CCDeW:

Climate Change and Demand for Water

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List of acronyms and abbreviations

AMP	Asset Management Plan (a review of water prices)
AWC	Available water capacity (mm/m of soil)
BLRA	Brewers and Licensed Retailers Association
BSDA	British Soft Drinks Association
CAMS	Catchment Abstraction Management Strategy
CCDeW	Project acronym: Climate change and the demand for water
Defra	Department for Environment, Food and Rural Affairs
EA	Environment Agency
EPA	Environmental Protection Agency
ET	Evapotranspiration
ETo	Reference evapotranspiration (mm/day)
EU FIRMA	European Union funded project on Freshwater Integrated Resource Management with Agents (ends February 2003)
FAO	Food and Agricultural Organisation (Rome)
GDP	Gross Domestic Product
GIS	Geographical Information System
IN	Irrigation needs (mm)
IWR	Irrigation water requirements program
Kc	Crop factor in evapotranspiration calculations
LTA	Long term average
MAFF	Ministry of Agriculture, Fisheries and Food
NSRI	National Soil Resources Institute (Cranfield University)
OFV	Ownership - Frequency - Volume
Ofwat	Office of Water Services (The economic regulator for the water industry in England and Wales)
P	Precipitation
PET	Potential evapotranspiration
pcc	Per capita consumption
PSMD	Potential soil moisture deficit (mm)
RAM	Resource Assessment Methodology
SI	Spray irrigation
SIC	Standard Industrial Classification
SMD	Soil moisture deficit (mm)
SSRC	Soil Sciences Research Centre formerly National Soil Resource Institute
UK	United Kingdom
UKCIP	United Kingdom Climate Impact Programme
UKCIP02	Nomenclature of United Kingdom Climate Impact Programme climate change scenarios produced in 2002
UKCIP98	Nomenclature of United Kingdom Climate Impact Programme climate change scenarios produced in 1998
UKMO	United Kingdom Meteorological Office
UKWIR	United Kingdom Water Industry Research
US	United States
VBA	Visual Basic Applications
WRZ	Water resource zone

Units of measurement

In addition to standard SI units, the following terms are used:

ha	hectare
ha.mm	hectare-millimetre (a volume equivalent to 1mm depth over 1 ha, which is 10 m^3).
l	litres
l/h/d	litres per head per day
d	day
ppm	parts per million
tcm	thousand cubic metres (= 1 megalitre, Ml)
t	tonne
Ml	Megalitre = 1 tcm

Definitions

(Agronomic) Irrigation need	The total annual depth of water needed on a given crop, taking into account the typical irrigation schedules recommended in England and Wales, and local soil and climate conditions.
Average irrigation need	The irrigation need averaged over a defined time period.
Design dry year irrigation need	The 80% non-exceedance need, i.e. meeting the need in 80% of years (calculated statistically over a defined time period).
(Agronomic) Optimum need	Defined to be the design dry year irrigation need.
Economic optimum need	The optimum need (as above) modified to take into account the marginal on-farm costs and benefits.
Volumetric irrigation demand	The total volume of water required for a given area./region. (average/dry year and agronomic/economic as appropriate)

Executive Summary

The Climate Change and Demand for Water Revisited project (CCDeW) revisits and updates the benchmark study by Herrington (1996) and takes advantage of new data sets, regional coverage of demand projections and new methodologies for climate impact assessment. Domestic demand, industrial and commercial water use and irrigated agriculture and horticulture are included in the CCDeW study. Leakage was excluded from the CCDeW study.

This report presents the outcome of an extensive UK research programme concerning: demand forecasting; demand management; sensitivity of demand to climatic variations; and sources of risk and uncertainty.

While the CCDeW study focuses on demand, climate change uncertainties feed into supply side and demand estimates of water requirements. Therefore, the report's conclusions should be seen as one element in the dynamic management of the supply/demand balance over the course of the next twenty years and beyond (see Section 9). Clearly, the extent to which water consumption will be influenced by climate change depends upon the sensitivity of different sectors to specific aspects of climate change as well as potential behavioural and regulatory changes, in part related to different socio-economic and climatic futures.

Methods

In determining the potential impact of climate on demand a range of models were employed. Models were selected variously for their ability to provide insights into the relevant aspects of water demand in a specific sector and their compatibility with available data. The models include statistical analysis for domestic demand (see Chapter 3), expert judgement combined with statistical models (for industrial and commercial demand, see Chapter 4), dynamic simulation (including domestic water use in Chapter 3 and crop water requirements in Chapter 5), dynamic optimisation (for land use, see Chapter 5) and agent-based social simulation (to explore behavioural changes, in Chapter 7).

Common to the assessment in each sector is the use of current UK Climate Impacts Programme's climate scenarios (UKCIP, 2002) and the Environment Agency water demand scenarios (Environment Agency, 2001a, b) based on the socio-economic reference scenarios developed under the Foresight "Environmental Futures" framework (DTI, 1999).

The UKCIP climate scenarios are based on a range of global greenhouse emission scenarios and climate sensitivities. The four scenarios are developed from the Hadley Centre's global climate model, utilising the high-resolution regional climate model runs for the 2080s. Four scenarios are presented representing Low, Medium-Low, Medium-High and High global emissions of greenhouse gases.

The science behind climate change is developing rapidly and the Intergovernmental Panel on Climate Change conclusion that anthropogenic climate change is inevitable appears increasingly robust (IPCC, 2001). However, the available climate change scenarios do not provide probabilistic projections of the future climate of the UK and many uncertainties remain as to the timing and extent of climate change. Deficiencies remain in understanding likely changes in the frequency of extended periods of high temperatures and droughts, which are the major concern of the water industry. The projections made in the CCDeW assessment are likely to prove relatively robust for gradual mean changes. However, they do not adequately capture the risks and uncertainties associated with extreme events (see Chapter 8).

The potential impacts of climate change have been reported relative to the EA reference scenarios of future water demand. The four EA scenarios detail how plausible socio-economic conditions (described in the Foresight scenarios) could result in plausible, increasing and decreasing, outcomes for water demand over time (see Section 2.1). For all sectors, the ‘choice’ of reference socio-economic scenario has a larger impact on the forecasted results for the 2020s than the direct impact of climate change. This suggests that innate uncertainty in future climate and socio-economic conditions remains a constraint on more precise projections.

Results

The results of the study are presented for each Environment Agency Region. The results are expressed as a percentage changes from a “without climate change” demand scenario that allows water resource practitioners to apply the results to their own projections of demand. The results apply to average demands only (with the exception of agricultural demand which are for design dry year), although some comments on the potential impacts on peak demands are included in the report. A summary of the results across the regions is shown below.

Domestic demand

For domestic demand, the socio-economic reference scenarios indicate a range of future demand in 2024/25 between 118 to 203 l/h/d, compared to 162 l/h/d in 1997/98. The additional impact of mean climate change on domestic demand is a modest increase in average annual demand, up to 1.8% by the 2020s. For the 2050s, the climate scenarios indicate an increase of 1.8%–3.7% above the socio-economic scenarios (see Section 3.4).

The effect of climate change on domestic demand is not appreciably different across the eight regions of England and Wales. However, in water resource zones where the micro-component composition of water demand is markedly different, the impact of climate change will differ. See for example, Table 3-9.

The study suggests that domestic demand will be sensitive to the interplay of warmer climates, household choices regarding water-using technologies and the regulatory environment. The CCDeW project developed an agent based social simulation model to explore these interactions. The model revealed that an increased frequency of drought could provide the catalyst for the adoption of water saving technologies and associated reductions in demand, or alternatively if the presumption of entitlement to a private good were to exceed the willingness to conserve water during periods of drought, increased frequency of drought could lead to consumers increasing their demand beyond the high reference scenarios. Critically the model identifies the extent of community interaction and particularly the mimicking of neighbour behaviour as a key determinant of the uptake of new water saving technologies. Neighbourly interaction also determines the extent to which households are influenced by policy agent exhortations to use less water in times of drought – closely knit communities appear to be less impressionable. The findings, although purely qualitative, suggest key social determinants of future water demand (see Chapter 8).

Impacts of Climate Change by Component of Water Demand For Selected Marker Scenarios

Domestic demand

	2020s	2020s	2050s
	Low	**Medium-High**	**Medium-High**
Alpha	0.9-1.2%	1.4-1.8%	2.7-3.7%
Beta			
Gamma		1.0-1.3%	
Delta			

Industrial/commercial demand

	2020s	2020s	2050s
	Low	**Medium-High**	**Medium-High**
Alpha	1.8-2.9%	1.7-2.7%	3.6-6.1%
Beta		1.8-3.0%	
Gamma		2.0-3.1%	
Delta		1.7-2.7%	

Agricultural demand

	2020s	2020s	2050s
	Low	**Medium-High**	**Medium-High**
Alpha	18%	19%	26%
Beta		19%	
Gamma		19%	
Delta		20%	

Industrial and commercial demand

Among the industrial/commercial sectors sensitive to climatic variations, soft drinks, brewing and leisure are likely to have the greatest impact on the overall requirements for public water supply. Climate change impacts in industry and commerce are likely to be higher in percentage terms – up to 2.8% in the 2020s – than the impacts on domestic consumption (see Chapter 4). The impacts do not appear notably different across the scenarios. In contrast to domestic demand, there do appear to be differences between the regions, attributable to the different mix of industrial/commercial sectors in each region (see Tables 4-3 and 4-9).

Agricultural and horticultural demand

Climate change could affect irrigation water use via changes in plant physiology, altered soil water balances, cropping mixes, cropping patterns that take advantage of longer growing seasons, and changes in demand for different foods (see Chapter 5). The survey of irrigation of outdoor crops in 2001 confirmed that water use for irrigation is currently growing at 2%-3% per annum, and provided a new baseline for the demand modelling (see Section 5.3).

Agroclimatic zones defined by soil-moisture-deficits will move northwards and westwards in the UK as a result of climate change. By the 2020s, central England will experience conditions similar to those currently typical of eastern England, and by the 2050s eastern, southern and central England will have irrigation needs higher than those currently experienced anywhere in England (see Section 5.5).

The climate change impacts (including changes in demand for water by crops, effects of CO_2 enrichment, and expected irrigation use) modelled in this study indicate increases in irrigation use of around 20% by the 2020s and around 30% by the 2050s (see Section 5.7). The impacts are region specific, with expected changes relative to the baseline, ranging from a decrease of 4% in the North West to an increase of 24%-25% in the Thames region.

Leisure sector demand

The analysis of potential impacts of climate change on the leisure sector has been limited by the paucity of historic data from which to establish relationships between climate variables and consumption (see Chapter 6).

Summary: England and Wales

The total impacts for England and Wales appears to be on the order of 2% for 2024/25, based on the Beta reference scenario and Medium-High climate scenario (see Section 9.2). The regional impacts vary from 1.3% in the North West to 3.9% in the Anglian region, where spray irrigation is a major factor. By the 2050s, increased climate change leads to greater impacts—perhaps a further increase of 1-2% in the regional impact of climate change.

Impacts of Climate Change on Demand for Water in England and Wales
For the Selected Marker Scenarios

	Climate change		
EA Reference	**Low**	**Med High**	**Med High(2050s)**
Alpha		1.4%	
Beta		2.0%	3.8%
Gamma	1.8%	2.0%	
Delta		1.8%	

Note: The shading in the 2050s cell indicates a rough estimate of the total regional effect of climate change on water demand. The EA reference scenarios are limited to 2024/25 and the CCDeW project did not project all components of demand to the 2050s.

Guidance and further assessment

The simplest guidance for using the CCDeW results is to apply the regional impacts reported here to the entire water company area. For example, the impact in the 2020s for domestic demand is between 0.9 and 1.8%, depending on region and scenario. An additional factor in headroom of, say, 1.5% would be justified. More detailed calculations are possible, based on the micro-components of demand, but may not be justified by the relatively modest climate impacts shown above. In the case of irrigated agriculture, the relatively larger impacts (on the order of 20%) may justify additional estimates at the water resource zone level.

Improved understanding of climate change impacts on demand is as important as for groundwater and hydrology. A continuation of present monitoring systems, especially for a sample of households, key industries and irrigation, is essential. The lack of data on industrial and commercial use is a major constraint. Detailed studies of specific dynamics are warranted, in particular the willingness and ability to reduce demand during periods of water shortage. The next major assessment should adopt a risk methodology employing probabilistic scenarios of climate change, including climatic variability and extremes, and linking climatic episodes to realistic responses by key users.

Part I: Introduction

1 The CCDeW project

The Climate Change and Demand for Water (CCDeW) project has undertaken a review of climate change impacts on water demand, revisiting and going beyond the benchmark study by Herrington (1996).

In this chapter of the report we outline the need for this work by looking at past studies of climate impacts on demand and their current place in water resources planning; present the aims of this study; and provide an overview of the project and the structure of this report.

1.1 Background—water demand and climate change

In the UK, outputs of UK Water Industry Research (UKWIR)/ Environment Agency work by Nigel Arnell (Arnell, 1998) have provided a base for most assessments of the potential impact of climate change on water resources (supply). Based on this study, and others, it is widely acknowledged that anthropogenic climate change will affect the quantity of water that is available to a growing and increasingly urbanised and affluent population in the United Kingdom (UK) (UK Climate Impacts Review Group, 1996; TWUL, 1998). However, less work has been conducted to determine how this population's demand for water for household use, industry and commerce, agriculture and leisure will be impacted by climate change.

At a global level, the IPCC (2001) has projected that climate change is unlikely to have a large impact on industrial and municipal demand for water but may substantially increase the demand for irrigation water. However at a national scale in the United States, researchers Richard Vogel, William Moomaw and Paul Kirshen at the National Centre for Environmental Research (Vogel *et al.*, 1999) examined the impact of climate change on water resources and found that:

- US climate related trends in water supply and shortages were region specific.
- Domestic use of water showed no national trends in relation to climate or household wealth, but when data was analysed regionally domestic water demand was sensitive to price and climate.
- Much of the variability in projections as to how climate change will impact on water demand can be explained by inter-regional differences.

This research points to a need for the study of specific climate change impacts on local or regional water demand. However, relatively few of these studies exist and no definitive methodology for undertaking such a study has been developed, though much can be learnt from Arnell *et al.*, (1994), Arnell (1996, 1999a, b) for existing water supply studies, and Downing *et al.* (2000); Environment Agency (1997) (1999); Fenn and Kemlo (1998); Wade *et al.* (1999); Weatherhead and Knox (2000) for water demand studies.

In the academic literature, the REGIS project (Holman *et al.*, 2002) has looked at the impacts of water resources in the North West of England and in East Anglia. This includes annual river flows, groundwater recharge and water quality but no mention is made of the impact of climate change on demand other than as input to the socio-economic scenarios.

The need for regional studies of water demand and supply under climate change in the UK was highlighted by regional consultations that were co-ordinated by the UK Climate Impacts Programme (UKCIP). For example in a report on the South East it was stated: "There is no doubt that one of the greatest challenges for the South East will be balancing the supply and demand for water. The area has the highest demand for water per head of any other area in the UK. During the summer of 1995 three of the water companies in the South East imposed restrictions on water use, including hosepipe bans. By the 2080s, the dry conditions experienced in 1995 will occur more frequently" (Wade *et al*., 1999). Wade and colleagues proceeded to say that demand for water increases considerably in hot summers, and that the management of water demand through water metering, the use of water saving devices, restrictions for some uses (golf courses and car washes) and increased awareness amongst the public to use water efficiently, will become more important.

To date, most of the regional assessments of water demand in the UK have been based on results in the Herrington report (Herrington, 1996) or related papers. Herrington (1996) examined potential climate change impacts on specific sectors, and reached the following conclusions:

- **Impact on commercial air-conditioning:** It was assumed that objections to water-based systems could be overcome. Estimated increases of 0.1% - 1.3% of then non-domestic public water supply consumption. Objections to water-based systems have not been overcome in the air-conditioning industry and consumption in this sector is likely to fall.
- **Golf courses:** An increase in the number of golf courses was anticipated and a 9%-20% increase in irrigation water required over the "no climate change scenario" was projected for the 1992-2021 period.
- **Agriculture and horticulture:** Estimated increase of ~ 12% over the "no climate change demand" scenario. This sector represented ~ 7% of non-domestic total.
- **Domestic demand:** Herrington looked at personal showering, lawn sprinkling and garden use. The proportion of households watering gardens was estimated to rise from 70% to 75% given general warming. Non-metropolitan demand (South and East England) expected to increase to 178.4 +/- 17.8 litres per head per day (l/h/d) by 2021 without climate change, and to 185.6 +/- 18.6 l/h/d given a 1.1°C warming by 2021.
- **Non-domestic sports and recreation:** Estimated increase of ~ 4% over the "no climate change demand" scenario, but sector represented <1.5% of non-domestic total demand.

Although in the UK, programmes such as Envirowise (formerly Environmental Technology Best Practice Programme (ETBPP)), the Watersave Network and initiatives from the Environment Agency National Water Demand Management Centre (NWDMC) have investigated water consumption from the perspective of national water conservation and water use efficiency, work in the water industry has focussed more specifically on how to account for climate change in the supply-demand balance.

Detailed projections of water demand are required by the utility companies as part of their forward planning, by regulators who evaluate industry performance and by environmental managers who plan for sustainable development (see for example Rees and Williams, 1993). Projections are also of interest to end-users who may wish to calculate or adjust their consumption.

In company plans, supply and demand are reported in separate tables, and climate change can be factored into both supply and demand. However, the emphasis in the plans is on understanding and managing risk. Typically, water companies have adjusted headroom - the safety margin between supply and demand – to reflect the increased uncertainty regarding climate change, rather than relying on projected impacts for both supply and demand. Notably, however, a few water companies have based their strategy on more detailed analysis using published information or conducting specific studies of their own. Mid-Kent Water (MKW) for example have applied neural networks to model incremental changes in weather variables and track the associated change in per capita consumption (pcc) and a study by Southern Water investigated the correlation between peak domestic demand and a number of climate variables including rainfall and temperature (Ball and Parker, 2001, personal communication). Results of many of the other company specific studies are not widely available, but knowledge of the outcomes gained by members of the CCDeW project team have informed this study.

In the period since the second Asset Management Plan (AMP2) review of water prices in the UK, the water industry has undertaken a structured programme of research and development to improve the basis for water resource planning. Some of the methodologies emerging from past UKWIR and Environment Agency Research and Development programmes (for example the demand forecasting methodology (UKWIR/NRA, 1995), the assessment of groundwater yields (UKWIR, 1995) and the impact of climate change on water resources (Arnell, 1999) provided the basis for constructing the building blocks with which current water resource plans were compiled. Others research studies conducted (for example the economics of demand management (UKWIR/Environment Agency, 1996), the assessment of outage (UKWIR, 1995) and the assessment of headroom, (UKWIR, 1998)) were more concerned with how the various elements of supply and demand management were put together to develop parts of the plan. The overall structure of the plan was set out in the Agency's Water Resources Planning Guideline (Environment Agency, 1997).

Whilst the output from the recent research and development projects has provided some important advantages over the previous approaches, their application in water resource planning has drawn attention to some important practical and theoretical issues. These include two joint UKWIR/Environment Agency projects: the first on a unified methodology for the determination of deployable output from water sources (UKWIR/Environment Agency, 2000) and the second on critical period groundwater yield (UKWIR/Environment Agency, 2001). The latter project considered the potential impact of climate change on groundwater resources. It is noted again, however, that though some of the reports deal with water demand and some with the impacts of climate change, none have related the two to each other.

For the current asset management planning round, the Environment Agency has released a Draft Water Resources Planning Guideline (Environment Agency, 2002, available on www.environment-agency.gov.uk). The work presented in the CCDeW report will be reviewed by the Agency with the aim of identifying and agreeing appropriately what may need to be done by companies to ensure water resources plans account for the latest indications of climate change impacts.

1.2 Aim and scope of the CCDeW study

The CCDeW project systematically aims to evaluate the impacts of climate change on water demand from domestic uses, industry and commerce, and agriculture and horticulture. Impacts on leisure and recreation are covered, but with less systematic treatment. The study:

- Explores the dynamics of water demand, using diagnostic statistics and expert opinion.
- Investigates the historical sensitivity of water demand to climatic variations.
- Compares the impacts under current scenarios.
- Includes different non-climatic reference scenarios.
- Evaluates key uncertainties, based on a range of socio-economic and climate scenarios and uncertainty in the underlying assumptions.
- Includes stakeholders and water experts in the design and review of the analysis.

These features go much further than the methods and data available in Herrington (1996) and constitute a significant step towards a "state of the art" climate change impact assessment. The results of CCDeW will feed into the on-going water resource planning process.

1.3 Overview of the CCDeW project and final report

The CCDeW project began in July 2000 to review the work conducted by Herrington (1996) and update the methodologies and findings considering new data, updated UKCIP climate scenarios (Hulme *et al.*, 2002), and demand scenarios developed by the Environment Agency (Environment Agency, 2001b).

A steering group made up of decision-makers from the water industry, Defra, UKCIP, the Environment Agency and Ofwat played an active role in guiding the project team in their work and making recommendations regarding the structure and content of the final report.

The project has also drawn on input from the wider water community in two workshops, the first to focus the project work plan and review recent research on climate change and water demand and the second to discuss specifics of the technical aspects of the models and methodologies selected by the project team.

This final report is intended to include sufficient detail to be useful to water resource managers but remain accessible to a less specialised audience.

The report is divided into three main parts:

- Part I is an introduction that provides the background, describes related research and work and details the means by which data used in this study was procured and generated.
- Part II describes the impacts of climate change on the four sectors (domestic, industry and commerce, agriculture and horticulture, and leisure). In

acknowledgement of the fact that readers of this report will be divided in terms of their interests, sectors have been analysed and presented independently. Each chapter stands alone with its appendices, in order that individuals can read each sector report in isolation. This inevitably means that there is some repetition within the full report, specifically concerning the use of scenarios and methods.

- Part III presents the regional impacts of climate change across the components of demand and brings together issues of confidence and robustness, cross-cutting synthesis, guidance for the use of the CCDeW assessment, and recommendations for further research.

A list of contributing authors and the project steering group members is given at the end of the report.

The first phase of the CCDeW project was presented to the Chartered Institute of Water and Environmental Management (Downing *et al.*, 2001). The paper provides an inventory of the components of water demand and a discussion of their sensitivity to climate change (Table 1-1). The ratings were subjective and qualitative, but indicated the major sensitivities and priorities for research. While total domestic demand was projected to be fairly level for the next decade (Environment Agency, 2001b), rising demand for garden watering and changes in bathing habits were projected to increase demand for water and be particularly sensitive to climate change.

The final column in Table 1-1 refers to the indirect impacts of climate change. For example in the domestic sector, with warmer weather people may wish to spend more time in their gardens, and have fountains to cool patios by evaporation. Alternatively of course, society may place a higher value on water conservation, which would restrain such non-essential, discretionary water use.

Industrial demand for water is decreasing in most of the UK, due to higher efficiency and reductions in heavy manufacturing. Within the industrial sector the market for beverages is likely to be affected by warmer weather as consumers drink more packaged drinks.

Electricity production requires water for cooling, with some returns to surface water bodies. Accordingly an increase in demand for air conditioning - which will increase the demand for electrical power - will increase the non-consumptive demand for water.

Demand for water by agriculture is strongly influenced by non-climatic factors including the relative price of crops, marketing strategies and consumer demands. Irrigated agriculture is currently expanding, largely in response to market demands for high quality produce and to reduce the risk of losses from drought. If consumer preferences were to change with warmer weather, so that people ate more vegetables and salads for example, demand for irrigated crops would increase. These crops in turn would need 10% to 20% more irrigation water than at present, to compensate for the forecast changes in evapotranspiration and rainfall by 2025 (Weatherhead *et al.*, 2000). Estimating the changes in water demand by agriculture is, however, complicated by the possibility of higher yields and improved water use efficiencies due to the projected higher atmospheric CO_2 levels, both of which are expected to reduce demand. Climatic change may also enable farmers to grow these crops in less water stressed regions of the UK, or lead to the introduction of new crops. In addition the agricultural sector is influenced by climate change impacts and responses outside the UK; water shortages in southern Europe for example might lead to a greater production of irrigated vegetables inside the UK.

The leisure sector could be strongly influenced by climate change as people partake in more outdoor recreation. Intuitively, the use of outside recreational facilities is expected to increase from a winter low through the spring, reaching a peak in summer and then falling back to a winter minimum. The main uses of public water supplies for outdoor leisure activities are:

- irrigation of golf courses (though this may be through direct abstraction rather than treated mains water)
- irrigation of sports pitches to create and maintain "playability"
- private swimming pools

Other outdoor water based leisure and recreation uses natural or man-made water bodies such as lakes, reservoirs and gravel pits, so apart from showering and washing facilities there would be no additional demands on public water supply.

Table 1-1. Sensitivity of water demand to climate change

Component	Trend	Sensitivity to climate change (direct impacts)	Secondary (indirect) impacts
Domestic			
Bathing	+	?	
Other indoor	-		
Garden watering	+	¦	¦
Agriculture			
Irrigated crops	+	?	¦
Processing	-	?	?
Industrial/commercial			
Beverages	+	?	¦
Energy	?	?	?
Manufacturing	-	?	?
Services	+	?	
Leisure			
Golf and parks	+	¦	?
Water centres, pools	+	?	?
Environment			
- Rivers, lakes	?	?	?
- Wetlands	?	?	?

Key:

+ Increasing trend - Decreasing trend ? Uncertain trend

? Low sensitivity, minor component of overall demand

? Medium sensitivity

¦ High sensitivity, climate an important element in seasonal or annual demand

Blank Not sensitive to climatic variations

Note: There are significant variations within each component of demand, especially for manufacturing. Same scale refers to feedbacks in secondary consumption.

Such secondary impacts of climate change are part of the context of the CCDeW project. The project methodology takes some of them into account through the use of socio-economic reference scenarios and behavioural models of climate-induced responses. However, the main focus of the assessment is the direct impacts of altered weather. Chapter 2 sets out our methodological framework, with further details in the subsequent sectoral chapters.

2 Project methodology

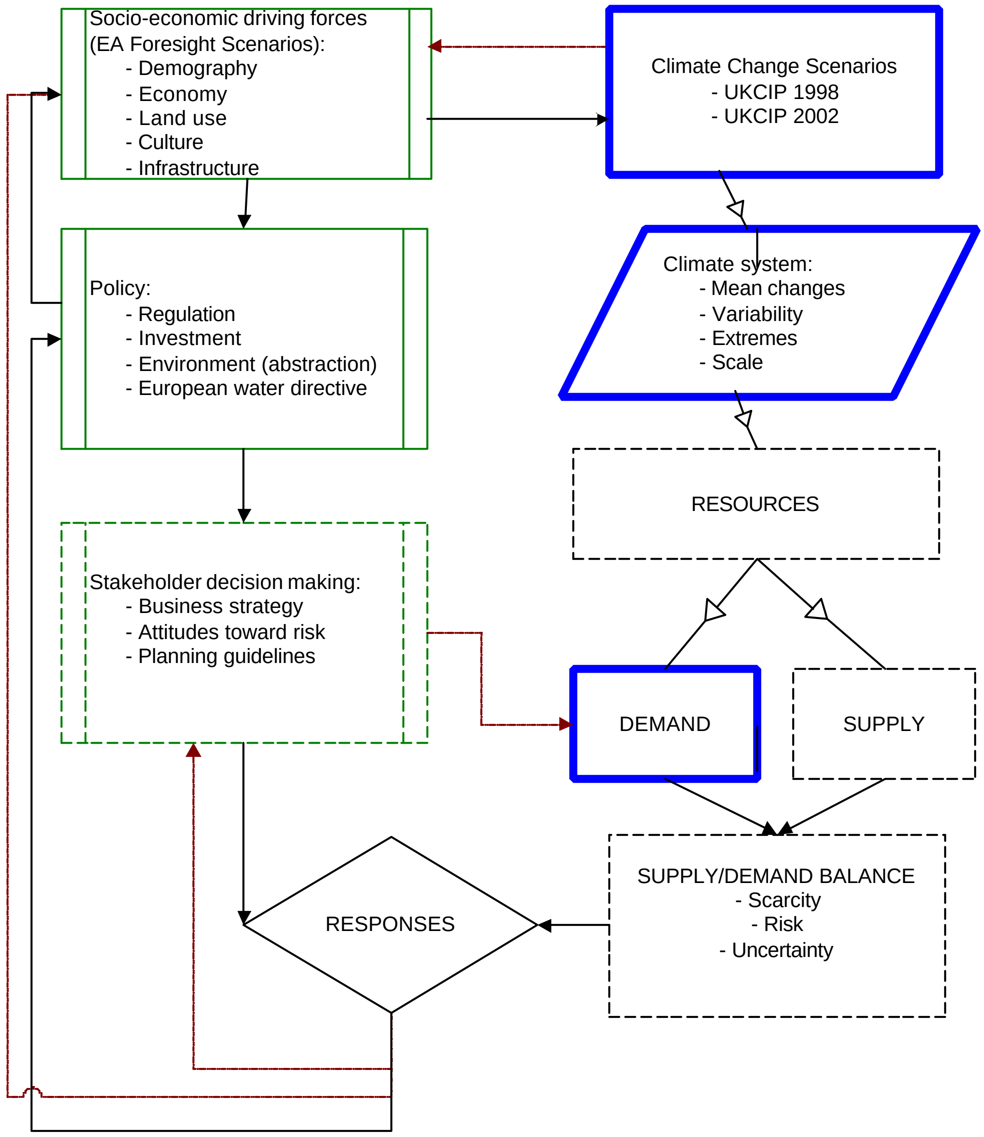
The relationship between climate and water resource supply and demand is complex (see Figure 2-1). The main aim of the CCDeW project is to look specifically at the relationship between climate systems and water demand – the links between the three boxes with heavy outlines in Figure 2-1. The extent to which demand for water will be influenced by climate change varies in accordance with the sensitivity of the different uses of water to specific changes in climate. An increase in the number of warm summer days will, for example, affect consumption of soft drinks, while an increase in mean temperature and lengthened growing season is expected to increase agriculture's need for irrigation.

To capture the impact of climate and socio-economic change on water demand, the CCDeW project has divided water demand into four distinct sectors: domestic, industrial and commercial, agricultural and horticultural, and leisure. Water demand in these sectors has been further disaggregated into micro-components for household demand, industry and commerce sectors (based on the Standard Industrial Classification (SIC, 1992) for industrial/commercial demand and crop categories for agricultural demand. Leisure demand includes aspects of these three components and the analysis summarises the impacts for leisure activities.

A range of models was used across the project to capture the impact of climate change on demand in each of the sectors. Models were chosen for their compatibility with available data and for their proven ability in similar analyses. The models, their validation and use are described in this report (see Part 2, Chapters 3 to 6).

Climate changes, and their impacts, will vary spatially across the UK and will unfold over time against a background of socio-economic change that will colour their extent and importance. Common to all of the analyses conducted for CCDeW are scenarios of future climate change and socio-economic development—the upper row in Figure 2-1. Of course, responses to climate change will mitigate the first-order impacts—the links along the left side of Figure 2-1.

This section provides the background and methodology related to the use of scenarios and the development of baseline data in the CCDeW work. Methodologies for the different sectors are also briefly introduced before the section is concluded with a discussion of constraints and uncertainties associated with the approach. Definitions of key terms can be found in Box 2-1.



- Solid boxes with heavy lines (blue) are the main focus of CCDeW project.
- Solid boxes with light lines (green) are covered in the socio-economic reference scenarios.
- Dashed boxes show components of demand that are not directly part of the CCDeW project, but are covered to some extent in the guidelines on using the results to stakeholder planning.

Figure 2-1. **Simplified schematic of climate change and water demand**

2.1 Use of scenarios

The future is uncertain. Scenarios are plausible, internally consistent, descriptions of possible futures. Scenarios can be predictive but in most current scenario exercises they are used to outline various future 'possibilities' as opposed to 'probabilities'. In this way, scenarios can be useful in planning as they provide a 'wind tunnel' for the testing of strategic plans against different possible futures (Ringland, 1998). Strategy testing exercises generally involve a range of scenarios to check the robustness of a plan under different conditions.

This project aims to improve existing scenarios for future water demand through consideration of how these scenarios could be affected by possible climate futures. These improved scenarios will then be of greater use to water managers in ensuring that their supply and demand management plans will be robust to a greater range of possibilities.

The water demand and climate scenarios used are described in the following sub sections. The Environment Agency reference scenarios provide demand forecasts developed for the Environment Agency's water resource strategy and make varying assumptions about the components and micro-components of demand.

2.1.1 Environment Agency reference scenarios for water demand

In 2001, the Environment Agency produced four scenarios for future water demand for their Water Resources Strategy for England and Wales (Environment Agency, 2001a, b). These scenarios present projected water demand for each water-consuming sector under socio-economic conditions described in the UK Foresight scenarios (DTI, 1999). Quantitative values are given for household, non-household and leakage components of the public water supply demand and agricultural spray irrigation, primary industry and manufacturing components of direct abstraction demand for each Environment Agency Region and each water company (as applicable) for the reference years 1997/98, 2009/10 and 2024/25.

The UK Foresight Programme was begun in 1994 to identify future challenges for the UK, bring together diverse expertise to meet these challenges and encourage public debate about the future (www.foresight.gov.uk). The Environmental Futures programme, in particular, aims 'to inform and stimulate debate among businesses, regulators and Government departments about the environment and to encourage them to develop strategies and policies that will prove robust to a range of environmental futures' (DTI, 1999). The programme developed four scenarios for a future United Kingdom differentiated broadly by their different assumptions regarding future social values (consumerism to community) and governance (globalisation to regionalisation). In broad terms the four socio-economic scenarios can be described as:

Box 2-1. Key definitions

The **baseline** (or base year) in this report refers to present conditions—for instance the 1997/98 water demand presented by the Environment Agency as background to its analysis of demands for the National and Regional Water Resource Strategies (EA, 2001b). We also refer to baseline data—a time series of observed climate or demand data, for instance monthly values for 1971-2000.

Scenarios are plausible, internally consistent descriptions of possible futures. We use two sets of scenarios in this report:

> **Climate scenarios** refer to potential future climatic conditions, here we use the recent UKCIP02 scenarios.
>
> **Socio-economic scenarios** refer to potential social, economic and political futures without the effect of climate change taken into account—in this report we use the Environment Agency scenarios of future water demand. In the agriculture chapter we refer to an additional socio-economic scenario, called the **trend scenario**. We refer to the socio-economic scenarios as **reference scenarios** whether it be the Environment Agency socio-economic scenario or the agricultural trend scenario**.**

The **impact** of climate change is the difference between water demand in a reference scenario with and without climate change. That is, climate change impacts are estimated for the same future time period (e.g., the 2020s) and not against the present (the baseline).

- **Provincial Enterprise Scenario:** a future in which the nation state disengages from international and economic systems of governance. This is a low wage and low investment scenario with little concern for social equity. Environment is perceived as low priority despite increased pressure on natural resources.

- **World Markets Scenario:** a future in which a highly developed and integrated world trading system generates high levels of economic growth. Although personal affluence rises, there is little concern for social equity and low concern for the environment, particularly among the less well off.

- **Global Sustainability Scenario**: a future where global institutions play a central role in resolving social and environmental problems. High levels of investment in research and development result in innovative clean technologies that benefit the environment.

- **Local Stewardship Scenario**: a future dominated by regional and local systems of government. Working at the local level, environmental problems are resolved through collective action.

Table 2-1. Assessment of influence of each scenario on the key drivers of demand

Component	**Driver of demand**	**Influence by scenario**			
		Alpha	**Beta**	**Gamma**	**Delta**
All	Cost of water	Very high	High	Medium	Medium
Household demand	Changes to personal washing use	Large increase	Large increase	Small decline	Small decline
	Garden watering	Increase	Increase	Slow decline	Moderate decline
	Miscellaneous	Moderate decline	High growth	High growth	Moderate decline
	Efficient technology	Small decrease	Moderate increase	Increase	Increase
	Regulations particularly effects on WC cistern volumes, power showers and garden watering	Slow decline	Decline	Rapid decline to low volume flush WC	Slow decline to low volume flush WC
	Metering	Very variable locally	Moderate	High	Moderate
Industry and Commerce	Economic growth	1.5%	3%	2%	1%
	Output of manufacturing industries	Increase	Decline	Decline	Decline
	Employment in business services	Decline	Increase	Increase	Increase
	Water-use minimisation activity	Low	Mixed	High	High
	Greening of business activities	Low	Low	High	High

Spray irrigation	Reform of national and international agricultural policies	Increase UK government support	Removal	Full reform	Increase national & regional support
	Role of supermarkets and food processing firms	Continued role	Expansion	Realign position	Marginal role
	Crop quality premium (potatoes)	High	Very high	Medium	Low
	Drought tolerant crop varieties	Low uptake	Low uptake	Very high uptake	High uptake
	Organic production	Low	Low	High	Very high
	Irrigation efficiency	Medium	High	Very high	High

Source: Environment Agency (2001b)

In their Scenario Approach to Water Demand Forecasting the Environment Agency (Environment Agency, 2001b) uses the indicators from the Foresight socio-economic scenarios to assess potential levels of future demand in light of changing water technology, economic growth, demographic change and consumer attitudes. The assessments of impacts of socio-economic change on components of water demand are given in Table 2-1. These extended water demand scenarios are labelled Alpha, Beta, Gamma and Delta to distinguish them from the Foresight scenarios to which they correspond namely Provincial Enterprise, World Markets, Global Sustainability, Local Stewardship respectively.

The CCDeW project has used the Environment Agency implementation of Foresight 'Environmental Futures' scenarios as the baseline of future demand against which potential climate change impacts will be assessed. More specifically, the public household demand scenario for public water supply, the industrial and commercial demand scenario for public water supply and direct abstraction and the spray irrigation scenarios for direct abstraction were used as baselines for climate impact assessment on household, industrial/commercial and agricultural/horticultural demand, respectively.

Note that for agriculture and horticulture, the Foresight and Environment Agency scenarios are developed further from those given above to describe characteristics specific to agriculture. The socio-economic reference scenarios applied in the agricultural analysis are described in more detail in Chapter 5. The agricultural analysis also includes an additional reference 'trend projection' scenario. (See Section 5.6.2 for additional details.)

2.1.2 UKCIP02 climate change scenarios

There are two main uncertainties surrounding the future of climate change: the amount of greenhouse gases that will be emitted; and the reaction of climate systems to the accumulated concentrations of GHGs. Greenhouse gas emissions can be monitored and anticipated under various socio-economic futures but the specific responses of global and local climate systems are unknown.

To address these two areas of uncertainty, the UKCIP climate change scenarios (Hulme *et al.*, 2002)) were used in the CCDeW project (www.ukcip.org.uk/climate_scen/~climate_scen.html). UKCIP socio-economic scenarios for greenhouse gas emissions are based on the Foresight Environmental Futures Programme (corresponding to the Environment Agency water demand scenarios) with increased specificity in factors related to emissions. Emissions were then used as input to constrain the Hadley global climate model (GCM) of the atmosphere, including a dynamic ocean circulation model. The climate sensitivity to the emission scenarios is generally estimated to range from 1.5 to 4.5 °C. The result of the UKCIP scenarios is estimated for a range of parameters related to global climate change.

The project has used the UKCIP02 climate change scenarios after initially testing methods on the UKCIP98 (Hulme and Jenkins 1998) scenarios. Table 2-3 summarises the differences in carbon dioxide concentrations and global average temperature changes between the 1998 and 2002 scenarios. The four UKCIP02 scenarios yield a range of global warming by the period 2071-2100 (referred to as the 2080s) of 2.0°C and 3.9°C. The absolute levels of warming are slightly higher than in the UKCIP98 scenarios, with a range from 1.1°C to 3.5°C, although this new range is slightly narrower. Hulme *et al*. (2002) provide more information on how the scenarios were produced and the differences between the two sets.

