic temporal structure of climate data.

The predicted effects of climate change on the temporal distribution of rainfall and reference evapotranspiration (ETo) at this weather station relative to the long-term average (baseline), for selected UKCIP02 scenarios, is summarised in Figure 1. It is predicted that there will be increases in ETo in every month with the greatest increases occurring in the winter months. However, in the context of irrigation demand this will have minimal impact. Of greater concern, are the predicted increases in the summer months when water demand peaks and when water availability is lowest. There is predicted to be an overall increase in winter rainfall and a decline in summer rainfall. Clearly, the combination of an increase in evaporative demand in the summer coupled with a reduction in summer rainfall, will impact on supplemental irrigation; under these conditions water demand would be expected to rise.

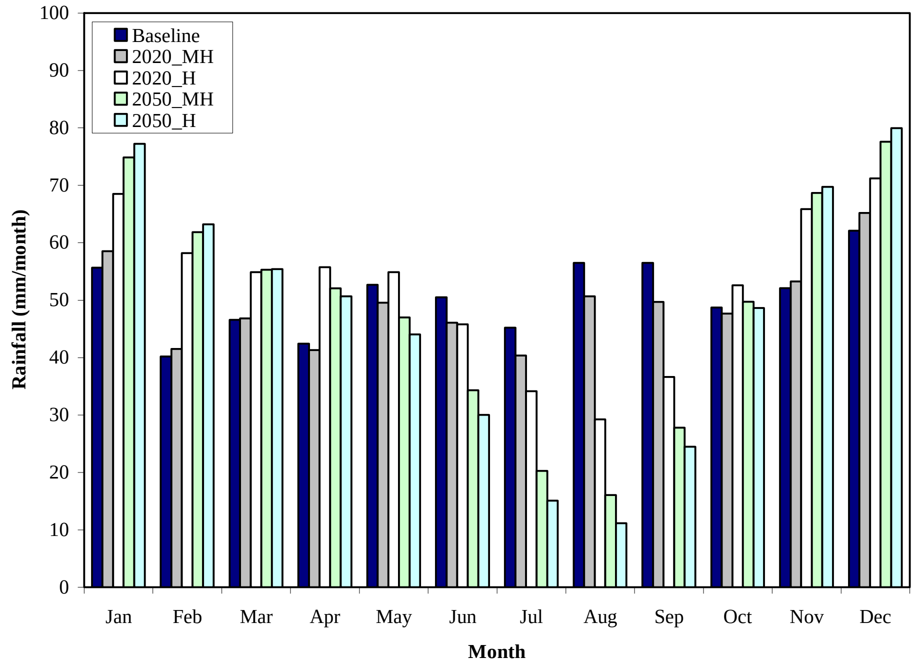
However, there may be increased opportunities for winter storage, due to higher stream flows during the winter months when increases in rainfall are predicted.

Figure 1 Simulated impacts of selected UKCIP02 scenarios on mean monthly (a) reference evapotranspiration (ETo) and (b) rainfall at Pershore, a weather station located within the Warwickshire Avon CAMS catchment.

(a) Reference evapotranspiration (ETo)



(b) Rainfall



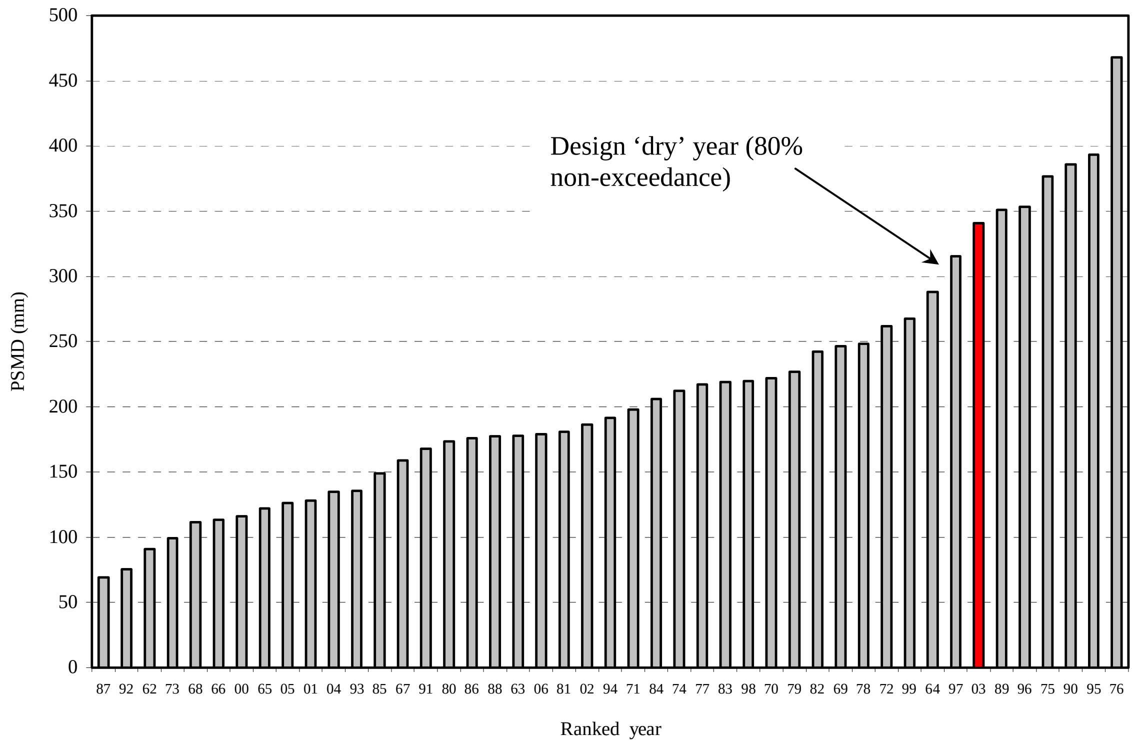
1.4 Using 2003 as a 'reference' dry year

In previous studies for the Environment Agency (e.g. Rees *et al*., 2003), the optimum or 'reasonable' irrigation needs (mm) for a range of crops grown under contrasting agroclimatic and soil conditions were estimated. These data reflected 'best practice' and were defined according to a 'reference' or 'design' dry year. In irrigation terms, this was statistically defined as the 'reasonable' irrigation needs in a year with an 80% probability of non-exceedance, i.e. meeting the irrigation need in 80 years in 100.

In this study, for consistency, a similar approach has been adopted. Thus, the impacts of climate change on agroclimate and on irrigation demand have been estimated with reference to a 'design' dry year. For assessing and mapping climate change impacts, the variable potential soil moisture deficit (PSMD) has been used. This takes into account the differences between rainfall and evapotranspairation (ETo) during the irrigation season and can be used to derive an index of 'aridity'. Previous studies (e.g. Knox *et al*., 1997; Rodriguez Diaz *et al*., 2006) have shown how this approach using PSMD can provide a high degree of correlation between agroclimate and irrigation need. A detailed description of the derivation of PSMD and its application for mapping aridity (using agroclimate zones) is given in Section 3.1.

However, when considering future 'dry' years and their likely impact it is useful to be able to relate a future 'design' dry year to an 'actual' historical year. Thus by analysing the observed variability in climate using a long-term historical time-series, a year with an 80% probability of non-exceedance in terms of agroclimate can be defined. To illustrate this, the annual maximum PSMD for a site in Bedfordshire over a 45-year period (1962-2006) has been calculated (Figure 2).

Figure 2 Ranked PSMD (mm) for Silsoe (Bedfordshire) between 1962-2006 showing 2003 as the reference 'design' dry year.



For this site, the calculated ‘design’ dry year equates to a year with a PSMD of 290 mm. By ranking the historical time-series, it is possible to identify a corresponding year in which a similar PSMD was recorded. In this example, the most recent ‘dry’ year that correlates most closely with the ‘design’ dry year is 2003. Hence, for the purposes of this study, 2003 has been used as a reference for a future ‘dry’ year.

1.5 Report structure

The project was undertaken in four discrete stages to match the project objectives:

1. Modelling and mapping the impacts of climate change on local agroclimate in the catchment;
2. Modelling the impacts of climate change on irrigation needs (depths of water applied) and volumetric irrigation water demand;
3. Reviewing and assessing the range of adaptation options available to farmers in order to adapt to changing water availability, and;
4. Organising a stakeholder workshop to present the project findings and to elicit feedback from a broad range of organisations with an interest in climate change, in terms of its impacts on local water resources, horticulture and farmer adaptation.

A brief outline of the research approaches and methodologies developed for each stage and the key findings arising form the research are presented in the following chapters. A summary of the research, conclusions and recommendations for further work are then provided.