Table 2-2. Global climate change estimates for three future 30-year periods centred on the decades of the 2020s, 2050s and 2080s and for various scenarios. Results for the UKCIP98 scenarios are shown for comparison with the UKCIP02 scenarios (temperature changes are with respect to the 1961-1990 average)

	2020s		**2050s**		**2080s**	
UKCIP02	ΔT(°C)	CO_2 (ppm)	ΔT(°C)	CO_2 (ppm)	ΔT(°C)	CO_2 (ppm)
Low	0.79	422	1.41	489	2.00	525
Medium-Low	0.88	422	1.64	489	2.34	562
Medium- High	0.88	435	1.87	551	3.29	715
High	0.94	437	2.24	593	3.88	810
UKCIP98						
Low	0.57	415	0.89	467	1.13	515
Medium-Low	0.98	398	1.52	443	1.94	498
Medium- High	1.24	447	2.11	554	3.11	697
High	1.38	434	2.44	528	3.47	637

The UKCIP provided data for a range of climatic variables from the UKCIP02 database, at both 50km and 5km resolutions. For each scenario, at 50km resolution, the UKCIP02 database included rainfall, temperature, relative humidity, radiation and wind speed. These were used in modelling for all the sectors. The agricultural modelling study was also based on information in the 5km databases, in spite of problems regarding the availability of certain climatic parameters when working at this resolution. 50km databases were used to verify the 5km database for selected variables.

The UKCIP02 database provided climate change data for three time slices (2020s, 2050s, and 2080s) and for four core emissions scenarios (Low, Medium-Low, Medium-High, and High). The UKCIP02 scenarios express future change relative to either a model simulated trend (50km resolution) or an observed trend (5km resolution). For the 50km database, future changes are expressed as anomalies to the simulated 50km trend; for the 5km database, future changes are expressed as absolute values relative to the observed database. The Met Office also provided 5km (observed) resolution data relating to a 1961-1990 long term average.

The uncertainty inherent in all climate change forecast scenarios is discussed in Chapter 8. The use of UKCIP scenarios, however, introduces specific limitations that need to be understood if the findings of this report are to be applied judiciously. The UKCIP02 scenarios are based on a nested model approach and rely heavily on emission levels (Hulme *et al.* 2002). The ocean-atmosphere HADCM3 experiments provided the boundary conditions to drive a high-resolution model of the global atmosphere (HADAM3H). The outputs of these experiments in turn provided the boundary conditions to drive the high-resolution regional model of the European atmosphere (HADRM3). The substantial computing costs associated with this method required that model simulations be limited to the periods 1961-90 and 2071-2100. The UKCIP02 scenarios were generated using a scenario that projects emission levels for the 2080s. Based on model outputs for this marker scenario, the backcasting technique of “pattern scaling” (perturbation of the respective global average temperature changes for the different periods) is used to obtain scenarios for the 2020s and the 2050s. Using this method, the change in emissions for the 2020s over the baseline period is negligible, making assessments of general climate change impacts for the 2020s particularly difficult. The limitations of this scenario-based method might explain some of the low level of impacts, relative to background variability, projected for the 2020s in some of the forecasts contained in this report.

2.1.3 Creating scenarios of climate impacts on water demand

The CCDeW project evaluated the combined impact of socio-economic change and climate change on water demand. This was done by analysing the impact of climate scenarios on water demand scenarios. However, as there are four Environment Agency scenarios for water demand and four UKCIP climate change scenarios, a total of 16 scenario permutations could have been applied in each impact sector. Clearly this would have involved considerable computer time and a bewildering array of results. It was decided that a core set of scenarios be selected to represent the expected range in results and a reasonable distribution of risk in England and Wales. Table 2-3 identifies these marker scenarios.

The Beta Environment Agency scenario (see Table 2.3) reflects a situation in which water demand is expected to increase in general and so represents the highest expected change to demand caused by socio-economic trends by the 2020s. The choice of Low and Medium-High climate change scenarios is to give a range of climate changes, from those where emissions are restricted to a fairly high emissions scenario. The focus of the project on the 2020s reflects the Environment Agency's water resources strategy of making 25 year projections (Environment Agency, 2001).

As indicated, the project methodology involved extending the reference scenarios of water demand from the EA (Alpha, Beta, Gamma and Delta) through the 2050s for the three sectors of water demand. Where necessary, the reference scenarios were extended beyond the EA planning horizon of 2024/25. This was done for all three components of demand for the Beta scenario through the 2050s. All four scenarios of domestic demand were extended through the 2080s for consistency in the modelling framework (see Chapter 3).

Resulting scenarios of water demand under climate change are expressed as percentage change from the associated reference scenarios.

Table 2-3. Marker scenarios for all sectors. The 2020s indicates the mean of a time slice for 2011-2040 and the 2050s for a time slice from 2041-2070.

		UKCIP02 Climate change scenarios			
EA scenarios	None	Low	Medium-Low	Medium-High	High
Present	Base year (1997/1998)				
Alpha	Reference			2020s	
Beta	Reference			2020s, 2050s	
Gamma	Reference	2020s		2020s	
Delta	Reference			2020s	

2.2 Baseline data

2.2.1 Creating socio-economic and climate data sets

The Environment Agency's water resource planning database was made available to the CCDeW project and this provided the baseline data for the analysis of potential incremental impacts on reference scenario demand. The database includes a detailed inventory of the micro-components of domestic demand by resource zone (some 125 for England and Wales), commercial and industrial sectors by company and micro-components of spray irrigation by region and is therefore suitable for presentation at the regional level. This database (of linked spreadsheets) has been used in conjunction with an *ArcView* database of water resource zones and regional boundaries.

The 125 water resource zones used in the Environment Agency scenarios have been condensed to 52 zones for the purpose of assigning climate change scenario values. Some of the smaller zones have been combined to form larger zones and their data aggregated. A table showing the relationship between the original water resource zones and the CCDeW zones is shown in Appendix 2-A. The boundaries of the eight Environment Agency Regions, and the 125 water resource zones were provided in digital form. The boundaries of the aggregated CCDeW zones were derived from these data (see Appendix 2-B).

The key climate variables of interest to the project were temperature (monthly maximum, minimum and mean), precipitation, radiation, potential evapotranspiration, relative humidity and wind speed. Monthly data were adequate as this was the resolution of most of the demand time series available to the project.

Daily site data from weather stations have been used in both the domestic and agricultural modelling work. These were made available, under licence, from the British Atmospheric Data Centre archive. The daily data were processed into monthly mean temperatures and precipitation totals.

The UKCIP 5km gridded climatology (historical monthly-means) has been summarised by resource zone to provide a consistent baseline climate time series for further analyses. The baseline data at 5km resolution, were made available by the UK Meteorological Office but the scenarios were available at the regional model resolution of 50km. The standard baseline is mean 1961-1990 values but monthly 5km resolution data were made available for the years 1961 - 2000.

The Environment Agency's water resources planning database was linked to the UKCIP02 50km resolution climate change scenarios produced by Atkins. The UKCIP02 50km resolution raw data for mean temperature, maximum temperature, minimum temperature and precipitation were downloaded from the UKCIP website, imported into *ArcView* and converted to a 50km grid. Each variable was calculated as an area weighted average of its water resource zone. The output files were imported into *Microsoft Excel* using *Visual Basic for Applications*. (This data set is available from the project team.)

For this project, the mean changes in the climate variables for the 2020s (2011-2040) and the 2050s (2041-2070) were used. These relate to changes from the average of the model simulated baseline period, 1961 to 1990. In most cases data at the 50km-grid resolution provided a suitable model input. However in order to calculate potential evapotranspiration for the purpose of modelling agricultural and garden water use, the 5km-grid monthly time series was required as a model input.

Potential evapotranspiration was calculated using the FAO Penman-Monteith method (http://www.fao.org/docrep/X0490E/x0490e06.htm). The parameters required for the calculation of potential evapotranspiration (i.e. temperature, radiation, wind speed and humidity) were available for the 5km baseline, 50km baseline and 50km future scenario time series. However for the 5km future scenario time series, the variables of radiation and humidity were not provided in the UKCIP02 scenarios. Radiation and vapour pressure therefore have been derived, using existing and published approaches. A detailed explanation of the methodology is provided in Chapter 5.

Where input data required for the Penman Monteith calculation was unavailable, the Blaney-Criddle method (Doorenbos and Pruit, 1992) of calculating potential evapotranspiration was used (at the site level only- see Chapter 3). The Blaney-Criddle method has a much simpler data requirement and was considered to be sufficiently accurate for calculating garden watering requirements in a soil water balance model.

In summary, monthly precipitation, mean, minimum and maximum temperature were calculated for 52 zones for the control model run and for the climate change scenarios- namely Low, Medium-Low, Medium-High and High emissions scenarios. These were further subdivided into the component water resource zones for analysis with the socio-economic scenarios. These data are available for interested parties. Potential evapotranspiration was calculated at both the 5km and 50km scale for the control model run and the climate change scenarios.

2.2.2 Data for input and validation

Historic data on domestic demand were obtained from water company records either at the household level or for groups of properties (such as control zones). The most suitable means of relating available domestic water consumption data to climate variables is by means of panel surveys that include consumption monitors. Where the data can be related to key household characteristics, it is possible to calibrate demand models. The project was provided with data from water companies in key regions, namely: South West, Southern (especially the control areas), Thames, Three Valleys, and North West. This data has been used as a means of validating models that simulate current climate and socio-economic conditions and to identify links between climate variables and demand.

A survey of irrigation of outdoor crops in England and Wales in 2001 was undertaken as part of this project. The results formed the irrigation water demand database required for the assessment of sensitivity of agricultural and horticultural demand to climate change.

The main source of detailed historic time series data on industrial/commercial water consumption is derived from meter readings and company billing records Water companies are not required to distinguish between industrial/commercial sectors in their regulatory returns to Ofwat and the Environment Agency. However, monthly industrial/commercial data were provided to this study for the period from 1998/1999 to 2000/2001 for various water resource zones (WRZ) in the south of England. Analysis of the data has allowed some general observations about the sensitivity of certain industrial/commercial sectors to climate to be made.

There are no consumption data specifically related to leisure facilities. Data on consumption in the leisure sector has had to be gleaned from various sources. The breakdown of industrial commercial consumption into the sectors identified by the Environment Agency (Table 4-4) does not identify the leisure sector (SIC code O) on its own. Consumption in this sector is included in the “other” category.

2.2.3 Modelling Overview

A range of models has been developed within the project:

- Statistical analysis for selected areas where household, enterprise or land parcel data are available. Such analyses have been developed by several water companies (e.g. Southern Water research on peak demand). These contribute to the diagnostic evaluation and model calibration of the domestic demand modelling work. A statistical relationship has also been developed to model the sensitivity of industrial and commercial water demand to average temperature.
- Dynamic simulation models have been used to capture the sensitivity of monthly domestic demand to present climatic variations, and the extension to future climate change. Such models incorporate the water industry methods (ownership-frequency of use-volume), allowing direct manipulation of changes in the structure of demand.
- Complex physical models have also been used to analyse the spatial and temporal sensitivity of irrigation water needs to future climate conditions and to investigate regional irrigation water demand under the new scenarios.
- A multi-agent simulation model, being developed for the EU funded FIRMA project (http://firma.cfpm.org/), has been incorporated into the project. This model provides a means of exploring assumptions regarding the interaction of consumer attitudes, adaptation to climate change and demand management (see Chapter 7).
- Expert judgement underpins the analysis, especially the interpolation from model results to the final database at the regional level.

Considerable effort was devoted to involving stakeholders and collecting data on present water demand. The analysis is constructed at a relatively fine scale (the water resource zones or gridded soil-water modelling) in order to provide aggregated estimates of climate change impacts at the regional level.

2.3 Constraints and Uncertainties

There are constraints and uncertainties in the CCDeW methodology. This type of analysis requires projections of future climate change and social, economic and institutional conditions, all of which become increasingly uncertain as the spatial and sectoral resolution and the period of the projection increase.

The Environment Agency reference scenarios which have been applied in the sectoral analyses, are exogenous to the study, meaning that the incremental effect of climate change does not feed back into changes in the ownership of water appliances. We illustrate some plausible behavioural responses to climate change using an agent-based simulation model (see Chapter 7).

The climate scenarios do not include changes in the frequency or magnitude of extreme events - neither the variance nor the probability of large scale climate anomalies are altered in the assessment. We provide some insight into such uncertainties in Chapter 8.

The results pertain to the regional level, although water companies plan at the water resource zone level - in Chapter 9 we suggest how to relate the CCDeW results to current water planning.

Further refinement of the methodology, not least combining the impacts of climate change on supply and demand, are warranted to provide robust guidance to water planners in the UK.

2.4 Appendices

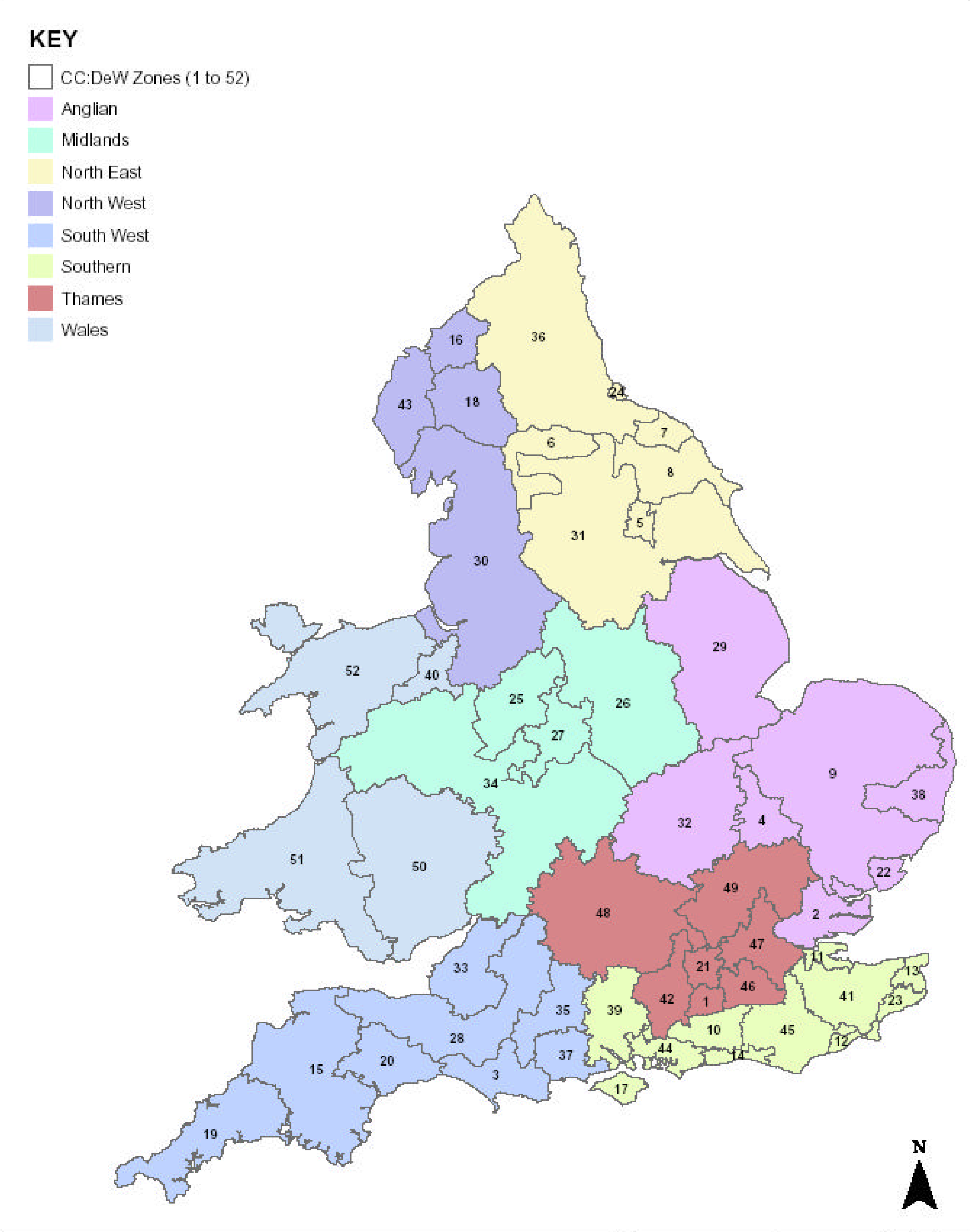
2.4.1 Appendix 2-A. Water resource zones and corresponding CCDeW units

EA Region	Water Company	Water Resource Zone	CCDeW Unit
Anglian	Anglian	Eastern	9
Anglian	Anglian	Northern	29
Anglian	Anglian	Western	32
Anglian	Cambridge		4
Anglian	Essex and Suffolk	Hartismere	2
Anglian	Essex and Suffolk	Hartismere	38
Anglian	Essex and Suffolk	Northern & Central	38
Anglian	Essex and Suffolk	Blyth	38
Anglian	Tendring Hundred		22
Midlands	Severn Trent	Staffs & Telford	25
Midlands	Severn Trent	East Midlands	26
Midlands	Severn Trent	Severn	34
Midlands	South Staffs		27
North East	Hartlepool		24
North East	Northumbrian		36
North East	York		5
North East	Yorkshire	Dales/GWZ	6
North East	Yorkshire	East SWZ	7
North East	Yorkshire	East GWZ	8
North East	Yorkshire	Grid/SWZ	31
North West	North West	Carlisle	16
North West	North West	Eden	18
North West	North West	Integrated System	30
North West	North West	Keswick	43
North West	North West	West Cumbria	43
South West	Bournemouth & W Hants	Alderney	37
South West	Bournemouth & W Hants	Stanbridge	37
South West	Bournemouth & W Hants	Hale	37
South West	Bournemouth & W Hants	Knapp Mill	37
South West	Bristol		33
South West	South West	Roadford	15
South West	South West	Colliford	19
South West	South West	Wimbleball	20
South West	Wessex	South	3
Southern	Folkestone & Dover		23
Southern	Mid Kent	Stansted	41
Southern	Mid Kent	Burham	41
Southern	Mid Kent	Maidstone	41
Southern	Mid Kent	North Down	41
Southern	Mid Kent	Canterbury	41
Southern	Mid Kent	Ashford	41
Southern	Mid Kent	The Weald	41

Southern	Mid Southern	Southern	42
Southern	Portsmouth	Portsmouth	44
Southern	Portsmouth	Gosport	44
Southern	Portsmouth	Waterlooville	44
Southern	Portsmouth	Bishops Waltham	44
Southern	Portsmouth	Bognor Regis	44
Southern	Portsmouth	Chichester	44
Southern	Portsmouth	Horndean	44
Southern	South East	Medway	45
Southern	South East	Mid Sussex	45
Southern	South East	Eastbourne	45
Southern	Southern	Sussex North	10
Southern	Southern	Kent Medway	11
Southern	Southern	Sussex Hastings	12
Southern	Southern	Kent Thanet	13
Southern	Southern	Sussex Coast	14
Southern	Southern	Isle of Wigth	17
Southern	Southern	Kingsclere	39
Southern	Southern	Andover	39
Southern	Southern	Broughton	39
Southern	Southern	Hants South & Winchester	39
Thames	Mid Southern	Northern	42
Thames	North Surrey		21
Thames	Sutton and East Surrey	Sutton	46
Thames	Sutton and East Surrey	East Surrey	46
Thames	Thames	Guildford	1
Thames	Thames	South East London	47
Thames	Thames	Thames Valley	47
Thames	Thames	Lee Valley	47
Thames	Thames	Henley	48
Thames	Thames	Slough/Wycombe/Aylesbury	48
Thames	Thames	Kennet Valley	48
Thames	Thames	South Oxfordshire	48
Thames	Thames	Swindon	48
Thames	Thames	North Oxfordshire	48
Thames	Three Valleys	Rickmansworth	49
Thames	Three Valleys	Watford	49
Thames	Three Valleys	Hatfield	49
Thames	Three Valleys	Iver	49
Thames	Three Valleys	Harlow	49
Wales	Dee Valley		40
Wales	Dee Valley		40
Wales	Welsh	Llyswen	50
Wales	Welsh	Brecon Portis	50
Wales	Welsh	Vowchurch	50
Wales	Welsh	Rhondda	50
Wales	Welsh	Cynon	50
Wales	Welsh	Grwyne/Cwmtillery	50
Wales	Welsh	Talybont	50
Wales	Welsh	Upper Lwyd	50
Wales	Welsh	South East Gwent	50
Wales	Welsh	Pilleth	50

Wales	Welsh	Ross-on-Wye	50
Wales	Welsh	Monmouth	50
Wales	Welsh	Whitbourne	50
Wales	Welsh	Hereford Conjunctive-Use	50
Wales	Welsh	Leintwardine	50
Wales	Welsh	Elan - Builth	50
Wales	Welsh	Pontsticill - Heads of Valley	50
Wales	Welsh	Sluvad/Court Farm/Llwynon	50
Wales	Welsh	South Pembrokeshire	51
Wales	Welsh	North Pembrokeshire	51
Wales	Welsh	Tywi Conjunctive Use Zone	51
Wales	Welsh	Mid & South Ceredigion	51
Wales	Welsh	North Ceredigion	51
Wales	Welsh	North Eryri-Ynys Mon	52
Wales	Welsh	Lleyn-Coastal Meirionnydd	52
Wales	Welsh	Dyffryn Conwy	52
Wales	Welsh	Capel Curig	52
Wales	Welsh	Dolwyddelan	52
Wales	Welsh	Tywyn-Aberdyfi	52
Wales	Welsh	Abergynolwyn	52
Wales	Welsh	Dolgellau	52
Wales	Welsh	Blaenau Ffestiniog	52
Wales	Welsh	Llwyngwril	52
Wales	Welsh	Betws-y-Coed	52
Wales	Welsh	Clwyd Coastal	52
Wales	Welsh	Bala	52
Wales	Welsh	Corris-Pennal	52
Wales	Welsh	Dinas Mawddwy	52
Wales	Welsh	Alwen Dee	52
Wales	Wessex	North	28

2.4.2 Appendix 2-B. CCDeW climate zones as applied in the CCDeW study



Drawing Title CC:DeW Climatic Zones	Scale 1:3,000,000	Drawn JT	Checked BP
Project CC:DeW	Drawing No.	Date 18/10/2002	

Part II: Sectoral analyses

3 Domestic demand

3.1 Introduction

This chapter presents estimates of the impact of climate change on domestic water demand. The methodology follows the overall project design, using reference scenarios of future demand from the Environment Agency and climate change scenarios from UKCIP to describe "percentage change" impacts at the regional level.

The analysis, and chapter contents, follows a sequence of steps:

- Characteristics of domestic demand are described (section 3.2).
- The methodology is presented in section 3.3. The steps are:
    - Compile baseline and scenario data.
    - Represent local impacts of climatic variations on domestic demand in a dynamic simulation model (CCDomestic). This model was run for a sample of water resource zones where detailed demand data were available. The model was validated against historical data, but only to a limited extent.
    - Calibrate the CCDomestic model to the EA reference scenarios in order to incorporate these underlying scenarios of water demand (ownership-frequency-volume) in the assessment of future climate impacts.
    - Scale up the water resource zone results to the EA regional level using statistical regressions.
- Results from the CCDomestic model are presented for the selected WRZs and at the regional level, indicating the impacts on the most sensitive micro-components.
- Conclusions revisit Herrington and note the present uncertainties.

Further discussion regarding uncertainty, guidance in interpreting the results and suggestions for further monitoring and research is found in Part III of this report (Chapters 8 and 9).

3.2 Characteristics of demand

An understanding of the nature of domestic demand for water can be obtained by examining information on household ownership of appliances, the frequency of their use and the volumes of water that they use.

Herrington (1996) described the different components of domestic demand as the "micro-components of demand" and summarised the components of domestic demand for the South and East, see Table 3-1 below. Herrington's projection for the south and east 2001 corresponds fairly closely to the EA base year estimate of some 162 l/h/d in 1997/98. Herrington acknowledged that patterns of house ownership and occupancy would influence domestic demand for water, but relied on only one projection of future water demand without climate change. His reference forecast for the south and east for the 2020s, 178 l/h/d is in the middle of the range of Environment Agency scenarios for the same regions.

Among indoor micro-components, two have been changing for a decade or more. Toilets have become more efficient following requirements for low flush toilets. On the other hand, new showers tend to use more water, and more people are having both showers and baths. The major trend in outdoor micro-components is greater watering of gardens. More households are using hose pipes and sprinklers. Gardens are more expensive—with designs and plants that require more water during warm and dry weather. These structural trends in ownership, frequency of use and volume of water used per use underpin the major differences between the EA scenarios.

3.3 Methodology

Figure 3-1 shows the overall approach adopted in this chapter, indicating links between input data sets, modelling and outputs. Following sections provide more detailed notes on the site model and regional estimation techniques.

3.3.1 Linking demand data to regional impacts modelling

The methodology takes advantage of data and models at three scales:

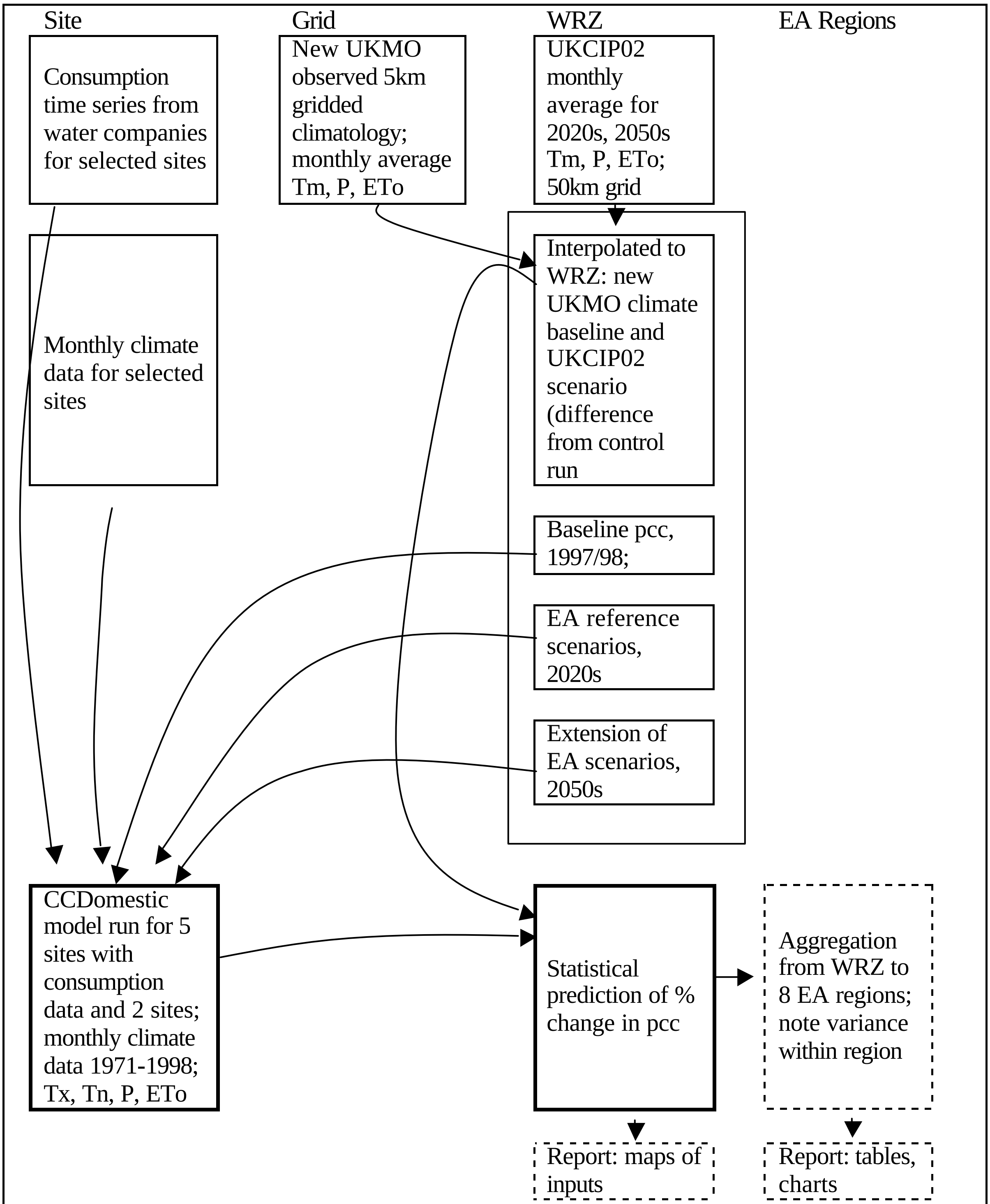
- At the site scale, e.g. a sample of water resource zones (WRZs), empirical data on the micro-components of demand are available and can be linked to climatic variations, using a dynamic simulation model.
- The Environment Agency Water Resources Strategy is based on estimates for WRZs, which roughly correspond to the intermediate spatial scale of gridded climate data and scenarios of climate change.
- The output of the assessment is a set of estimates of climate change impacts at the Environment Agency Regional scale.

The first step involved compiling the input data set (first two rows of the chart). Several water companies made available data on domestic demand either at the household level or for regions (such as control zones). Some water company estimates of the sensitivity of demand to climatic variations were presented at CCDeW meetings.

Table 3-1. Domestic demand for south and east (1976-2021) litres/capita/day). South and east composed of Southern, Thames, South West and Anglian EA regions, taken from Herrington. Bottom lines compare the Environment Agency scenarios for total domestic use for the same regions.

Component	**1976**	**1991**	**2001**	**2011**	**2021**
WC use	36.0	35.5	34.9	34.3	33.6
Personal washing	33.5	46.5	51.2	56.6	61.6
Clothes washing	13.5	21.7	21.4	20.7	22.0
Dish washing	10.2	11.8	11.1	11.0	11.0
Waste disposal unit	0.1	0.4	0.8	1.1	1.5
Car washing	0.7	0.9	1.1	1.3	1.5
Lawn sprinkling	0.1	2.5	4.3	6.6	8.7
Other garden use	1.1	3.8	4.8	5.9	7.2
Miscellaneous use	25.8	23.9	25.6	28.5	31.3
Total domestic use	**121.0**	**147.0**	**155.2**	**166.0**	**178.1**
Environment Agency reference scenarios			**1997/1998**		**2024/5**
Alpha			161.7		202.6
Beta			161.7		198.7
Gamma			161.7		133.1
Delta			161.7		117.6

Source: Herrington (1996) p. 34; Environment Agency Excel database (2001).



Notes: Boxes in solid lines are data sets. The heavy lines indicate model analyses and the dashed lines show the final deliverables.

Figure 3-1. Climate change scenario methodology for domestic water demand modelling

Table 3-2. Selected water resource zones indicating demand data availability and sites with historic climate data

Company	Resource zone	Climate site	Company pcc data
Thames Water	South Oxfordshire	Oxford	Yes
Three Valleys Water	Resource zone 2	Rothamsted	Yes
South West Water	Colliford	Penzance	Yes
North West Water	Integrated system	Knutsford	Yes
Northumbrian Water	Keilder supported	Durham	No
Dwr Cymru- Welsh Water	North-Eryri-Ynys Mon	Anglesey	No
Southern Water	Hants South & Winchester	Southampton	Yes

The main impact analysis instrument was a dynamic simulation model of domestic demand (CCDomestic). Empirical-statistical relationships were explored in the first phase of the project.

Seven sites were selected for the site modelling, representing the diversity of regional situations (Table 3-2). The selection of WRZs was based on the availability of historic climate data and corresponding per capita consumption (pcc) data.

For each resource zone, the Environment Agency estimates of current ownership, frequency of use and volume-per-use for the micro-components of domestic demand have been extracted. Monthly climate data for a nearby station was obtained from the British Atmospheric Research Centre. For some of the sites, pcc data were available to test the plausibility of the model estimates of sensitivity to present climatic variations.

The Environment Agency Water Resources Strategy is based on estimates for WRZs, which roughly correspond to the intermediate spatial scale of gridded climate data and scenarios of climate change.

Spatial climate data were obtained for the UKCIP02 climate scenarios (see www.ukcip.org.uk) and for the UK Met Office baseline climatology. Atkins interpreted the climate scenarios for each WRZ and Cranfield interpreted the new baseline climatology at WRZ level.

The Environment Agency Water Resources Strategy database includes 125 WRZs. For each WRZ, the present water demand is estimated for a standard set of micro-components (Table 3-3), using the industry-standard ownership, frequency and volume (OFV) methodology.

In most cases the model assumes that ownership and frequency change over time. The estimated volume of water used for each event, however, only changes when new technology is introduced (as in water-saving toilets or power showers).

The strategy projects the components of demand for each WRZ to the 2020s for four reference scenarios (Table 3-4). This WRZ database is central to the CCDeW methodology for the domestic sector. It represents the baseline of future demand without climate change. To match the time scale of climate change, the reference demand was projected beyond the Environment Agency 2020s horizon (see below).

The output of the project is a set of estimates of climate change impacts at the Environment Agency regional scale. The methodology required scaling up from the site-WRZs to the regional level.

The lower tier in Figure 3-1 shows the analytical steps. At the site level, a systems dynamic model, CCDomestic, was run (described in more detail below). The purpose of the simulation model is to take the annual OFV estimates and include their (monthly) sensitivity to climatic variations, by changing the frequency of use (but not the volume-per-use). The output of the model is a time series from the 1980s to 2100 for each site and for the micro-components of domestic demand that are likely to be sensitive to climatic variations.

The output of the CCDomestic model was statistically evaluated to prepare a set of transfer functions. The data available in the WRZ level database served as inputs to these functions. The transfer functions were then used to predict sensitivity to climate change for all WRZs—for four reference scenarios and four climate scenarios.

The final step involved the aggregation of the results from the 125 WRZs to the Environment Agency Regional level (the main lower right box).

3.3.2 Climate data and scenarios in the CCDomestic model

The UKCIP02 climate scenarios contain estimates of changes (from the model control run) for mean monthly temperature and monthly precipitation. The results of the study are presented for the eight Environment Agency Regions, but because some of the analysis has been conducted at WRZ scale, the CCDeW database needed to contain climate data at both scales. Some of the WRZ, especially in the South East and in Wales, are relatively small. Given the way in which the 50km data were themselves estimated it was decided to create a smaller number of CCDeW zones made up from a number of complete WRZ. This reduced the number of WRZs for which the Agency had conducted its domestic analysis from 125 to 52 (see Appendices 2-A and 2-B, above). The UKCIP02 climate scenarios were downscaled to this resolution (see Chapter 2).

The CCDomestic model can be run in two modes. For the period from 1971 to 1999 (or the latest year of recorded weather data) the model was run in a historical mode. That is, the actual, observed monthly climate data were used in the CCDomestic simulations. This proved useful for validation purposes—to compare the output of say the 1990s with recorded water use at a WRZ (expressed as pcc) or company region level.

The second mode was to simulate 1981 to 2100, at a monthly time step, using a generated time series of climate data (mean monthly temperature and precipitation). The weather generator followed the form:

$$\mathbf{T = Tm + R + Ts * R + dTm}$$

Where **T** is monthly temperature

Tm is the average monthly mean temperature for the historical record

R is a random number from a distribution with mean 0 and standard deviation of 1

Ts is the standard deviation of mean monthly temperature **(Tm)**

dTm is the change in mean temperature for the given UKCIP02 scenario.

The UKCIP02 climate change scenarios (Low, Medium-Low, Medium-High and High) included estimates of mean monthly changes for each time period. These incremental changes were used to generate time series of climate change. Since reliable estimates at the monthly level were not provided in the UKCIP scenarios, inter-annual variability in climate was not changed. The modelled impacts of climate change are the simulation results with climate change, minus the simulation results for the generated climate without climate change.

This approach provided a consistent treatment of weather in the CCDomestic model—the reference scenario was generated in the same way as the scenarios of climate change.

The historical and generated time series were similar. Figure 3-2 shows the cumulative distributions and x-y correlations for mean monthly temperature for the Rothamsted-Three Valleys site. A slight difference in the extremes is apparent, although the mean values are very similar. By comparison, the cumulative distribution for the High climate change scenario is clearly warmer (but shows a similar cumulative distribution, only with a higher mean value).

It should be emphasised that the approach to generating climate time series does not include any changes in the future variability of climate. Nor is there any persistence in weather from one month to the next. As indicated in Figure 3-2, the limitations are not likely to be serious for fairly small changes in climate (as expected in the 2020s) and for mean changes over a run of years (as in the average of the 2020s). However, concerns for future risks of extreme monthly weather or for runs of hot summers followed by dry winters cannot be reliably evaluated using this approach.

3.3.3 The CCDomestic model

Table 3-3 shows the components of domestic pcc used in the Environment Agency analysis and the corresponding components encoded in the CCDomestic simulations. It was assumed that most of the components of domestic demand were not sensitive to climatic variations. For instance, dish washing, clothes washing and water used in direct heating were assumed to be less significantly altered by warmer weather than activities such as garden watering and bathing. These non-sensitive micro-components were grouped in one category in the model. Their values are taken from the Environment Agency reference scenarios and not affected by climate change.

The model was forced by the Environment Agency's OFV estimates. Since the Environment Agency reference scenarios do not correspond to the model start and end years, additional estimates of OFV were required. From the 1970s to 1997/98, OFV estimates were backcast using plausible assumptions. However, it should be noted that data on appliance ownership, frequency of use and volume are not necessarily reliable for the 1970s and early 1980s.

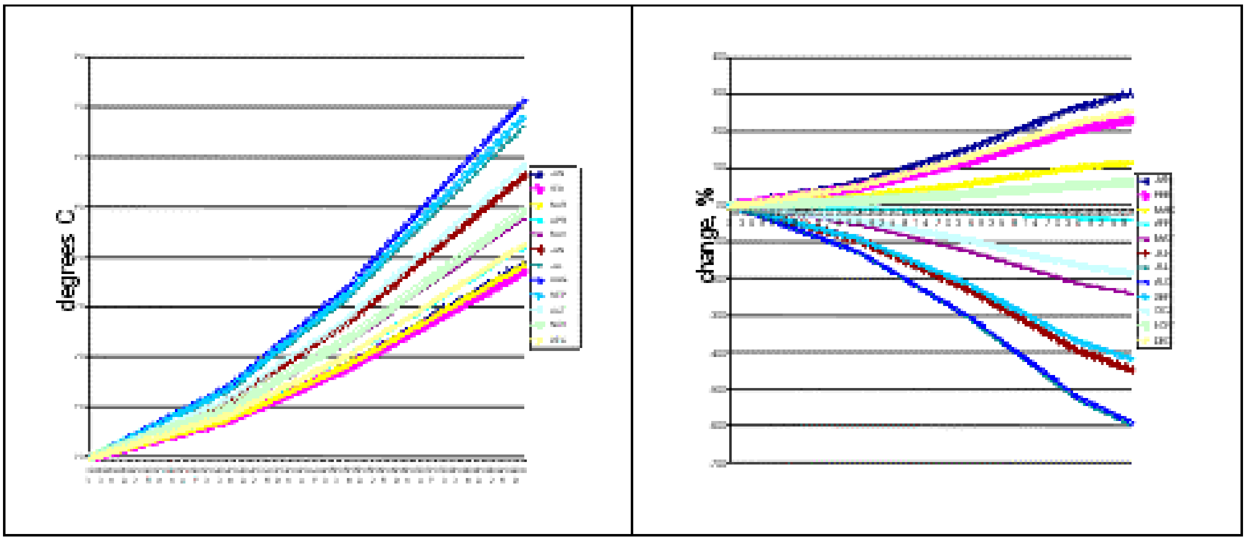


Figure 3-2. Monthly scenarios of climate change for Rothamsted (Three Valleys WRZ 2), based on UKCIP02 High scenario, for mean monthly temperature (left) and precipitation (right)

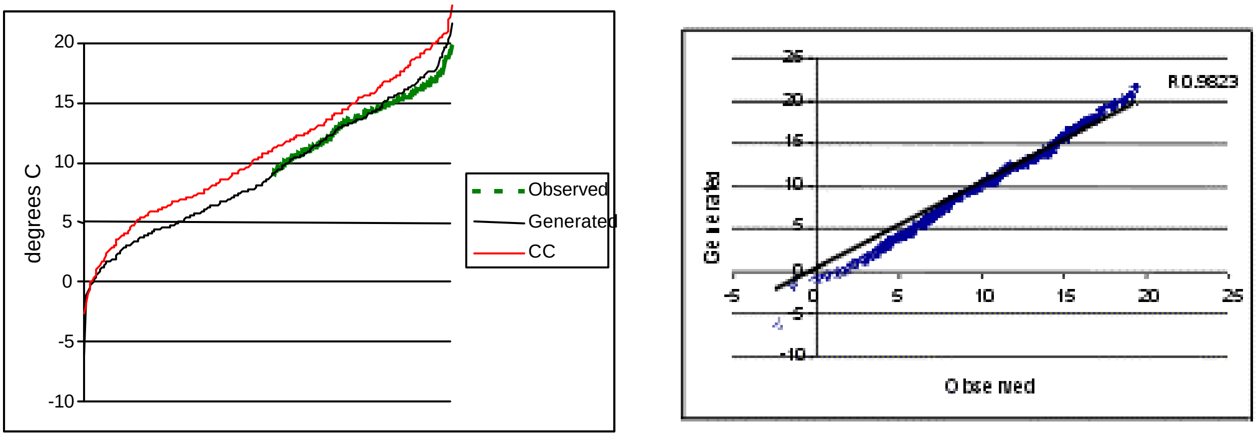


Figure 3-3. Comparison of historical and generated monthly temperature for the Rothamsted-Three Valleys WRZ. The data are for 1970 – 1996 (observed) and 27 years generated from the observed mean and standard deviation. Left shows the cumulative distributions—each time series is ordered from lowest value to highest and plotted. The average values in the middle of the curves are similar, although the generated series has lower and higher extremes. The upper curve is for the High climate change scenario, from the 2020s onward. The figure on the right plots the two ordered time series against each other, showing the high correlation.

Table 3-3. Components of domestic demand

Environment Agency			CCDomestic	
Component	**Demand**	**Micro-component**	**Component**	**Micro-component**
Car washing	0.7	Car washing	Car washing	
Garden watering	6.1	Sprinklers – garden use Other garden	Gardens	Sprinklers - garden use Other garden
Personal washing	33.3	Bath Shower Power shower Hand basin	Bathing	Bath Shower Power shower
Miscellaneous	13.1	Miscellaneous	Miscellaneous	
Clothes washing	14	Manual clothes washing Washing machines	Not sensitive to climate	Manual clothes washing Washing machine
Dish washing	7.7	Dishwasher Dish washing by hand		Dishwasher Dish washing by hand
Toilet use	25	Toilets		Toilets
Direct heating systems	0.1	Direct heating		Direct heating

Note: Demand is % of household total estimated for 1997/98.
Source: Environment Agency (2001b).

Table 3-4. Foresight scenarios used in the Environment Agency Water Resources Strategy

	Water demand	Environmental issues and priorities	Values	UK GDP (pa)
Alpha (Provincial enterprise)	Stable	Low priority placed on the environment. Low levels of investment creating significant environmental problems	Individualist	1.5%
Beta (World markets)	Increases	Environmental improvement not a priority. Emphasis on issues which impact on the individual or local area	Consumerist	3%
Gamma (Global sustainability)	Declines	Sustainable development accorded high political priority. Resource use efficiency drives policy	Conservationist	2%
Delta (Local Stewardship)	Declines	Sustainable development closely integrated into all areas of decision making. Effective community action resolves local environmental problems	Conservationist	1%

OFV projections beyond 2020s were also made. These are extensions of the scenarios developed by the Environment Agency. In many cases, the values in 2020s had reached a plateau or not been altered at all (often volume is unchanged), in such cases the 2020s values have simply been extended. In other cases the trend—of increasing or decreasing values—has been extrapolated, albeit with fairly conservative changes. The relatively conservative approach means that the scenarios for the 2050s represent a continuation of climate change against a reference OFV that closely represents the 2020s.

In addition, the model used the Environment Agency estimates of population. However, all of the results are presented as per capita consumption (in l/h/d), so population growth *per se* does not influence the model results.

3.3.4 Impact sectors: the micro-components of demand

This section describes the calculation of domestic demand, and its sensitivity to climatic variations, in the CCDomestic simulation model.

The indoor micro-components that are sensitive to climate change include an adjustment to the frequency of use, based on accumulated degree days. That is, in prolonged warmer weather the frequency of car washing, bathing and some miscellaneous uses are assumed to increase. Degree days represent the accumulation of time at which temperature is above a threshold of 10 °C. For example, a month with a mean temperature of 15°C and 30 days, would have 150 degree days: {(15°C – 10°C) * (number of days in the month)}. Table 3-5 shows the average degree days for 1961-1990 and the degree days when temperatures are 2°C warmer. This increase in degree days, for example the 50% increase in May with warming of 2°C, is tested for correlation with water demand for personal washing. The assumed behavioural link is that with warmer weather people perspire more, leading to an increased frequency of washing.

The relationship between degree days and frequency of use involves a simple assumption (Figure 3-4 shows a stylised relationship). As degree days accumulate, frequency of use increases, by up to 25% in this example. The relationship between degree days and frequency of use varies somewhat between the sites where the model was run—it is one of the means to adjust the model sensitivity to climatic variations. Figure 3-4 also shows examples of the degree day curves from the CCDomestic model for Three Valleys. Note that the model does not change the volume of water use, and the ownership of appliances is not linked to the climate scenarios.

The method for estimating garden watering is based on soil moisture deficits.

The water balance component follows a generic model developed by the Food and Agriculture Organisation (1986), by which the monthly climate data are translated into a soil water balance for a given month (t):

Available soil water (t) =

Available soil water (t-1)
\+ **Rainfall (t)**
– **Adjusted Potential Evapotranspiration (t)**

Table 3-5. Example of degree days for a temperature threshold of 10°C

Month	Temperature Average	Degree Days Average	Degree Days with +2 deg C	Increase in Degree Days
Jan	3.9	0	0	
Feb	3.9	0	0	
Mar	5.8	0	9	
Apr	8.1	15	75	400%
May	11.6	112	174	56%
Jun	14.8	249	309	24%
Jul	16.8	335	397	19%
Aug	16.3	285	347	22%
Sep	13.9	165	225	36%
Oct	10.8	93	155	67%
Nov	6.7	0	18	
Dec	4.8	0	3	

Note: Averages are for the period 1961-1990. Degree days are calculated for each month (e.g., July 1971) then the average is taken for the 30-year period. This results in different estimates of the monthly average degree days than if the climatological average (shown in the Table for information) is used.

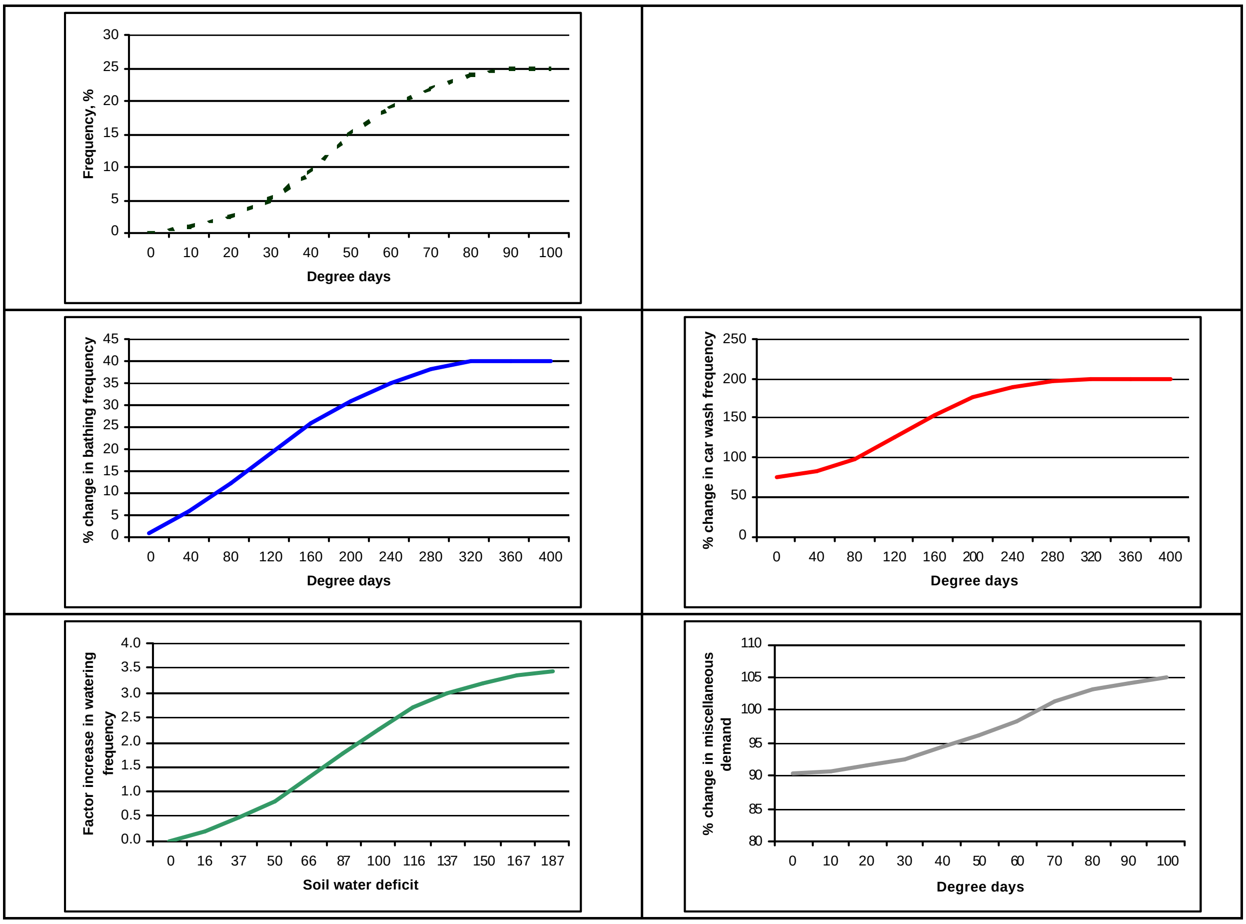


Figure 3-4. Conversion of degree days to increased frequency of use. Top left: idealised relationship; others are from the CCDomestic model for Three Valleys. Middle row: percentages increase in frequency of bathing (left) and car washing (right); Bottom row: factor applied to frequency of garden watering (left) and percentage change in miscellaneous demand.

Potential evapotranspiration (ETo) was calculated according to the Blaney-Criddle method (described in Doorenbos and Pruit, 1992) and provided as an input in the model (see Appendix 3-A). The Blaney-Criddle method was used due to the lack of all of the variables to use the Penman-Monteith formula (see Chapter 2). ETo was adjusted for garden water demand by using the standard coefficients for a mixture of shrubs and grass. Coefficients range from 0.8, in winter months when little growth is expected, to 1.1 at the height of the summer when plants require more water than in the reference ETo. Rainfall in excess of ETo or greater than the water holding capacity of the soil (assumed to be 50 mm in the root zone) is lost to runoff or groundwater. The soil water deficit is the accumulated difference between the plant requirements and the amount of water available.

For climate change studies, the ETo was further adjusted to include the savings expected by higher CO_2 concentrations. Experiments, field studies and detailed model results indicate that plants are likely to use less water with higher CO_2 concentrations as they will be better able to regulate transpiration through leaf stomata. In this analysis, a fairly modest water use efficiency factor has been assumed - 15% for 2050, scaled from 1960 (when CO_2 concentrations were 250 ppm, compared to 350 in the 1990s).

The potential soil-water demand for garden watering was modified to reflect household behaviour. Ownership of watering devices was taken from the reference scenarios. Sprinklers and other devices (e.g., hosepipes and by hand) have different profiles of use. It was assumed that sprinklers would be used to meet up to 60% of the calculated demand while other devices would achieve only a 30% efficiency (in the case of the Southampton model; these parameters are adjusted slightly to tune the model to the EA reference scenarios as discussed below). The modelled water use for gardens was further constrained by seasonal factors were that indicate the likelihood of households to apply water in given months, ranging from no watering in December to February to 2.0-2.5 times the soil water deficit in June to August (again for the Southampton site model).

Other outdoor uses include paddling pools and car washing. Both micro-components are sensitive to climatic variations but are very minor proportions of total domestic demand. Pool demand was included in the CCDomestic miscellaneous component. Relatively little sensitivity to climatic variations was incorporated, using the degree day approach. Car washing demand also follows the degree day approach noted above.

3.3.5 Model validation with historical demand data

The CCDomestic model estimates the sensitivity of domestic water demand to climatic variations. It does not include overt demand management, and the CCDeW project reports estimates of the effects of climate change on unconstrained demand.

For several sites, data sets on actual consumption were available and sufficient to provide a rough validation test of the CCDomestic model. For the validation exercise, the model used historical climate data. The approach is illustrated in the following figures, using the Thames Water region as an example. The result for the Thames Water region is positive, although relatively weak with an R^2 of about 0.15 (Figure 3-5).

A similar example is shown for Three Valleys. The time series of seasonal demand from 1996 to 1999 (Figure 3-6) shows similar behaviour, although the spring peak in 1997 (a drought year) is notably displaced in the CCDomestic model to the late summer and autumn. Figure 3-7 indicates a poor correlation between the observed and modelled demand in the spring through autumn. The correlations for two other regions are shown in Figures 3-7 and 3-8. Strong correlations are apparent in the Southern region for summer and both summer and winter for the Colliford area in the South West region.

These comparisons of observed and modelled demand have some limitations. The available time series are generally limited to a few years, and sometimes for large regions (as in the Thames Region). The model does not included detailed data on each micro-component and its change over time (e.g., ownership of power showers). Actual demand is often restricted (either voluntarily or not) whereas the model portrays unconstrained demand.

However, the results indicate that the CCDomestic model appears to capture a representative degree of sensitivity to present climatic variations. If anything, the model is likely to be too conservative and underestimate the effect of extreme events on demand.

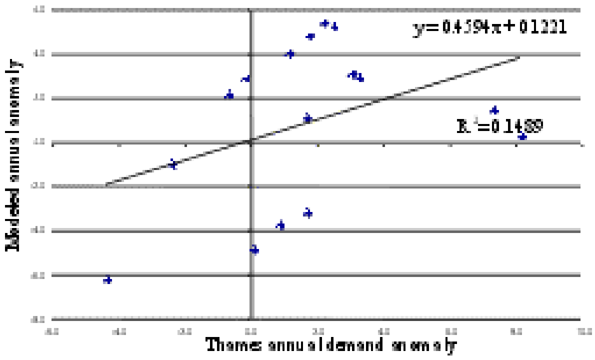


Figure 3-5. Comparison of modelled and observed seasonal demand for Thames Water region for 1977-1997. The data annual anomalies (difference between the annual domestic water use survey and the linear trend in the time series). The observed data (x-axis) are from Thames Water. The model data (y-axis) are based on Oxford climate data. Drought years in 1977, 1982-84 and 1997 have been removed from the time series. The regression and correlation are shown.

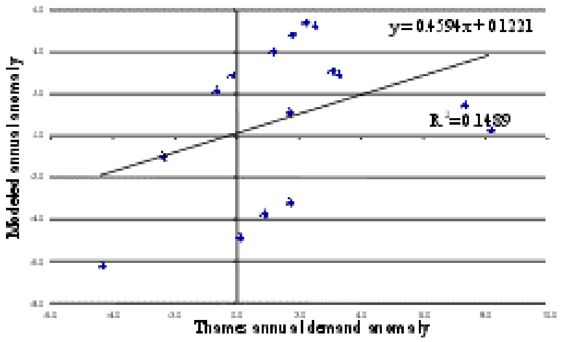


Figure 3-6. Comparison of modelled and observed seasonal demand for Three Valleys Water region for spring through autumn, 1996-1999. The data are seasonal anomalies. The observed data (x-axis) are from Three Valleys Water. The model data (y-axis) are based on Rothamsted climate data. The linear regression (not shown) shows no apparent correlation between the data sets.

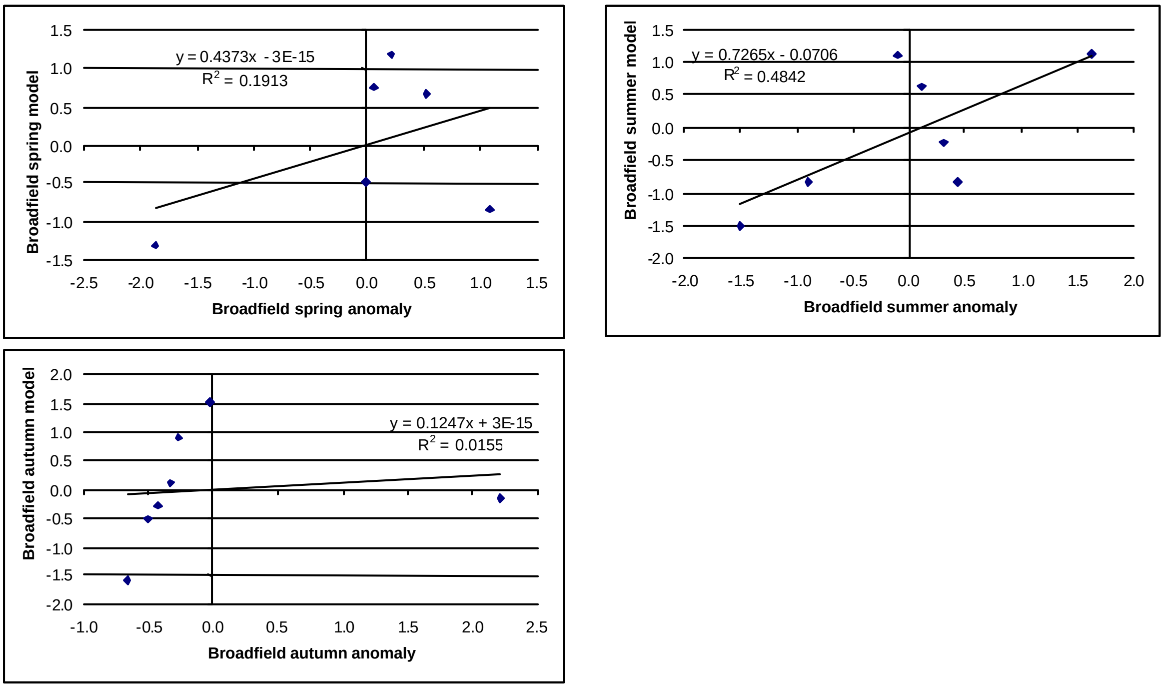


Figure 3-7. Comparison of modelled and observed seasonal demand for Southern region, for spring (top left), summer (right) and autumn (lower left), for 1995 to 2000. The data are plotted as anomalies. The observed data (x-axis) are for the Broadfield control area, of Southern Water. The model data (y-axis) are for Hants South and Winchester water resource zone and Southampton climate data. Linear regressions and correlations are shown.

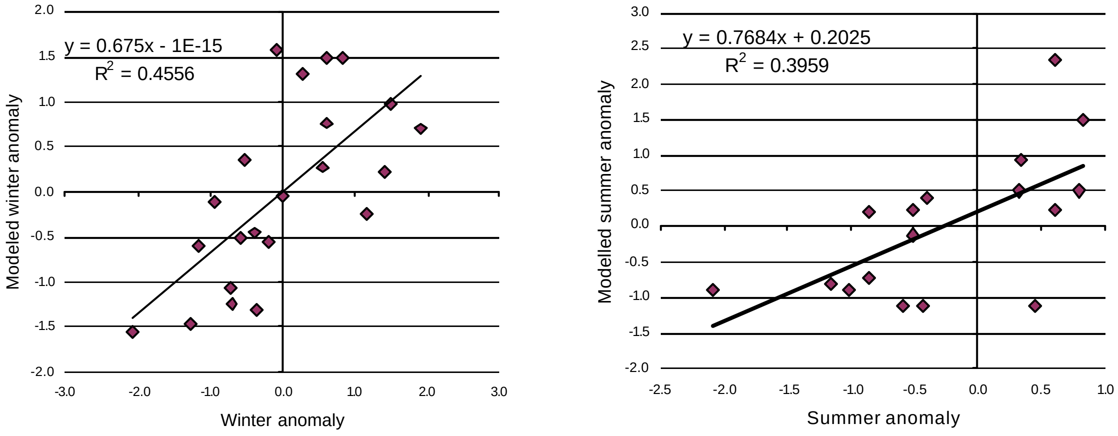


Figure 3-8. Comparison of modelled and observed seasonal demand for South West region, for winter (left) and summer (right), for 1977 to 1998. The data are plotted as anomalies (difference between the seasonal demand and average for the time series, divided by the standard deviation for the time series). The observed data (x-axis) are from South-West Water, from the Colliford water resource zone. The model data (y-axis) are based on Penzance climate data.

3.3.6 Model calibration to EA reference scenarios

Once the model validation at the site level was completed, the CCDomestic model was calibrated to the Environment Agency reference scenarios for a selection of water resource zones. The calibration exercises used the generated reference climate—that is the projections from 1981 to 2100 without climate change. The purpose of the calibration was to ensure that the model replicates as closely as possible the EA reference scenarios—including the CCDomestic model's translation of the impact of climatic variations on demand but not including the additional changes from the greenhouse gas emissions scenarios of climate change. The calibration generally involved altering the degree day-frequency curves described above.

Table 3-6 compares the EA Alpha scenario (top panel) with the CCDomestic model simulations (the middle panel), showing the difference between the two in the bottom panel. While each site model was calibrated against the range of reference scenarios, the correspondence with the Alpha scenario is typical. The total difference for the present and 2020s is quite small—under 2% of per capita consumption. The match is somewhat lower in 2100 (but the climate impacts are relatively greater then too).

The largest residual error is in car washing, but this is a very small component of demand. More important is the bias toward overestimating the demand for garden watering, by over 10% in the 2020s. However, the largest micro-component sensitive to climatic variations, bathing, matches is well calibrated in the model.

With the calibrated models for each site, all combinations of reference and climate change scenarios were run. This site-level data base was then used to scale up to region-wide estimates of the impacts of climate change.

Table 3-6. Calibration of CCDomestic simulation to Environment Agency Alpha scenario

EA Alpha, l/h/d	2000	2020s	2100
Garden	15	19	21
Car	1	2	2
Miscellaneous	17	21	23
Bath	39	78	73
NonClimate	93	82	76
Total	165	202	195
Model, l/h/d			
Garden	16	22	23
Car	1	2	2
Miscellaneous	17	21	24
Bath	40	79	77
NonClimate	94	81	75
Total	168	204	200
Difference (%)			
Garden	5.2	11.6	7.5
Car	7.4	-25.0	-9.9
Miscellaneous	1.3	1.2	2.6
Bath	1.9	0.9	5.6
NonClimate	1.2	-1.1	-1.7
Total	**1.8**	**1.1**	**2.6**

Note: Results for South Oxfordshire water resource zone. NonClimate refers to the other micro-components not sensitive to climate variations, taken from the reference scenarios.

3.3.7 Scaling up from the selected water resource zones to the EA regional level

The site results, for seven sites, four reference scenarios and four climate scenarios, were archived in a database. Extrapolation to the remainder of the 125 WRZs in the database was achieved through a set of regression equations. While a number of statistical tests were conducted, a relatively simple set of equations achieved satisfactory correlations.

The best predictors were:

- Environment Agency reference scenario, where Alpha=1, Beta=2, Gamma=4 and Delta=3.
- Ratio of garden watering demand to total demand in 2020s, without climate change.
- Ratio of personal washing to total demand in 2020s without climate change.
- Total per capita consumption.
- Mean annual temperature change (in °C) for the Medium-High UKCIP02 scenario in 2020s.
- Mean annual precipitation change (in mm/month) for the Medium-High UKCIP02 scenario in 2020s.

Regression equations were calculated for each of the marker climate scenarios—Low and Medium-High scenarios of climate change in 2020s and the Medium-High scenario in the 2050s. The resulting equations are shown in (Table 3-7). Each of the equations accounts for a reasonable proportion of the variance - with correlations of 0.6 to 0.8. Including the total pcc in the equation (as an absolute value some two orders of magnitude greater than the predicted changes) improved the correlations but, counter-intuitively, resulted in negative coefficients for bathing and temperature. The relatively higher intercept for the 2050s scenarios is taken into account by the negative coefficient for garden watering. Further details of the statistical equations are found in Appendix 3-C.

These equations were then used to estimate climate change impacts for each of the WRZs, for each Environment Agency reference scenario and climate scenario. Since the impacts are almost indistinguishable between the Alpha and Beta scenario and between the Gamma and Delta scenarios, the results have been grouped together.

Table 3-7. Regression equations to extrapolate from site to regional climate change impacts

Climate impact	Intercept	EA	Garden	Bath	Tm	Pr	Total	R^2
Low 2020s	1.47	0.27	1.92	-2.52	-1.98	0.25	0.01	0.79
Med-High 2020s	2.03	0.27	1.35	-3.38	-2.14	0.26	0.01	0.81
Med-High 2050s	6.00	0.62	-2.16	-10.43	-5.02	0.83	0.03	0.61

3.4 Model Results: Climate change impacts on domestic demand

To ensure appropriate inference from the modelled results it should be remembered that:

- The reference case is the projection of domestic demand following the OFV scenarios from the Environment Agency Water Resources Strategy with a generated climate that is similar to the present.
- The climate change impact is the difference between the model results for the reference case and those for a generated climate having the same mean changes as the UKCIP02 scenarios.
- The results are presented as the percentage difference between the two simulations of the CCDomestic model, for the same time period.
- The results presented here are for a five-year average, centred around either 2025 or 2055. This removes some of the variability inherent in using a generated climate.

The possible combinations of results are the four Environment Agency reference scenarios (Alpha to Delta) *x* the four UKCIP02 scenarios (Low to High) *x* selected time periods. As agreed with the project steering group, results for ‘marker’ scenarios are presented, namely:

- Gamma reference scenario, Low climate scenario, 2020s
- All four reference scenarios, Medium-High climate scenario, 2020s.
- Beta reference scenario, Medium-High climate scenario, 2050s.

The results at the site level are presented first and include a description of the relative contribution to the total changes in pcc for the climate-sensitive micro-components. The results are then ‘scaled up’ to the regional level.

3.4.1 At the site level

The site results are the basis for extrapolating to the other water resource zones and aggregating to the Environment Agency Region level. The design of the CCDomestic model facilitates running all combinations of the reference and climate change scenarios. In fact, the results confirm the selection of marker scenarios.

For the 2020s, the results are fairly consistent between Environment Agency reference scenarios and climate scenarios (Figure 3-9). Climate change implies an increase of about 1% in total domestic water demand. The variation across reference scenarios is greater than between the climate scenarios. For example, in south Oxfordshire the two reference scenarios with higher per capita consumption (Alpha and Beta) imply a climate change impact of about 1.5%, while the more environmentally oriented scenarios (Gamma and Delta) suggest impacts of less than 1%.

For the 2050s (Figure 3-10), the effects of climate change are larger - across the sites and scenarios, results range from about 1.5% to over 3.5%. Again, the difference between the reference scenarios is more noticeable than the difference between climate scenarios. Appendix 3-B provides model estimates for each of the seven sites.

The proportion of the site-level (or water resource zone level) changes due to individual micro-components is shown in Table 3-8. Caution should be applied in interpreting these results - the model is designed (and to the limited extent possible, validated) to yield estimates for total per capita consumption. The calculations by micro-components provide greater detail and realism, but not necessarily accuracy. Nevertheless, some insight into the nature of the impacts is gained by exploring the micro-component sensitivity to climate change.

For the four selected WRZs, the impact of climate change in the 2020s is 1.2% - 1.7% for the Beta scenario (which has the largest climate impacts) and 0.8% - 1.0% for the Delta scenario (typically with the smallest impacts). The contribution of garden watering to these total impacts is on the order of 25%-30% for the Beta scenario and 15%-20% for the Delta scenario. Note that garden watering decreases strongly overall in the Delta scenario (as does total pcc). Most of the impact is through increased bathing - baths, showers and power showers. The frequency of bathing is assumed to be able to increase, by up to 40% for baths and 60% for showers. In the Environment Agency reference scenarios, the frequency of use of baths is up to 0.3 baths per person per day, with showers and power shower frequency of 0.4 and 0.6 showers per person per day (these are for the Beta scenario).

The figures for the 2050s follow the same pattern, with bathing accounting for an even greater proportion of total demand. (The decrease in demand for Integrated System reflects an abnormally wet year in the simulated weather for this period.)

Table 3-8. Contribution of micro-components to WRZ impact of climate change

	Beta		**Delta**	
	2020s	**2050s**	**2020s**	**2050s**
South Oxfordshire				
Garden	29.8%	18.1%	17.3%	6.2%
Car	4.1%	5.4%	2.6%	3.5%
Misc	0.4%	0.4%	0.4%	0.7%
Bath	65.7%	76.0%	79.7%	90.0%
Total	**1.7%**	**3.1%**	**1.1%**	**2.0%**
Three Valleys				
Garden	33.3%	21.7%	20.8%	7.7%
Car	3.7%	5.2%	2.9%	3.5%
Misc	0.5%	0.5%	0.8%	0.7%
Bath	62.4%	72.6%	75.8%	88.1%
Total	**1.7%**	**3.1%**	**1.0%**	**1.9%**
Integrated system				
Garden	23.7%	-2.2%	12.8%	-0.6%
Car	3.7%	6.2%	2.2%	3.2%
Misc	0.7%	0.6%	1.1%	0.8%
Bath	71.9%	95.5%	84.0%	96.6%
Total	**1.2%**	**1.9%**	**0.8%**	**1.5%**
Kielder				
Garden	27.3%	14.9%	16.3%	4.8%
Car	3.7%	4.9%	2.5%	3.1%
Misc	0.5%	0.6%	0.6%	0.7%
Bath	68.5%	79.5%	80.7%	91.3%
Total	**1.5%**	**3.0%**	**0.9%**	**2.0%**

Notes: Climate scenario is the Medium-High, although relative contribution is similar for all of the climate scenarios. Total is the WRZ pcc for the climate scenario as a percentage increase from the Environment Agency reference scenario.

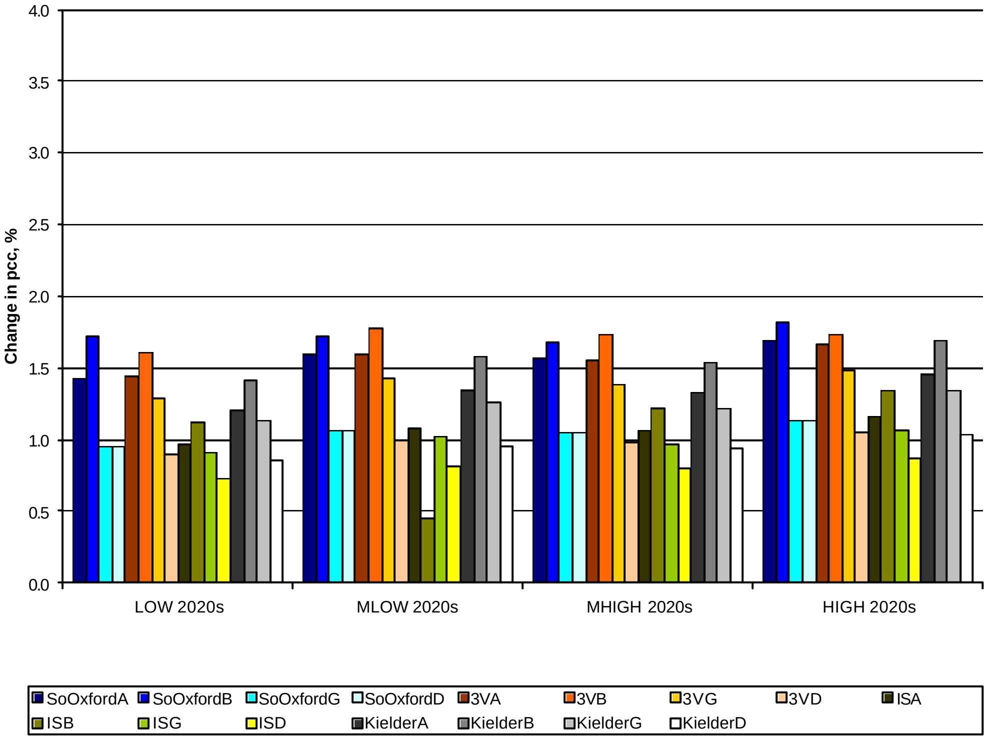


Figure 3-9. Selected site results for reference (Alpha-A, Beta-B, Gamma-G and Delta-D) and climate change (Low to High) scenarios, for 2020s. The selected WRZs are south Oxfordshire (Thames region), Three Valleys (Anglian region), Integrated System (Northwest) and Kielder (Northeast). The other sites used have a similar range of results.

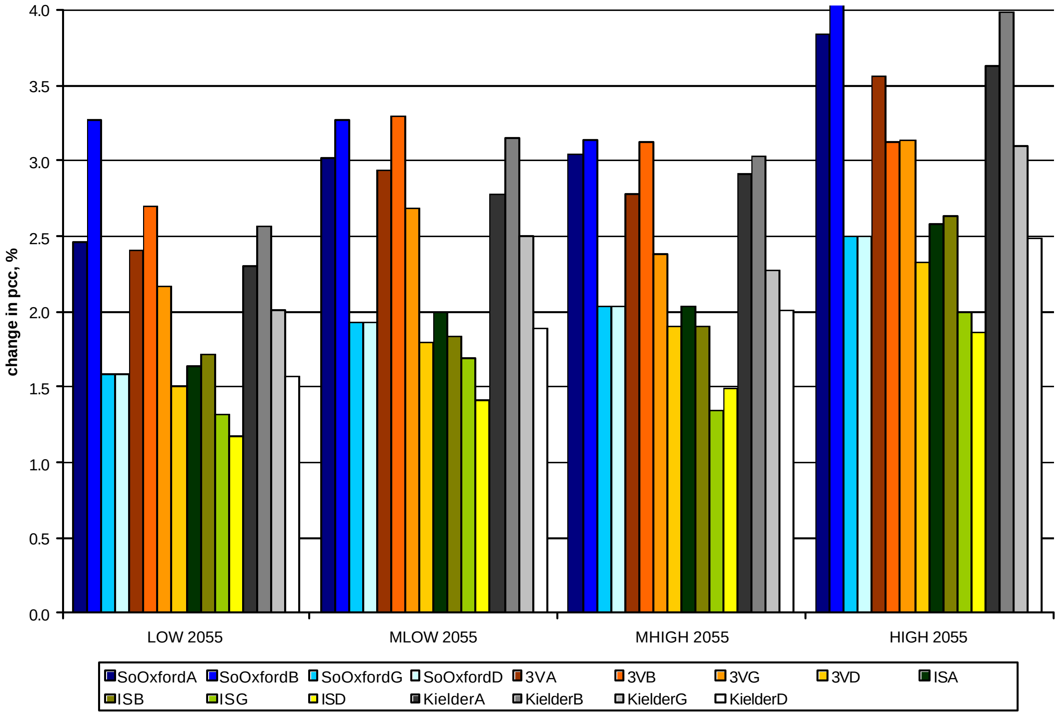


Figure 3-10. Selected site results for reference (Alpha-A, Beta-B, Gamma-G and Delta-D) and climate change (Low to High) scenarios, for 2050s. The WRZs are as for above.

3.4.2 At the regional level

Across the regions and climate scenarios, the impacts in the 2020s are in the range of 1.3% to 1.8%, increasing to over 3% by the 2050s, for the Alpha and Beta scenarios (Table 3-9). There is relatively little difference between the regions—a maximum spread of less than 0.5% in the climate impacts in the 2020s.

The Gamma and Delta scenarios imply lower climate change impacts - of the order of 1% for the 2020s, with a range across the regions of +/- 0.25%. The 2050s scenario shows higher impacts, but still significantly less than for the Alpha and Beta reference scenarios.

Firm estimates of the proportion of the regional impacts attributable to individual micro-components are beyond the scope of this project. However, the CCDomestic simulation model uses micro-components to build up a picture of total per capita consumption, and results at the site level are shown above. In Table 3-10 regional estimates of the proportion of the total impact for garden watering and bathing are shown. While these are based on the site level results, they are rounded off and adjusted to represent a consistent view across the regions and time periods. In particular, we feel the impacts of garden watering are somewhat under-represented in the model. The differences between the climate scenarios are relatively small and are grouped together for the reference scenarios.

Table 3-9. Regional estimates of climate change impacts on domestic demand, % change

	Alpha and Beta Reference Scenarios		
Region	**Low 2020s**	**M-High 2020s**	**M-High 2050s**
Anglian	1.45	1.83	3.04
Midlands	1.71	1.83	3.68
North East	1.36	1.48	3.04
North West	1.31	1.43	2.97
Southern	1.33	1.45	2.92
South West	1.26	1.39	2.81
Thames	1.26	1.37	2.67
EA Wales	1.34	1.45	2.79

	Gamma and Delta Reference Scenarios		
Region	**Low 2020s**	**M-High 2020s**	**M-High 2050s**
Anglian	1.00	1.28	2.18
Midlands	1.19	1.10	2.30
North East	1.00	1.13	2.10
North West	1.04	1.08	2.11
Southern	0.99	1.07	1.81
South West	0.97	0.95	1.92
Thames	0.87	1.02	2.05
EA Wales	0.93	1.06	2.05

Table 3-10. Percentage of total climate impact due to garden watering and bathing

Region	Alpha and Beta Reference Scenarios 2020s		2050s	
	Garden	**Bathing**	**Garden**	**Bathing**
Anglian	35	60	25	70
Midlands	25	70	15	75
North East	25	65	15	75
North West	25	70	15	75
Southern	35	60	25	70
South West	25	70	15	80
Thames	30	65	20	75
EA Wales	25	70	15	80

Region	Gamma and Delta Reference Scenarios 2020s		2050s	
	Garden	**Bathing**	**Garden**	**Bathing**
Anglian	25	70	15	80
Midlands	15	80	10	85
North East	20	75	10	85
North West	15	80	10	85
Southern	20	75	10	85
South West	15	80	10	85
Thames	20	75	10	85
EA Wales	15	80	10	85

3.5 Conclusion

Herrington employed a range of statistical models correlating climatic variables with demand for water in southern England as observed during the 1970s and 1980s. We have relied primarily on dynamic simulation models calibrated for a range of water resource zones. We included several statistical explorations as well as social simulation results that indicate qualitative responses to climatic variations and water scarcity. Clearly the dynamic simulation model is more conservative than statistical correlations. For instance, the regression equations developed from data on demand from South West Water indicate an increase in demand of 7% (winter) to 21% (summer) for the 2050s (i.e., a temperature increase of 2.3°C) (see Appendix 3-D). In contrast the simulation results for the South West region show an increase of about 3% in the annual average for the 2050s. The dynamic simulation tracks changes in the micro-components of demand (which is difficult to do in regression equations) and assumes some dampening of the elasticity of demand to climatic variations. For example, a maximum number of showers or baths per week is assumed and garden watering is not assumed to occur all year round even if the temperatures are relatively warm.