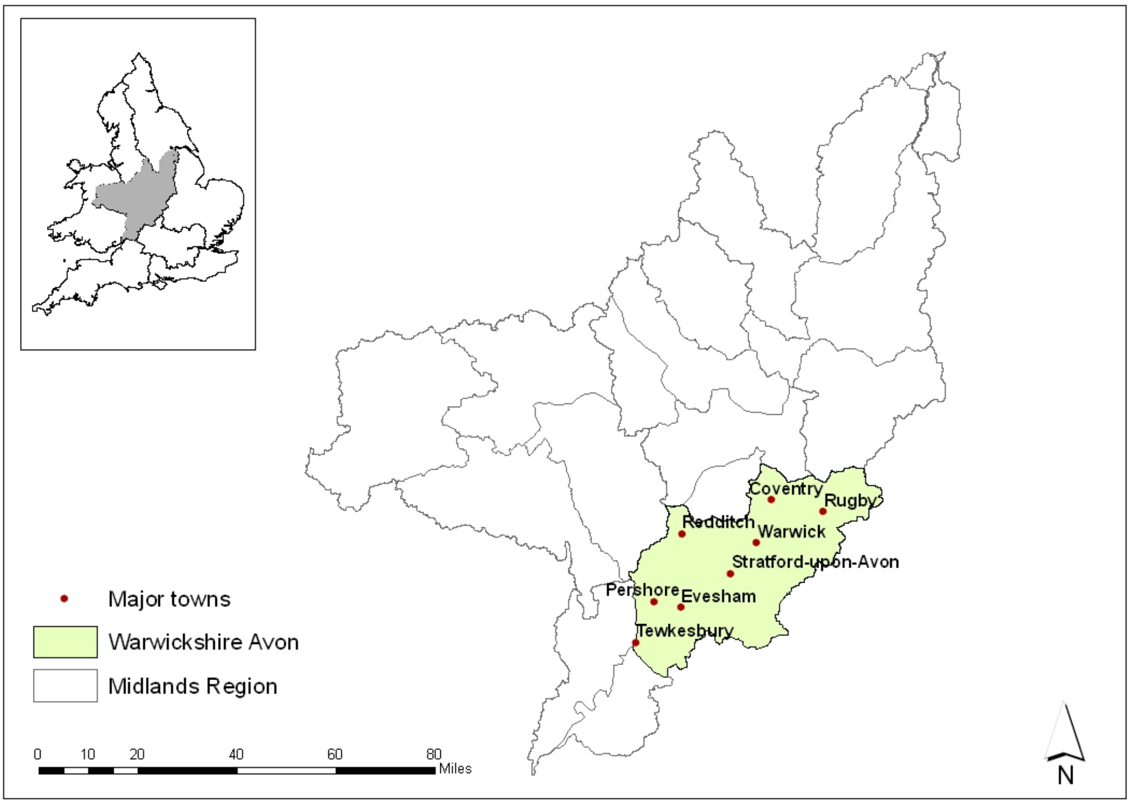
2 Case study catchment

This chapter provides a brief overview of the case study catchment's main characteristics in terms of soils, climate, land use, water resources and irrigation practices. Readers interested in a more comprehensive assessment of the catchment's hydrological characteristics and current assessment of water resource availability are referred to the Agency's CAMS document for the catchment, which has recently been published (EA, 2006).

2.1 Soils, climate, land use and water resources

The area chosen for this study is the Warwickshire Avon catchment, which is located in the EA Midlands Region (Figure 3). The catchment itself covers approximately 2900 km² of central England encompassing the counties of Warwickshire (49.2%), Herefordshire and Worcestershire (22.7%), Gloucestershire (13.6%), Northamptonshire (5.4%), West Midlands (4.8%), Leicestershire (3.2%) and Oxfordshire (1.1%). The River Avon and its tributaries are the major surface water bodies in the catchment. Apart from several minor sources of groundwater, the catchment has significant groundwater resources around Coventry, Warwick, Kenilworth, Bromsgrove, the Cotswolds and Stratford-upon Avon.

Figure 3 Warwickshire Avon CAMS catchment (CAMS 40).



2.1.1 Soils

The composition of soil types found in the catchment and their proportional area covered is summarised in Table 2. The dominant soil types are clay and loan which account for 61% of all soils; in terms of irrigation these would be classified as being soils with a medium available water capacity (AWC) (MAFF, 1982).

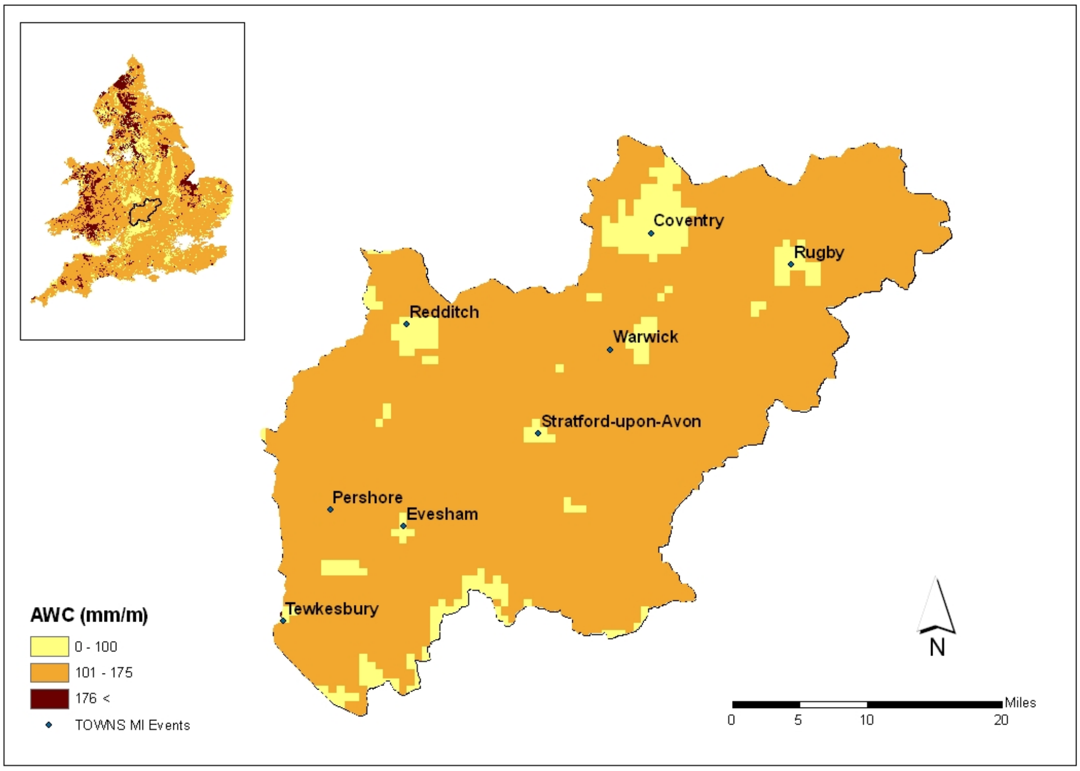
Table 2 Reported soil types in the Warwickshire Avon CAMS.

General soil type	Proportion of CAMS area (%)	Soil available water capacity (AWC)
Clay	45	Medium
Loam	16	Medium
Loam/clay	32	Medium
Loam/gravel	3	Low
Silt/clay	3	Medium
Silt	1	Medium
Total	**100**	**-**

Source: adapted from EA (2005) and MAFF (1982).

Using a geographical information system (GIS) and the National Soil dataset for England at 1 km grid resolution, the dominant soil types in the catchment have been reclassified and mapped according to their available water capacity (AWC). The following classes were defined: low AWC representing a soil with <100 mm/m; medium AWC 101 -175 mm/m, and high AWC soil > 176 mm/m. The soil AWC map for the catchment is shown in Figure 4.

Figure 4 Soil types in the Warwickshire Avon CAMS catchment (CAMS 40), classified according to soil available water capacity (AWC).



2.1.2 Land use

Agriculture plays a significant role in the catchment's economy and contributes to 90% of land-use. The major farming activities in the catchment include arable crop production, grazing, dairy and beef cattle as well as horticulture and market gardening in the Vale of Evesham (EA, 2005). Fruit and vegetable production from this region constitute a significant proportion of those supplied to the major multiples (supermarkets) in England. It is consumer demands for high quality, consistent supplies of premium grade produce that are driving the demand for increased dependence on irrigation.