The treatment of climate change has also improved. Herrington assumed the worst-case scenario, while the CCDeW project benefited from two rounds of formal GCM-based scenarios under the UKCIP. However, there are substantial limitations to the UKCIP scenarios, especially for the 2020s (as discussed in 2.1 above). A move toward fully probabilistic scenarios is a required next step.

The CCDeW project is built upon a baseline and projections at the water resource zone level. This provides improved assessment of regional water demand—largely missing from the Herrington benchmark. However, there is relatively little spread between the regions in the impact of climate change—a range of less than 0.5%.

Neither CCDeW nor Herrington are able to provide definitive estimates of the impacts of climate change (over the course of the next two decades or more) for individual micro-components. However, the CCDomestic simulation model uses micro-components to build up a picture of total per capita consumption. Most of the modelled impacts is attributed to the increased use of baths, showers and power showers and are based on the assumption that the frequency of bathing is likely to increase. The agent based social simulation model (reported in Chapter 7) indicates that an increased frequency of drought could trigger long-term reductions in demand through adoption of water saving technology. Or, consumers might increase their demand beyond even the high reference scenarios if the presumption of entitlement to a private good exceeds willingness to conserve water during periods of drought.

The CCDeW results are primarily oriented toward long term demand and its sensitivity to mean changes in climate. However, peak demand and demand management are important for water planning. We come back to the issues of uncertainty and extreme events in Chapter 8.

Table 3-11 summarises the main uncertainties in the domestic assessment. The CCDeW results are primarily oriented toward long term demand and its sensitivity to mean changes in climate. The estimates may well be conservative. For example, peak demand (triggered by hot and dry years) and demand management (part of the regulatory toolkit) are important for water planning but neither are intrinsic to the CCDomestic model. We come back to the issues of uncertainty and extreme events in Chapter 8.

Table 3-11. Summary of uncertainties in domestic demand assessment

Underestimate climate impacts	Overestimate climate impacts
Lack of changes in extreme events	Effect of regulation or prices not included (e.g., during droughts)
Frequency of use capped in S-shaped relationship to degree days	Adoption of water-saving technology
No behavioural link between climate and ownership of appliances	Climatic triggers applied at the monthly scale whereas peaks in demand are often only for a few days
Use of garden watering to cool the environment not included	Smaller households may reduce constraints on water use (e.g., more appliances per person)

Bias uncertain
Soil-water deficit drives garden watering
Relationship to climatic variables other than temperature (e.g., humidity)
Metered use might encourage conservation (through awareness and pricing) or peak use (with increased willingness to pay for water)

3.6 Appendices

3.6.1 Appendix 3-A. Baseline data and calculation of potential evapotranspiration

Precipitation: Data for the modelled present day climate (1961 to 1990) are given in **mm/day.**
The **change** with respect to the modelled present day climate is given as a **percentage**.
Temperature: Data for the modelled present day climate (1961 to 1990) are given in **^{o}C**.
The **change** with respect to the modelled present day climate is given as **^{o}C**.

Potential evapotranspiration **(ETo)**, has been estimated using the Blaney-Criddle method (see Doorenbos and Pruit, 1992), a relatively simple approach that relies on temperature data, a measure of sunshine hours and an adjustment factor which depends on minimum relative humidity, sunshine hours and daytime wind estimates.

$$\textbf{ETo (day)} = \mathbf{p\ (0.46\ Tmean + 8)}$$

Where **ETo** is potential evapotranspiration,
p is percentage of annual sunshine hours, calculated by latitude,
Tmean is mean temperature.

Daily ETo is multiplied by the number of days per month to calculate monthly ETo. p-Coefficients for the mid-high latitudes are given in Table 2-5 below.

Table 3-12. Mean daily percentage (p-coeffcient) of annual daytime hours for different latitudes

	Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Ave**
Latitude	**North**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Ave**
	South	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**Ave**
60°		0.15	0.2	0.26	0.32	0.38	0.41	0.4	0.34	0.28	0.22	0.17	0.13	0.27
55		0.17	0.21	0.26	0.32	0.36	0.39	0.38	0.33	0.28	0.23	0.18	0.16	0.27
50		0.19	0.23	0.27	0.31	0.34	0.36	0.35	0.32	0.28	0.24	0.2	0.18	0.27
45		0.2	0.23	0.27	0.3	0.34	0.35	0.34	0.32	0.28	0.24	0.21	0.2	0.27
40		0.22	0.24	0.27	0.3	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21	0.27
35		0.23	0.25	0.27	0.29	0.31	0.32	0.32	0.3	0.28	0.25	0.23	0.22	0.27

3.6.2 Appendix 3-B. Site level results

The following tables report the site model (CCDomestic) results. The Reference columns of each table are the Environment Agency scenario for the present (2000) and as projected to 2025, 2055 and 2085, in l/h/d. The middle columns shows the simulation results for the Low and Medium—High scenarios of climate change (from the UKCIP2002), in l/h/d. The differences between the climate change and reference case are shown in the right-most columns, in %. The table header includes the water company, resource zone and climate station. Summary results for all scenarios are shown in Table 3.10 for all climate change scenarios.

Table 3-13. Three Valleys, Resource zone 2, Rothamsted

	Reference				**Climate change, Low**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
Alpha										
Garden	16.5	29.7	32.6	39.2	30.8	34.3	40.8	3.8%	5.2%	4.1%
Car	1.1	1.6	1.6	1.6	1.7	1.8	1.9	5.2%	11.1%	18.3%
Misc	30.4	38.0	39.4	1.6	38.0	39.4	1.9	0.0%	0.1%	18.3%
Bath	43.5	72.6	71.8	40.6	74.6	75.2	40.6	2.7%	4.7%	0.1%
NonClim	88.0	77.1	74.6	71.6	77.1	74.6	77.2	0.0%	0.0%	7.8%
Total	*179.4*	*219.0*	*219.9*	*225.6*	*222.1*	*225.2*	*233.1*	*1.4%*	*2.4%*	*3.3%*
Beta										
Garden	15.8	32.6	36.6	44.2	33.8	38.5	46.1	3.8%	5.2%	4.1%
Car	1.1	2.3	2.5	2.5	2.5	2.7	2.9	5.3%	11.0%	18.2%
Misc	30.4	37.7	40.4	2.5	37.7	40.4	2.9	0.0%	0.1%	18.2%
Bath	43.2	78.8	78.5	43.7	81.0	82.3	43.7	2.7%	4.8%	0.1%
NonClim	88.1	67.5	63.1	79.1	67.5	63.1	85.4	0.0%	0.0%	7.9%
Total	*178.6*	*219.0*	*221.1*	*230.7*	*222.5*	*227.1*	*239.2*	*1.6%*	*2.7%*	*3.7%*
Gamma										
Garden	16.5	24.3	25.9	31.9	25.2	27.2	33.2	3.7%	5.2%	4.1%
Car	1.1	1.1	1.1	1.3	1.1	1.3	1.5	5.4%	11.0%	18.2%
Misc	30.1	26.8	25.7	1.3	26.8	25.7	1.5	0.0%	0.1%	18.2%
Bath	42.6	43.1	40.2	25.7	44.1	41.9	25.7	2.3%	4.2%	0.1%
NonClim	87.6	58.5	53.1	38.0	58.5	53.1	40.6	0.0%	0.0%	6.8%
Total	*177.9*	*153.9*	*146.1*	*148.5*	*155.8*	*149.3*	*152.7*	*1.3%*	*2.2%*	*2.8%*

Delta										
Garden	16.5	7.3	4.3	4.7	7.5	4.5	4.9	3.6%	5.1%	4.0%
Car	1.0	0.6	0.6	0.6	0.6	0.6	0.7	5.7%	10.9%	18.5%
Misc	30.2	23.7	21.6	0.6	23.8	21.7	0.7	0.0%	0.1%	18.5%
Bath	42.6	40.0	37.2	21.6	40.9	38.7	21.6	2.3%	4.1%	0.1%
NonClim	87.9	62.3	56.9	35.5	62.3	56.9	37.9	0.0%	0.0%	6.7%
Total	*178.2*	*133.9*	*120.5*	*117.9*	*135.1*	*122.3*	*120.6*	*0.9%*	*1.5%*	*2.3%*

	Reference				**Climate change, Med-High**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
Alpha										
Garden	16.5	29.7	32.6	39.2	30.8	33.9	40.0	3.9%	4.1%	2.0%
Car	1.1	1.6	1.6	1.6	1.7	1.8	2.1	5.7%	14.7%	30.5%
Misc	30.4	38.0	39.4	1.6	38.0	39.4	2.1	0.0%	0.1%	30.5%
Bath	43.5	72.6	71.8	40.6	74.8	76.3	40.6	3.0%	6.3%	0.1%
NonClim	88.0	77.1	74.6	71.6	77.1	74.6	80.4	0.0%	0.0%	12.3%
Total	*179.4*	*219.0*	*219.9*	*225.6*	*222.4*	*226.1*	*235.7*	*1.6%*	*2.8%*	*4.5%*
Beta										
Garden	15.8	32.6	36.6	44.2	33.8	38.1	45.1	3.9%	4.1%	2.0%
Car	1.1	2.3	2.5	2.5	2.5	2.8	3.2	6.0%	14.6%	30.5%
Misc	30.4	37.7	40.4	2.5	37.7	40.4	3.2	0.1%	0.1%	30.5%
Bath	43.2	78.8	78.5	43.7	81.2	83.5	43.8	3.0%	6.4%	0.2%
NonClim	88.1	67.5	63.1	79.1	67.5	63.1	89.0	0.0%	0.0%	12.5%
Total	*178.6*	*219.0*	*221.1*	*230.7*	*222.8*	*228.0*	*242.3*	*1.7%*	*3.1%*	*5.0%*
Gamma										
Garden	16.5	24.3	25.9	31.9	25.3	27.0	32.5	3.9%	4.1%	2.0%
Car	1.1	1.1	1.1	1.3	1.1	1.3	1.7	6.1%	14.5%	30.5%
Misc	30.1	26.8	25.7	1.3	26.8	25.8	1.7	0.1%	0.1%	30.5%
Bath	42.6	43.1	40.2	25.7	44.2	42.5	25.7	2.6%	5.6%	0.1%
NonClim	87.6	58.5	53.1	38.0	58.5	53.1	42.0	0.0%	0.0%	10.7%
Total	*177.9*	*153.9*	*146.1*	*148.5*	*156.0*	*149.6*	*153.7*	*1.4%*	*2.4%*	*3.5%*

	Delta									
Garden	16.5	7.3	4.3	4.7	7.5	4.5	4.8	3.8%	4.1%	2.0%
Car	1.0	0.6	0.6	0.6	0.6	0.6	0.8	6.4%	14.5%	30.5%
Misc	30.2	23.7	21.6	0.6	23.8	21.7	0.8	0.0%	0.1%	30.5%
Bath	42.6	40.0	37.2	21.6	41.0	39.2	21.6	2.5%	5.4%	0.1%
NonClim	87.9	62.3	56.9	35.5	62.3	56.9	39.3	0.0%	0.0%	10.5%
Total	*178.2*	*133.9*	*120.5*	*117.9*	*135.2*	*122.8*	*122.0*	*1.0%*	*1.9%*	*3.4%*

Table 3-14 South West Water, Colliford, Penzance

		Reference			**Climate change, Low**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
	Alpha									
Garden	9.9	12.9	13.7	15.4	13.2	14.2	16.1	2.9%	3.8%	4.9%
Car	1.1	1.5	1.6	1.6	1.6	1.8	2.0	6.5%	13.7%	22.1%
Misc	34.9	44.6	46.1	1.6	44.6	46.1	2.0	0.0%	0.1%	22.1%
Bath	40.2	70.6	72.7	46.2	72.9	77.7	46.2	3.3%	6.9%	0.1%
NonClim	69.9	62.4	60.7	72.4	62.4	60.7	79.5	0.0%	0.0%	9.7%
Total	*156.0*	*192.0*	*194.8*	*195.1*	*194.8*	*200.6*	*203.3*	*1.5%*	*3.0%*	*4.2%*
	Beta									
Garden	9.9	12.9	13.0	13.7	13.2	13.5	14.4	2.9%	3.8%	4.9%
Car	1.1	1.6	1.9	2.4	1.7	2.1	2.9	6.4%	13.5%	21.9%
Misc	34.9	44.1	45.4	2.4	44.1	45.4	2.9	0.0%	0.1%	21.9%
Bath	40.2	75.6	79.4	45.3	78.1	85.0	45.3	3.3%	7.0%	0.1%
NonClim	69.7	56.2	53.3	80.3	56.2	53.3	88.3	0.0%	0.0%	9.9%
Total	*155.8*	*190.4*	*193.0*	*193.3*	*193.4*	*199.4*	*202.5*	*1.6%*	*3.3%*	*4.8%*
	Gamma									
Garden	16.5	23.9	25.7	29.8	24.6	26.7	31.2	2.9%	3.8%	4.9%
Car	1.1	1.1	1.2	1.3	1.2	1.3	1.6	6.5%	13.6%	21.7%
Misc	30.2	26.8	25.7	1.3	26.8	25.8	1.6	0.0%	0.1%	21.7%
Bath	40.9	43.6	39.9	25.7	44.9	42.4	25.7	3.1%	6.3%	0.1%
NonClim	87.6	58.5	53.1	37.8	58.5	53.1	41.2	0.0%	0.0%	9.1%
Total	*176.3*	*154.0*	*145.6*	*146.3*	*156.1*	*149.3*	*151.5*	*1.4%*	*2.5%*	*3.6%*

	Delta									
Garden	9.9	3.1	2.5	3.8	3.2	2.6	4.0	2.9%	3.6%	4.8%
Car	1.0	0.6	0.6	0.6	0.7	0.6	0.7	6.9%	13.5%	21.6%
Misc	34.8	29.7	27.1	0.6	29.7	27.1	0.7	0.0%	0.1%	21.6%
Bath	40.1	41.8	38.1	26.1	43.1	40.4	26.2	3.0%	6.2%	0.1%
NonClim	69.8	52.7	48.4	35.8	52.7	48.4	39.0	0.0%	0.0%	9.0%
Total	*155.6*	*127.9*	*116.6*	*113.5*	*129.3*	*119.1*	*117.1*	*1.1%*	*2.2%*	*3.2%*

		Reference			**Climate change, Med-High**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
	Alpha									
Garden	9.9	12.9	13.7	15.4	13.3	14.1	15.8	3.0%	2.9%	2.7%
Car	1.1	1.5	1.6	1.6	1.7	1.9	2.2	7.4%	18.4%	36.1%
Misc	34.9	44.6	46.1	1.6	44.6	46.1	2.2	0.0%	0.1%	36.1%
Bath	40.2	70.6	72.7	46.2	73.2	79.4	46.3	3.6%	9.2%	0.2%
NonClim	69.9	62.4	60.7	72.4	62.4	60.7	83.3	0.0%	0.0%	15.0%
Total	*156.0*	*192.0*	*194.8*	*195.1*	*195.1*	*202.2*	*207.1*	*1.6%*	*3.8%*	*6.1%*
	Beta									
Garden	9.9	12.9	13.0	13.7	13.3	13.4	14.1	3.0%	2.9%	2.7%
Car	1.1	1.6	1.9	2.4	1.7	2.2	3.2	7.3%	18.4%	36.0%
Misc	34.9	44.1	45.4	2.4	44.1	45.4	3.2	0.0%	0.1%	36.0%
Bath	40.2	75.6	79.4	45.3	78.4	86.8	45.3	3.6%	9.3%	0.2%
NonClim	69.7	56.2	53.3	80.3	56.2	53.3	92.6	0.0%	0.0%	15.3%
Total	*155.8*	*190.4*	*193.0*	*193.3*	*193.7*	*201.2*	*206.9*	*1.7%*	*4.2%*	*7.0%*
	Gamma									
Garden	16.5	23.9	25.7	29.8	24.6	26.5	30.6	3.0%	2.9%	2.7%
Car	1.1	1.1	1.2	1.3	1.2	1.4	1.8	7.4%	18.4%	36.1%
Misc	30.2	26.8	25.7	1.3	26.8	25.8	1.8	0.0%	0.1%	36.1%
Bath	40.9	43.6	39.9	25.7	45.1	43.2	25.8	3.4%	8.4%	0.2%
NonClim	87.6	58.5	53.1	37.8	58.5	53.1	43.1	0.0%	0.0%	14.1%
Total	*176.3*	*154.0*	*145.6*	*146.3*	*156.3*	*149.9*	*153.0*	*1.5%*	*3.0%*	*4.6%*

Delta									
Garden	9.9	3.1	2.5	3.8	3.2	2.5	3.9	3.1%	2.7%	2.7%
Car	1.0	0.6	0.6	0.6	0.7	0.7	0.8	7.9%	18.1%	35.5%
Misc	34.8	29.7	27.1	0.6	29.7	27.1	0.8	0.0%	0.1%	35.5%
Bath	40.1	41.8	38.1	26.1	43.2	41.2	26.2	3.3%	8.2%	0.2%
NonClim	69.8	52.7	48.4	35.8	52.7	48.4	40.8	0.0%	0.0%	13.9%
Total	*155.6*	*127.9*	*116.6*	*113.5*	*129.4*	*119.9*	*118.9*	*1.2%*	*2.9%*	*4.7%*

Table 3-15 Dwr Cymru-Welsh, North-Eyri-Ynys Mon, Anglesey

	Reference				**Climate change, Low**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
Alpha										
Garden	9.1	12.3	13.6	16.0	12.6	13.9	16.4	2.3%	2.7%	2.8%
Car	1.0	1.4	1.5	1.5	1.5	1.6	1.8	4.9%	9.3%	15.2%
Misc	33.9	43.7	45.5	1.5	43.7	45.5	1.8	0.0%	0.0%	15.2%
Bath	41.1	72.1	73.4	46.0	74.2	77.4	46.0	2.9%	5.4%	0.1%
NonClim	67.9	60.6	59.7	74.8	60.6	59.7	81.2	0.0%	0.0%	8.5%
Total	*153.0*	*190.1*	*193.6*	*197.6*	*192.6*	*198.1*	*204.7*	*1.3%*	*2.3%*	*3.6%*
Beta										
Garden	16.3	33.1	37.8	43.6	33.8	38.8	44.8	2.3%	2.7%	2.8%
Car	1.1	2.3	2.4	2.4	2.4	2.7	2.8	4.8%	9.1%	15.2%
Misc	30.4	37.7	40.4	2.4	37.7	40.4	2.8	0.0%	0.0%	15.2%
Bath	42.8	79.8	78.8	43.7	82.1	83.0	43.7	2.9%	5.4%	0.1%
NonClim	88.1	67.5	63.1	79.3	67.5	63.1	86.0	0.0%	0.0%	8.5%
Total	*178.7*	*220.4*	*222.6*	*230.2*	*223.6*	*228.1*	*238.5*	*1.4%*	*2.5%*	*3.6%*
Gamma										
Garden	17.0	24.7	26.8	31.4	25.3	27.5	32.3	2.3%	2.7%	2.8%
Car	1.0	1.1	1.1	1.2	1.1	1.2	1.4	4.7%	8.9%	15.1%
Misc	30.1	26.8	25.7	1.2	26.8	25.7	1.4	0.0%	0.1%	15.1%
Bath	42.3	44.6	40.6	25.7	45.9	42.8	25.7	2.9%	5.4%	0.1%
NonClim	87.6	58.5	53.1	38.4	58.5	53.1	41.6	0.0%	0.0%	8.6%
Total	*178.1*	*155.7*	*147.4*	*148.5*	*157.6*	*150.4*	*152.8*	*1.2%*	*2.1%*	*2.9%*

	Delta									
Garden	17.0	7.3	4.4	4.7	7.5	4.6	4.8	2.3%	2.7%	2.8%
Car	1.0	0.6	0.5	0.6	0.6	0.6	0.7	5.1%	9.3%	15.3%
Misc	30.2	23.7	21.6	0.6	23.8	21.7	0.7	0.0%	0.0%	15.3%
Bath	42.2	42.1	37.6	21.6	43.3	39.6	21.6	2.9%	5.4%	0.1%
NonClim	87.9	62.3	56.9	35.9	62.3	56.9	39.0	0.0%	0.0%	8.6%
Total	*178.4*	*136.1*	*121.0*	*118.2*	*137.5*	*123.3*	*121.5*	*1.0%*	*1.8%*	*2.8%*

	Reference				**Climate change, Med-High**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
	Alpha									
Garden	9.1	12.3	13.6	16.0	12.8	13.7	16.4	3.9%	1.3%	2.8%
Car	1.0	1.4	1.5	1.5	1.5	1.7	2.0	5.6%	12.4%	26.6%
Misc	33.9	43.7	45.5	1.5	43.7	45.5	2.0	0.0%	0.1%	26.6%
Bath	41.1	72.1	73.4	46.0	74.4	78.7	46.1	3.2%	7.2%	0.2%
NonClim	67.9	60.6	59.7	74.8	60.6	59.7	85.1	0.0%	0.0%	13.8%
Total	*153.0*	*190.1*	*193.6*	*197.6*	*193.0*	*199.3*	*208.9*	*1.5%*	*2.9%*	*5.7%*
	Beta									
Garden	16.3	33.1	37.8	43.6	33.8	38.3	43.5	2.3%	1.2%	-0.3%
Car	1.1	2.3	2.4	2.4	2.4	2.7	3.1	5.4%	12.4%	26.7%
Misc	30.4	37.7	40.4	2.4	37.7	40.4	3.1	0.0%	0.1%	26.7%
Bath	42.8	79.8	78.8	43.7	82.3	84.5	43.8	3.2%	7.2%	0.2%
NonClim	88.1	67.5	63.1	79.3	67.5	63.1	90.2	0.0%	0.0%	13.7%
Total	*178.7*	*220.4*	*222.6*	*230.2*	*223.9*	*229.1*	*241.7*	*1.6%*	*2.9%*	*5.0%*
	Gamma									
Garden	17.0	24.7	26.8	31.4	25.3	27.1	31.3	2.3%	1.2%	-0.3%
Car	1.0	1.1	1.1	1.2	1.1	1.3	1.6	5.4%	12.5%	26.5%
Misc	30.1	26.8	25.7	1.2	26.8	25.8	1.6	0.0%	0.1%	26.5%
Bath	42.3	44.6	40.6	25.7	46.1	43.6	25.7	3.2%	7.2%	0.2%
NonClim	87.6	58.5	53.1	38.4	58.5	53.1	43.7	0.0%	0.0%	14.0%
Total	*178.1*	*155.7*	*147.4*	*148.5*	*157.8*	*150.8*	*154.1*	*1.3%*	*2.3%*	*3.8%*

	Delta									
Garden	17.0	7.3	4.4	4.7	7.5	4.5	4.7	2.3%	1.3%	-0.2%
Car	1.0	0.6	0.5	0.6	0.6	0.6	0.7	5.4%	12.6%	26.5%
Misc	30.2	23.7	21.6	0.6	23.8	21.7	0.7	0.0%	0.1%	26.5%
Bath	42.2	42.1	37.6	21.6	43.5	40.3	21.6	3.2%	7.2%	0.1%
NonClim	87.9	62.3	56.9	35.9	62.3	56.9	40.9	0.0%	0.0%	14.0%
Total	*178.4*	*136.1*	*121.0*	*118.2*	*137.7*	*123.9*	*123.4*	*1.1%*	*2.4%*	*4.4%*

Table 3-16 North West Water, Integrated system, Knutsford

		Reference			**Climate change, Low**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
	Alpha									
Garden	7.8	13.0	14.1	15.9	13.3	14.3	16.1	1.9%	1.5%	1.3%
Car	0.8	1.2	1.3	1.5	1.3	1.5	1.7	3.8%	7.9%	13.1%
Misc	21.0	27.1	28.9	1.5	27.1	29.0	1.7	0.0%	0.0%	13.1%
Bath	37.6	73.0	77.4	30.2	74.6	80.3	30.3	2.1%	3.8%	0.1%
NonClim	85.0	78.4	76.2	77.8	78.4	76.2	82.8	0.0%	0.0%	6.4%
Total	*152.2*	*192.8*	*198.0*	*200.7*	*194.7*	*201.2*	*206.1*	*1.0%*	*1.6%*	*2.7%*
	Beta									
Garden	16.3	33.4	38.1	43.0	34.1	38.7	43.5	1.9%	1.6%	1.3%
Car	1.1	2.3	2.5	2.5	2.4	2.6	2.8	3.9%	7.8%	13.1%
Misc	30.4	37.7	40.4	2.5	37.7	40.4	2.8	0.0%	0.0%	13.1%
Bath	42.7	79.4	78.7	43.7	81.2	81.7	43.7	2.2%	3.8%	0.1%
NonClim	88.1	67.5	63.1	79.4	67.5	63.1	84.6	0.0%	0.0%	6.5%
Total	*178.6*	*220.4*	*222.8*	*229.7*	*222.9*	*226.6*	*235.8*	*1.1%*	*1.7%*	*2.7%*
	Gamma									
Garden	17.0	24.9	27.0	30.9	25.4	27.4	31.4	2.0%	1.6%	1.3%
Car	1.1	1.1	1.1	1.3	1.1	1.2	1.4	3.9%	7.8%	13.2%
Misc	30.1	26.8	25.7	1.3	26.8	25.7	1.4	0.0%	0.0%	13.2%
Bath	42.1	44.4	40.6	25.7	45.3	42.0	25.7	2.0%	3.5%	0.1%
NonClim	87.6	58.5	53.1	38.4	58.5	53.1	40.7	0.0%	0.0%	6.0%
Total	*178.0*	*155.7*	*147.6*	*148.0*	*157.1*	*149.5*	*150.9*	*0.9%*	*1.3%*	*2.0%*

	Delta									
Garden	17.0	7.4	4.5	4.6	7.6	4.5	4.7	1.9%	1.6%	1.3%
Car	1.0	0.6	0.5	0.6	0.6	0.6	0.7	4.0%	7.7%	13.4%
Misc	30.2	23.7	21.6	0.6	23.8	21.7	0.7	0.0%	0.1%	13.4%
Bath	42.1	41.9	37.5	21.6	42.7	38.8	21.6	2.0%	3.5%	0.1%
NonClim	87.9	62.3	56.9	35.9	62.3	56.9	38.0	0.0%	0.0%	5.9%
Total	*178.3*	*136.0*	*121.0*	*118.2*	*137.0*	*122.4*	*120.4*	*0.7%*	*1.2%*	*1.9%*

	Reference				**Climate change, Med-High**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
	Alpha									
Garden	7.8	13.0	14.1	15.9	13.3	14.1	15.6	1.9%	-0.2%	-1.9%
Car	0.8	1.2	1.3	1.5	1.3	1.5	1.9	4.3%	10.5%	23.4%
Misc	21.0	27.1	28.9	1.5	27.2	29.0	1.9	0.0%	0.1%	23.4%
Bath	37.6	73.0	77.4	30.2	74.7	81.3	30.3	2.4%	5.0%	0.1%
NonClim	85.0	78.4	76.2	77.8	78.4	76.2	86.0	0.0%	0.0%	10.5%
Total	*152.2*	*192.8*	*198.0*	*200.7*	*194.8*	*202.0*	*209.0*	*1.1%*	*2.0%*	*4.1%*
	Beta									
Garden	16.3	33.4	38.1	43.0	34.1	38.0	42.2	1.9%	-0.2%	-1.9%
Car	1.1	2.3	2.5	2.5	2.4	2.7	3.0	4.3%	10.6%	23.6%
Misc	30.4	37.7	40.4	2.5	37.7	40.4	3.0	0.0%	0.1%	23.6%
Bath	42.7	79.4	78.7	43.7	81.4	82.7	43.7	2.4%	5.1%	0.1%
NonClim	88.1	67.5	63.1	79.4	67.5	63.1	87.9	0.0%	0.0%	10.7%
Total	*178.6*	*220.4*	*222.8*	*229.7*	*223.1*	*227.0*	*238.0*	*1.2%*	*1.9%*	*3.6%*
	Gamma									
Garden	17.0	24.9	27.0	30.9	25.4	26.9	30.4	1.9%	-0.2%	-1.9%
Car	1.1	1.1	1.1	1.3	1.1	1.2	1.6	4.5%	10.2%	23.6%
Misc	30.1	26.8	25.7	1.3	26.8	25.7	1.6	0.0%	0.1%	23.6%
Bath	42.1	44.4	40.6	25.7	45.4	42.5	25.7	2.2%	4.7%	0.1%
NonClim	87.6	58.5	53.1	38.4	58.5	53.1	42.2	0.0%	0.0%	9.9%
Total	*178.0*	*155.7*	*147.6*	*148.0*	*157.2*	*149.5*	*151.5*	*1.0%*	*1.3%*	*2.4%*

Delta										
Garden	17.0	7.4	4.5	4.6	7.6	4.5	4.5	1.9%	-0.2%	-1.9%
Car	1.0	0.6	0.5	0.6	0.6	0.6	0.7	4.0%	10.7%	23.8%
Misc	30.2	23.7	21.6	0.6	23.8	21.7	0.7	0.1%	0.1%	23.8%
Bath	42.1	41.9	37.5	21.6	42.8	39.2	21.6	2.2%	4.6%	0.1%
NonClim	87.9	62.3	56.9	35.9	62.3	56.9	39.4	0.0%	0.0%	9.8%
Total	*178.3*	*136.0*	*121.0*	*118.2*	*137.1*	*122.8*	*121.7*	*0.8%*	*1.5%*	*3.0%*

Table 3-17 Northumbrian Water, Keilder supported, Durham

	Reference				**Climate change, Low**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
Alpha										
Garden	5.8	10.9	12.8	15.5	11.2	13.3	16.2	2.7%	3.7%	4.1%
Car	0.8	1.1	1.3	1.4	1.2	1.4	1.7	5.0%	10.1%	17.1%
Misc	20.2	26.4	27.8	1.4	26.4	27.8	1.7	0.0%	0.1%	17.1%
Bath	37.2	73.6	75.8	28.4	75.6	79.6	28.5	2.6%	5.0%	0.1%
NonClim	81.9	75.9	74.8	76.3	75.9	74.8	82.6	0.0%	0.0%	8.2%
Total	*145.8*	*187.9*	*192.5*	*196.2*	*190.2*	*196.9*	*203.3*	*1.2%*	*2.3%*	*3.6%*
Beta										
Garden	16.2	33.0	37.6	43.1	33.9	39.0	44.8	2.7%	3.7%	4.1%
Car	1.1	2.2	2.4	2.3	2.4	2.6	2.8	5.1%	9.9%	17.2%
Misc	30.4	37.7	40.4	2.3	37.7	40.4	2.8	0.0%	0.1%	17.2%
Bath	43.8	78.3	77.7	43.7	80.3	81.7	43.7	2.6%	5.2%	0.1%
NonClim	88.1	67.5	63.1	77.7	67.5	63.1	84.3	0.0%	0.0%	8.4%
Total	*179.6*	*218.8*	*221.2*	*228.0*	*221.9*	*226.8*	*236.7*	*1.4%*	*2.6%*	*3.8%*
Gamma										
Garden	16.9	24.7	26.6	31.0	25.3	27.6	32.3	2.7%	3.7%	4.1%
Car	1.0	1.0	1.1	1.2	1.1	1.2	1.4	5.4%	10.1%	17.3%
Misc	30.1	26.8	25.7	1.2	26.8	25.7	1.4	0.0%	0.1%	17.3%
Bath	43.2	43.5	40.5	25.7	44.5	42.3	25.7	2.3%	4.5%	0.1%
NonClim	87.6	58.5	53.1	38.0	58.5	53.1	40.8	0.0%	0.0%	7.4%
Total	*179.0*	*154.5*	*147.0*	*147.6*	*156.3*	*150.0*	*151.9*	*1.1%*	*2.0%*	*2.9%*

Delta										
Garden	16.9	7.3	4.4	4.6	7.5	4.6	4.8	2.7%	3.7%	4.1%
Car	1.0	0.6	0.5	0.6	0.6	0.6	0.6	5.3%	10.0%	17.5%
Misc	30.2	23.7	21.6	0.6	23.8	21.7	0.6	0.0%	0.1%	17.5%
Bath	43.2	40.5	37.5	21.6	41.4	39.2	21.6	2.3%	4.4%	0.1%
NonClim	87.9	62.3	56.9	35.6	62.3	56.9	38.2	0.0%	0.0%	7.2%
Total	*179.3*	*134.4*	*120.9*	*117.8*	*135.6*	*122.8*	*120.7*	*0.9%*	*1.6%*	*2.4%*

	Reference				**Climate change, Med-High**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
Alpha										
Garden	5.8	10.9	12.8	15.5	11.2	13.1	15.8	2.8%	2.7%	1.8%
Car	0.8	1.1	1.3	1.4	1.2	1.4	1.9	5.7%	14.0%	30.1%
Misc	20.2	26.4	27.8	1.4	26.4	27.8	1.9	0.0%	0.1%	30.1%
Bath	37.2	73.6	75.8	28.4	75.8	80.9	28.5	2.9%	6.7%	0.2%
NonClim	81.9	75.9	74.8	76.3	75.9	74.8	86.3	0.0%	0.0%	13.1%
Total	*145.8*	*187.9*	*192.5*	*196.2*	*190.4*	*198.1*	*206.9*	*1.3%*	*2.9%*	*5.5%*
Beta										
Garden	16.2	33.0	37.6	43.1	34.0	38.6	43.9	2.8%	2.7%	1.8%
Car	1.1	2.2	2.4	2.3	2.4	2.7	3.1	5.5%	14.0%	30.3%
Misc	30.4	37.7	40.4	2.3	37.7	40.4	3.1	0.0%	0.1%	30.3%
Bath	43.8	78.3	77.7	43.7	80.6	83.0	43.8	2.9%	6.8%	0.2%
NonClim	88.1	67.5	63.1	77.7	67.5	63.1	88.2	0.0%	0.0%	13.4%
Total	*179.6*	*218.8*	*221.2*	*228.0*	*222.1*	*227.9*	*240.0*	*1.5%*	*3.0%*	*5.3%*
Gamma										
Garden	16.9	24.7	26.6	31.0	25.3	27.3	31.6	2.8%	2.7%	1.8%
Car	1.0	1.0	1.1	1.2	1.1	1.2	1.6	5.4%	14.4%	30.5%
Misc	30.1	26.8	25.7	1.2	26.8	25.7	1.6	0.1%	0.1%	30.5%
Bath	43.2	43.5	40.5	25.7	44.7	42.9	25.7	2.6%	6.1%	0.2%
NonClim	87.6	58.5	53.1	38.0	58.5	53.1	42.5	0.0%	0.0%	11.9%
Total	*179.0*	*154.5*	*147.0*	*147.6*	*156.4*	*150.4*	*153.1*	*1.2%*	*2.3%*	*3.7%*

	Delta									
Garden	16.9	7.3	4.4	4.6	7.5	4.5	4.7	2.8%	2.6%	1.8%
Car	1.0	0.6	0.5	0.6	0.6	0.6	0.7	5.6%	14.2%	30.5%
Misc	30.2	23.7	21.6	0.6	23.8	21.7	0.7	0.0%	0.1%	30.5%
Bath	43.2	40.5	37.5	21.6	41.5	39.7	21.6	2.5%	5.9%	0.1%
NonClim	87.9	62.3	56.9	35.6	62.3	56.9	39.7	0.0%	0.0%	11.7%
Total	*179.3*	*134.4*	*120.9*	*117.8*	*135.7*	*123.4*	*122.3*	*0.9%*	*2.0%*	*3.8%*

Table 3-18 Southern Water, Hants South and Winchester, Southampton

	Reference				**Climate change, Low**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
	Alpha									
Garden	10.8	18.7	18.2	18.0	19.1	18.9	18.6	2.1%	3.5%	3.1%
Car	1.1	1.6	1.6	1.7	1.6	1.8	2.0	6.2%	11.5%	18.4%
Misc	26.8	35.4	37.3	1.7	35.4	37.3	2.0	0.0%	0.1%	18.4%
Bath	44.6	86.7	88.6	38.5	88.9	93.4	38.6	2.6%	5.4%	0.1%
NonClim	80.1	70.3	65.9	86.5	70.3	65.9	92.8	0.0%	0.0%	7.2%
Total	*163.4*	*212.5*	*211.6*	*206.0*	*215.3*	*217.2*	*213.2*	*1.3%*	*2.7%*	*3.5%*
	Beta									
Garden	17.0	34.4	39.0	45.5	35.2	40.4	46.9	2.1%	3.5%	3.1%
Car	1.2	2.5	2.7	2.7	2.7	3.0	3.2	6.1%	11.6%	18.3%
Misc	30.4	37.7	40.4	2.7	37.7	40.4	3.2	0.0%	0.1%	18.3%
Bath	43.7	82.4	81.8	43.7	84.6	86.3	43.8	2.6%	5.5%	0.1%
NonClim	88.1	67.5	63.1	82.9	67.5	63.1	89.0	0.0%	0.0%	7.4%
Total	*180.4*	*224.6*	*227.0*	*235.9*	*227.7*	*233.2*	*244.0*	*1.4%*	*2.7%*	*3.4%*
	Gamma									
Garden	17.7	25.7	27.6	32.7	26.2	28.6	33.8	2.1%	3.5%	3.1%
Car	1.1	1.2	1.2	1.4	1.2	1.4	1.7	6.0%	11.7%	18.7%
Misc	30.2	26.8	25.7	1.4	26.8	25.8	1.7	0.0%	0.1%	18.7%
Bath	43.1	45.7	41.8	25.7	46.7	43.8	25.7	2.3%	4.8%	0.1%
NonClim	87.6	58.5	53.1	39.7	58.5	53.1	42.3	0.0%	0.0%	6.4%
Total	*179.7*	*157.9*	*149.6*	*151.3*	*159.6*	*152.7*	*155.1*	*1.1%*	*2.1%*	*2.5%*

	Delta									
Garden	17.7	7.6	4.6	4.9	7.8	4.7	5.0	2.1%	3.6%	3.2%
Car	1.1	0.6	0.6	0.6	0.7	0.7	0.8	5.9%	11.4%	18.4%
Misc	30.2	23.8	21.7	0.6	23.8	21.7	0.8	0.0%	0.1%	18.4%
Bath	43.1	43.1	38.6	21.6	44.0	40.4	21.6	2.3%	4.7%	0.1%
NonClim	87.9	62.3	56.9	37.1	62.3	56.9	39.4	0.0%	0.0%	6.3%
Total	*180.0*	*137.4*	*122.3*	*119.7*	*138.6*	*124.3*	*122.3*	*0.9%*	*1.7%*	*2.2%*

		Reference			**Climate change, Med-High**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
	Alpha									
Garden	10.8	18.7	18.2	18.0	19.1	18.7	18.2	2.1%	2.7%	1.1%
Car	1.1	1.6	1.6	1.7	1.7	1.9	2.2	7.0%	15.5%	29.0%
Misc	26.8	35.4	37.3	1.7	35.4	37.3	2.2	0.0%	0.1%	29.0%
Bath	44.6	86.7	88.6	38.5	89.2	95.0	38.6	2.9%	7.2%	0.1%
NonClim	80.1	70.3	65.9	86.5	70.3	65.9	95.9	0.0%	0.0%	10.9%
Total	*163.4*	*212.5*	*211.6*	*206.0*	*215.6*	*218.8*	*216.2*	*1.4%*	*3.4%*	*4.9%*
	Beta									
Garden	17.0	34.4	39.0	45.5	35.2	40.1	46.0	2.1%	2.7%	1.1%
Car	1.2	2.5	2.7	2.7	2.7	3.1	3.5	7.0%	15.5%	28.9%
Misc	30.4	37.7	40.4	2.7	37.7	40.5	3.5	0.0%	0.1%	28.9%
Bath	43.7	82.4	81.8	43.7	84.9	87.8	43.8	3.0%	7.3%	0.1%
NonClim	88.1	67.5	63.1	82.9	67.5	63.1	92.1	0.0%	0.0%	11.1%
Total	*180.4*	*224.6*	*227.0*	*235.9*	*228.0*	*234.5*	*246.5*	*1.5%*	*3.3%*	*4.5%*
	Gamma									
Garden	17.7	25.7	27.6	32.7	26.3	28.4	33.1	2.1%	2.7%	1.1%
Car	1.1	1.2	1.2	1.4	1.2	1.4	1.8	6.7%	15.6%	29.3%
Misc	30.2	26.8	25.7	1.4	26.8	25.8	1.8	0.0%	0.1%	29.3%
Bath	43.1	45.7	41.8	25.7	46.9	44.5	25.7	2.6%	6.5%	0.1%
NonClim	87.6	58.5	53.1	39.7	58.5	53.1	43.5	0.0%	0.0%	9.6%
Total	*179.7*	*157.9*	*149.6*	*151.3*	*159.7*	*153.2*	*155.9*	*1.2%*	*2.4%*	*3.0%*

	Delta									
Garden	17.7	7.6	4.6	4.9	7.8	4.7	4.9	2.1%	2.7%	1.1%
Car	1.1	0.6	0.6	0.6	0.7	0.7	0.8	6.5%	15.2%	29.1%
Misc	30.2	23.8	21.7	0.6	23.8	21.7	0.8	0.0%	0.1%	29.1%
Bath	43.1	43.1	38.6	21.6	44.2	41.0	21.6	2.5%	6.3%	0.1%
NonClim	87.9	62.3	56.9	37.1	62.3	56.9	40.6	0.0%	0.0%	9.4%
Total	*180.0*	*137.4*	*122.3*	*119.7*	*138.7*	*124.9*	*123.5*	*1.0%*	*2.2%*	*3.1%*

Table 3-19 Thames Water, South Oxfordshire, Oxford

	Reference				**Climate change, Low**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
	Alpha									
Garden	16.6	21.0	21.4	22.5	21.7	22.3	23.7	3.3%	4.3%	5.4%
Car	1.1	1.6	1.6	1.7	1.7	1.8	2.0	5.6%	11.0%	18.2%
Misc	17.2	21.2	22.3	1.7	21.3	22.3	2.0	0.0%	0.1%	18.2%
Bath	40.6	77.6	77.2	23.2	79.7	81.0	23.2	2.7%	5.0%	0.1%
NonClim	93.6	81.2	78.4	75.9	81.2	78.4	81.8	0.0%	0.0%	7.7%
Total	*169.1*	*202.5*	*200.9*	*198.9*	*205.4*	*205.8*	*206.2*	*1.4%*	*2.5%*	*3.7%*
	Beta									
Garden	15.6	31.9	36.4	41.3	33.1	38.5	44.4	3.8%	5.8%	7.5%
Car	1.2	2.4	2.6	2.6	2.6	2.9	3.1	6.3%	13.2%	21.1%
Misc	30.4	37.7	40.4	2.6	37.7	40.4	3.1	0.0%	0.1%	21.1%
Bath	41.3	79.1	78.7	43.7	81.5	83.4	43.8	3.0%	6.0%	0.1%
NonClim	88.1	67.5	63.1	79.6	67.5	63.1	86.8	0.0%	0.0%	9.0%
Total	*176.6*	*218.6*	*221.2*	*228.4*	*222.4*	*228.4*	*239.2*	*1.7%*	*3.3%*	*4.8%*
	Gamma									
Garden	16.3	7.1	4.3	4.4	7.3	4.5	4.7	3.4%	4.4%	5.5%
Car	1.1	0.6	0.6	0.6	0.7	0.6	0.7	5.5%	11.3%	18.4%
Misc	30.2	23.8	21.6	0.6	23.8	21.7	0.7	0.0%	0.1%	18.4%
Bath	40.7	40.8	36.6	21.6	41.8	38.2	21.6	2.5%	4.5%	0.1%
NonClim	87.9	62.3	56.9	35.1	62.3	56.9	37.6	0.0%	0.0%	7.1%
Total	*176.2*	*134.6*	*119.9*	*117.2*	*135.8*	*121.8*	*120.1*	*1.0%*	*1.6%*	*2.4%*

Delta										
Garden	16.3	7.1	4.3	4.4	7.3	4.5	4.7	3.4%	4.4%	5.5%
Car	1.1	0.6	0.6	0.6	0.7	0.6	0.7	5.5%	11.3%	18.4%
Misc	30.2	23.8	21.6	0.6	23.8	21.7	0.7	0.0%	0.1%	18.4%
Bath	40.7	40.8	36.6	21.6	41.8	38.2	21.6	2.5%	4.5%	0.1%
NonClim	87.9	62.3	56.9	35.1	62.3	56.9	37.6	0.0%	0.0%	7.1%
Total	*176.2*	*134.6*	*119.9*	*117.2*	*135.8*	*121.8*	*120.1*	*1.0%*	*1.6%*	*2.4%*

	Reference				**Climate change, Med-High**			**Difference, %**		
	2000	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
Alpha										
Garden	16.6	21.0	21.4	22.5	21.7	22.1	23.1	3.4%	3.5%	3.1%
Car	1.1	1.6	1.6	1.7	1.7	1.9	2.1	6.5%	14.6%	29.5%
Misc	17.2	21.2	22.3	1.7	21.3	22.3	2.1	0.0%	0.1%	29.5%
Bath	40.6	77.6	77.2	23.2	79.9	82.3	23.2	3.0%	6.6%	0.1%
NonClim	93.6	81.2	78.4	75.9	81.2	78.4	84.8	0.0%	0.0%	11.7%
Total	*169.1*	*202.5*	*200.9*	*198.9*	*205.7*	*207.0*	*209.0*	*1.6%*	*3.0%*	*5.1%*
Beta										
Garden	15.6	31.9	36.4	41.3	33.0	37.7	42.6	3.4%	3.4%	3.1%
Car	1.2	2.4	2.6	2.6	2.6	2.9	3.3	6.3%	14.6%	29.2%
Misc	30.4	37.7	40.4	2.6	37.7	40.4	3.3	0.0%	0.1%	29.2%
Bath	41.3	79.1	78.7	43.7	81.5	83.9	43.8	3.0%	6.7%	0.1%
NonClim	88.1	67.5	63.1	79.6	67.5	63.1	89.1	0.0%	0.0%	11.9%
Total	*176.6*	*218.6*	*221.2*	*228.4*	*222.3*	*228.1*	*240.0*	*1.7%*	*3.1%*	*5.1%*
Gamma										
Garden	16.3	7.1	4.3	4.4	7.3	4.4	4.6	3.4%	3.5%	3.1%
Car	1.1	0.6	0.6	0.6	0.7	0.7	0.8	5.8%	14.8%	29.3%
Misc	30.2	23.8	21.6	0.6	23.8	21.7	0.8	0.0%	0.1%	29.3%
Bath	40.7	40.8	36.6	21.6	41.9	38.8	21.6	2.8%	6.0%	0.1%
NonClim	87.9	62.3	56.9	35.1	62.3	56.9	38.9	0.0%	0.0%	10.8%
Total	*176.2*	*134.6*	*119.9*	*117.2*	*136.0*	*122.4*	*121.4*	*1.0%*	*2.0%*	*3.5%*

	Delta									
Garden	16.3	7.1	4.3	4.4	7.3	4.4	4.6	3.4%	3.5%	3.1%
Car	1.1	0.6	0.6	0.6	0.7	0.7	0.8	5.8%	14.8%	29.3%
Misc	30.2	23.8	21.6	0.6	23.8	21.7	0.8	0.0%	0.1%	29.3%
Bath	40.7	40.8	36.6	21.6	41.9	38.8	21.6	2.8%	6.0%	0.1%
NonClim	87.9	62.3	56.9	35.1	62.3	56.9	38.9	0.0%	0.0%	10.8%
Total	*176.2*	*134.6*	*119.9*	*117.2*	*136.0*	*122.4*	*121.4*	*1.0%*	*2.0%*	*3.5%*

3.6.3 Appendix 3-C. Regression analyses for the regional results

This Appendix provides details of each statistical regression used to interpret from the site-WRZ simulation results to the other WRZs, and so to provide regional estimates. The Tables include:

- Regression statistics—the correlations and standard error in predicting the climate change impact on total pcc using the input variables described above.
- Analysis of Variance (ANOVA)—including degrees of freedom (df) and significance of the F-test
- Regression statistics—including the standard error for each input variable.

Also shown is the plot of the residuals for the total pcc. This shows two clusters, for the Alpha-Beta and Gamma-Delta reference scenarios, and the spread of predictions, well within 0.5 percentage points of the predicted value for the 2020s and about 1.0 for 2050s. These plots are good indicators of the robustness of the predicted values.

Low climate change for 2020s

Table 3-20. Regression statistics, Low climate change for 2020s

	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**	**Lower 95.0%**	**Upper 95.0%**
Intercept	1.47	0.68	2.15	0.04	0.05	2.87	0.05	2.89
EA no.	0.27	0.08	3.48	0.00	0.11	0.43	0.11	0.43
GardenR 20205	1.92	0.99	1.94	0.07	-0.14	3.98	-0.14	3.98
BathR 2020s	-2.52	1.38	-1.83	0.08	-5.39	0.35	-5.39	0.35
DTmMH 2020s	-1.98	0.53	-3.75	0.00	-3.07	-0.88	-3.07	-0.88
DPrMH 2020s	0.25	0.10	2.57	0.02	0.05	0.45	0.05	0.45
Total pcc 2020s	0.01	0.00	5.13	0.00	0.01	0.02	0.01	0.02

Table 3-21. Regression statistics, Low climate change for 2020s

Multiple R	0.89
R Square	0.79
Adjusted R Square	0.73
Standard Error	0.14
Observations	28.00

Table 3-22. ANOVA, Low climate change for 2020s

	Df	**SS**	**MS**	**F**	**Significance F**
Regression	6.00	1.42	0.24	12.88	0.00
Residual	21.00	0.3865	0.02		
Total	27.00	1.81			

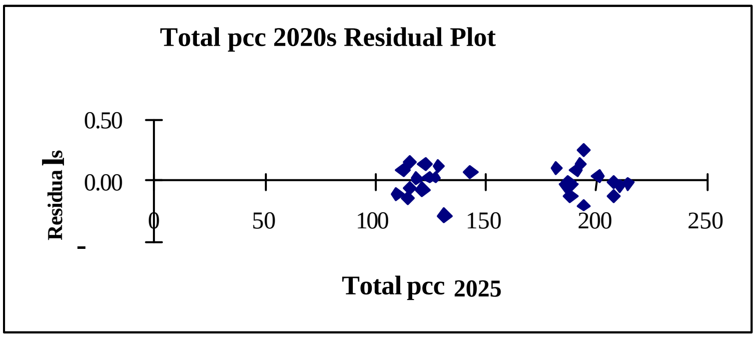


Figure 3-11. Total pcc 2020s residual plot, Low climate change

Medium-High climate scenario for 2020s

Table 3-23. Regression statistics, Medium-High climate scenario for 2020s

	Coeff	Std Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	2.03	0.67	3.05	0.01	0.65	3.41	0.65	3.41
Ean	0.27	0.08	3.58	0.00	0.11	0.43	0.11	0.43
GardenR2020	1.35	0.97	1.40	0.17	-0.65	3.36	-0.65	3.36
BathR2020s	-3.386	1.35	-2.51	0.02	-6.18	-0.56	-6.18	-0.58
dTmMH2020s	-2.14	0.51	-4.15	0.00	-3.21	-1.07	-3.21	-1.07
dPrMH2020s	0.26	0.10	2.77	0.01	0.06	0.46	0.07	0.46
Total pcc 2020s	0.01	0.00	5.59	0.00	0.01	0.02	0.01	0.02

Table 3-24. Regression statistics, Medium-High climate scenario for 2020s

Multiple R	0.90
R Square	0.81
Adjusted R Square	0.76
Standard Error	0.13
Observations	28.00

Table 3-25. ANOVA, Medium-High climate scenario for 2020s

	df	SS	MS	F	Significance F
Regression	6.0	1.60	0.26	15.24	0.00
Residual	21.0	0.37	0.02		
Total	27.0	1.97			

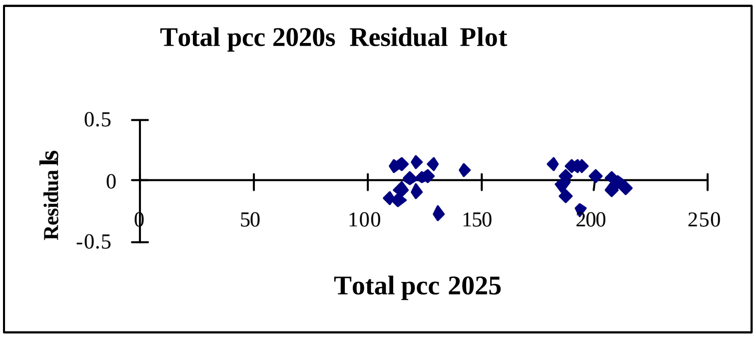


Figure 3-12. Total pcc residual plot, Medium-High climate scenario 2020s

Medium-High climate scenario for 2050s

Table 3-26. Regression statistics, Medium-High climate scenario for 2050s

	Coeffic	Std Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	6.00	2.40	2.50	0.02	1.01	11.00	1.01	11.00
Ean	0.67	0.27	2.25	0.03	0.05	1.19	0.05	1.19
GardenR20205	-2.16	3.47	-0.62	0.54	-9.41	5.09	-9.42	5.09
BathR2020s	-10.43	4.86	-2.14	0.04	-20.54	-0.32	-20.54	-0.32
dTmMH2020s	-5.02	1.86	-2.70	0.01	-8.88	-1.16	-8.88	-1.16
dPrMH2020s	0.83	0.34	2.42	0.02	0.12	1.54	0.12	1.54
Total pcc 2020s	0.03	0.09	3.70	0.00	0.01	0.05	0.01	0.05

Table 3-27. Regression statistics, Medium-High climate scenario for 2050s

Multiple R	0.78
R Square	0.61
Adjusted R Square	0.50
Standard Error	0.48
Observations	28.00

Table 3-28. ANOVA, Medium-High climate scenario for 2050s

	Df	SS	MS	F	Significance F
Regression	6.00	7.48	1.23	5.46	0.00
Residual	21.00	4.79	0.23		
Total	27.00	12.28			

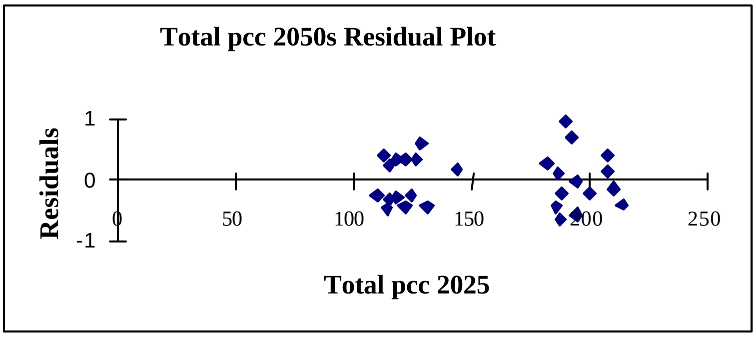


Figure 3-13. Total pcc residual plot, Medium-High climate scenario

3.6.4 Appendix 3-D. Statistical regression of demand and climatic variables

The length and the resolution of demand data series restrict analysis of demand data. Examples given here use data from South West Water and Thames Water Utilities Limited. Climate relationships have been made with seasonal demand for South West water, whereas for Thames Water monthly demand has been analysed against daily weather data.

South West Water: A 22-year series of water demand data was obtained from household surveys conducted since 1977 in which twice-yearly meter readings were taken. From these meter readings South West Water has provided annual, summer and winter consumption data for each household in litres per day. Daily temperature and precipitation data were available from the British Atmospheric Data Centre for the weather station at Penzance (50.117^{o}N, -5.542^{o}W, elevation 19 metres) so this was chosen as a suitable location for analysis. Approximately 55 households were identified in the Penzance area from the WIS (water into supply) Zone Allocation in the Strategic Supply Area of Colliford and information about property location in the household survey.

Daily climate data was summarised initially into monthly precipitation, dry days per month (where a dry day is defined as a day with zero rainfall following three days with zero rainfall) and mean maximum temperature for the month.

Figure 3-11 shows the time-series of summer and winter household demand data from 1977 to 2000. Information on hosepipe bans and non-essential-use bans was also provided by South West Water. These indicated that the winter of 1978 and the summers of 1983, 1984, 1989, 1990 and August 1995 to March 1996 were subject to hosepipe restrictions. The summers of 1984, 1989 and the summer of 1995 through to spring 1996 also had non-essential use bans in the Penzance area, which would have reduced water consumption below expected values during these periods. The Figure 3-11 clearly shows these effects particularly for the summer of 1984 and the winter of 1995/6.

Relationships were sought using 3-monthly averages of temperature, precipitation and dry days plus season-long averages. Regression of the demand data against the monthly climate data showed a relationship between mean maximum temperature for March - July and summer demand with an R^2 of 0.343 (significant at 99% level). If the years with a hosepipe ban are removed this increases to an R^2 0.683 using data averaged for June, July and August (Figure 3-12). Relationships with precipitation were more difficult to find and none were statistically significant, however slightly more correlation is seen with the use of dry day totals. The maximum R^2 of 0.135 comes from June dry days when hosepipe ban years are removed but this is not significant at the 95% level.

For winter demand mean maximum temperature for February and March alone give the highest relationship with an R^2 of 0.304, which is significant at the 99% level (Figure 3-12). This is not improved by removing winter 1995/6 data (the only year with winter water use restrictions). For precipitation no significant relationship could be found between single or multiple months and winter. Using dry days, December gives the highest R^2 (0.216) against winter demand, which is significant at the 95% level.

Based on the two relationships shown in Figure 3-12, we could say that a 2.3^{o}C rise in summer temperature (for 2050 – UKCIP02 Medium-High scenario) would result in an increase of 74 litres per day per household in summer water demand – about 21% above the summer average. For winter a 1.5^{o}C increase (again 2050 – UKCIP02 Medium-High scenario) might result in a 24 litre per day per household increase in winter consumption – approximately 7% above the winter average.

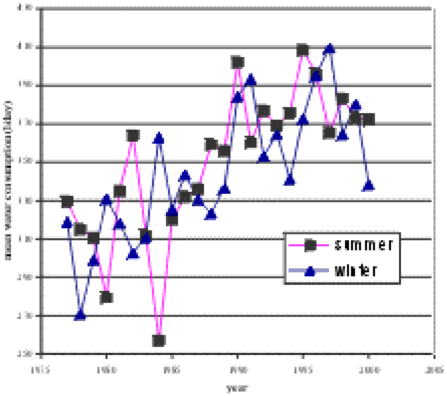


Figure 3-14. Time series of water consumption based on meter read values from 55 properties in the Penzance area of South West Water

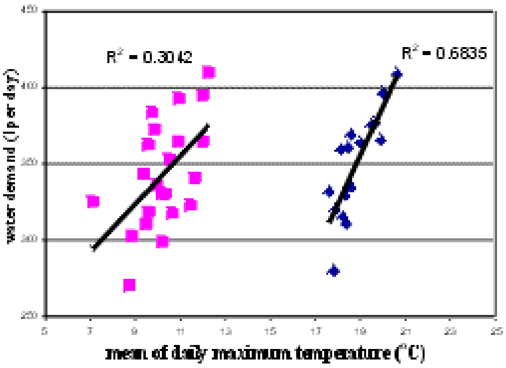


Figure 3-15. Scatter graph of mean maximum temperature (June, July and August for summer and February, March for winter) against household water demand for the Penzance area. Years subjected to water restrictions have been omitted.

Thames Water: The water demand data was provided by Thames Water and comprised monthly weighted Domestic Water Use Survey (DWUS) data by resource zones from 1996 to 2000. The TWUL (Thames Water Utilities Ltd) data on average water consumption in the Thames Region were selected for the analysis. The Met Office provided historical weather data from the British Atmospheric Data Centre. A London weather station (near Whitehall) was selected. This station is relatively data-rich and is probably fairly representative of London, which itself represents a significant component of total demand in the region.

Daily maximum air temperature and hourly precipitation from January 1996 to July 2000 were used. Total precipitation and total number of dry days were used to quantify dry conditions in a specific period. A dry day was defined as for the South West Water analysis. Temperature, dry days and precipitation deficit were averaged over two, three and four month periods and plotted against the monthly demand data. All data were standardised against their respective means over analysis period to produce anomaly indices for each period.

Figure 3-13 shows the relationship between climatic indices and water demand using a three month averaging period. Within the limitations of the current data set this was the most effective averaging period. An R^2 of 0.736 was found with maximum temperature, which is significant at the 99% level. An R^2 of 0.197 was obtained between dry days and water demand, which was significant at the 92.5 % level and provided an improvement on the regression with monthly data (R^2 0.45).

Based on this a predictive model of summer (July-September) demand was developed using these three month weather indices for the period 1996 to 1999. The equation was fitted to the observed indices using numerical optimization, with positive limitations, resulting in the following predictive model:

$$\text{Demand\_indicator} = 0.16 \times \text{T\_indicator}^{2.90} + 1.63 \times \text{Dry\_indicator}^{6.46.}$$

Figure 3-14 plots the above equation for a range of changes in the weather. The Total curve is the sum of the two components of the equation, relating to temperature (T) and dry days. As the weather becomes warmer and dry days increase, domestic demand in the summer increases. For instance, demand would be 2% greater than the annual average if both temperatures and number of dry days are 40% higher than average.

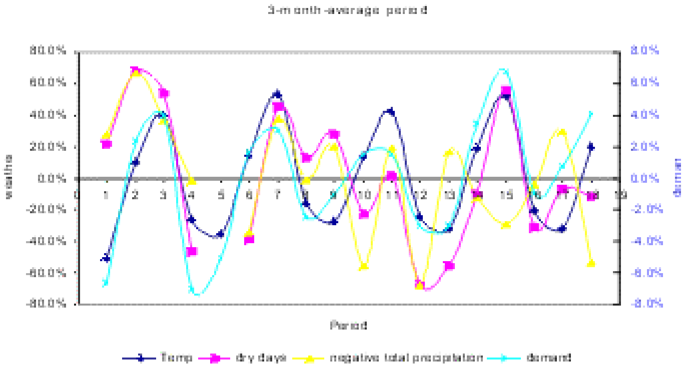


Figure 3-16. Domestic demand plotted against temperature, dry days and total precipitation (*-1) using 3- month averages.

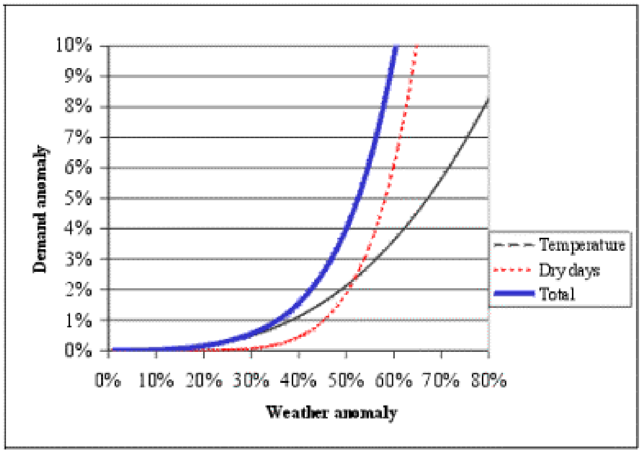


Figure 3-17. Model of summer domestic demand based on mean maximum temperature and dry days for the Thames water region.

Using the linear relationship between maximum temperature and demand only, a 2.8°C rise in summer temperature in the south east of England (UPCIP02 2050s Medium-High scenario) results in an increase in pcc of 3.1 l/day (approximately 2% above the average). For winter a 1.5°C increase in temperature (UPCIP02 2050s Medium-High scenario) results in a 1.65 l/day increase in pcc (approximately 1.1% above the average). The sensitivity for Thames is much lower than for South West Water because of the much shorter time series (all of which fall in the warm 1990s) and also the necessity of fitting a model which includes all months of the year rather than calculating the relationship seasonally.

The results from these two sites show considerable variation in sensitivity to climate and which for the South West is much higher than the CCDomestic model results. Obviously to extrapolate from these linear relationships is meaningless as they show a much simpler picture in which no account is taken of socio-economic changes and because they are based on one climate variable alone. However they do give a useful indication of the present sensitivity of demand. The relatively short time series and also the inclusion of the very hot years experienced in the 1990s also have a skewing effect on the data from the South West increasing the sensitivity of demand to maximum temperature.

4 Industry and commerce

4.1 Introduction

The purpose of this chapter of the report is to describe the key influences on the interaction between climate change and the demand for water from the industrial and commercial sectors in England and Wales.

Included below are:
- The characteristics of the industrial and commercial sectors' demands and a review of the data available.
- A description of the model and data generation applied in this analysis.
- A description of the historical relationship between climate variables and demand.
- The outline methodology and an explanation as to how it has been applied to assess potential climate change impacts.
- A description of the Environment Agency demand scenarios.
- A summary of the model and model findings
- An approach for a more detailed assessment of impacts that could be applied by a water company if it were able to assemble more detailed time series data on monthly industrial/commercial consumption from which relationships between water consumption and climate variables could be derived.

4.2 Characteristics of industrial/commercial demands

It is common practice in the water industry to breakdown total water consumption into discrete sectors of industry and commerce. At the simplest level a distinction is made between consumption in the industrial and the commercial/service sectors (using Standard Industrial Classification, SIC). This disaggregated approach, used by the Environment Agency (Environment Agency, 2001) has been applied in this study and is described in Section 4.2.2 below.

The following paragraphs summarise the information from trade associations and other bodies on water consumption in specific sectors identified during the first stage of the project.

4.2.1 Sectoral characteristics of water demand and demand data

Soft drinks: Although data on current consumption of soft drinks and predictions for consumption over the next five years are available, there is no available data on total water used in the manufacturing process, or on specific water consumption.

The British Soft Drinks Association (BSDA) does not consider climate change to be a major influence on its operations and has not explored its impact. There is however an assumption within the industry that higher temperatures and consumption will result in more consumption. This assumed relationship between temperature and consumption is not, however, borne out by historical data, which suggests that “affluence” and “fashions/ preferences” exert a more powerful influence than temperature on the demand for soft-drinks. For example, *Sunny Delight* transformed consumption in 1998, increasing consumption of fruit drinks by 50%.

Most soft drinks consumed within the UK are produced within the country. The water required as an ingredient for the drinks tends to be from manufacturers' own sources (springs and boreholes), although public water supplies may be used for the washing and cleaning plant and for bottling equipment.

Brewing: The Brewers and Licensed Retailers Association (BLRA) has provided a surfeit of general information about their water use and current trends in water use and ale consumption. As with BDSA, the BLRA supposes that hotter weather typically leads to a short-term increase in consumption of their products. Beer production in the UK has however fallen by over 10% (to 56.5 million hectolitres) in the last 25 years. During the same period, water consumption by the brewing sector has decreased by 32% as a result of improvements in production processes and rationalisation of the trade – the number of breweries has fallen from 140 to 80 in the past 25 years. This trend is likely to continue, though less dramatically, due in part to the Climate Change Levy (which calls for a 10% reduction in energy consumption by 2010), since water pumping, heating and cooling uses a high proportion of total energy.

Air conditioners: Enquiries suggest that most systems are likely to be refrigerant-based rather than water-based systems. These will have a high energy use, but no water requirement. In addition current health concerns about poorly maintained water based air conditioning systems mean that water consumption in this sector, already perceived to be very small, is likely to fall. Air-conditioning has therefore not been considered in this analysis.

Laundries: No data on laundry use have been located, and this does not appear to be a sub-sector identified by water companies in their consumption records. Higher ambient temperatures might reasonably be expected to lead to an increase in the frequency of changes of clothes and hence in the frequency of clothes washing – for domestic clothes washing this has been taken into account in the per capita consumption calculations (see Chapter 3). Based on the fact that the laundry sub-sector is relatively small no further analysis of this industry has been undertaken here.

In summary, of those industrial/ commercial sectors likely to be impacted by climate change, soft drinks, brewing and leisure (see Chapter 6) are likely to have the greatest impact on the overall requirements for public water supply (see Table 4-1).

Table 4-1. Sub-sectors of the industrial commercial sector considered important in terms of climate change impacts

Sector	SIC Code	Environment Agency Sectors
Soft drinks	DA	} Food and drink
Brewing	DA	}
Leisure – particularly hotels and recreational parks (examined in Chapter 6)	H	Hotels

Note: Private swimming pools are considered separately.

4.2.2 Regional breakdown in industrial/commercial demands

The regional differences in climate change impacts on temperature and precipitation have to be set in the context of spatial differences in the pattern of industrial/commercial consumption for different sectors.

The relative distribution of industrial/commercial consumption in 1997/98 for each of the Agency Regions and within each sector is summarised in Table 4-2. The percentages given in the Table have been derived from the baseline information used by the Agency in its Regional and National demand forecasts. Although the Environment Agency had requested information from water companies using a standard template, the returns varied widely. The categorisation into 19 sectors eventually used by the Agency was a compromise reflecting the variability in responses. There may be differences between water companies and hence between regions in the way industrial/commercial customers have been allocated to given SIC codes.

Those sectors in each region with more than 10% contribution to total regional industrial/commercial demands are summarised in Table 4-3. Inspection of Table 4-3 illustrates the main regional differences in the composition of industrial/commercial sectors, with manufacturing and chemicals predominately in the Midlands, North East and North West, and agriculture in Anglian, South West, Southern and Wales. The hotel sector is important throughout and has relative contributions of greater than 10% in the South West, Southern and Wales. Food and drink is also important, with relative contributions of greater than 10% in Anglian, North East and South West.

The retail figures appear slightly anomalous, with a wide range of variation from 8% (Midlands) to almost 38% (Thames). The differences probably reflect different socio-economic behaviour across England and Wales, but may also arise from differences in the way in which customers are allocated to SIC codes in Water Company billing databases.

Table 4-2. Regional breakdown of industrial commercial demand by sector 1997/1998 - percentage of total regional industrial/commercial demand

		Region							
		Anglian	**Midlands**	**North East**	**North West**	**South West**	**Southern**	**Thames**	**Wales**
Industrial Sector		**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
	Extraction	0.0%	0.0%	0.0%	0.0%	0.3%	0.5%	0.2%	0.0%
	Utilities	1.2%	0.0%	0.0%	0.0%	0.0%	1.0%	8.1%	0.0%
	Fuel refining	0.0%	0.0%	0.0%	0.0%	0.1%	2.8%	0.0%	0.0%
	Chemicals	6.7%	15.6%	28.3%	22.4%	6.2%	1.2%	13.7%	10.1%
	Minerals	0.4%	0.4%	0.0%	0.0%	0.0%	0.8%	0.9%	0.0%
	Metals	0.7%	13.9%	10.6%	9.1%	0.0%	1.7%	0.1%	7.8%
	Machinery	13.3%	7.8%	9.7%	6.0%	8.2%	0.9%	1.0%	8.5%
	Electrical equipment	0.3%	0.1%	0.0%	0.0%	0.0%	2.1%	1.1%	0.0%
	Transport	2.6%	1.1%	0.0%	0.0%	0.0%	1.4%	4.4%	0.0%
	Food and drink	17.3%	8.0%	12.1%	10.9%	3.8%	6.4%	8.9%	9.0%
	Textiles	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	0.1%	0.0%
	Wood	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Paper	0.8%	0.2%	0.0%	0.0%	0.0%	1.8%	3.4%	0.0%
	Rubber	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%	0.0%
	Construction	0.1%	0.0%	0.0%	0.0%	0.1%	1.0%	0.3%	0.0%
Industry Sector Total		**44%**	**47%**	**61%**	**48%**	**19%**	**23%**	**42%**	**35%**
Service Sector		**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
	Retail	25.7%	8.0%	14.1%	5.9%	20.5%	20.2%	37.7%	22.5%
	Education and Health	6.5%	8.4%	7.6%	10.6%	10.7%	13.4%	7.9%	10.2%
	Hotels	5.9%	7.1%	5.4%	9.5%	16.0%	11.7%	6.7%	11.4%
Service Sector Total		**38%**	**23%**	**27%**	**26%**	**47%**	**45%**	**52%**	**44%**
Agriculture		**13%**	**4%**	**2%**	**3%**	**27%**	**14%**	**3%**	**11%**
Other Total		**5%**	**25%**	**10%**	**23%**	**8%**	**18%**	**3%**	**10%**

Table 4-3. Major sectors contributing to regional industrial/commercial demand (based on 1997/98 data from Environment Agency, 2001)

Environment Agency Region	Sectors	% (total regional industrial/commercial consumption)
Anglian	Retail	25.7
	Food and drink	17.3
	Machinery	13.3
	Agriculture	13.2
Midlands	Other	24.9
	Chemicals	15.6
	Metals	13.9
North East	Chemicals	28.3
	Retail	14.1
	Food and drink	12.1
	Metals	10.6
North West	Other	22.8
	Chemicals	22.4
	Food and drink	11.0
	Education and health	10.6
South West	Agriculture	26.5
	Retail	20.5
	Hotels	16.0
	Education and health	10.8
Southern	Retail	20.2
	Agriculture	14.0
	Education and health	13.4
	Other	12.6
	Hotels	11.7
Thames	Retail	37.7
	Chemicals	13.8
Wales	Retail	22.6
	Hotels	11.4
	Agriculture	10.6
	Education and health	10.2
	Chemicals	10.1

4.2.3 Historical characteristics of industrial/commercial demand

The pattern of changes in non-household demand can been observed through data published by OFWAT in its annual reports on, water costs, water supply and water leakages. Figure 4-1 tracks total non-household demand for each Agency Region and shows a generally declining trend from 1989 across all regions. The aggregated data does not pick-out inter-annual variations related to specific climate characteristics.

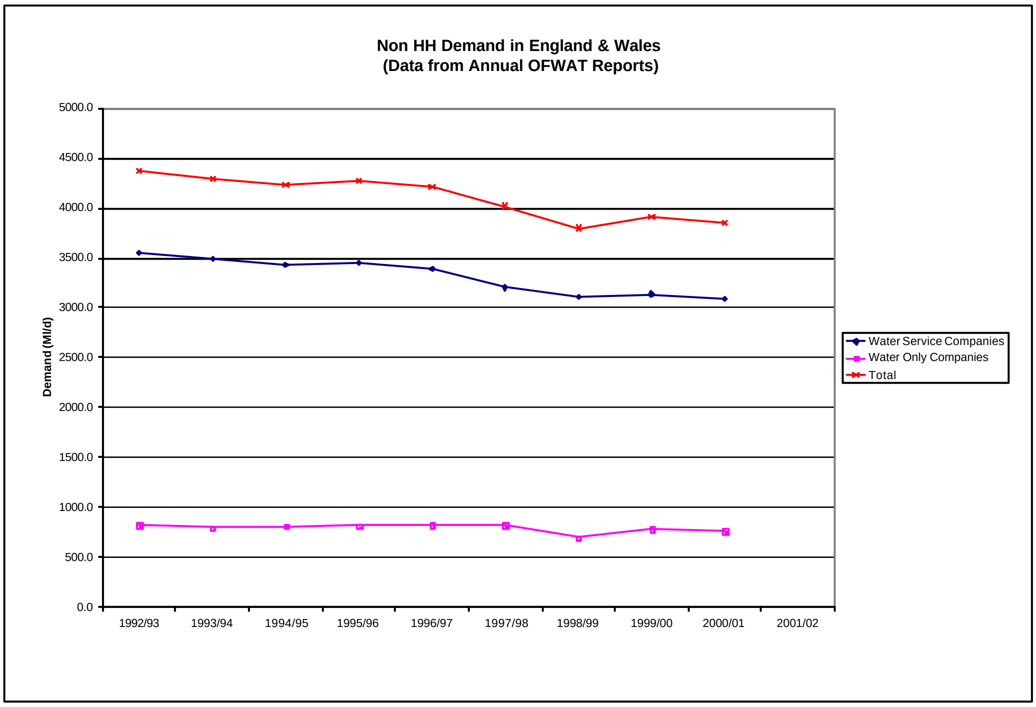


Figure 4-1. Annual changes in total non-household demand

4.2.4 Future characteristics of industrial commercial demand

In its demand forecasts for the National and Regional Water Resource Strategies (Environment Agency, 2001b), the Environment Agency uses projections of gross output and employment as proxies for future industrial and service sector water demand respectively. The baseline industrial/commercial forecasts used for this study are those developed by the Environment Agency for each water company. Note that the database of future industrial/commercial demand provided by the Environment Agency did not include data for individual water resource zones; the analysis has therefore been conducted at water company level.

Although major new “wet” industries are considered unlikely, significant step changes in industrial commercial demand associated with the closure of a major customer, or rapid development of a new business parks or similar facility are common, and often present a much greater influence than any long-term trend in either sector. These effects are not apparent in the aggregated data shown in Figure 4-1.

Comparison of past forecasts against realised demand suggests that uncertainties in forecasting future industrial/commercial demands are often greater than those for household demands. The implication is that any impact of climate change on industrial/commercial demand has to be set in the context of high uncertainty in the baseline forecasts. This is illustrated by the range of percentage changes in non-household demand seen in the forecasts derived by the Agency from the Foresight Scenarios (see Table 4.6). This uncertainty is discussed in more detail in Chapter 8.

4.3 Methodology

The basic assumption applied in this chapter is that for any industrial/commercial sector, changes in water consumption could arise from a change in the per unit water use and/or from a change in the demand for the product or service being consumed.

The UKWIR/Environment Agency report, "Forecasting Water Demand Components: Best Practice Manual" (UKWIR/ Environment Agency, 1997) recommends that, because of their sensitivity different climate change influences, the forecasting of future consumption be carried out separately for the industrial and for the commercial sectors. For example, changes in industrial consumption are related to indicators of economic activity such as GDP either at local, regional or national scale, whilst changes in service sector consumption are more closely related to employment statistics.

4.3.1 Data availability

Although water companies still report unmeasured non-household consumption in the annual returns to OFWAT, this component constitutes a relatively small proportion of distribution input. The main source of detailed historic time series data on industrial/commercial water consumption is therefore derived from meter readings and company billing records. Some trade associations have industry wide data on annual water consumption trends, but, as discussed below, these are of little use for the type of analysis required in this project.

Many water companies distinguish between industrial/commercial customers on the basis of SIC Codes (Standard Industrial Classification) (SIC, 1992) in their billing database(s). This categorisation also feeds through to the analysis of water consumption and forecasting of future demands. A summary of the SIC codes commonly used in the water industry is given in Table 4-4. The Table also shows the sectors used by the Environment Agency in its disaggregated approach linked to SIC codes as used for the Regional and National Water Resource Strategies (Environment Agency, 2001). The Agency has broken non-household use of public water supplies down into 19 sectors related to the two letter SIC (92) class. The Agency forecasts provide the reference cases from which climate change impacts have been assessed in this project. Accordingly the non-household model developed here is based on the 19 sectors identified by the Agency; of these 15 are classified as "industrial", 3 as "service", with 1 "other" category. The "other" category has been further subdivided for the purpose of this study so as to identify "indoor agricultural customers" who rely on the public supply of water for their greenhouses, but this classification does not include "animal watering" even though this was one of the micro-components identified in the Environment Agency reference scenarios. Note that the "indoor agriculture" category, included in this section, is considered to be different from the outdoor Agriculture and Horticulture sector in Chapter 5.

Water companies are not required to distinguish between industrial/commercial sectors in their regulatory returns to OFWAT and the Environment Agency. Apart from the largest users of water, whose consumption is recorded monthly, revenue meters are generally read on a quarterly basis. This limits the availability of monthly data and the usefulness of monthly data sets in assessing historical relationships between climate and water demands.