2.1.3 Water resources

For the Warwickshire Avon catchment, the first CAMS cycle started in May 2002. A consultation document was published by January 2005 and the final strategy document published in June 2006 (EA, 2006). The resource availability status (integrated water resource management unit (WRMU) status) for the 22 surface and groundwater resource management units, identifies 13 units that have "no water available", 4 that are "over-licensed" and 5 that are "over-abstracted". A detailed assessment of each WRMU is provided in the CAMS strategy document (EA, 2006). There are no resource management units defined as having "water available" although licenses may still be granted at high flows.

2.2 Licensed and abstracted volumes for irrigation

The Agency maintains a record of all individual abstractions in their National Abstraction Licensing Database (NALD). For this study, data from NALD for 1998 to 2004 were made available. A summary of the total number of licenses, total licensed volume and proportion abstracted in 2003 (reference dry year) is summarised in Table 3.

Table 3 Number of licences, volumes licensed and abstracted volumes by purpose of use for the Vale of Evesham (located within the Warwickshire Avon CAMS 40 Catchment) in 2003.

Purpose	Number of licences	Total volume licensed (m^3)	Proportion abstracted in 2003 (%)
Domestic and general farming	3	9787	0.0
SI: direct	51	1178469	4.5
SI: horticulture and nurseries	6	48851	43.6
Domestic/ general farming and SI: direct	17	52212	9.1
Public water supply	2	995346	0.0
Domestic and general farming and SI: horticulture and nurseries	1	4069	0.00
SI: storage	3	18184	65.2
SI: horticulture and nurseries: storage	1	15909	0.0
Total	84	2322827	-

The EA NALD database shows that there were a total of 84 abstraction licences in the catchment held by 58 licence holders. Of these, 62 licences relate to spray irrigation, representing 54% of the total licensed abstraction and 7% of the actual abstraction in 2003.

The location of the spray irrigation licences are highly concentrated within a relatively small area in the Vale of Evesham as shown in Figure 5.

Figure 5 Location of abstraction points for spray irrigation in the Vale of Evesham, part of the Warwickshire Avon CAMS catchment (CAMS 40).

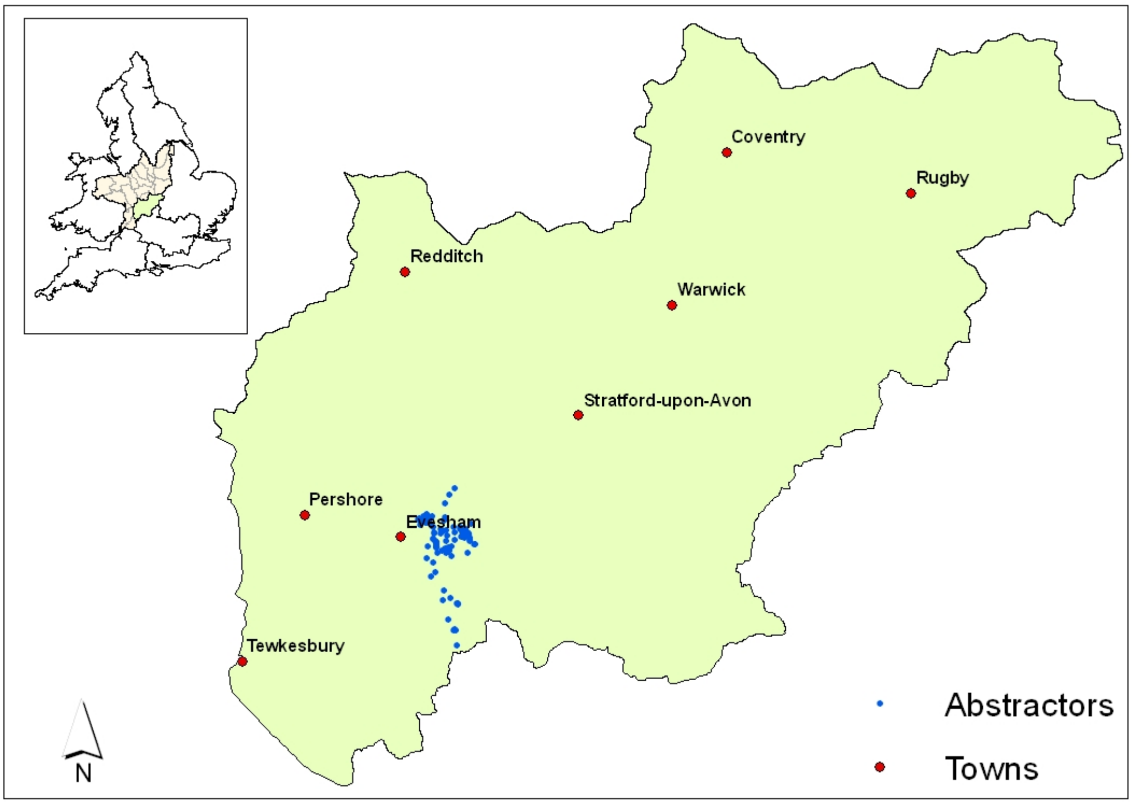
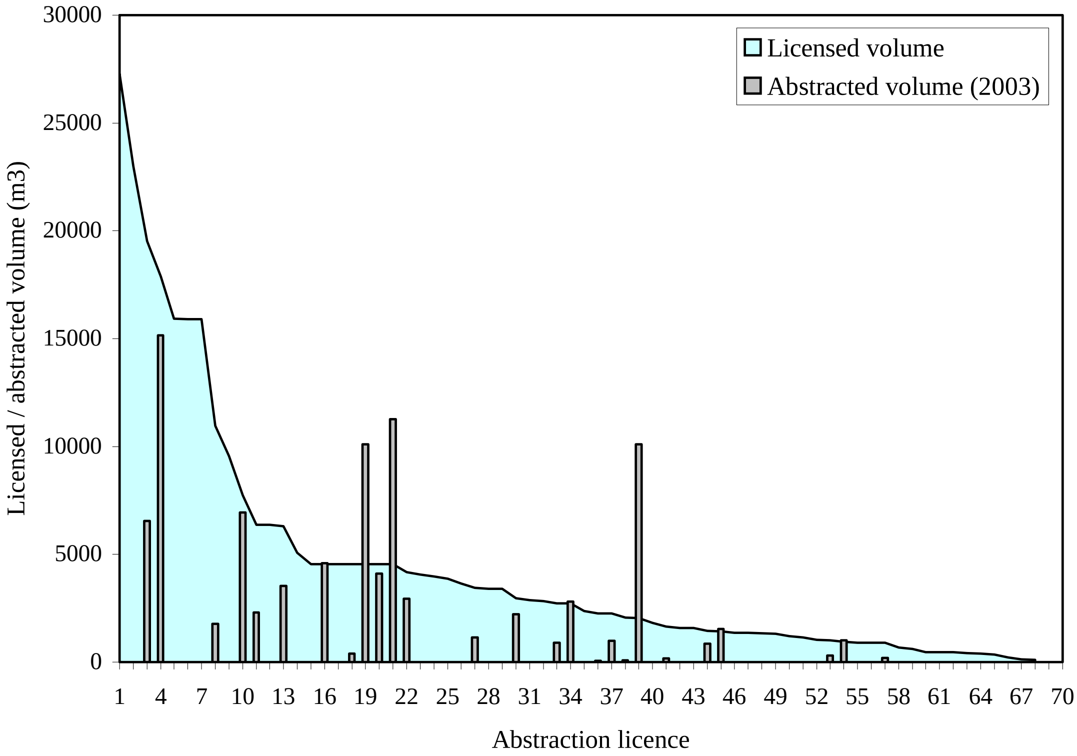


Table 4 Proportion of licensed volume abstracted for spray irrigation in the Vale of Evesham located within the Warwickshire Avon CAMS 40 Catchment) between 1998 and 2004.

NALD reported year	Licensed volume (m^3)	Abstracted volume (m^3)	Proportion abstracted (%)
1998	327801	70940	22
1999	327801	37387	11
2000	327801	63437	19
2001	327801	36637	11
2002	327801	58078	17
2003	327801	92006	28
2004	327801	79033	24
Average	**327801**	**62503**	**19**

The volumes of water abstracted for irrigation vary significantly from year to year depending on the summer weather in each year (Table 4). However, even in a very dry year, such as 2003 the total volume abstracted represented only a third of the total licensed volume. A comparison between the total licensed volume and volume abstracted for irrigation in 2003 versus size of licence is shown in Figure 6. The data illustrates that there are a significant number of “sleeper licenses”, due possibly to farmers who have either moved out of irrigated production, or have not used their licensed allocation for rotational reasons and thus were not irrigating in that year.

Figure 6 Comparison of licensed and abstracted volumes for spray irrigation in 2003 in the Warwickshire Avon CAMS catchment (CAMS 40).



2.3 Survey of irrigation practices

Since 1955, the government (Defra and formally MAFF) has collected statistics on agricultural irrigation in England and Wales, through the ‘Irrigation of Outdoor Crops’ Surveys. These have been carried out roughly triennially, most recently in 1990, 1992, 1995, 2001 and 2005.

For this study, data from the 2001 Irrigation Survey (England) were obtained and aggregated to CAMS (catchment) level. It should be noted, however, that the survey results do vary significantly from year to year, depending on the summer weather and thus the need for supplemental irrigation. Nationally 2001 was considered a relatively “wet” year (Figure 2), but the reported area irrigated was almost as high as in the very dry year of 1995, when the previous survey was undertaken. For the purposes of this study, the 2001 survey results therefore provide a useful guide to typical irrigation practices within the catchment. The results from the latest (2005) Irrigation Survey are currently being compiled and were not available for research purposes.

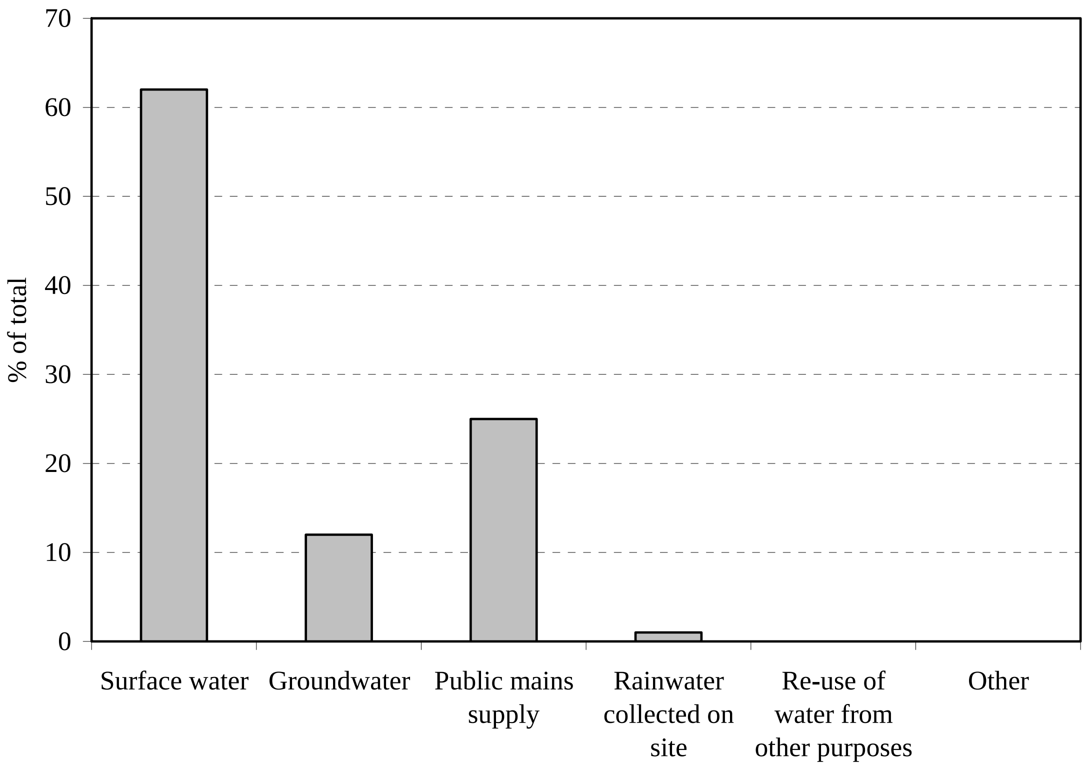
The areas irrigated and volumes of water applied in the Warwickshire Avon CAMS in 2001, by crop category, based on the 2001 Irrigation Survey (Weatherhead and Danert, 2002), are summarised in Table 5. The data confirm that vegetables and potatoes constitute the most important crops, accounting for 63% and 18% of the total area irrigated, respectively (or 1% and 1%, nationally). The average total depth of water applied to these crops was 65 - 80 mm (or 650 – 800 m^3 ha^{-1}).

Table 5 Summary of estimated areas irrigated and volume of irrigation water applied in the Warwickshire Avon CAMS , in 2001, by crop category.

Crop category	Area irrigated (ha)	Irrigation volume applied (m^3)
Early potatoes	2	1000
Maincrop potatoes	203	160100
Sugar beet	4	1000
Orchard fruit	80	20000
Small fruit	26	6100
Vegetables for human consumption	716	457000
Grass	39	11375
Cereals	64	0
Other crops grown in the open	9	18798
Total	**1143**	**675373**

The Irrigation Survey data also provides information on water sources (Figure 7) and irrigation application methods (Figure 8).

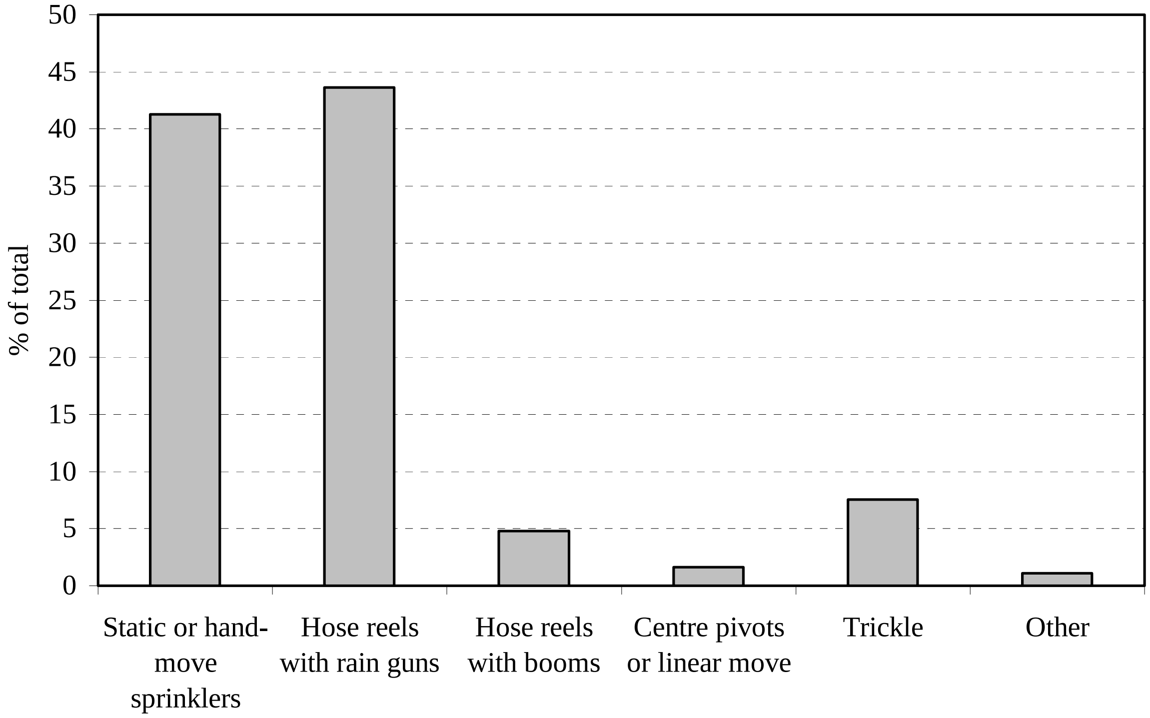
Figure 7 Water sources used for irrigation in the Warwickshire Avon CAMS catchment (CAMS 40), based on Defra 2001 Irrigation Survey.



The data confirms that that most irrigation water is abstracted directly from rivers and streams (62%), with groundwater accounting for approximately 12%; the remainder comes from public mains supply (25%) and rainwater harvesting (1%).

Nationally, hose-reels fitted with rain-guns are the dominant method of irrigation (72%). However, in this catchment hose-reels account for only 44%, with static or hand-move sprinklers being extensively used (41%). This is primarily due to their suitability for use on high-value horticultural crops where a greater degree of irrigation control and automation is required. The potential to irrigate smaller, more frequent applications is more valuable on many horticultural crops. Trickle is still a specialist method, but its use is growing steadily.

Figure 8 Water sources used for irrigation in 2001 in the Warwickshire Avon CAMS catchment (CAMS 40).



3 Mapping changes in agroclimate

This chapter describes how a climatic indicator has been developed and applied to the catchment to model and map the spatial and temporal impacts of climate change on agroclimate (and hence irrigation). A series of agroclimate zone maps have been produced for the Warwickshire Avon CAMS for the baseline and for selected UKCIP02 scenarios. A brief description of the methodology and the derived maps is provided.