Table 4-4. Standard Industrial Classification (SIC) Codes

SIC Codes				Environment Agency Sectors
Code	**Sub-code**	**Industries**	**Sub-sector**	
A		Agriculture	Nurseries	included in "other"
C	CA	Extraction	energy materials	Extraction[1]
	CB	Mining/quarrying		Minerals [1]
D	DA	Manufacturing	food and drink	Food and drink[1]
	DB		textiles	Textiles[1]
	DC		leather/products	
	DD		wood/products	Wood[1]
	DE		paper	Paper[1]
	DF		coke, petroleum	Fuel refining[1]
	DG		chemicals	Chemicals [1]
	DH		rubbers, plastics	Rubber[1]
	DI		non-metal mineral prods	
	DJ		metals, fabricated prods	Metals [1]
	DK		machinery/equip	Machinery[1]
	DL		electrical/optical equip	Electrical equipment[1]
	DN		transport equipment	
E		Utilities		Utilities[1]
F		Construction		Construction[1]
G		Retail, wholesale		Retail[2]
H		Hotels	caravan parks, camp sites, restaurants	Hotels [2]
I		Transport	support, post/telecom	Transport[2]
J		Financial		
K		Real estate	developments, renting	
L		Public admin, defence		
M		Education		
N		Health		Education and Health[2]
O		Social, recreational, sporting		
				Other

Note: [1] Industrial sector
[2] Business sector

Nevertheless monthly industrial/commercial data were provided to this study for the period from 1998/99 to 2000/2001 for various water resource zones (WRZ) in the South of England. Analysis of the data has allowed some general observations about the sensitivity of certain industrial/commercial sectors to climate to be made, and has also informed the development of a conceptual model to assess the potential impacts of climate change.

On the basis of discussion within the Project Team, members of the Project Steering Group and representatives from water companies during progress meetings and workshops, the industrial sectors most likely to be affected by climate change were agreed upon and are shown in Table 4-5.

Table 4-5. Sectors expected to be affected by climate change

Sector	**SIC Code**	**Environment Agency Sectors**
Soft drinks	DA	Food and drink
Brewing	DA	Food and drink
Air conditioning	DK	Machinery
Swimming pools	O	Other
Laundries	O	Other
Leisure – particularly hotels and recreational parks (examined in Chapter 6).	H	Hotels

For each of the sectors identified, a search of available information and data on water use was conducted using the internet, published information, telephone interviews and face to face meetings. A summary of the sources of information and the types of data available are given in Appendix 4-A.

The general conclusion reached is that the lack of reliable data on water use makes it difficult to link the level of water consumption with local climate. In particular, the general lack of monthly consumption data meant that it was difficult to establish robust relationships between consumption and climate variables such as temperature and precipitation.

Monthly water consumption data for individual industrial/commercial sectors are only available for a few years and access to many of the data sets is constrained by company policy. The difficulty in obtaining primary water consumption data for the industrial/ commercial sectors was a constraint on this study, much as it was for the Environment Agency in its report on the demand forecasting methodology used for the National and Regional Water Resource Strategies (Environment Agency, 2001).

Following discussion with water industry practitioners at various project workshops and consultation with Project Steering Group, it was decided to use such time series data of consumption as were available to identify general relationships between climate variables and consumption, and then use these to estimate potential impacts of climate change on demand arising from the industrial and commercial sectors.

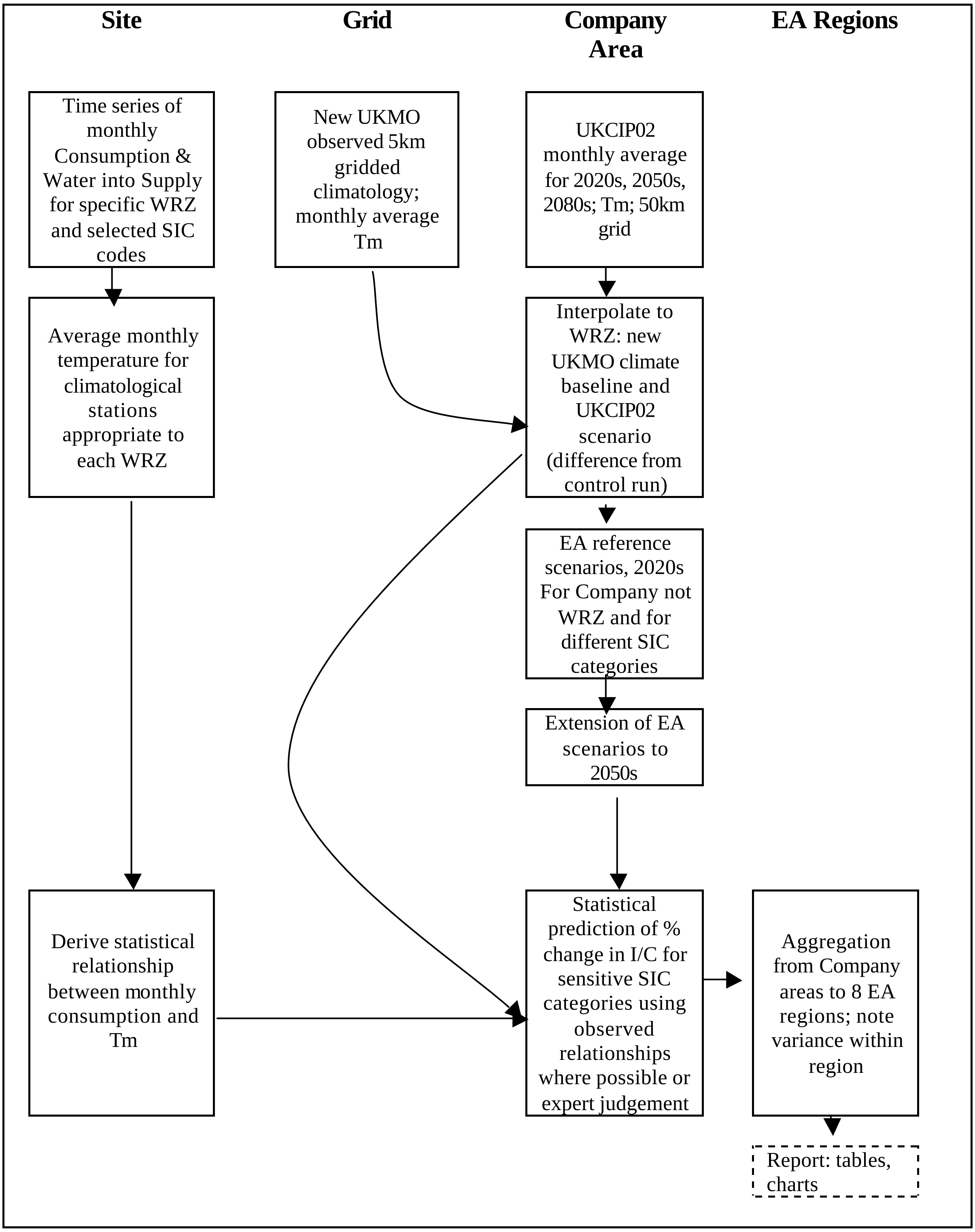


Figure 4-2. The applied approach, indicating links between input data sets, modelling and outputs

4.3.2 Environment Agency demand scenarios

Details of the Environment Agency forecasts for the different industrial sectors for the baseline and for the four socio-economic scenarios were provided for use in this study at water company level.

Table 4-6 shows the percentage changes in total non-household demand from 1997/1998 to 2024/2025 without climate change for the baseline case and for the four Foresight socio-economic scenarios as forecast by the Agency. The spread of the forecasts in 2024/2025 for all the socio-economic scenarios is illustrated in Figure 4-3.

Table 4-6 2024/2025 Environment Agency Forecasts – excluding climate change. Percentage changes from the 1997/1998 baseline

Region	1997/98 Ml/d	2024/2025 Percentage change from 1997/1998				
		Baseline	Provincial Enterprise Alpha	World Markets Beta	Global Sustainability Gamma	Local Stewardship Delta
Anglian	491	30.0%	15.1%	37.8%	-20.2%	-28.7%
Midlands	591	42.8%	25.2%	36.1%	-27.5%	-30.4%
North East	587	35.4%	18.1%	35.7%	-36.9%	-39.2%
North West	536	24.6%	10.5%	24.6%	-41.4%	-43.1%
South West	383	22.1%	6.6%	31.4%	-13.5%	-27.9%
Southern	242	20.8%	5.8%	26.2%	-23.9%	-34.2%
Thames	856	26.9%	5.2%	38.4%	-32.4%	-43.2%
EA Wales	262	38.3%	21.5%	43.8%	-19.7%	-29.0%
Total	**3947**	**30.6%**	**13.3%**	**34.6%**	**-28.8%**	**-35.9%**

Source: Environment Agency 2001b

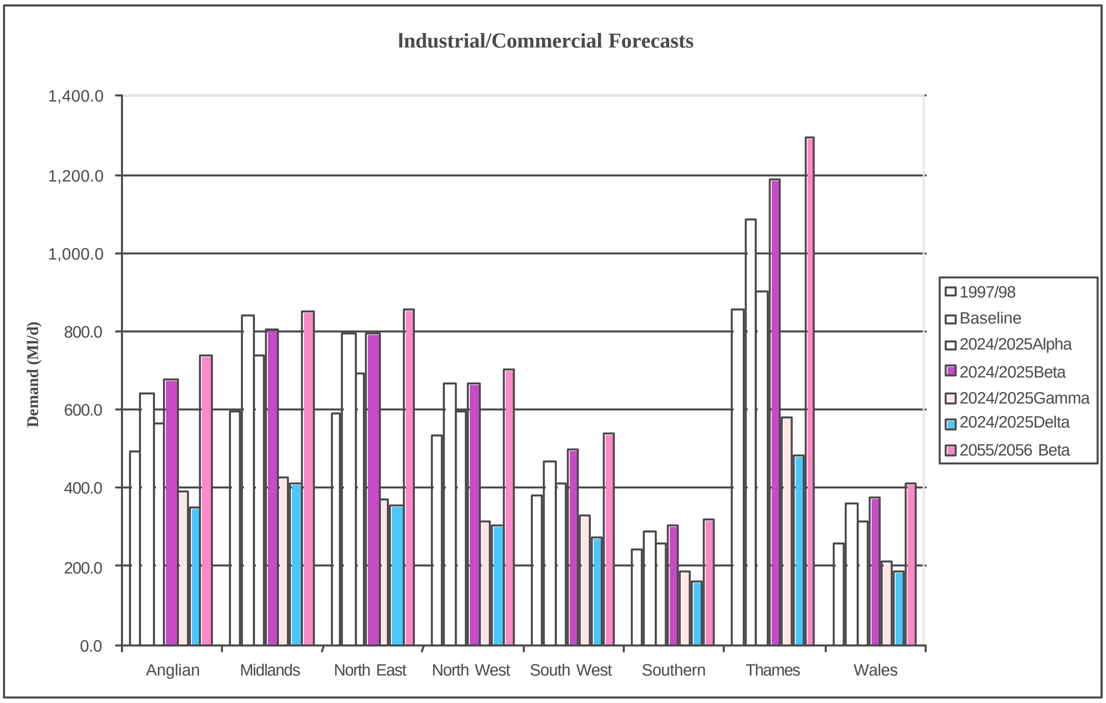


Figure 4-3. Industrial/commercial forecasts in 2024/2025 and 2055/2056

The Environment Agency study forecast future demands up to 2024/2025 – for this study the potential impact on demands up to the 2050s was required. Long-term forecasting of industrial/commercial consumption is less reliable than forecasting domestic consumption. Industrial commercial water consumption is particularly sensitive to changes in the economy, with secular trends in demand often masked by abrupt changes brought about by external forces such as the closing down of major plants/factories, or the creation of new industrial/business parks. Accurate forecasts become increasingly difficult the longer the forecast period.

For the purpose of this analysis a very simple method was used to extend the Environment Agency forecasts to the 2050s. It was assumed that the absolute change in demand for each sector and in each water company area between 2019/2020 and 2024/2025 would be repeated over the much longer period from 2024/2025 to 2054/2055. In those instances in which extrapolation of the decline resulted in negative consumption, the 2054/2055 demand was set to zero.

The projections for the Beta scenario for the 2050s are also shown in Figure 4-3. The simple forecasting method maintains the same relative mix of consumption by each sector that is found in the Agency's projections for 2024/2025. This is considered to be appropriate for the comparative analysis of possible changes in consumption due to climate change up to 50 years ahead of the present day.

4.3.3 Inputs for the CCDeW industrial/commercial model

The overall methodology for the CCDeW industrial/commercial model is set out in Figure 4-2. The analysis has been based on monthly time series of consumption for given sectors and the forecasts of sectoral annual demands from the Environment Agency's Water Resource Strategy (Environment Agency, 2001). Data used in this chapter is based on the UKCIP02 gridded data at the 50km scale.

The analysis has been conducted at water company scale and the results are presented at the Environment Agency Region scale.

4.3.4 Relationship between climate variables and demand

Examination of data from various water resource zones in Southern Region provides insight into the direct and indirect impacts of climate on individual sectoral demands. Typical plots for the water consumption of customers in the Hotel and the Agricultural sectors are shown in Figure 4-4 and Figure 4-5; the lines in each plot represent different customers within the water resource zone.

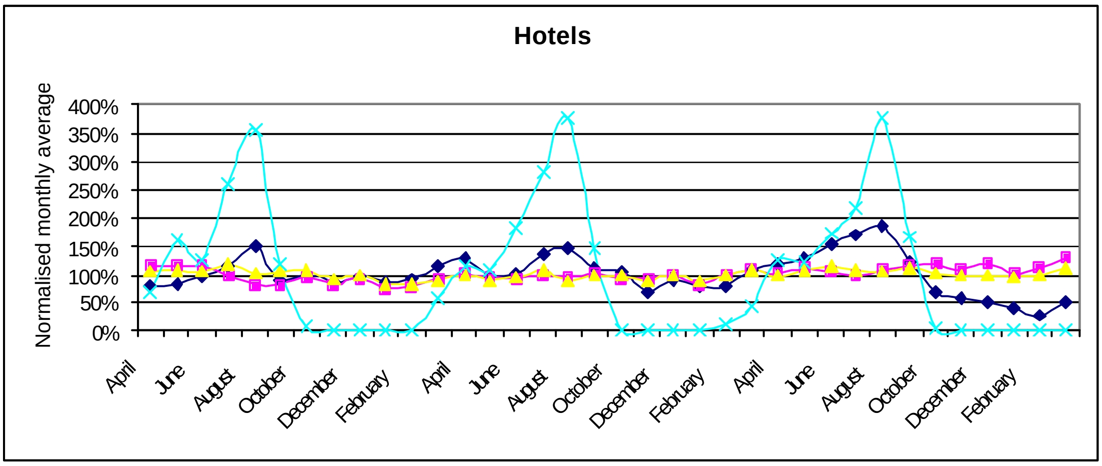


Figure 4-4. Typical seasonal variation in public water supply demand for Hotels – Southern Region WRZ

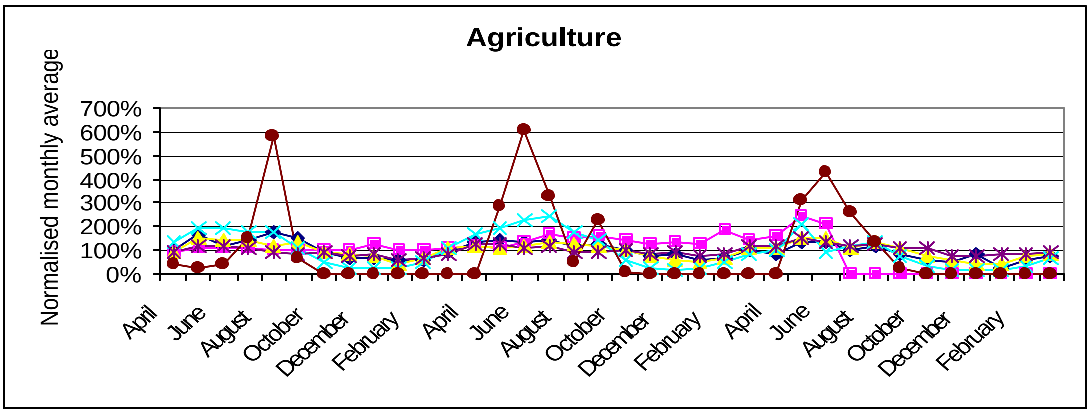


Figure 4-5. Typical seasonal variation in public water supply demand for Agriculture – Southern Region WRZ

Sectors, such as the hotel, recreation and leisure industries and agriculture exhibit a strong seasonal variation in demand. The amplitude of the seasonal variation appears to be related to location, in that coastal areas exhibit a higher range than inland areas. Other, manufacturing-based industries show very little seasonal variation. The greatest part of the seasonal variation in water use is related to the UK summer holidays and influx of international visitors in the summer months. Without site specific and contemporary time series data on factory output (that may be affected by summer shut-downs) and water consumption, it is not possible to investigate how water use per unit of consumption might change with climate.

Data, for each of the industrial/commercial sectors in each of the WRZs for which data were available, covered the period from 1998 to 2001 only, although monthly data for the total distribution input into each WRZ were provided for the period since 1989. It was observed that during the period for which data on monthly sectoral demands were available, there was little change in the relative percentages of monthly industrial/commercial demand in each sector. The observed percentages of sectoral demands were therefore used to estimate the time series of monthly demands for each sector for the period from 1989.

Using such time series data as were available, linear relationships between temperature and normalised consumption in each sector were derived. Note that in some WRZs, there was no consumption recorded in some sectors. A summary of the types of relationships observed is given in Table 4-7.

Table 4-7. Examples of observed relationships between average temperature and normalised demand

Sector		Slope	R^2
Hotels - coast	H	0.084	0.76
		0.055	0.73
		0.058	0.73
Hotels - inland	H	0.014	0.32
Recreation	O	0.054	0.44
		0.065	0.62
Business	Included in Environment Agency category "other"	0.024	0.65
Manufacturing	D	0.020	0.53
Indoor agriculture	A	0.184	0.61

Note: Units of slope is, % change in demand per ^{o}C.

As might have been expected the greatest slope appeared for the Hotel and Recreation industries in coastal areas (a sector that is discussed further in Chapter 6) followed by the business sectors, and then manufacturing. The slope for the agricultural sector was less than might have been expected, but as noted above, the "agriculture" category in this chapter describes glasshouses but not outdoor irrigation which is included in Chapter 5.

At one CCDeW workshop it was suggested that the number of degree days might also be used to represent climate. The analysis described above was repeated using degree days, rather than mean temperature. The observed relationships were less significant than those derived using average temperature. Analyses using maximum temperatures and precipitation respectively were also undertaken – again the observed relationships were less significant than those derived using average temperature.

It was therefore decided to restrict the analysis of future impacts to average temperature. For the purpose of estimating potential climate change impacts, each industrial sector was allocated one of the following categories of sensitivity to climate change: high, medium, low and nil. A summary of the allocations is given in Table 4-8.

Note that although not identified as climate sensitive industries, the minerals and extraction sectors may be required to use more water during dry periods for wetting-down dust under warmer climate conditions; the same may apply to the construction sector. In addition, if temperatures remain high (>28^{o}C) for a few days, the construction industry may have to use ice to cool concrete mixers down, increasing the overall water requirement associated with cement mixing. The very small percentage of total industrial/commercial demand represented by these sectors means that their impact on total demand at regional level is small. For the purpose of this analysis these sectors have been allocated a high sensitivity.

Ambient temperature and the electrical power requirement for air-conditioning are known to be highly correlated. Assuming the same technology is applied, an increase in popularity for domestic and commercial air conditioning will increase demand for water required to generate the power for the air-conditioners. Consideration of water demand for electricity generation was, however, specifically excluded from the ambit of the study.

Table 4-8. Assumed sensitivity of each sector to climate change

Sector	Assumed sensitivity to climate
Industrial sectors	
Extraction	High
Utilities	Low
Fuel refining	Nil
Chemicals	Low
Minerals	High
Metals	Low
Machinery	Low
Electrical equipment	Medium
Transport	Low
Food and drink	High
Textiles	Nil
Wood	Nil
Paper	Nil
Rubber	Nil
Construction	High
Service Sectors	
Retail	Medium
Education and Health	Medium
Hotels	High
Other (including Business)	Low
Agriculture	Medium

4.4 Model summary

A simple model has been set up to translate the impact of a given change in average temperature into a percentage change in demand using the linear relationships discussed in Section 4.3.4.

The input data for the model comprise:

- Forecast annual demand in the 2020s and 2050s under the four socio-economic scenarios, for each water company area and for each of the sectors identified by the Environment Agency.
- Relationships between temperature and normalised demand as informed by the analysis summarised in Table 4-8 and the categorisation of the assumed sensitivity of each sector to climate change given in Table 4-6.
- Change in average annual temperature from the reference climate at each time-slice.

The change in demand that is attributable to climate change was then calculated for each sector, for each water company, and then aggregated to produce a regional total. The results were then expressed as the percentage change in demand from the reference case attributed to climate change.

4.5 Model results

4.5.1 Sectoral and regional results

The results of the analysis for each sector are given in Table 4-9. The results are expressed in terms of the percentage change in annual demand. The results presented in Tables 4.9 are percentage changes from the baseline - no climate change and non socio-economic scenarios case. The percentage change for each sector for each of the scenarios Alpha to Delta are the same, however, because the relative contribution of industrial and commercial activity differs in different regions, the percentage change in any total will differ. Note that the temperature changes that are attributable to climate change, vary monthly so the seasonal distribution in demand would also be expected to change in comparison with the reference case. It is reasonable to assume that significant participation in certain outdoor activities such as swimming and other water based recreation will only take place once the temperature has exceeded a given threshold, therefore the application of relationships similar to those given in Table 4-9, will tend to over-estimate climate change impacts.

A summary of the results of the analysis is given in Table 4-9 expressed as the percentage change from, “Without Climate Change” reference socio-economic scenario.

Table 4-9. Changes in annual average industrial/commercial demand for each sector for the Medium-High climate change scenario, expressed as a percentage of the without climate change reference demand

	Anglian		**Midlands**		**North East**		**North West**		**Southern**		**South West**		**Thames**		**Wales**	
Industrial Sector	**2025/24**	**2055/56**	**2025/24**	**2055/56**	**2025/24**	**2055/56**	**2025/24**	**2055/56**	**2025/24**	**2055/56**	**2025/24**	**2055/56**	**2025/24**	**2055/56**	**2025/24**	**2055/56**
Extraction	-	-	-	-	-	-	-	-	6.4%	13.6%	5.7%	12.0%	6.4%	13.6%	-	-
Utilities	1.0%	2.0%	-	-	-	-	-	-	1.0%	2.0%	0.9%	2.0%	1.0%	2.1%	-	-
Fuel refining	-	-	-	-	-	-	-	-	-	-	0.0%	0.0%	-	-	-	-
Chemicals	0.9%	2.0%	0.9%	1.9%	0.8%	1.7%	0.8%	1.7%	1.0%	2.1%	0.9%	2.0%	1.0%	2.1%	0.8%	1.8%
Minerals	6.3%	13.4%	6.0%	12.8%	-	-	-	-	6.3%	13.5%	-	-	6.4%	13.6%	-	-
Metals	0.9%	1.9%	0.9%	1.9%	0.8%	1.7%	0.8%	1.7%	1.0%	2.0%	-	-	1.0%	2.1%	0.8%	1.8%
Machinery	0.9%	1.9%	0.9%	1.9%	0.8%	1.7%	0.8%	1.7%	1.0%	2.1%	0.9%	1.9%	1.0%	2.1%	0.8%	1.8%
Electrical equipment	2.3%	4.9%	2.2%	4.7%	-	-	-	-	2.3%	5.0%	-	-	2.3%	5.0%	-	-
Transport	1.0%	2.0%	0.9%	1.9%	-	-	-	-	1.0%	2.0%	-	-	1.0%	2.1%	-	-
Food & drink	6.1%	12.9%	5.9%	12.6%	5.3%	11.2%	5.2%	11.1%	6.4%	13.6%	6.1%	12.9%	6.4%	13.6%	5.5%	11.7%
Textiles	0.0%	0.0%	0.0%	-	-	-	-	-	0.0%	0.0%	-	-	-	-	-	-
Wood	-	-	-	-	-	-	-	-	0.0%	0.0%	-	-	-	-	-	-
Paper	0.0%	0.0%	0.0%	0.0%	-	-	-	-	0.0%	0.0%	-	-	0.0%	0.0%	-	-
Rubber	-	-	-	-	-	-	-	-	0.0%	0.0%	-	-	0.0%	0.0%	-	-
Construction	6.3%	13.4%	-	-	-	-	-	-	6.3%	13.4%	6.1%	13.0%	6.4%	13.6%	-	-
Industrial Sector Totals	2.7%	5.6%	1.6%	3.3%	1.4%	2.9%	1.5%	3.0%	2.9%	6.0%	1.9%	4.0%	2.2%	4.7%	2.2%	4.7%
Service Sector																
Retail	2.2%	4.7%	2.2%	4.6%	2.1%	4.0%	1.9%	4.0%	2.3%	4.9%	2.5%	4.7%	2.3%	5.0%	2.0%	4.2%
Education & Health	2.2%	4.7%	2.2%	4.6%	2.1%	3.9%	1.9%	4.0%	2.3%	4.9%	2.5%	4.7%	2.3%	5.0%	2.0%	4.2%
Hotels	6.1%	13.0%	5.9%	12.6%	5.8%	10.7%	5.2%	11.1%	6.4%	13.5%	6.6%	13.0%	6.4%	13.6%	5.5%	11.7%
Service sector totals	2.8%	5.8%	3.3%	6.9%	2.8%	5.2%	2.8%	5.8%	3.3%	6.9%	3.9%	7.6%	2.8%	5.9%	2.8%	5.9%
Agriculture	2.2%	4.7%	2.2%	4.6%	2.0%	4.1%	1.9%	4.0%	2.3%	4.9%	2.2%	4.7%	2.3%	5.0%	2.0%	4.3%
Other totals	0.0%	0.0%	0.9%	1.9%	0.8%	1.7%	0.8%	1.7%	0.8%	1.8%	0.8%	1.8%	0.7%	1.6%	0.8%	1.8%
Overall totals	**2.6%**	**5.4%**	**1.7%**	**3.4%**	**1.7%**	**3.2%**	**1.7%**	**3.4%**	**2.5%**	**5.2%**	**2.8%**	**5.5%**	**2.5%**	**5.2%**	**2.2%**	**4.7%**

Table 4-10. Regional estimates of climate change impacts on industrial/commercial demand, expressed as % change from baseline

Scenario	2020sL Gamma	2020sMH Alpha	Beta	Gamma	Delta	2050sMH Beta
Anglian	2.4%	2.6%	2.6%	2.7%	2.5%	5.7%
Midlands	1.8%	1.7%	1.8%	2.0%	1.7%	3.9%
North East	1.9%	1.7%	1.8%	2.1%	1.8%	3.6%
North West	1.9%	1.7%	1.8%	2.1%	1.8%	3.8%
Southern	2.5%	2.4%	2.7%	2.8%	2.4%	5.7%
South West	2.9%	2.7%	3.0%	3.1%	2.7%	6.1%
Thames	2.6%	2.5%	2.5%	2.9%	2.6%	5.4%
EA Wales	2.3%	2.3%	2.4%	2.6%	2.3%	5.2%

The results show differences between the Agency regions. The differences arise from the different mix of industrial/commercial sectors within each region. Those regions in which the sectors sensitive to climate change constitute a greater proportion of industrial/commercial demand, will exhibit higher sensitivity to climate change. Differences between regions also arise from differences in the impact on each sector of the drivers assumed for each of the socio-economic scenarios.

Estimates of the potential impacts of climate change on evaporative losses from private swimming pools are given in Table 4-11; details of the assumptions and calculations are given in Chapter 6.

Table 4-11. Estimates of water losses from private swimming pool use

	2020s without climate change	2020s with climate change
Evaporation losses (mm/season)	375	389
Estimated loss Ml/d		
Anglian	4.3	11.2
Midlands	3.4	8.8
North East	0.2	2.4
North West	0.3	2.5
South West	3.1	8.2
Southern	3.3	8.5
Thames	5.6	14.6
EA Wales	0.1	1.1
Total	**20.3**	**57.4**

4.6 Conclusion and recommendations

A pragmatic approach to the estimation of potential climate change impacts on industrial/commercial demands has been adopted. The results presented in 4-9 and 4-10 suggest that:

- The impacts are small in comparison with the range of forecast demands for each of the four reference socio-economic scenarios, and with the percentage change in forecast baseline demands between 1997/98 and 2024/25 as summarised in Table 4-6.
- Inspection of the temperature/consumption relationships for WRZs in Southern Region suggests that for some sectors there are differences between coastal WRZs and those located in-land. Given that the analysis has been conducted on data at water company level, rather than WRZ level, it has not been possible to accommodate this type of spatial difference in the analysis.
- More detailed analysis of the relationship between consumption and climate variables such as temperature is recommended, but depends on the availability of appropriate data, and could be conducted at the WRZ scale if required. Once more refined temperature/consumption relationships have been determined, the analysis described in earlier sections could be repeated following the steps shown in Figure 4-6. This approach is described more fully in the guidelines of Section 9.4.
- Much greater discrimination between water consumption data in various industrial/commercial sectors and for different regions is a prerequisite for a better understanding if the impact of climate on water demand is to be achieved. Although it is recognized that the reluctance on behalf of companies to have their core data displayed in the public domain, may restrict the exchange of data between water companies and external bodies, the following recommendations for data collection would improve the robustness of future analysis:
    - Allocation of SIC codes to industrial/commercial customers to be consistent across water companies
    - Monthly meter readings to be consolidated into monthly water consumption data on a water resources zone level
    - Where patterns of consumption within a given sector vary across a water resource zone – for example a zone that includes inland urban areas, and coastal areas popular for tourism – additional sub-zones to be considered for industrial/commercial data.

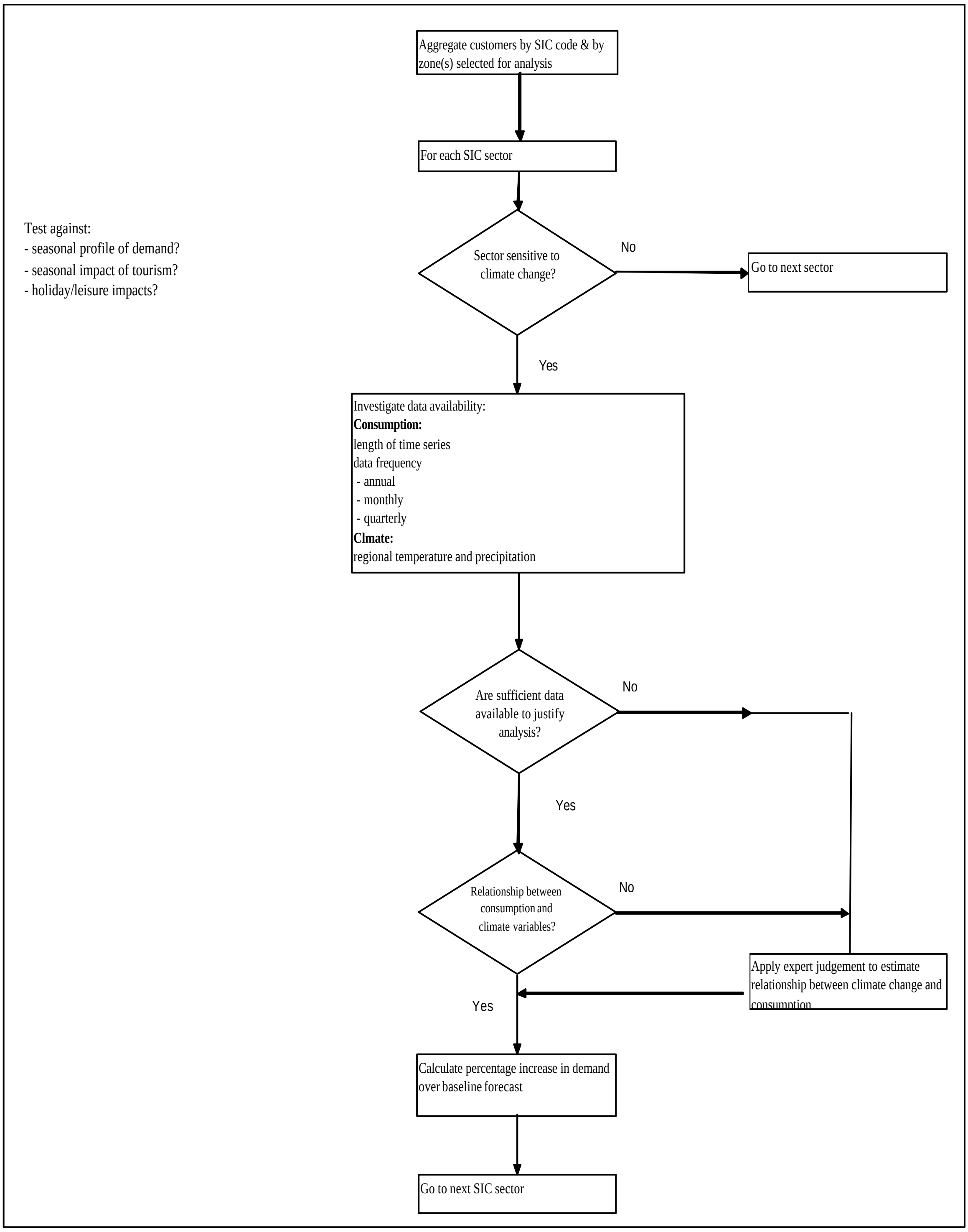


Figure 4-6. Flow chart for analysis using detailed monthly consumption data

4.7 Appendix

4.7.1 Appendix 4-A. Industrial and commercial sectors: sources and types of data

For each of the components selected, the main sources of data from the preliminary search, and a summary of the data content are shown in the table below. For some of the components, reliable data on water use and the impacts of climate change is extremely limited. Where this is the case, potential sources have been identified and a general description of water use and potential impacts upon use have been included.

Table 4-12. Industrial and commercial sectors: sources and types of data

Industrial sector	Main sources of information	Data type
Soft drinks	British Soft Drinks Association	BSDA has done no work on climate change and don't think any of their members will have done either. Feel that sales are directly affected by hot weather and affluence – need to try and pull apart – but changes in climate will have proportionate impact on demand.
	The 2001 Sucralose Soft Drinks Report – UK Market Review	Derive from sales and climatic data. Sales Data: • Warm summer weather is cited as a major short term influence • Projection for next five years for 3% per annum growth • Annual consumption at 12,000 million litres (200 litres per person) • Most drinks produced in the UK. Least is bottled water (70% UK)
Swimming pools	Chartered Institute of Public Finance and Accountability – Leisure and Recreation Statistics 1998-99	**Public** expenditure on swimming pools has not significantly increased in the last six years. All expenditure has been on indoor swimming pools – possible shift to outdoor requiring new pools, but no substantive information.
	Swimming Pool and Allied Trader Association,	**Private.** No information provided from Trade Association. Very much linked to affluence as well as climate change.
Air conditioning	Only sources identified include: 1. Dept. of the Environment Report – Climate Change and the Demand for Water, HMSO, 1996 (Paul Herrington, Univ. of Leicester) 2. Individual manufacturers' marketing literature on the web, e.g. The Air Conditioning Company (this company provide mainly evaporative cooling systems (water based).	Trend is very much towards air cooling systems (water systems – concerns over legionnaires disease and need to be installed for whole buildings (not ideal unless whole buildings let)). Air - high energy but not high direct water use. Sealed systems. Mostly portable air cooled system manufacturers, though example given is one of water based system.

Industrial sector	Main sources of information	Data type
	systems (water based).	
Brewing	UK Brewers and Licensed Retailers Association (	**Biennial report on energy and water**. In summary: • 35 million m^3 water used per year • **production** of beer itself accounts for 36%, mostly from private wells and springs • 70% of water used for **steam raising, cooling and washing** (from municipal supplies) is discharged as trade effluent • reduced water consumption by 30% since mid/late 1970's • Specific production of beer (units of water used per unit of beer produced) had dropped from 9 in 1974 to 6 in 1996)- the smaller brewery the higher the figure (range 8.5 to 5.8) • Energy consumption reduced by 40% in same period, though static since 1992
	Brewing and the Environment, (Sept 2000, BLRA)	Annual production of beer about 57million hectolitres. Total water used is this plus 35 million m^3.
	DTI/DETR Environmental Technology Best Practice Programme. Good Practice Guide – Reducing Water and Effluent Costs in Breweries	Aimed at smaller breweries (<500,000 hectolitres/year). Fairly straightforward to reduce use by about 40%. Cost of water supply and effluent = cost of energy. Best practice = 3.4 water for 1 of product.
	National Statistics, March 2001 for 'Food, drink and tobacco'	Manufacturing output index: 1995 – 100.0, 1996 – 101.0, 1997 – 104.6 1998 – 101.9, 1999 – 101.5, 2000 – 100.1
Laundries	National Association of the Launderette Industry	No information made available
Leisure	Much of the information is only available commercially. : Institute of Public Finance – Financial Information Services Report on the Leisure Industry.	
	British Hospitality Association – Trends and Statistics, 2001.	Information on tourism forecasts (nos. and purpose – foreign and domestic) and room occupancy.
	English Tourism – Consultation Document 'Perspectives on English Tourism' http://englishtourism.org.uk	Tourism trends in last 10 years and identifies emerging issues which may cause tourism to change in the future.
	Outdoor Industries Association –	Number of activity and caravan

Industrial sector	Main sources of information	Data type
	Development Plan 2000-2003	holidays declining in the UK. Camping increased by 10% in the 1990s.
	Center Parcs	Leading leisure park organisation. Not much room for increasing numbers under current infrastructure – year round occupancy rate of over 90%. No apparent plans for further developments as yet. 3 in the UK at present. No detailed information provided.

Part II: Sectoral analyses

5 Agriculture and horticulture

This section of the CCDeW project assesses the sensitivity of irrigation water demand in agriculture and horticulture to climate change. This section:

- Summarises the characteristics of agricultural and horticultural irrigation water demand;
- Describes the methodology and presents the base data;
- Discusses the direct impacts of elevated atmospheric CO_2 on crop water use and yield;
- Calculates the impacts of climate change, in three steps:
  - impacts of changes in rainfall and potential evapotranspiration on optimum irrigation needs (depths);
  - resulting impacts on irrigation water demand (volumes), under the various socio-economic scenarios;
  - combined impacts including the effects of enhanced atmospheric CO_2 enrichment on yield and hence area cropped;
- Discusses the limitations and risks; and
- Summarises the main conclusions from this section.

5.1 Characteristics of agricultural/horticultural irrigation water demand

Between 1% and 2% of water use in England and Wales is for irrigation of crops. Although this is relatively small, it is a consumptive use concentrated in the drier catchments in the direst months, and can become the largest abstractor in some catchments in dry summers.

The micro-components of demand used in this section are the crop categories previously defined for MAFF surveys, namely early potatoes, main crop potatoes, sugar beet, vegetables (including salad crops), soft fruit (particularly strawberries), orchard fruit (mainly apples), cereals, grass (for pasture and silage), and “other”. This last category is very varied, including for example herbs and Christmas trees.

Over the last 20 years, there has been a significant change in the relative importance of these categories. The proportion of irrigation on grass and cereals has been declining steadily. In contrast there has been increased irrigation of high value crops, particularly potatoes and vegetables for human consumption. By 2001, potatoes accounted for 52% of the total irrigated area, and 57% of the total volume of irrigation water applied (Table 5-1), whilst field vegetables accounted for 27% and 26% respectively. This trend is at least partly driven by the major supermarkets’ demand for quality, consistency and continuity of supply, which can only be guaranteed by irrigation.