3.1 Defining an agroclimatic indicator

Because global warming will influence temperature and rainfall patterns, there are likely to be direct impacts on soil moisture, and hence irrigation need (depths of water applied). In England, these climatic changes will vary both spatially and temporally. One widely adopted approach to assess the impact of climate change on spatial irrigation demand is to use an agroclimatic indicator to define and map agroclimatic zones (Knox *et al*., 2006). These zones are similar to those used by the EA in their procedure for assessing and setting abstraction licenses for irrigation (Rees *et al*., 2003).

In this study, the variable potential soil moisture deficit (PSMD) has been used as an agroclimatic indicator. It reflects the daily balance between rainfall and reference evapotranspiration (ETo) during the summer months when irrigation is required. For a given site, the PSMD in each month is calculated from:

$$PSMD_i = PSMD_{i-1} + ET_i - P_i$$

Where

$PSMD_i$ = potential soil moisture deficit in month i, mm

ET_i = potential evapotranspiration of short grass in month i, mm

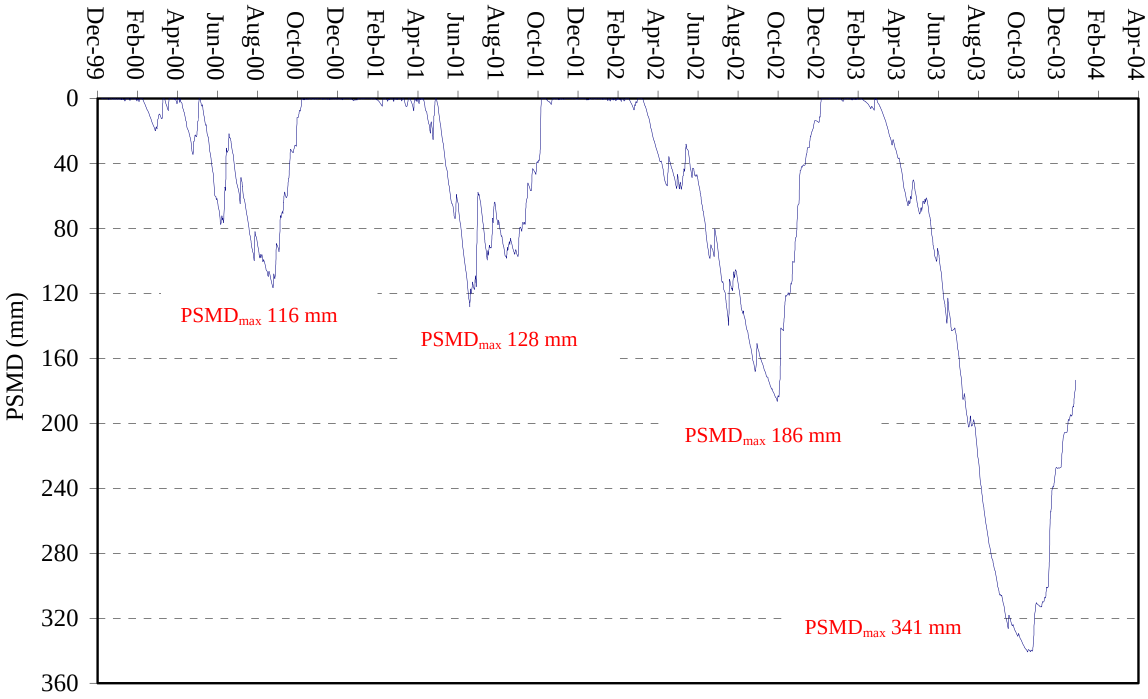
P_i = rainfall in month i, mm

In months where $P_i > (PSMD_{i-1} + ET_i)$, no soil moisture deficit is assumed to occur and $PSMD_i = 0$. In the UK, soil moisture deficits typically start to build up in early spring as ET > P, peak in mid summer (July-August) and then decline through autumn and winter as P > ET. Therefore in the UK, the estimation of PSMD can start with January as month i = 1. The maximum PSMD of the 12 months of the year is termed $PSMD_{max}$.

An example of the observed variation in annual $PSMD_{max}$ between 2000 and 2003 is shown in Figure 9. The data shows how the PSMD varies from year to year depending on the balance between P and ET. In 2000 the maximum annual $PSMD_{max}$ reached 116 mm; compared against other years in a long-term time series this represented a very wet year (Figure 2). In contrast, the $PSMD_{max}$ in 2003 reached 341 mm, the 7th highest value recorded over the last 45 years.

For the purposes of mapping agroclimate, $PSMD_{max}$ is therefore a useful climatic indicator. The values used for mapping in this study represented the long-term average $PSMD_{max}$ for each 25 km^2 grid pixel in the catchment, based on the UKCIP02 baseline climatology.

Figure 9 Derivation of $PSMD_{max}$ for a representative site between 2000 and 2003.

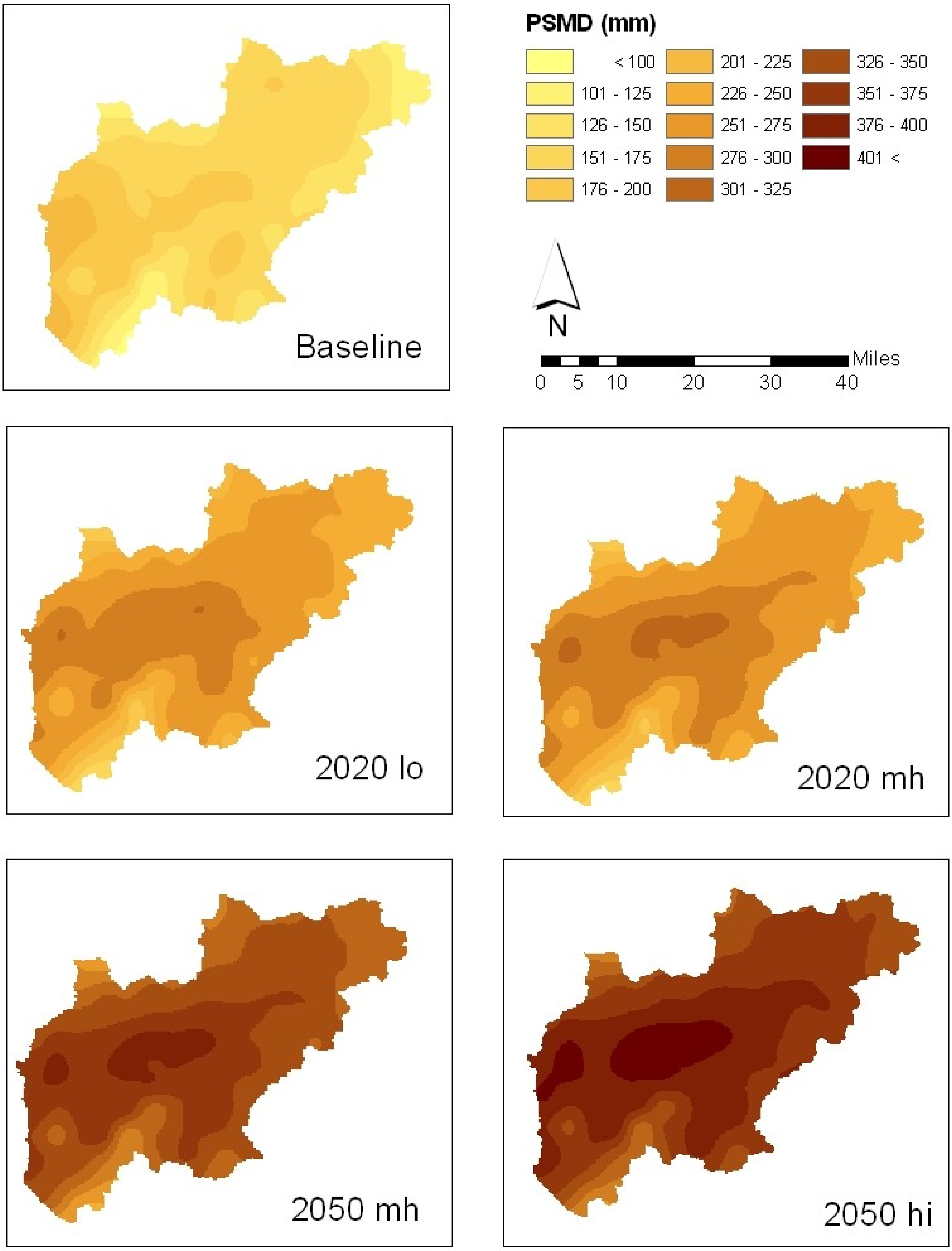


Using a GIS, the mean monthly rainfall and ET_o, at 25 km^2 resolution, were extracted from the UKCIP02 database. A simple water balance model (monthly time-step) was then used to estimate the $PSMD_{max}$ for each grid pixel, for the baseline and each climate change scenario. The $PSMD_{max}$ datasets were imported into a GIS and converted from grid pixel to point (centroid) format. The attribute value ($PSMD_{max}$) of each grid pixel was appended to each centroid. A contouring function was used to generate the PSMD point data into a surface, by applying a triangulated irregular network (TIN). This method is commonly used to digitally represent point data as a continuous surface. Once a TIN is applied, points are joined in a network of triangles with each point representing a vertex of a triangle. The area of each resulting triangle forms a plane in the TIN from which a surface can be generated.

A PSMD contour map for the baseline and each UKCIP02 scenario were produced. The contour data were reclassified into agroclimatic zones. The zones were chosen to match the typical irrigation application depth that might be applied during a single irrigation in England. Apart from zone 1 (PSMD ≤100 mm), each zone was defined with a 25 mm interval; agroclimatic zone 1 representing the wettest zone and zone 14 representing the driest (PSMD >400 mm), respectively. An agroclimatic zone map for the baseline and for selected UKCIP02 scenario, for the Warwickshire Avon CAMS catchment, was produced (Figure 10).

The maps illustrate how climate change will have a significant impact on local agroclimate in the Warwickshire Avon CAMS. At present, the highest agroclimate zones (5-7) are located around Worcester, Evesham, Tewkesbury and Gloucester. These correspond to areas where horticultural production and irrigation water demand are concentrated, particularly in and around the Vale of Evesham. By the 2020s, all agroclimate zones (corresponding to highest irrigation need) increase in aridity, appear to spread northwards and westwards across the catchment. By the 2050s the entire catchment is predicted to have a drier agroclimate than is currently experienced anywhere in the driest parts of the catchment.

Figure 10 Spatial distribution of agroclimatic zones for the baseline (1961-90) and selected UKCIP02 climate change scenario in the Warwickshire Avon CAMS.



4 Impacts of climate change on irrigation water use

Climate change will impact on irrigation water use by affecting plant physiology, soil water balances, cropping patterns, the areas irrigated, the methods used and the volume of water demanded (and abstracted if available) for irrigation. This chapter focuses specifically on how the predicted changes in agroclimate (Chapter 3) will impact on the main horticultural crops of interest, in terms of their irrigation need (depths of water applied) and seasonal (volumetric) irrigation water demand. The impacts of elevated levels of atmospheric CO_2 on crop productivity and water demand are complex and have not been considered. There are also other feedbacks which are difficult to quantify, and beyond the scope of this study.

Using climatic datasets derived from the UKCIP02 climatology, a water balance computer model has been used to simulate the annual irrigation needs for a range of crop categories grown in the catchment. This data has been combined with information relating to cropped and irrigated areas to estimate current and future water demand in the catchment. All outputs relate to a reference ‘design’ dry year. A brief description of the data processing, modelling approaches, forecasts and implications for water management in the catchment are provided.

4.1 Modelling irrigation need (mm)

For this study, the net annual irrigation needs (depths of water applied, mm) for the main horticultural crops grown in the catchment were simulated using ‘Irrigation Water Requirements’ (IWR), a computer water balance model developed by Hess (1994). The IWR model estimates the daily soil water balance for a selected crop and soil type, working from daily rainfall (P) and reference evapotranspiration (ETo) data. The IWR model uses a two layer (topsoil and subsoil) soil water balance to estimate the daily soil water storage, incorporating inputs of rainfall and irrigation and outputs of evapotranspiration and drainage. For each year of the available weather records, the model outputs data on the crop water use, any irrigation applied and the proportional yield loss due to any water stress. Readers interested in a more detailed explanation of the model are referred to Knox *et al*. (1996).

For each site, the IWR model requires input data relating to (i) crop cover development and rooting characteristics, (ii) soil water holding characteristics, and (iii) the planned irrigation schedule. Five crop categories were modelled, namely: maincrop potatoes (*Solanum tuberosum*), sugar beet (*Beta vulgaris*), vegetables, small fruit and orchard fruit. Carrots (*Daucus carota*) were used to represent vegetables, strawberries (*Fragaria spp*.) for small fruit and mature apples (*Malus spp*) for orchard fruit. The crop growth characteristics were defined to simulate typical UK irrigated cropping, and were derived from published literature including experimental and research data (Knox *et al*., 1997; Weatherhead *et al*., 2002; Rees *et al*., 2003).

A soil with a medium available water capacity (AWC) was defined to reflect the dominant soil types found in the catchment (Table 2). Modelled irrigation applications were based on a typical irrigation schedule (plan). The irrigation plans used in this study were defined to reflect typical UK irrigated cropping, based on published literature (MAFF, 1982; Bailey 1990) and industry guidance (Weatherhead *et al*., 2002).

In order to run the IWR model, daily time-step long-term (20 year) weather data relating to rainfall and reference evapotranspiration (ETo) are required. The representative weather station in the catchment (Pershore, Latitude 52:06:36N; Longitude: 2:04:29W) was used. Historical daily weather data for this station was available (1979 to 1998). Using a procedure developed by Knox *et a*l (2006), the historical dataset for Pershore was perturbed using scaling factors derived from the 50 km x 50 km UKCIP02 baseline and future climatology. A series of 20-year daily datasets for rainfall and ETo for each UKCIP02 scenario were derived.

The IWR model was then run for each crop*soil type*climate permutation, using firstly the historical (baseline scenario) climate data for Pershore, and then for each UKCIP02 climate change scenario. The simulated annual irrigation needs for each permutation were then statistically analysed to calculate the 'design' dry year needs, defined as the '80% non-exceedance' needs, i.e. meeting the irrigation need 80 years in 100. The estimated 'design' dry year irrigation needs for each crop category, for the baseline and for selected UKCIP02 scenario are summarised in Table 6.

Table 6 Estimated 'design' dry year theoretical irrigation needs (mm) for each crop category, for the baseline and each UKCIP02 scenario.

Crop category	Design dry year irrigation need (mm)						
	Baseline	**2020L**	**2020H**	**2050L**	**2050H**	**2080L**	**2080H**
Maincrop potatoes	258	306	300	330	390	372	474
Vegetables	200	225	225	250	300	275	375
Sugar beet	175	200	225	225	275	275	375
Small fruit	140	175	180	200	240	225	330
Top fruit	200	200	240	240	280	280	360

The IWR modelling suggests that climate change will have a significant impact of seasonal (annual) irrigation needs for all the crop types considered. The greatest predicted increases in irrigation need (mm) are for small fruit (strawberries) although the overall areas currently irrigated are still quite small compared to field scale vegetables and potatoes.

Clearly, these agronomic increases in water requirement would have a major impact on the volumes of water demanded for horticulture in the region, with consequent impacts on the volumes of water abstracted, both in summer and winter.

4.2 Theoretical volumetric irrigation demand (m^3)

A summary of the estimated cropped and irrigated areas for the Warwickshire Avon catchment are given in Table 7. The cropped areas were derived from Defra's June 2004 Agricultural Census. The proportion (%) of each crop category irrigated was derived from the 2001 Defra Irrigation Survey (Weatherhead and Danert, 2002). Not all the cropped area is irrigated due to various agronomic and economic factors. The total cropped area in the catchment is 9123 ha and the total irrigated area is 3463 ha indicating that approximately 38% of the crops in the catchment are irrigated.

By combining the theoretical 'design' dry irrigation needs (mm) (Table 6) with information on irrigated areas (Table 7), an estimate of total theoretical volumetric irrigation demand (m^3)

can be derived. The predicted changes in volumetric irrigation demand, by crop category, for each climate change scenario, is summarised in Table 8. However, it should be noted that for some crop categories (notably potatoes, sugar beet and small fruit) the estimated irrigated areas given in Table 7 are markedly higher than those presented in Table 5.

Table 7 Estimated cropped and irrigated areas for each crop type, in the Warwickshire Avon CAMS catchment.

Crop category	Cropped area (ha)	Proportion irrigated (%)	Estimated irrigated area (ha)
Maincrop potatoes	3361	69	2319
Vegetables	2085	35	730
Sugar beet	1568	6	94
Small fruit	403	50	201
Top fruit	1707	7	119

Table 8 Estimated increase in theoretical 'dry' year volumetric irrigation water demand (%) in the Warwickshire Avon CAMS catchment, by crop category, from the baseline for each UKCIP02 scenario.