Table 5-1 Distribution of irrigated area and water use between crop categories in 2001

Crop category	Irrigated area (%)	Water used (%)
Early potatoes	5	4
Maincrop potatoes	47	53
Sugar beet	6	3
Orchard fruit	1	1
Small fruit	3	3
Vegetables	27	26
Grass	3	2
Cereals	3	1
Other crops	5	7

Source: 2001 irrigation survey

In the UK, irrigation water demand varies enormously between years depending on summer weather. For economic reasons, it is not sensible to design for the extreme dry year (or for the average). Irrigation capacity, and hence abstraction licences, are typically based on a supply statistically sufficient to meet demand 80 years out of 100, referred to here as the 80th centile demand or simply “dry-year demand”.

The water demand for each micro-component is modelled as the product of:
- the area planted;
- the proportion irrigated;
- the optimum depth of water required in a dry year;
- the proportion of the optimum depth in a dry year that is actually applied; and
- the efficiency of application.

All the demands given here are for unconstrained supply in the 80th centile dry year, and assume no major changes in water prices. Actual water use may (will) be limited by water availability and increased costs

5.2 Methodology

The impact of climate change, in its widest sense, on crop water requirements requires consideration of change at various levels (Figure 5-1). Firstly, the changes in atmospheric CO2 levels have a direct impact on plant physiology, directly affecting how they grow and how much water they transpire. Secondly, impacts via changes in local weather, particularly rainfall and evapotranspiration, affect the soil water balance and hence the irrigation needs. Both process affect yield and quality and hence the economics of growing and irrigating particular crops. Changes in temperature and the occurrence of frost can also alter where each crop can be best grown. Finally, it may be that climate change elsewhere, particularly in southern Europe, would significantly change imports and hence the areas grown in the UK.

All these impacts have to be assessed within the context of present underlying trends and the expected impacts of alternative socio-economic scenarios even without climate change.

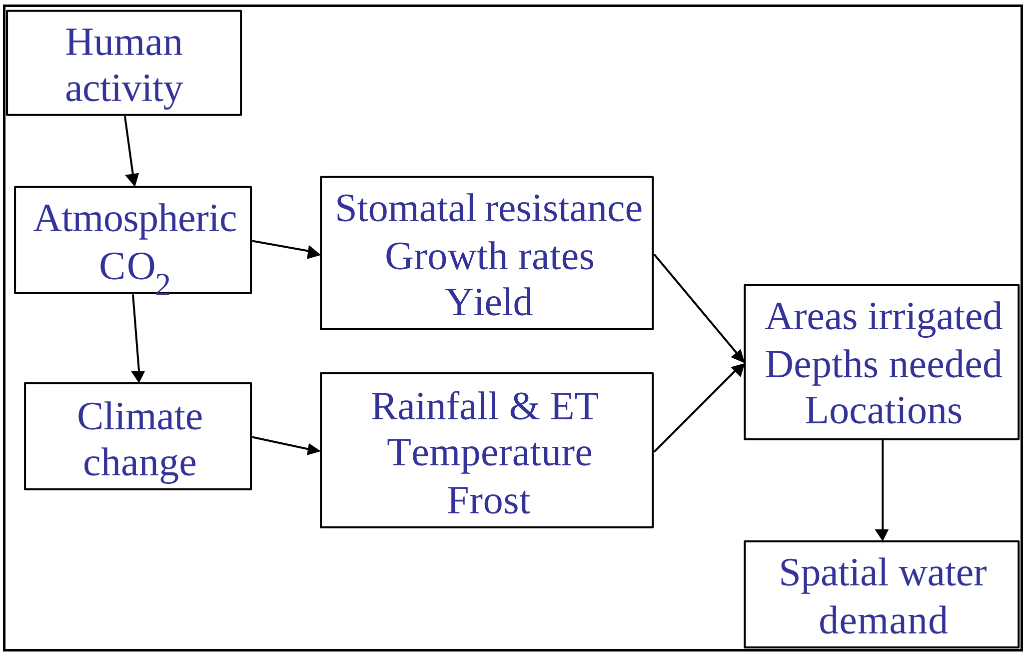


Figure 5-1 A simplified view of climate change impact process on irrigation water demand

In order to obtain a robust framework in which to make the assessment, this study has had to rely on different approaches and sources for the relevant impacts.

- A survey was undertaken of irrigation of outdoor crops in England in 2001 (Weatherhead and Danert, 2002), and subsequently extended to Wales, to update the database of present irrigation water use. Crop modelling and multiple regression analysis were used to estimate underlying trends and “2001 dry year” values (i.e. what would have happened if 2001 had been a dry year).
- A literature review and computer modelling were undertaken to assess the importance of enhanced atmospheric CO_2 on crop growth and transpiration, relative to those effects that take place via changes in rainfall and evapotranspiration, for important irrigated crops at selected sites (Gallaher, 2001).
- The IWR model, used previously to calculate the reasonable irrigation needs (as depths) of different crops for the Environment Agency (Weatherhead *et al.*, 2002), was used in this study to investigate the spatial and temporal sensitivity of irrigation need to the various changes in evapotranspiration and rainfall derived from the UKCIP98 and later UKCIP02 climate change predictions.
- The IrriGrowth water demand forecasting model, used previously to calculate future regional water demand (volumes) without climate change for the Environment Agency (Weatherhead *et al.*, 2000; Environment Agency, 2001a, 2001b), was used to investigate the sensitivity of regional demand to the selected UKCIP02 climate change predictions. This included a review was undertaken of previous studies predicting land-use changes in England and Wales as a result of climate change, with particular reference to irrigated cropping.
- The Irrigrowth results were then combined with the direct impacts of atmospheric CO2 on yield to produce best estimates of the overall climate change impact.

Table 5-2 summarises the inputs, modelling and outputs.

Table 5-2. Summary of inputs, modelling, and outputs (agricultural and horticultural component)

SCALE	INPUTS	MODELLING	OUTPUTS
Site (21 weather stations)	Long-term (20 year) daily weather data for 21 weather stations (P and ETo) UKCIP (98 and 02) climate change ratios	Weather station climate data processing (perturbing historical data)	Production of UKCIP “changed” weather station climate datasets
	UKCIP (98 and 02) “changed ” weather station climate datasets Crop, soil and irrigation schedule input files	Irrigation Water Requirements (IWR) computer program (water balance modelling)	Annual and design dry year irrigation needs, by crop, by station, by climate scenario.
	UKCIP 5km and 50km ETo and P datasets “Changed” weather station datasets (ETo and P)	PSMD modelling	PSMD estimates, by site and scenario, for input into regression analyses
	Design dry year irrigation needs PSMD estimates	Regression analyses	Regression equations to predict irrigation need based on PSMD
	PSMD estimates Irrigation need regression equations	Definition of agroclimatic zones Irrigation need look up table modelling	Irrigation look up tables, for each climate scenario
Grid pixel	UKCIP (98 and 02) (5km) database	Database analysis to derive baseline and future climate “change” ratios	UKCIP (98 and 02) climate change ratios
	UKCIP (98 and 02) (5km and 50km) databases for selected climatic variables	Modelling to derive ETo based on FAO Penman-Monteith equation	UKCIP 5km and 50km ETo datasets
	UKCIP (5km) (ETo and P) and PSMD (5km) datasets EA Region (catchment) boundary dataset	Spreadsheet modelling to estimate future PSMD GIS modelling agroclimatic zones	Agroclimatic zone maps, for UKCIP baseline and future scenarios (5km)
	Soils AWC (1km) and UKCIP98 PSMD (5km) datasets MAFF June cropping census (2km) dataset	GIS overlay modelling crop, soil AWC and PSMD Spreadsheet modelling – matrix table analysis	Production of regional matrix tables (crop v soil v agroclimatic zone)
	Matrix tables, 98 baseline and scenarios Irrigation look up tables	Spreadsheet modelling - weighted irrigation needs analysis	Weighted irrigation needs tables, by crop, by EA Region, by climate scenario
	agroclimatic zone maps (’98 and ‘02 scenarios)	GIS comparison of agroclimatic zones	UKCIP02 weighted irrigation need tables
National	Defra June 2000 Cropping census	Spreadsheet conversion from county to EA regional level	Regional cropping data for IrriGrowth
	Defra June 2000 Cropping census MAFF 1995 Irrigation Survey questionnaire Irrigation survey data (5600) Postzon (postcode) database EA Region (catchment) boundary dataset	Definition of 2001 Irrigation Survey questionnaire Production of mailing database Production of 2001 Irrigation Survey database GIS postcode modelling –aggregation by EA Region	2001 Irrigation survey data Irrigation survey report - national Regional baseline dry year irrigation statistics for input into IrriGrowth model
	EA Water Resources Strategy 2025 report Optimum Water Use for Agriculture (Phase III) report	Socio economic driver analysis Irrigation cost/benefit analysis; economic optima	Socio-economic drivers for IrriGrowth
	Regional cropping data Regional baseline dry year irrigation statistics Weighted irrigation needs tables for climate scenarios Socio-economic drivers for socio-economic scenarios	IrriGrowth demand modelling	Volumetric irrigation demand predictions (by crop, by EA Region, by climate scenario and by socio-economic scenario)

5.3 Baseline irrigation data

The best information on present irrigation water use in England and Wales comes from the surveys of irrigation of outdoor crops carried out roughly every three years by MAFF. These used identical questions between 1982 and 1995, and a similar survey was undertaken within this project for 2001 (Appendix 5-A), giving now seven sets of directly comparable data. The areas grown and water applied nationally are summarised in Table 5-3 and Table 5-4.

Table 5-3. Irrigated areas (ha), by crop category, 1982-2001

Crop category	1982	1984	1987	1990	1992	1995	2001
Early potatoes	8050	7720	5360	8510	8180	8730	7300
Maincrop potatoes	22810	34610	29520	43490	45290	53390	69820
Sugar beet	15770	25500	10100	27710	10520	26820	9760
Orchard fruit	3100	3250	1330	3320	2280	2910	1580
Small fruit	3610	3560	2230	3470	2750	3250	3770
Vegetables	14810	17460	11040	25250	20200	27300	39180
Grass	16440	18940	6970	15970	7240	10690	3970
Cereals	14800	24700	7510	28100	7160	13440	4620
Other crops	4100	4890	2440	8650	4320	9120	7280
Total	**103490**	**140630**	**76500**	**164470**	**107940**	**155650**	**147270**

Note: Summing errors due to rounding.
Data up to 1992 for England and Wales, data for 1995 and 2001 for England only.

Table 5-4 Volumes of water applied ('000m^3), by crop category, 1982-2001

Crop category	1982	1984	1987	1990	1992	1995	2001
Early potatoes	4680	4920	2350	6770	5590	9345	5710
Maincrop potatoes	15280	32730	14700	51170	38520	74460	69940
Sugar beet	8260	17370	3430	20320	4860	21295	4630
Orchard fruit	2180	2430	550	2930	1220	2445	900
Small fruit	1890	2660	970	3180	2000	4320	3370
Vegetables	6830	11390	4640	18450	12180	25500	34120
Grass	10030	13550	3550	13100	4280	9920	2320
Cereals	5040	8300	2160	11830	2260	5625	1470
Other crops	1020	4030	1270	6040	4160	11160	8840
Total	**55210**	**97380**	**33620**	**133790**	**75070**	**164070**	**131300**

Note: summing errors due to rounding.
Data up to 1992 for England and Wales, data for 1995 and 2001 for England only.

However, this data partly reflects the weather in each census year, superimposed on any underlying trends in demand, whereas for modelling we are concerned with dry year demand. Figure 5-2 shows, for example, the ranked theoretical irrigation needs (mm) for maincrop potatoes grown at Silsoe (Bedfordshire) for 1970 to 2001, with the survey years shaded.

Weatherhead *et al.* (1994) developed a method for analysing the irrigation survey data using calculated theoretical irrigation needs (depths) for each crop as the independent climate variable in a multiple linear regression analysis. The regression results show the underlying growth rates in the areas irrigated, in the proportion of each crop irrigated and in the depth applied. The results also allow the area and volume figures for any year to be adjusted to simulate 'design' dry year conditions occurring in that year.

The imputed 2001 dry year values (i.e. what would have occurred if 2001 had been a dry year) are shown in Table 5-5. The underlying growth rates, expressed as percentages of the imputed 2001 dry year values, are shown in Table 5-6.

The results confirm a continued increase in irrigation of high value crops, *viz*. potatoes, small fruit and vegetables, and a decline in the irrigation of sugar beet, orchard fruit, grass and cereals. The underlying growth in the total volume applied, from 1982 to 2001, was around 2.5% per annum. This compares with previous estimates of 2% per annum from 1982 to 1990 and 3% per annum from 1982 to 1995 (Weatherhead *et al*., 1997).

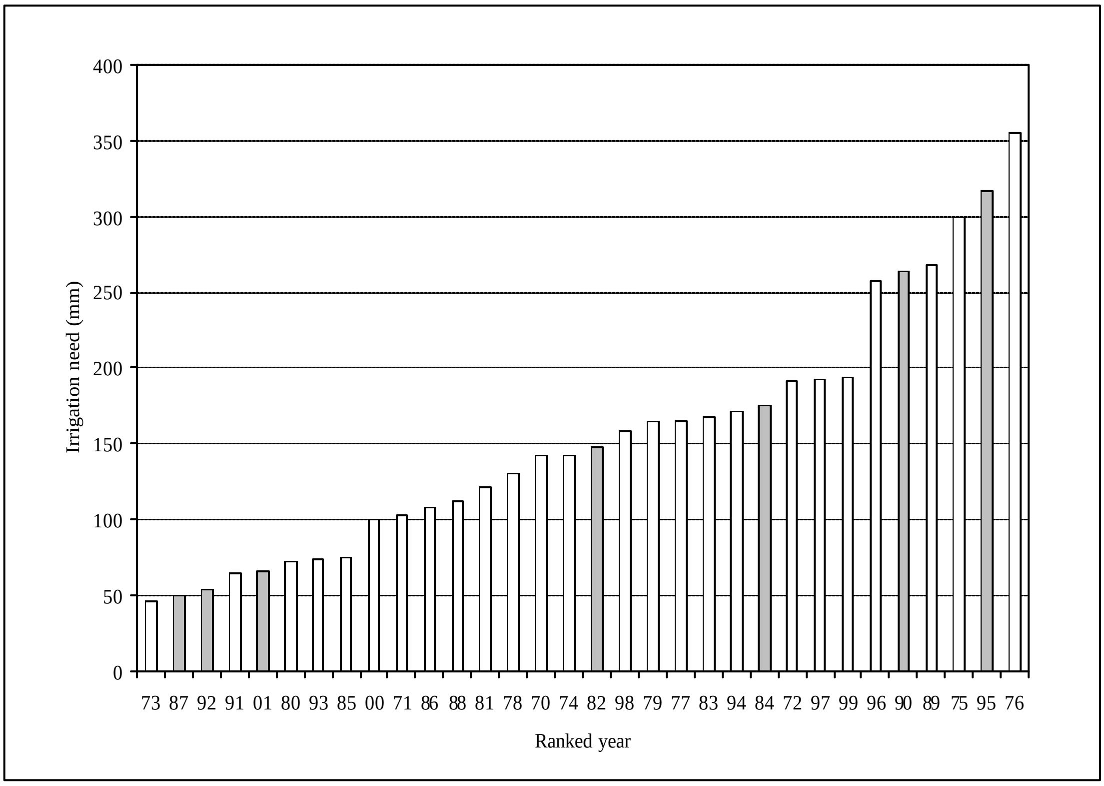


Figure 5-2. Ranked theoretical irrigation needs (mm) for maincrop potatoes grown on a medium AWC soil at Silsoe (Bedfordshire), 1970-2001. Shaded columns represent irrigation survey years.

Table 5-5 Areas irrigated (ha) and volumes of water applied ('000m^3) for 2001 (actual) and 2001 (if a dry year).

Crop category	2001 (actual)		2001 (if a dry year)	
	areas	volumes	areas	volumes
Early potatoes	7300	5710	9449	9385
Maincrop potatoes	69820	69940	71681	87510
Sugar beet	9760	4630	21555	16141
Orchard fruit	1580	900	2503	2097
Small fruit	3770	3370	4104	4619
Vegetables	39180	34120	42158	39050
Grass	3970	2320	9430	8590
Cereals	4620	1470	15131	6479
Other crops	7280	8840	9153	12551
Total	**147270**	**131300**	**185164**	**186421**

Note: Summing errors due to rounding and statistical adjustments. Other crops dry year values taken as ratio from other crops. Total from summing individual crops, not from regression of totals. Data for England only.

Table 5-6 Underlying growth rates (%) in dry year values for area irrigated, average depth and total volume applied, 1982-2001.

Crop category	Change per annum on 2001 dry year value, %		
	Area irrigated	Average depth	Volume applied
Early potatoes	0.8%	2.4%	2.7%
Maincrop potatoes	3.3%	1.8%	3.7%
Sugar beet	-1.3%	0.1%	-0.7%
Orchard fruit	-2.1%	-0.2%	-1.9%
Small fruit	0.3%	2.3%	2.3%
Vegetables	3.1%	2.3%	3.8%
Grass	-6.1%	0.8%	-3.5%
Cereals	-3.9%	0.4%	-2.6%
Other crops	-	-	-
Overall	**1.3%**	**2.1%**	**2.5%**

Note: Due to imperfect correlation in the data, the individual growth rates for area and depth do not agree exactly with the growth rates for volume, nor the overall growth rates. Data for England only.

The 2001 survey responses were also aggregated to Environment Agency Region and Environment Agency Wales by postcode, using a geographical information system (GIS). (Note that the Environment Agency Wales boundary is not identical to the England/Wales boundary). The total areas irrigated and volumes applied are summarised in Table 5-8, for the actual 2001 and for a 2001 dry year. The dry year values for each micro-component (crop category) in each region form the base year for the subsequent modelling.

Table 5-7. Areas irrigated (ha) and volumes of water applied ('000m^3) by Environment Agency Region and for Environment Agency Wales for 2001

EA Region	2001 (actual)		2001 (if a dry year)	
	areas	**volumes**	**areas**	**volumes**
North East	10941	8893	12948	12863
North West	1580	914	1876	1508
Midlands	28021	25478	39254	39949
Anglian	80260	68822	100463	95885
Thames	8333	12565	9005	16454
Southern	14817	12024	17744	15984
South West	2126	1698	2511	2398
EA Wales	1944	1362	2370	2244
Total	**148022**	**131756**	**186219**	**187467**

Notes: summing errors due to rounding and statistical adjustments
Data for England and Wales

5.4 Impacts of increased atmospheric CO_2 on plant physiology

5.4.1 Literature review

Changes in atmospheric CO_2 impacting directly on crop physiology could be a potentially significant driver on irrigation water demand. A study for this project by Gallaher (2001) identified a range of reported impacts on factors as diverse as leaf growth and structure, stomatal resistance, transpiration rates (and hence leaf cooling), transpiration efficiency, photosynthesis, growth-stage durations, root-to-shoot ratios, rooting depth, plant growth, yield and crop quality. Some of these interact with other limiting resources and/or with temperature changes. Many interact with water use, and may interact differently for irrigated and non-irrigated cropping.

Gallaher (2001) found many of the reported results to appear inconsistent, and suggested that this may be the result of different experimental conditions and objectives. Most experiments have been carried out within controlled laboratory environments over short periods of time (e.g. as used commercially in glasshouses). Few studies have examined the effect of long-term continuous exposure to elevated CO_2, when plant adaptation might occur. Very few studies have simulated field conditions, where wind can be an important factor in determining water use and water stress can become a limiting factor. A summary of the reported changes is given in Table 5-8.

Table 5-8 Estimated percentage (%) changes to crop growth parameters for a doubling of atmospheric CO_2 concentration, and values used in this study

Crop growth parameter affected	Range of % changes derived from literature review	Percentage (%) change used in this study*
Photosynthetic rate increase	28 - 60 %	30 %
Transpiration rates reduce	12 - 40 %	30 %
Stomatal resistance increases	12[2] – 35%[3] or 70 - 100 %[4]	30 %
Growth increases	28 - 41 %	30 %
Yield increases	25 – 40 %	30 %
Root yields increase	5-10 %[3], 35-56 %, 18-75 %[4]	30 %
Leaf areas increase	20-30 %	30 %
Growth stage lengths reductions	4-7 days	4-7 days

Notes: [1] Based on the consensus of results found within the literature review.

[2] Estimate of likely percentage occurring naturally in field conditions exposed to elevated CO_2 (based on experimental results).

[3] Results from labs/controlled conditions.

[4] Estimated percentage ranges (based on estimates by other research workers).

The literature review concluded that the interactions between the many direct and indirect impacts make modelling difficult and potentially unreliable. The modelling in this project has been based on the simplifying assumption that crop growth rates would be increased by 30% on average for a doubling of CO_2, directly affecting crop cover, crop height and yield, themselves impacting on water use and crop areas.

5.4.2 Impacts of elevated CO_2 on crop water use

The changes in atmospheric CO_2 concentrations assumed in the UKCIP02 scenarios are shown in Table 5-9.

Table 5-9 Estimates of changes in atmospheric CO_2 concentration (ppm) for the UKCIP02 climate change scenarios

UKCIP02 scenario	Low	Medium Low	Medium-High	High
Current	350	350	350	350
2020s	422	422	435	437
2050s	489	489	551	593

Gallaher (2001) used Cranfield University's crop water balance model IWR (Hess, 1994) to simulate the direct impacts of elevated CO_2 levels on crop water use. Her calculations related to the earlier UKCIP98 CO_2 levels for the 2020s, but the conclusions remain relevant. The increased plant growth rates will increase crop cover, crop height and leaf area index, increasing water use. In contrast, the increase in stomatal resistance will decrease water use. The exact impacts and interactions will vary with crop and climatic conditions.

These impacts were studied at three agroclimatically contrasting sites (Wye, Silsoe and Shawbury) and for two crops (maincrop potatoes and sugar beet). Revised crop factors (Kc values, defined as ETo/ETc) were first derived using the FAO's Penman-Monteith equation. Long-term weather data for Silsoe was used to calculate the average reference evapotranspiration (ETo) and average crop evapotranspiration (ETc) with the appropriate percentage changes to the crop growth parameters (crop height, leaf area index, and stomatal resistance) corresponding to the climate change scenario being modelled. These crop factors were then used in the IWR model to calculate average irrigation needs for maincrop potatoes and sugar beet at each of the three sites.

When the effects of changes in crop height, leaf area index and stomatal resistance were modelled together, there was minimal net change in irrigation requirements. Similarly, the effects of shorter growing seasons were minimal.

For the purposes of the water demand modelling at regional level, it has been assumed that these impacts effectively cancel out. However, this simplification would not be valid when considering individual crops or sites.

5.4.3 Impacts of elevated CO_2 on yield and cropping

The higher atmospheric CO_2 concentrations will increase the potential yield of many crops, due to improvements in the carbon partitioning within the plants. The increased plant growth in root crops, for example, results in an increase in the storage organs, e.g. the main sugar beet taproot and potato tubers, increasing the yield. Where this is the case, the crops could be harvested earlier for the same yield - reducing water requirements, or at normal harvest time to take advantage of the higher yield. Yield increases could, however, result in less land being planted to grow the same volume of produce, reducing water use.

For modelling water demand, the average yield increases assumed (Table 5-10) are again based on the 30% increase that the crop growth parameters exhibit when exposed to a doubling of atmospheric CO_2 levels. The same values have been used for all crops under current conditions although this could be refined. Possible yield reductions in some crops due to higher temperatures (see for example Parry *et al.*, 2002) have not been modelled.

Table 5-10. Estimated changes in average yield (%) due to enhanced atmospheric CO_2 concentrations for the UKCIP02 climate change scenarios

UKCIP02 scenario	Low	Medium Low	Medium-High	High
2020s	6	6	7	7
2050s	12	12	17	21

5.5 Irrigation need modelling

This section presents the results for the first stage of the assessment, including:

- Processing of climate change;
- Modelling of annual irrigation need (depths) based on climate data;
- Correlating needs and potential soil moisture deficit;
- Calculating weighted needs; and
- Mapping of agroclimatic zones for the present (baseline) and climate scenarios.

These steps provide the weighted irrigation needs (depths) required as input into the water demand model (IrriGrowth), reported in the following section. A brief description of the methodologies developed to complete each stage is given below.

5.5.1 Climate change data pre-processing

The driving climatic variables required to run the IWR model are daily rainfall (P) and reference crop evapotranspiration (ET). An existing network of 21 weather stations was used in this study. These stations were chosen to represent the typical range of agroclimatic conditions across England and Wales, rather than to provide uniform geographical coverage (Table 5-11). An attempt was made to identify stations located within areas of high irrigation intensity and water demand.

Table 5-11. Mean summer precipitation (P_s) (Apr-Sept), and mean annual maximum potential soil moisture deficit for grass ($PSMD_g$), for the 21 weather stations, based on 1979-98

Weather station	P_s (mm)	PSMD* (mm)
Cockle Park, Northumbria	341	156
Gatwick, W. Sussex	320	224
Gleadthorpe, Nottinghamshire	309	150
Hurn, Hampshire	314	247
Keele, Staffordshire	375	114
Kirton, Lincolnshire	290	262
Leeming, Yorkshire	301	267
Lynham, Oxford	316	276
Mepal, Cambridge	273	171
Milford Haven, Pembrokeshire	375	190
Morley, Norfolk	289	165
Pershore, Worcester	314	246
Rosewarne, Cornwall	385	115
Shawbury, Shropshire	312	183
Silsoe, Bedford	299	201
Slapton, Devon	395	176
Wattisham, Suffolk	280	275
Wellesbourne, Warwickshire	299	169
Wisley, Surrey	296	159
Writtle, Kent	283	187
Wye, Kent	307	213

Note: * calculated using the IWR model.

A "changed" climate database, was created for each weather station by perturbing each observed (historical) time series by monthly ratios derived from the relevant UKCIP02 database. For example, all the daily precipitation values in July would be altered by the same percentage in each year of the record. In contrast to stochastic weather generators, this approach has the virtue of simplicity whilst maintaining a realistic temporal structure of climate data. It assumes that the relative variability in climate from day to day and year to year (i.e. the shape of the frequency distribution) remains constant.

The climate change scenarios used in this study were initially based on UKCIP98 (Hulme and Jenkins, 1998), and then updated using the UKCIP02 scenarios (Hulme *et al*., 2002). Data for a range of climatic variables were used from the UKCIP02 database, at 50km and 5km resolutions, respectively. For each scenario, at 50km resolution, the UKCIP02 database provided estimates for a wide range of climatic parameters, including rainfall, temperature, relative humidity, radiation and wind speed. In this study, modelling was based on information in the 5km databases in spite of problems regarding the availability of certain climatic parameters when working at this resolution. 50km databases were used to verify the 5km database for selected variables.

The UKCIP02 database provided climate change data for three time slices (2020s, 2050s, and 2080s) and for four core emissions scenarios (Low, Medium-Low, Medium-High, and High). The UKCIP02 scenarios express future change relative to either a model simulated trend (50km resolution) or an observed trend (5km resolution). For the 50km database, future changes are expressed as anomalies to the simulated 50km trend; for the 5km database, future changes are expressed as absolute values relative to the observed database. In this study, 5km (observed) resolution data relating to a 1961-1990 long term average were obtained from the Met Office.

The geographic co-ordinates for each of the 21 weather stations were used to locate the corresponding 5km^2 grid pixels in the UKCIP02 database. For each corresponding 5km grid pixel, the mean monthly rainfall (P) was extracted from the UKCIP02 database, for the future scenarios.

Unfortunately, the UKCIP02 5km databases does not contain data relating to reference crop evapotranspiration (ET). (Note, 5km ET data were available in UKCIP98). However, the variables necessary to derive the Penman-Monteith Reference ET (Allen *et al.*, 1994, 1998) namely, temperature, radiation, wind speed and humidity, were available in the UKCIP02 5km reference trend database, but unfortunately, only selected variables (temperature and windspeed) were available for the future climate change databases. Two different procedures were therefore developed to firstly derive Penman-Monteith Reference ET for the reference trend database, and secondly, using the limited data to estimate ET for each future scenario. It should be recognised, however, that any methodology that estimates ET based on limited data is subject to error. For example, the Blaney-Criddle method (Doorenbos and Pruitt, 1992) has been used in the past to estimate ET where only temperature data are available; this method can significantly over or under-estimate ET. The empiricism involved in any ET prediction using a single weather factor is inevitably high, with the consequence that such approaches are not recommended and their estimates should be treated with caution.

Due to the missing data in UKCIP02, the derived 5km databases for ET for the future scenarios, although based on the Penman-Monteith Reference ET method, are subject to lower levels of confidence than for the 5km reference trend database.

For the UKCIP02 50km reference trend and future databases, the variables necessary to derive Penman-Monteith Reference ET were available. Using the same procedure used for the 5km reference trend database, Penman-Monteith Reference ET was estimated for the 50km trend and for each future scenario. Although not used directly in the irrigation modelling, these 50km ET databases provided a useful check and comparison against the derived 5km ET databases.

For each weather station, a monthly ratio between the UKCIP02 trend and each future scenario, for each variable (P and ET) were calculated. Eight sets of monthly ratios, for each weather station, were produced. The historical daily P and ET time series (1979-98) for each weather station were then perturbed using the monthly ratios, for each scenario. In all, eight derived climate change databases for each weather station were generated.

A computer program was written to convert each database into a format suitable for input into IWR, the daily water balance irrigation scheduling model. It should be noted that the years generated for each scenario (e.g. 2005, 2006, 2007 etc.) were nominally assigned, and should not to be interpreted literally.

An illustration of the changes in the dimatic variables driving irrigation demand: For illustrative purposes only, the changes in mean monthly P and ET for a single weather station (Silsoe, Bedfordshire) are shown in Figure 5-3 and Figure 5-4 respectively.

With climate change, summer rainfall decreases markedly in all scenarios except the 2020s Low, which as one might expect, mirrors closely the pattern of the current baseline climate. However, in the winter months, marginal increases in rainfall are shown. The temporal pattern of ET remains broadly similar to the baseline, but with overall higher rates of ET. The highest increases in ET rates are in the summer months.

For irrigation, the changes in P and ET are significant. They suggest (for this site) much higher evaporative demands during the growing season and drier summers, and therefore a net increase in the requirement for irrigation. In winter, however, the increases in rainfall offer scope for greater conservation of winter rainfall and increased on-farm winter storage.

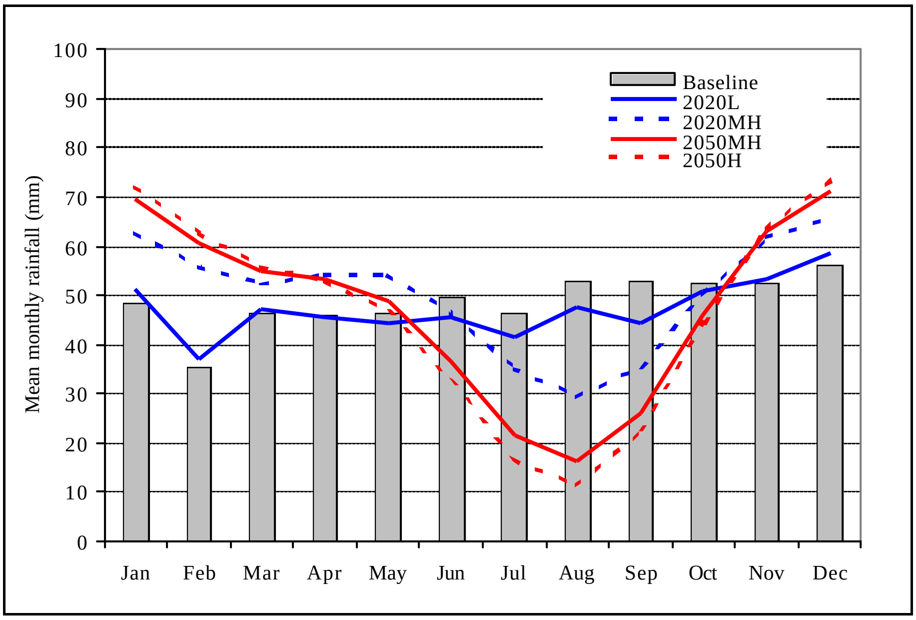


Figure 5-3. Comparison of mean monthly rainfall (mm/month) for Silsoe (Bedfordshire) for the baseline (present climate) and UKCIP02 scenarios

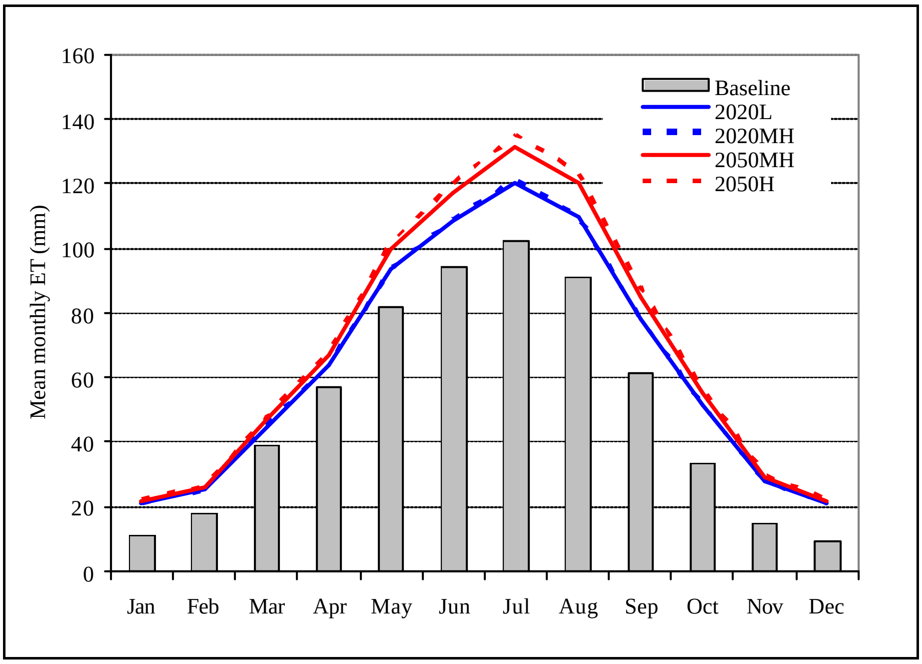


Figure 5-4. Comparison of mean monthly evapotranspiration (ET) (mm/month) for Silsoe (Bedfordshire) for the baseline (present climate) and UKCIP02 scenarios

5.5.2 Annual irrigation need modelling

The net annual irrigation needs for eight individual crop categories were calculated using ‘Irrigation Water Requirements’ (IWR), a computer model developed at Cranfield University by Hess (1994) and described in detail by Knox *et al*. (1996). Based on daily rainfall (P) and reference-crop evapotranspiration (ETo), the IWR model estimates the daily soil water balance for a selected crop and soil type.

For each site, the model requires input data relating to (1) the crop cover development and rooting characteristics, (2) soil water holding characteristics and (3) the planned irrigation schedule.

Eight crop categories were modelled, namely: early and maincrop potatoes (*Solanum tuberosum*), sugar beet (*Beta vulgaris*), cereals (*Hordeum spp*.), permanent grassland (*Lolium spp*.), vegetables (grown in the open), small fruit and orchard fruit. Carrots (*Daucus carota*) were used to represent vegetables, strawberries (*Fragaria spp*.) as a proxy for small fruit and mature apples (*Malus spp*.) for orchard fruit. These categories match those used in the June Agricultural Censuses and the irrigation surveys. The crop growth characteristics simulated in the model were defined to reflect typical UK irrigated cropping, and were derived from a combination of literature searches and experimental and research data.

Three soils (a loamy sand, a medium sandy loam and a loamy peat) were chosen to represent texturally contrasting soils with low, medium and high available water capacities (AWC), respectively.

Modelled irrigation applications were based on a typical irrigation schedule. Again, the irrigation plans used in the IWR model were defined to simulate typical UK irrigated cropping. Although originally based on schedules defined by MAFF (MAFF, 1982) and

Bailey (1990) they were modified based on observations from recent on-farm irrigation practice (Weatherhead *et al*., 2002).

The IWR model was run for each weather station/soil-type/crop/UKCIP02 climate change scenario permutation. The estimated annual irrigation needs for each permutation were statistically analysed to estimate the 'design' dry year needs, defined as the '80% exceedance' needs, i.e. meeting the irrigation need in 80 years out of 100.

To illustrate the potential impact of climate change on a major irrigated crop (maincrop potatoes), the estimated 'design' dry year irrigation needs for that crop, at each weather station, for the baseline climate and each UKCIP02 scenario were calculated (Table 5-12).

For all scenarios, at all sites, an increase in 'design' dry year irrigation need is shown. The changes, however, vary across the country, reflecting the varying regional impact of climate change. On average, however, for the selected crop (maincrop potatoes), the increases in dry year irrigation need from the current trend are in the order of 30-40% for the 2020s and 70-80% for the 2050s.

Table 5-12. Design dry year irrigation needs (mm) for maincrop potatoes, and change in irrigation need (%), at each weather station by UKCIP02 scenario

Site	**Design need (mm)**	**Change in irrigation need (%)**			
UKCIP02 scenario	Baseline climate	2020s Low	2020s Med High	2050s Med High	2050s High
Cockle Park, Northumbria	159	34	50	78	84
Gatwick, W. Sussex	228	30	39	65	80
Gleadthorpe, Notts	165	57	53	81	109
Hurn, Hampshire	256	30	34	57	71
Keele, Staffordshire	142	27	89	140	140
Kirton, Lincolnshire	270	25	23	42	58
Leeming, Yorkshire	254	20	28	48	57
Lyneham, Oxford	282	18	26	47	60
Mepal, Cambridge	166	51	47	78	100
Milford Haven, Pembs	203	31	26	44	46
Morley, Norfolk	168	52	61	93	104
Pershore, Worcester	242	24	29	57	72
Rosewarne, Cornwall	146	14	63	86	68
Shawbury, Shropshire	205	33	72	112	111
Silsoe, Bedford	214	38	43	70	86
Slapton, Devon	181	24	76	107	102
Wattisham, Suffolk	255	24	43	65	68
Wellesbourne, Warwick	193	43	38	68	88
Wisley, Surrey	144	41	44	79	104
Writtle, Kent	215	31	37	64	75
Wye, Kent	206	35	47	77	84
Average	**195.18**	**+33**	**+46**	**+74**	**+84**

5.5.3 Correlating irrigation needs with potential soil moisture deficit

In crop modelling, potential soil moisture deficit (PSMD) is a useful and commonly used variable to assess the impact of climate on irrigation needs. PSMD is preferable to other climatic variables because it reflects the balance between rainfall and crop requirements in the summer months. In order to derive the 'weighted' irrigation needs for input into the IrriGrowth model and to produce the agroclimatic zone maps, a methodology using the UKCIP02 database to calculate PSMD for both the individual weather station sites and for GIS modelling was necessary.

For each weather station, for the baseline climate and each UKCIP02 climate change scenario, the mean annual maximum PSMD (mm) was calculated. This allowed the estimated percentage change in PSMD (%), relative to the trend, for each weather station, and for each UKCIP02 future climate change scenario to be calculated (Table 5-13).