Crop category	Baseline (m^3)	Estimated increase in irrigation demand (%)					
		2020L	2020H	2050L	2050H	2080L	2080H
Maincrop potatoes	5982540	19	16	28	51	44	84
Vegetables	1459801	13	13	25	50	38	88
Sugar beet	164659	14	29	29	57	57	114
Small fruit	282086	25	29	43	71	61	136
Top fruit	238928	0	20	20	40	40	80

For the dominant irrigated crop types (potatoes and vegetables) the modelling suggests that theoretical irrigation water demand is predicted to increase from the current baseline (theoretical dry year position) by between 13-19% for the 2020s, between 25-51% for the 2050s and 38-84% by the 2080s.

It should be noted that the baseline figures represent total 'theoretical' water demand; actual water abstraction (demand) in an equivalent dry year (2003) was considerably less, due to various agronomic, economic and water resource reasons. However, the baseline figures do provide a useful guide as to how future water demand (unconstrained) could increase. To derive a more realistic estimate of future 'actual' water demand, the estimated percentage change figures given in Table 8 could readily be applied to actual abstraction data for a recent dry year (2003).

5 Adapting to climate change

5.1 Farmer options

For individual growers, climate change will impact on various agronomic, economic and environmental aspects of horticultural production. Under conditions of changing water availability, farmers will need to consider and implement various coping strategies or adaptation options. Their choice of options will depend on their perceptions of climate change and the threats (and opportunities) it presents to their business.

This section provides a broad scale assessment of the farmer options and responses to climate change. It is based on a targeted postal survey to all the irrigation abstractors in the sub-catchment,. The adaptation survey aimed to investigate how local horticultural growers might adapt to changes in water availability as a consequence of climate change, the range of adaptation options available to them and the perceived time-scales required for adaptation. The postal survey was complemented by a number of meetings with key informants and supplemented by literature review.

A postal questionnaire survey was developed and targeted to all irrigation abstractors in the case study catchment as identified from the Agency's NALD database. The questionnaire sought to obtain information from individual growers on their perceptions of climate change across a range of subject areas, including policy issues, and how climate change might impact on their business and over what relevant time-scales. It also requested feedback from growers with respect to their views on the range of adaptation options available in the context of (i) increasing water availability, (ii) improving water management, or (iii) changing soil and crop management practices if future restrictions in water availability were to occur. In all, 58 surveys were sent, and 11 returned, representing a 20% response rate. A summary of the key findings relating to the specific questions raised is presented below. The results are expressed as a percentage of total responses.

Based on what you have heard about climate change and its impacts in the media, to what extent do you view climate change as a threat?

Serious threat	Major threat	Moderate threat	Minor threat	No threat
0%	40%	40%	20%	0%

How serious do you consider the threat of climate change on water availability for your business?

Serious threat	Major threat	Moderate threat	Minor threat	No threat
20%	40%	20%	20%	0%

The abstractors are asked to comment on a range of possible effects of climate change on their business, and the likely time-scales over which these might start. The results are summarised in Table 9.

Table 9 Farmer perceptions of the effects of climate change (values expressed as % of total responses).

Possible effects of climate change	Beginning to have effect	Near future (5-10 yrs)	Long-term (10 yrs +)	Not foreseeable	Total
Reduction in yield	18	37	18	27	100
Less water available	0	50	38	12	100
Lower farm income	22	44	12	22	100
Longer growing season	44	12	33	11	100
New crops grown	38	12	12	38	100

The survey data confirmed that most farmers consider climate change to present a major threat to their business. As expected, an even higher proportion consider climate change to present a serious threat in terms of securing water to their business. However, they are uncertain over the time-scales over which the likely impacts will take effect. Most farmers questioned believed that in the near future (5 to 10 years) there will be less water available for irrigation and that crop yields and farm incomes will be reduced. Many farmers believed that climate change was already beginning to have a discernable effect on agronomic practices, with longer growing seasons and some new crops being grown.

The abstractors are also asked to comment on the extent to which they considered particular policy issues represented a barrier to adapting positively to climate change. The survey results are summarised in Table 10.

Table 10 Summarized responses of farmers' perception of the barriers to positive adaptation to climate change (values expressed as % of total).

Barrier	Not an issue	A minor issue	A major issue	Total
Inadequate policies	0	10	90	100
Inadequate financial support	0	25	75	100
Lack of clear information	10	40	50	100
Lack of technical support	0	56	44	100

The majority of survey respondents considered that inadequate policies combined with a lack of financial support were currently the main major barriers to adapting positively to climate change. Opinions were split roughly equally in terms of considering whether there was a lack of clear information and technical support.

Finally, the farmers were asked to consider a range of adaptation options that they might consider implementing (or have done already) in response to restrictions in water availability, through for example, responses to changes in water regulation or drought. The options were categorised into coping strategies that related to (i) increasing water availability, (ii) improving water management, and (iii) changing their soil and crop management practices. The results are summarised in Table 11.

Table 11 Summary of farmer responses for adapting to water shortage (values expressed as % of total).

Water shortage coping strategy	Have done already	Considered implementing	Technically possible, but no plans	Technically impossible	Total
Increase water availability					
Obtain additional summer abstraction licence	0	40	60	0	100
Obtain winter abstraction licence and build winter storage (individual)	14	29	43	14	100
Buy water from another abstractor	0	0	34	66	100
Convert to public mains water	43	14	43	0	100
Harvest rainwater	50	17	33	0	100
Re-use waste water from farm buildings	42	29	29	0	100
Improve water management					
Increase efficiency through better equipment	66	17	17	0	100
Increase efficiency through better scheduling	63	25	12	0	100
Increase efficiency through better use of rainfall	17	33	33	17	100
Change soil and crop management					
Introduce lower water use or drought tolerant crop varieties	12	0	50	38	100
Decrease the irrigated area	14	14	14	58	100
Improve soil structure to improve water retention	29	13	29	29	100
Other					
Stop irrigation, keep licence	20	0	40	40	100
Stop irrigation, sell licence	0	0	60	40	100

To obtain more water, the preferred choices for farmers have been to harvest rainwater from land and farm buildings, convert to mains water, and/or to re-use waste water. Many believed that they had already improved irrigation efficiency through better equipment and scheduling. This may be a direct response to the proposed changes in abstraction licensing currently being proposed where demonstrating efficient use is likely to constitute one of the tests for abstraction licence renewal (EA, 2005). Whilst building a winter storage reservoir remains a viable option, it appears that most farmers in the survey were reluctant to invest in long-term strategic developments given the short-term economic uncertainty surrounding agricultural production and the changing reliability of local water resources.

Reducing the irrigated area, and/or moving out of irrigated production (e.g. selling licence) were considered by the majority of growers to be technically unfeasible, given the high capital costs associated with investments in irrigation.

5.2 Stakeholder responses

The final stage in the project was to organise a stakeholder workshop in the case study catchment. The objective was to provide a brief overview of the project and its key findings in the context of climate change impacts on water for horticulture and the adaptation options and responses available to farmers and other relevant stakeholders. The workshop comprised of a series of short technical presentations combined with a number of group exercises designed to engage the stakeholders in providing quantitative feedback across a number of key themes, including water resources, climate change impacts, and adaptation.

The workshop provided quantitative feedback from a broad range of stakeholders on their attitudes to climate change, the perceived threats and opportunities, adaptation options, as well as identifying gaps in knowledge and priorities for further research. An evening workshop entitled "Climate change and horticulture in the Vale of Evesham: impacts, farmer options and responses" was held in Evesham on Thursday 3rd August 2006. The event was well attended, and attracted 55 participants from a range of stakeholder sectors.

For the purposes of analysing the workshop feedback, individual stakeholders were grouped according to five specific sectors, namely academia and research, government and local authority, farmers/growers, industry and consulting and specialist interest groups. A summary of the groups is provided in Table 12.

Table 12 Summary of stakeholder groups attending workshop.

Stakeholder group	No of delegates	Sample organisations represented
Academia and research	9	Cranfield University, Pershore College, Warwick HRI, Oxford University, Umeå University (Sweden)
Government and local authority	12	Worcester City Council, Wychavon District Council, Environment Agency, Worcestershire County Council, Government Office for the West Midlands
Farmers and growers	10	Solari Farming, Allensmore Nurseries Ltd., Bulmers, Chicory Crops Ltd., Evesham Vale Growers
Industry and consulting	9	Bidwells, Evenproducts, Revaho, CCFRA, land agents, independent consultants
Specialist interest groups	15	CLA, NFU, Tyndall Centre for Climate Change Research, Chamber of Commerce Hereford and Worcester, UKCIP, Sustainability West Midlands

A series of three short technical presentations were made to provide delegates with a brief introduction to key water resources management issues in the catchment (CAMS, abstraction licensing, RSA, etc), climate change impacts on irrigation and farmer adaptation options. Following the question and answer session, delegates were then asked to answer a series of 15 structured multiple-choice questions; these were mounted on posters around the room. In each delegate pack, a set of coloured stickers was provided. These were colour-coded in order to be able to identify the responses to each question by stakeholder group. The individual responses to selected questions have been aggregated and analysed by stakeholder group, and the key findings summarised below.

Based on what you have heard in the media about climate change and its potential impacts, to what extent do you view climate change as a threat to your livelihood?

Table 13 Summary responses by stakeholder group on the perceived threat of climate change to their livelihood (values expressed as % of total).

Stakeholder group	Serious threat	Major threat	Moderate threat	Minor threat	No threat	Don't know	Didn't Respond	Total
Academia and research	0	43	29	0	0	0	28	100
Government and local authority	0	9	18	9	27	0	37	100
Farmers / growers	33	22	0	11	0	0	34	100
Industry and consulting	22	11	33	0	0	0	34	100
Specialist interest groups	7	33	20	7	7	0	27	100

How serious do you consider the threat of climate change on the availability of water resources in your catchment?

Table 14 Summary responses by stakeholder group on the perceived threat of climate change on local catchment water availability (values expressed as % of total).

Stakeholder group	Serious threat	Major threat	Moderate threat	Minor threat	No threat	Don't know	Didn't Respond	Total
Academia and research	29	71	0	0	0	0	0	100
Government and local authority	0	45	9	0	0	0	46	100
Farmers / growers	22	22	33	0	0	0	33	100
Industry and consulting	55	11	0	0	0	0	34	100
Specialist interest groups	40	20	0	7	0	0	33	100

The data suggests that over 50% of growers attending the workshop considered climate change to present a major to serious to threat on their business. Their perception of the risks were probably influenced by the preceding technical presentations which provided detail on the local impacts on agroclimate and irrigation need. Representatives from government agencies and local authorities, although concerned about climate change and its wider implications, understandably considered that the direct impact of climate change on their business *per se*, would be limited, since their role is primarily policy implementation. In contrast, those from academia and research considered that climate change would present a significant risk to local water resources availability for agriculture in the study catchment.

What effects do you think climate change will have on the agricultural sector and over what time-scale?

Table 15 Comparison of all stakeholders' responses with regards possible effects of climate change on the agricultural sector (%).

Possible effects of climate change	Beginning to have an effect or expected in the future	Not in the foreseeable future
Reduction in yields	77	23
Less water available	100	0
Lower farm incomes	68	32
Longer growing season	90	10
New crops grown	100	0

There was an overwhelming agreement from all stakeholder sectors that climate change would impact on crop productivity (reduction in yields), that less water would be available, but that a longer growing season would result in new crops being cultivated (e.g. Navy beans, maize, sunflowers). However, a third of respondents believed that farm incomes would not be adversely affected.

Finally, the workshop participants were asked to assess to what extent they believed more water could be abstracted in the catchment under conditions of climate change (Table 16).

Table 16 Summary stakeholder responses on whether **they believed more water could be abstracted in the catchment under conditions of climate change** values expressed as % of total).

Stakeholder group	No	Maybe	Yes	Don't know	Did not respond	Total
Academia and research	43	43	0	14	0	100
Government / local authority	0	55	0	9	36	100
Farmers / growers	0	67	0	0	33	100
Industry and consultants	22	33	22	0	23	100
Specialist interest groups	20	13	0	33	34	100

The feedback from stakeholders was mixed, depending on the extent to which specific businesses were dependant on local water resources. Despite the preceding presentations on climate change and its impact on local agroclimate and water resources, farmer perceptions regarding future water availability were unclear; in contrast, nearly half of the academia and research stakeholder group believed that future additional water would be unavailable.

6 Summary and Recommendations

Datasets derived from the UK Climate Impacts Programme (UKICIP02) climatology have been used to model and map the future agroclimatic conditions under which agriculture might operate and the consequent impacts on irrigation need and volumetric demand. This was complimented by a postal survey to abstractors and a stakeholder workshop, to review and assess farmer adaptation options and responses. The key findings, implications for water resource management and recommendations for further work are summarised below.

Using GIS, a series of agroclimate maps have been produced, for the baseline and each UKCIP02 scenario. The maps show major changes in agroclimate within the catchment over the next 50 years. The driest agroclimate zones are currently located around Worcester, Evesham, Tewkesbury and Gloucester, corresponding to areas where horticultural production and irrigation demand are most concentrated. By the 2020s, all agroclimate zones are predicted to increase in aridity. By the 2050s the whole catchment is predicted to have a drier agroclimate than is currently experienced anywhere in the driest parts of the catchment. This will have major impacts on the pattern of land use and water demand.

Using an irrigation scheduling computer model the impacts of these climate changes on the depths of irrigation water applied and on volumetric demand have been simulated. The analysis suggests that climate change would increase ‘dry’ year water demand for the crops currently irrigated in the Vale of Evesham by around 13-20% by the 2020s, 25-50% for the 2050s and 38-84% by the 2080s. This will inevitably impact on the water demand-supply balance, with more frequent restrictions on irrigation water abstraction.

These estimates exclude the impacts of any increases in demand due to changes in socio-economic policy. The crop sectors most impacted will be potatoes, field-scale vegetables and small fruit production. However, the impacts of elevated atmospheric CO_2 concentration on fertilisation and hence water use and crop productivity in these crop sectors has not been investigated. The changing climate is also likely to result in new crops being grown and some crops that are currently un-irrigated requiring irrigation.

With climate change, farmers will need to implement coping strategies to respond to changing water availability. Farmer adaptation options and responses will depend to a large extent on their perception of the risks and/or opportunities that climate change presents to their business. The postal survey confirmed that most farmers consider climate change to present a major threat to their business, but they are uncertain over the time-scales over which the impacts will take effect. Most farmers questioned believed that in the near future (5 to 10 years) there will be less water available for irrigation and that crop yields and farm incomes will be reduced. Many farmers believed that climate change was already beginning to have a discernable effect on agronomic practices, with longer growing seasons and some new crops being grown.

Farmers were also asked whether they had already started adapting to water shortages, through for example, responses to changes in water regulation or drought. To obtain more water, the preferred choices for farmers have been to convert to mains water, harvest rainwater from land and farm buildings, and/or to re-use waste water. Many believed there was scope to improve irrigation efficiency through better equipment and scheduling. Whilst building a winter storage reservoir remains a viable option, most farmers are reluctant to invest in long-term strategic developments given the short-term economic uncertainty surrounding agricultural production and the changing reliability of local water resources.

Finally, a workshop was held in the catchment to outline the findings and to obtain feedback from a broad range of stakeholders, including representatives from academia and research, government and local authority, industry and consulting and specialist interest groups. The workshop provided a useful opportunity for stakeholders to raise their awareness of the key issues, and to explain and compare their attitudes and perceptions to climate change.

This scoping study has highlighted some of the potential impacts that climate change may have on irrigated horticultural production in the Vale of Evesham, focusing on water demand and farmer adaptation. However, due to its limited geographical focus and scale of enquiry, there remain a number of fundamental gaps in knowledge that need to be addressed, if a more integrated assessment of the impacts of climate change in the rural sector in this region is to be achieved. The key areas that warrant further investigation include:

- Investigating farmer costs associated with adapting to climate change. Better information is needed to help both growers and the regulatory agencies assess the relative costs and benefits of various adaptation options;
- Using case study agribusinesses, to test the UKICIP “climate adaptation: risk, uncertainty and decision-making framework” tool. This could help farmers, the regulatory authority and stakeholders assess the local risks posed by climate change, and work out how best to respond. The tool has been used in other vulnerable sectors to judge the significance of the climate change risk, compared to other risks, so that the appropriate adaptation measures can be implemented. It would involve undertaking case study farm assessments, comparing the different adaptation options and their financial and environmental impacts. It would also provide information to help avoid mal-adaptations that might be unbeneficial at catchment level (in terms of water resources management) or at individual farm level (such as investments in additional water storage);
- Extending the methodologies developed across a wider geographical focus (e.g. Warwickshire Avon CAMS). This would also enable new climate change scenarios from ‘UKCIPnext’ to be evaluated;
- To investigate the impacts on UK irrigators of climate change elsewhere, particularly in countries where horticultural exports are in competition with local agribusiness;
- To assess which new crops which might be grown in the region, and how those that are currently un-irrigated might impact on water demand if irrigation becomes necessary;
- Addressing, with the regulator, how a potential reduction in water resources due to climate change would be allocated between existing abstractors and environmental river flow objectives. This would be useful for assessing farmer adaptations options in response to changes in the magnitude of summer and winter river flows, and could be tested using a hydrological modelling approach in a local catchment (e.g. Badsey Brook). This could provide useful information on climate change impacts in support of the CAMS process.

7 Acknowledgements

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