Table 5-13. Mean annual maximum PSMD (mm), and change in PSMD (%), at each weather station for UKCIP02 scenarios

Site	**PSMD (mm)**	**Change in PSMD (%)**			
UKCIP02 scenario	Baseline climate	2020s Low	2020s Med High	2050s Med High	2050s High
Cockle	156	33	67	104	118
Gatwick	207	40	54	98	116
Gleadthorpe	147	64	60	109	128
Hurn	247	38	47	83	96
Keele	119	22	142	219	247
Kirton	262	31	30	59	71
Leeming	267	22	34	62	73
Lynham	276	23	35	70	83
Mepal	159	61	44	92	112
Milford	190	23	27	54	65
Morley	147	58	81	129	148
Pershore	246	26	37	75	91
Rosewarne	122	11	91	129	144
Shawbury	190	41	123	176	192
Silsoe	201	47	56	101	118
Slapton	176	15	97	138	147
Wattisham	267	28	51	78	89
Wellesbourne	170	56	56	100	118
Wisley	139	41	46	98	119
Writtle	187	38	52	92	108
Wye	203	28	56	96	111
Average	**185.36**	**+36**	**+61**	**+103**	**+119**

For all scenarios, at all sites, PSMD increases. Again, the changes vary significantly across the country, reflecting the spatial heterogeneity in climate change impacts. On average, however, the increases in PSMD above the baseline climate are in the order of 30-60% for the 2020s and 100% for the 2050s.

To demonstrate the impact of climate change, a comparative analysis of the changes in PSMD against the historical variation in PSMD for a single weather station (Silsoe, Bedfordshire) has been completed. Using daily long-term weather data for the period 1970-2001 the annual maximum PSMD and long-term average (LTA) PSMD for the site were estimated. Using the perturbed climate change databases for the same site (Section 3.3.4) the annual maximum PSMD for each UKCIP02 scenario were estimated. The annual maximum PSMD for the historical time series were then ranked. PSMD values corresponding to the LTA and each UKCIP02 scenario were identified from the time series. The results are summarised in Figure 5-4.

At Silsoe, the LTA PSMD is 201 mm, corresponding roughly to a PSMD that occurred in 1977. The estimated PSMD for the 2020s Low and 2020s Medium-High scenarios were 295 mm and 314 mm, respectively. These equated roughly to the years 1997 and 1975. The estimated PSMDs for the 2050s Medium-High and 2050s High scenarios were significantly higher, 403 mm and 438 mm, respectively. These corresponded roughly to the years 1989 and 1976 (the driest year in the last 30 years). PSMD is a useful indicator for assessing potential irrigation needs. The data in Figure 5-5 demonstrates how climate change might impact on PSMD. Clearly, the data presented in Table 5-13 and Figure 5-5 suggest that climate change will have a significant impact on irrigation, and that recent dry years (e.g. 1990 and 1995) might become more typical of the summer weather experienced in the near future (2020s).

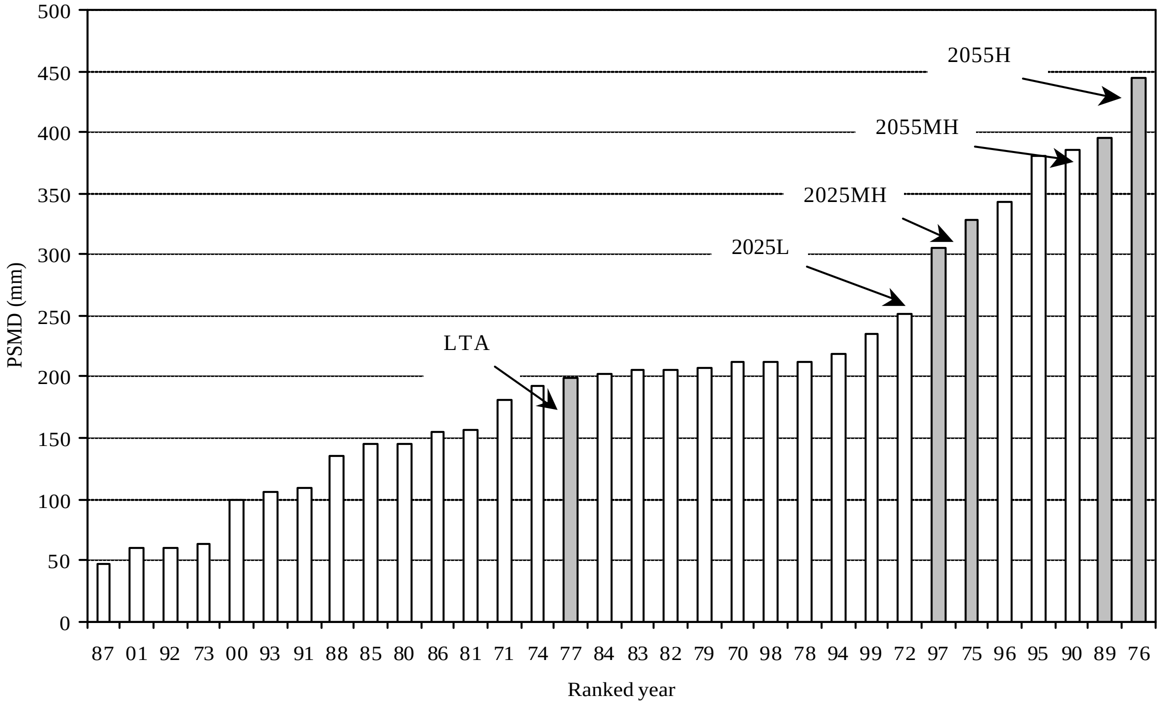


Figure 5-5. Maximum annual PSMD (mm) for Silsoe (Bedfordshire), 1970-2001 (ranked). Long-term average (LTA) PSMD and estimated PSMD for UKCIP02 scenarios are also shown.

5.5.4 Producing irrigation look up tables

In order to estimate the irrigation needs for a particular crop at any point in England and Wales (with or without climate change), a correlation between the modelled irrigation needs for that crop at a specific site (described above) and a national climatic database is necessary. For each crop category and for each soil type, a correlation between the PSMD and 'design dry year' irrigation needs at each weather station was derived by linear regression analysis. The PSMD data for each weather station were then used to define agroclimatic zones. In total, eleven zones were defined, with zone 1 representing the wettest (<75mm PSMD) and zone 17 the driest (>450 mm PSMD).

Using the regression equations, the 'design dry year' irrigation needs for each crop, grown on each soil type, in each agroclimatic zone, was estimated. The data were summarised as irrigation 'look up' tables. These look up tables enable the 'dry year' irrigation need (depth applied in mm) for any crop grown in a specific soil type, in a particular agroclimatic zone to be estimated. A similar procedure is currently being implemented by the Environment Agency to assist in setting volumetric irrigation demands for abstraction licenses for spray irrigation (Weatherhead *et al.*, 2002).

5.5.5 Agroclimatic zone mapping

The irrigation look up tables rely on the use and definition of agroclimatic zones to delimit areas of common PSMD. In order to use these irrigation look up tables to assess irrigation needs across larger areas, rather than for individual sites (i.e. weather stations), a procedure to map agroclimate (PSMD) was necessary. For the baseline climate, the mean monthly precipitation (P) for each 5km grid pixel was calculated from the UKCIP02 database. Using the derived 5km ETo database (described in Section 3.3.4) a monthly balance between P and ET to estimate monthly PSMD was completed. In months where P>ET, no deficit occurs. In months where ET>P, the deficit that accrues in that month is then carried forward to the following month. Soil moisture deficits typically start to build up in early spring, peak in mid summer (July-August) and then decline through until autumn. For each 5km grid cell, the maximum cumulative PSMD was calculated.

The procedure was repeated for each UKCIP02 future scenario. Using a GIS, these grid pixel data were interpolated to produce a contoured PSMD map. The contour data were reclassified to represent agroclimatic zones.

The agroclimatic zone map for the baseline climate is shown in Figure 5-6 (note that only nine agroclimatic zones are present in the present, baseline climate).

It should be noted that in this study, to match the UKCIP02 scenarios, the baseline agroclimatic zone map has been produced from the UKCIP02/Met Office 5km databases. Previous agroclimatic zone maps (e.g. Optimum use of water for agriculture studies for the Environment Agency) used a different PSMD database, derived from LandIS, the Land Information System held by National Soil Resources Institute (formally SSLRC). The LandIS and UKCIP02/Met Office databases are derived from different time series and are not therefore directly comparable. The resulting spatial distribution of agroclimatic zones in each baseline map are therefore slightly different, and caution should be exercised when referring to agroclimatic zone maps that the relevant map (and the corresponding look-up table) are being used.

Agroclimatic zone maps for each UKCIP02 scenario are shown in Figure 5-7 to Figure 5-10. (For these printed maps, zone 11 represents zones 11 and above).

As expected, the agroclimatic zone map for the baseline climate shows areas of highest PSMD in the eastern and south eastern parts of the country. This corresponds to regions where irrigation needs are highest.

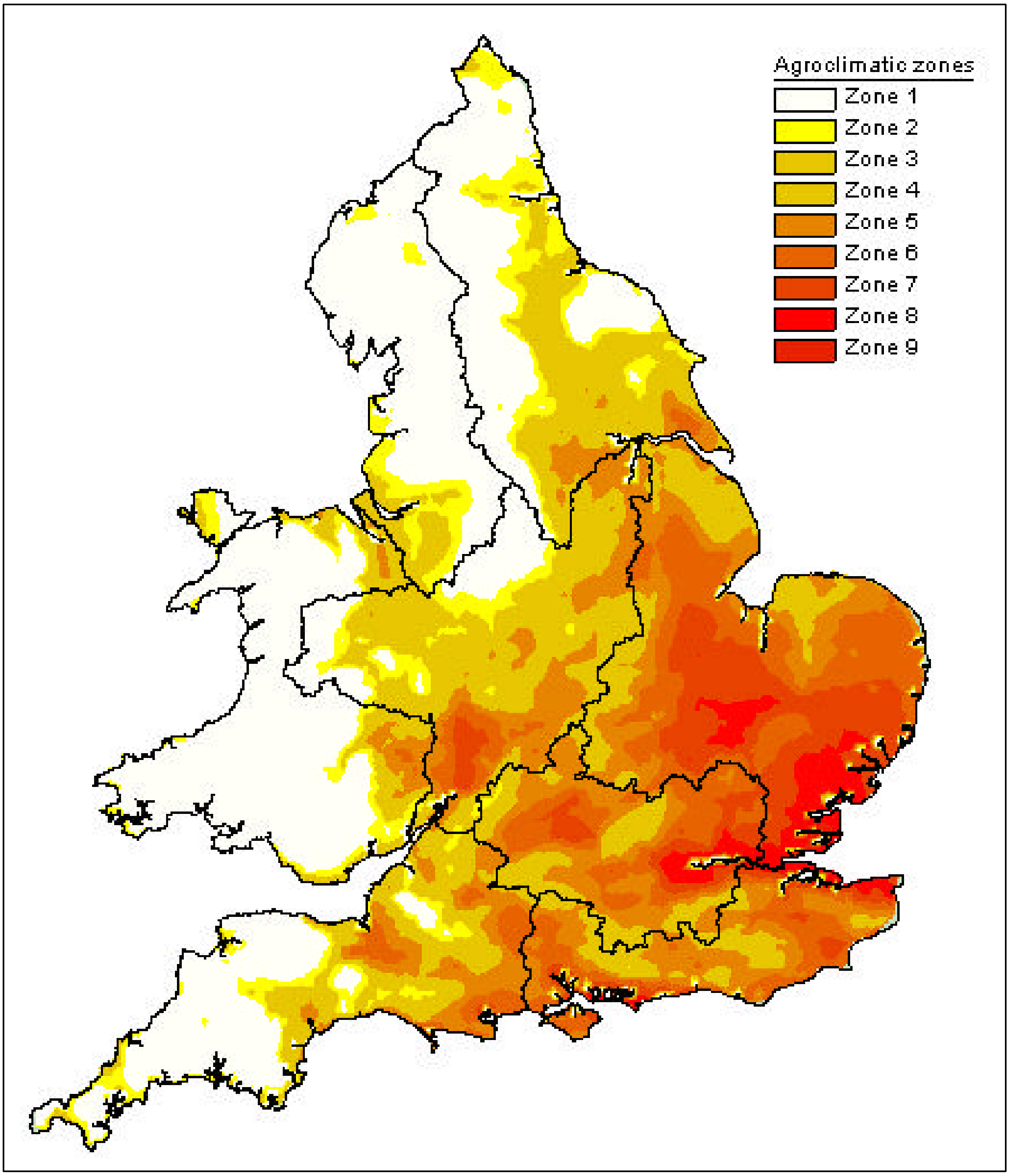


Figure 5-6. Agroclimatic zone map for the baseline (present) climate, based on the 5km Met Office data

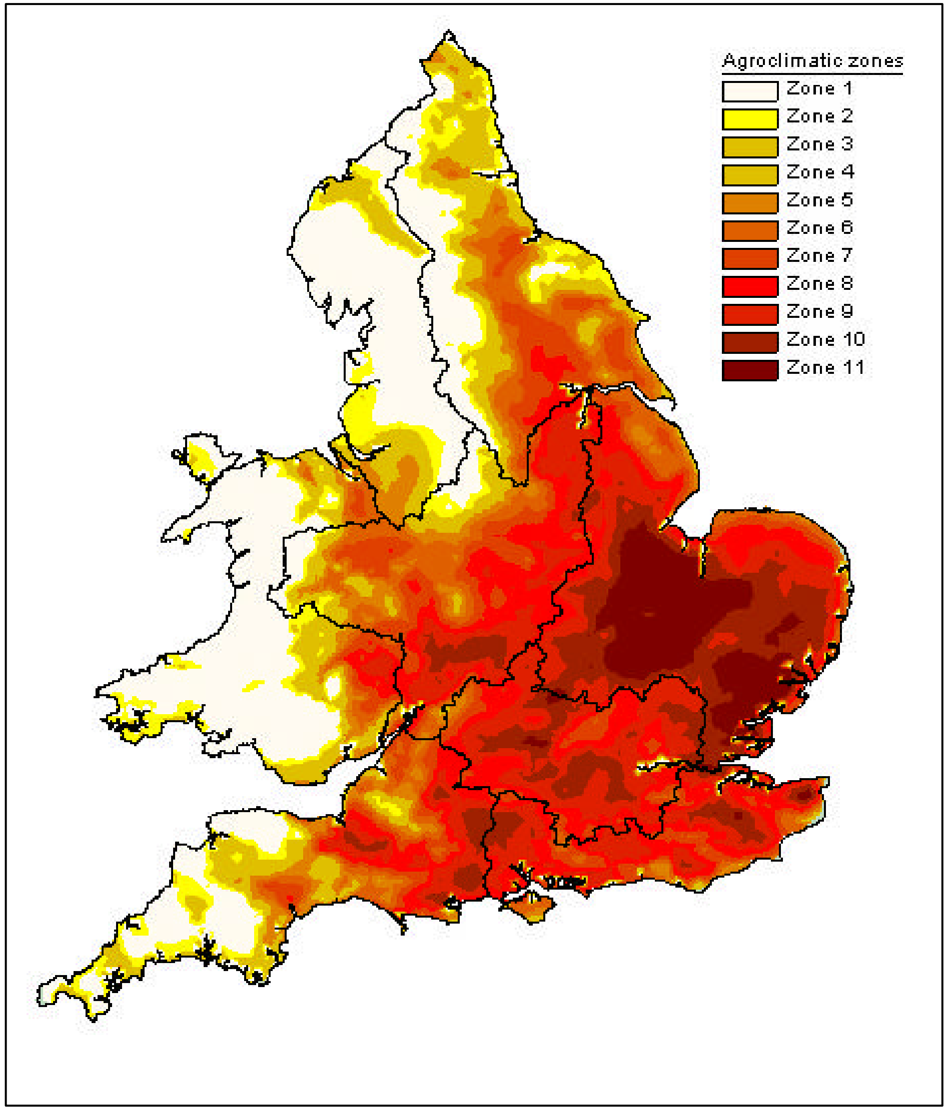


Figure 5-7. Agroclimatic zone map for UKCIP02 2020s Low scenario

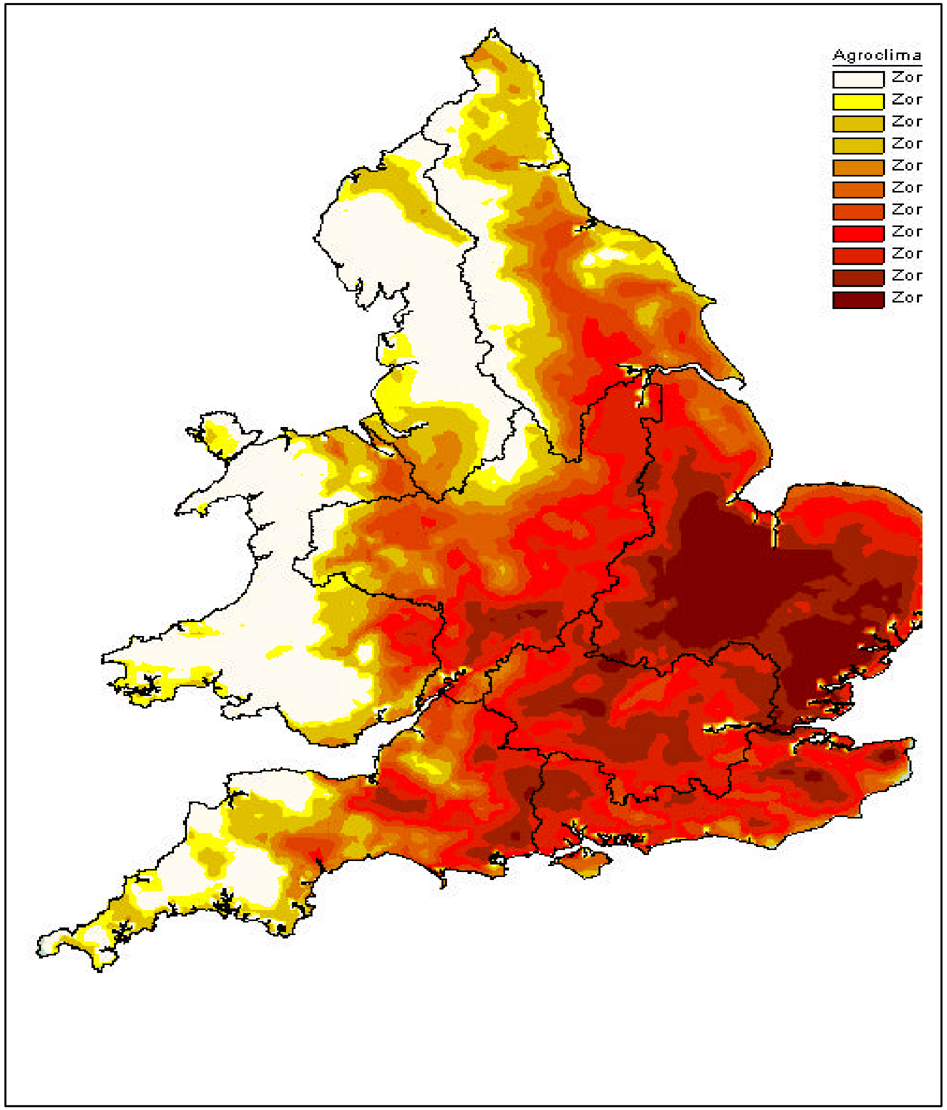


Figure 5-8. Agroclimatic zone map for UKCIP02 2020s Medium-High scenario

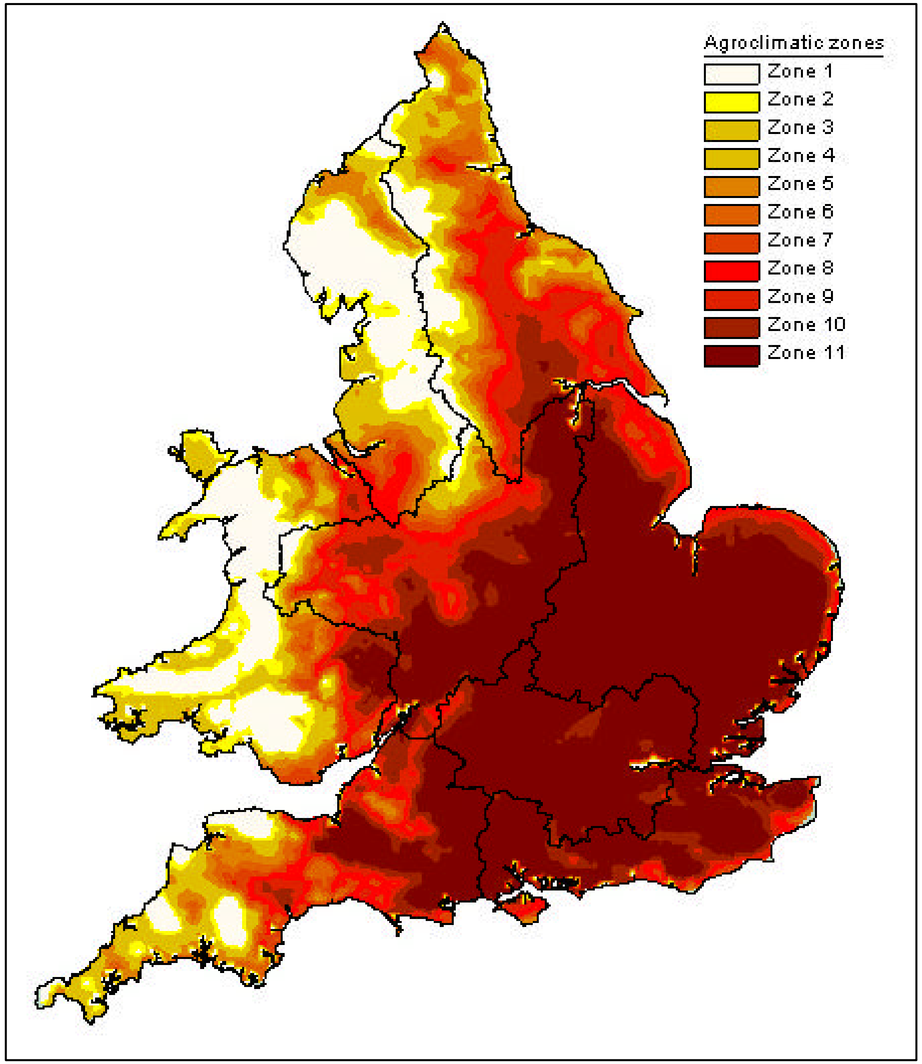


Figure 5-9. Agroclimatic zone map for UKCIP02 2050s Medium-High scenario

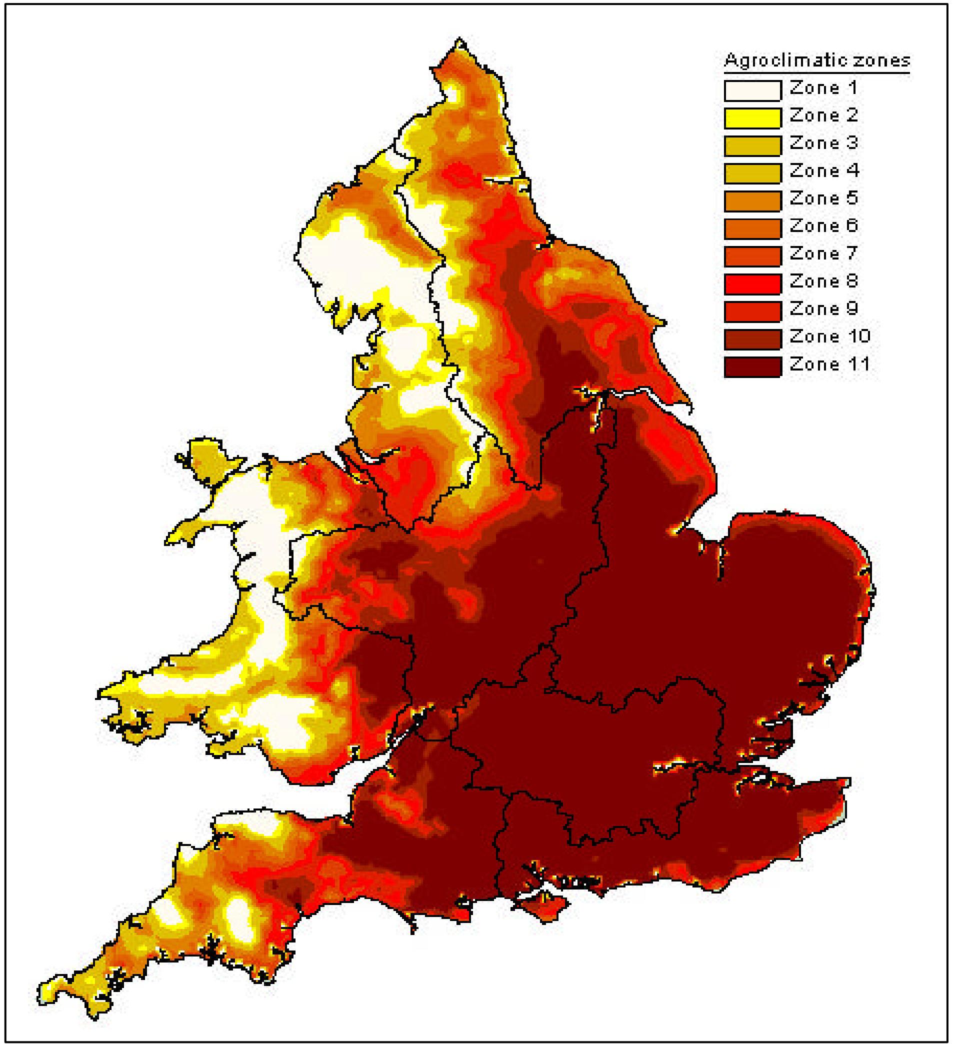


Figure 5-10. Agroclimatic zone map for UKCIP02 2050s High scenario

With climate change, the extent of the higher agroclimatic zones gradually starts to spread northwards and westwards. Even for the 2020s scenarios, increases in PSMD from the present climate are significant, with eastern regions becoming drier and central England adopting a climate more typical of eastern England at present. By the 2050s, PSMD's across much of the country increases substantially. Indeed, much of eastern, southern and central England are classified as zones eight to ten, representing agroclimatic conditions more typical of PSMD's experienced in recent very dry years (e.g. 1990 and 1995). These changes in agroclimate are consistent with some of the findings reported by Hulme *et al,* (2002) relating to temperature, precipitation and soil moisture. For example, they state that annual (and particularly summer) average soil moisture across the whole country, will decrease, with the highest reductions – 40% or more by the 2080s – occurring in the High emissions scenario in southeast England. Hulme and colleagues also project that by the 2080s about one summer in three will be both hotter and drier than the hot, dry summer of 1995, and nearly all summers will be hotter.

5.5.6 Calculating weighted irrigation needs

The irrigation look up tables provide an estimate of irrigation need (depth in mm) for a defined crop grown on a specific soil type, in a particular agroclimatic zone, for a particular UKCIP02 scenario. However, in order to produce a single irrigation need value for each crop category, for each EA Region, for input into the Irrigrowth model, a spatial assessment and relative weighting of the distribution of each crop type in relation to the variation in soils in which the crop is grown, and the agroclimatic zone in which it is located, is required. A brief description of the procedure to determine weighted irrigation needs is given below.

Using a GIS, for the baseline climate and each UKCIP scenario, the following spatial data were integrated:

- Land use databases for each crop category, derived from the MAFF 1994 Agricultural and Horticultural Cropping Census (2km resolution);
- A national soils database classified to reflect available water capacity (AWC) (1km resolution);
- Agroclimatic zone databases to reflect the spatial variation in PSMD (5km resolution);
- A database for each crop category, derived from the MAFF 1995 Irrigation Survey, identifying the proportion of each crop irrigated.

By combining these databases, the proportion of each irrigated crop category located within each agroclimatic zone, in each soil AWC type, was estimated. The results were produced as a matrix table for each Environment Agency Region. These summarise the proportion of each irrigated crop, weighted for soil type and agroclimatic zone. An example matrix table for maincrop potatoes, for the baseline (present climate), for Environment Agency Anglian Region, is shown in Table 5-14.

Table 5-14. Matrix table for maincrop potatoes in Anglian Region showing the percentage split (%) in irrigated area, by agroclimatic zone, by soil AWC, for the baseline climate

Soil AWC	**Agroclimatic zone**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
Low	0	0	0	0.2	3.4	5.2	7.2	0.2	0	0	0	16.2
Medium	0	0	0	0.3	8.7	24	33.1	0.9	0	0	0	67.0
High	0	0	0	0	0	3.7	12.8	0.3	0	0	0	16.8

Note: It is estimated, for example, that 24% of irrigated maincrop potatoes in Anglian Region are grown in agroclimatic zone 6 on a medium AWC soil).

The procedure was repeated for each crop category/EA Region/UKCIP permutation. Working at the Agency Region level, each relevant matrix table was combined with the irrigation look up tables, to calculate a weighted design dry year irrigation need. These values represented the weighted irrigation need (expressed in depths of water (mm) applied) for each crop category, weighted for crop location, the proportion of that crop irrigated, soil type and agroclimatic zone.

The procedure and matrix tables were originally developed using the UKCIP98 baseline and climate change databases. The matrix tables have subsequently been updated using adjustment factors to account for the changes in the extent of agroclimatic zones between the UKCIP98 baseline scenario and the UKCIP02 scenario databases. The resulting weighted irrigation need tables are summarised in Table 5-15. This table provided the input data for the IrriGrowth model.

Table 5-15. Weighted irrigation needs (mm in a dry year), by crop category, by Environment Agency Region, by UKCIP02 scenario.

	Early potatoes	Maincrop potatoes	Sugar beet	Orchard fruit	Small fruit	Vegetables	Grass	Cereals
Baseline								
Anglian	126	243	176	159	354	231	268	132
Midlands	108	206	150	119	335	196	217	107
Southern	120	233	179	136	345	220	238	112
South West	103	200	140	123	333	184	216	112
Thames	119	231	179	145	339	205	238	129
North East	109	199	145	119	331	188	204	100
North West	99	177	124	119	325	162	193	86
EA Wales	101	198	140	118	332	177	198	97
2020sL								
Anglian	151	310	230	216	387	294	339	178
Midlands	129	266	201	168	363	253	277	149
Southern	142	293	0	183	373	277	298	149
South West	114	232	0	151	348	214	249	137
Thames	146	308	247	211	375	274	315	185
North East	119	228	169	0	344	215	232	120
North West	100	181	128	0	326	165	197	89
EA Wales	106	214	153	132	338	191	213	108
2020sMH								
Anglian	153	316	235	222	390	300	346	182
Midlands	130	271	204	171	365	257	282	152
Southern	143	297	0	186	375	281	302	152
South West	116	236	0	154	349	217	253	140
Thames	148	313	252	215	377	279	321	189
North East	120	231	172	0	345	218	235	122
North West	100	182	129	0	327	167	199	90
EA Wales	106	216	155	134	339	193	215	109
2050sMH								
Anglian	171	364	274	262	413	345	397	215
Midlands	148	323	248	213	389	307	334	189
Southern	161	348	0	227	399	329	353	184
South West	131	281	0	193	370	259	300	174
Thames	169	371	302	264	404	330	378	231
North East	134	270	205	0	362	255	273	149
North West	108	204	147	0	337	187	222	106
EA Wales	116	247	182	163	352	222	246	132
2050sH								
Anglian	177	382	288	278	421	363	416	228
Midlands	155	343	266	230	399	327	355	203
Southern	168	367	0	242	408	348	372	196
South West	137	299	0	209	379	275	319	188
Thames	177	393	322	282	414	349	400	246
North East	139	286	219	0	370	270	289	161
North West	112	216	157	0	342	197	233	113
EA Wales	121	262	194	177	358	235	260	143

5.6 Volumetric demand and socio-economic scenarios

This section takes as input the changes in optimum irrigation need (depth) and assesses the resulting impacts on irrigation water demand (volumes) under the various socio-economic scenarios. The irrigation demand forecasting spreadsheet model IrriGrowth was developed previously for the Environment Agency (Weatherhead *et al.*, 2000) to analyse future irrigation water demand at regional and national levels (Environment Agency, 2001a). It was used to model unconstrained demand from a 1995 baseline scenario to 2025, without climate change.

IrriGrowth allows for the spatial variability in cropping, soil, agro-climate and irrigation practice, for the prediction of agronomic and economic demand, and for alternative socio-economic scenarios to be modelled. It includes factors predicting the changes in the total areas of each crop type being grown, the likelihood of it being irrigated, the relationships between optimum demand and economic demand, the irrigation efficiencies, and the likely proportions of the gross economic demand that the average irrigator will want and be able to apply.

A set of simplified scenarios was included relating to the baseline and four future socio-economic scenarios. The model calculates the dry-year water demand for each crop for each year based on these assumptions, and aggregates them to regional and then to national level.

For this project, the IrriGrowth model was further developed to include the weather change aspects of climate change (evapotranspiration and rainfall), using the weighted irrigation need factors described earlier. It was extended to model until 2055 (rather than 2025), and revised to start from a 2001 baseline (rather than 1995). It does not currently include the direct impacts of enhanced atmospheric CO_2 on the crops, either through changes in water use or in yield.

5.6.1 Baseline data for 2001

The baseline data used for 2001 are shown in Table 5-16. The data on crop areas are taken from county level data recorded by the Defra 2001 cropping survey, aggregated to Environment Agency Region level data using an existing matrix (Weatherhead *et al.*, 1994). The data on irrigated areas and depths applied are taken from the 2001 irrigation survey, adjusted to be a dry year as described earlier. The percentages irrigated are calculated directly from the above data.

Table 5-16. IrriGrowth baseline data for 2001 dry year

	Early potatoes	Maincrop potatoes	Sugar beet	Orchard fruit	Small fruit	Vegetables	Grass	Cereals
Total crop areas for 2001								
Anglian	7545	48088	128800	3715	1989	64932	294633	904904
Midlands	3542	20241	24589	4444	1259	11339	659597	386866
Southern	1447	2985	0	11045	2279	5624	240960	176902
South West	1967	4950	339	2836	597	3500	950036	264305
Thames	327	1930	872	762	466	1967	221354	235976
North East	1250	18600	19069	64	238	13292	598865	401960
North West	1516	7499	1619	82	102	5311	584992	84547
EA Wales	2481	4300	1951	3423	608	1866	1153594	82493
Total E&W	20075	108592	177239	26371	7537	107832	4704031	2537952
Irrigated areas for 2001 dry year (ha)								
Anglian	5733	41753	9856	808	1635	21630	3967	10384
Midlands	1375	10967	10181	437	712	8010	1675	3989
Southern	960	2736	0	1125	897	8698	1987	331
South West	334	964	205	12	337	177	126	0
Thames	233	5138	4	0	358	2115	416	9
North East	475	8572	1303	0	37	989	1002	394
North West	286	631	0	0	0	479	251	0
EA Wales	522	1151	0	121	135	59	357	11
Total E&W	9919	71912	21549	2504	4111	42158	9782	15118
Water applied for 2001 dry year (000m3)								
Anglian	5991	49730	5583	895	2003	19418	3760	4201
Midlands	1521	13606	9234	255	590	9517	989	1922
Southern	902	3234	0	786	1059	7279	1249	109
South West	160	994	244	19	529	109	0	0
Thames	217	10136	5	0	250	1702	1063	4
North East	433	8525	1091	0	37	810	1110	235
North West	128	429	0	0	0	202	418	0
EA Wales	303	1026	0	135	146	17	563	15
Total E&W	9655	87680	16157	2090	4615	39053	9151	6485
2001 Weighted optimum demand (mm)								
Anglian	126	243	176	159	354	231	268	132
Midlands	108	206	150	119	335	196	217	107
Southern	120	233	179	136	345	220	238	112
South West	103	200	140	123	333	184	216	112
Thames	119	231	179	145	339	205	238	129
North East	109	199	145	119	331	188	204	100
North West	99	177	124	119	325	162	193	86
EA Wales	101	198	140	118	332	177	198	97
2001 Weighted ratio economic/optimum demand factors								
All	95	100	90	65	100	100	50	50
2001 assumed efficiencies- (%)								
All	70	80	80	80	80	80	90	90

5.6.2 The socio-economic scenarios

The Foresight Programme *Environmental Futures* (DTI, 1999) had identified four socio-economic scenarios (Provincial Enterprise, World Markets, Global Sustainability and Local Stewardship). These scenarios were extended for the Environment Agency (Weatherhead *et al.,* 2000) to cover agricultural and horticultural irrigation demand in England and Wales. The Environment Agency re-labelled the extended scenarios Alpha, Beta, Gamma and Delta respectively, to emphasise that these are not the only possible interpretations. A reference trend scenario (called there the "baseline scenario") was defined to link the base year (1997/98) and the year when a future socio-economic scenario starts. The same irrigation scenarios are used in this project, and summarised in Box 5-1 (reproduced from Weatherhead *et al.,* 2000). The reference trend scenario is included as well - to provide consistency with earlier assessments.

The input data for each of the four socio-economic futures and the reference trend scenario are shown in Table 5-17. The same factors are used for all Environment Agency Regions, but, as they are applied to each Environment Agency Region's own 2001 data, they have different effects in different regions.

The factors were originally determined for forecasts from 1995 to 2025. Similar factors (and extrapolations) are used here for 2001 to 2050 to simplify comparison, and in the absence of better data. Adaptation to climate change impacts is not included, so the same factors are used for each climate scenario.

Box 5-1. Description of scenarios as extended to agricultural and horticultural demand.

Reference trend scenario

This scenario is drawn from the forecast of 'most likely' demand for irrigation water derived in the 1994 demand study (Weatherhead *et al.*, 1994). It assumed a continuation of the reform of CAP under the GATT/WTO regime whereby levels of agricultural support are reduced, farm commodity prices move towards world market levels, and about 15% of the (1992) cropped area is taken out of production. The predictions over a 25 year period for crop areas, yields and prices were obtained by the iterative use of the Manchester University Agricultural Policy model (Burton, 1992).

The reference trend scenario assumes a decline in real commodity prices which reduce the absolute feasibility of irrigation, especially of crops which previously attracted Government support. Horticulture and field scale vegetables are less affected, and therefore become relatively more attractive to farmers. The need for irrigation to deliver quality assurance is strengthened, with continuing increasing dominance of supermarket outlets. Although the total crop areas of most crops decline, the % of crops irrigated increases, with the exception of cereals and grains. There are modest increases in average depths applied in pursuit of quality benefits, and due to the adoption of permanent systems on fruit and some field vegetables. Irrigation efficiencies increase gradually reflecting technological developments.

The reference trend scenario lies somewhere between the CAP regime prior to the 1992 MacSharry reform and the Foresight global market, free trade scenario.

Alpha (Provincial Enterprise)

This scenario is dominated by a commitment to private consumption, but with policy interventions to serve national and locally defined interests and priorities. A modified CAP applies, supporting and protecting a relatively intensive, regionally focussed agriculture which promotes the concept of home produce and self sufficiency. This serves to increase the irrigated proportion of crops such as potatoes, sugar beet, field-scale vegetables and horticulture, although total crop areas decline gradually as yields increase. Irrigation depths increase in order to supply quality conscious markets with limited import substitution opportunities. Water shortages and high potential profitability of irrigation eventually encourage greater efficiency in use.

Beta (World Markets)

This scenario is characterised by emphasis on private consumption and free, integrated world trade. Agriculture becomes increasingly concentrated, industrialised, and driven by global markets. The CAP is abandoned, European farm commodity prices fall, although world prices themselves rise marginally. UK agriculture is subject to strong international competition, which further concentrates production towards larger business units. Imports reduce the total areas of potatoes, sugar beet and orchard fruit. An emphasis on quality favours irrigation on high value potato and horticultural crops. Reduced prices discourage growth in sugar beet irrigation. Pressure on water resources and emergence of water as an economic, tradable commodity force up water prices, and further concentrate irrigation in the large scale agri-business sector. This results in more intensive irrigation of those crops that are irrigated. Irrigation efficiencies increase gradually reflecting technological developments.

Gamma (Global Sustainability)

This scenario demonstrates a more pronounced commitment to social and environmental priorities, delivered through collective action at a global and international level. Imports again reduce the total areas of potatoes, sugar beet and orchard fruit. CAP reform switches support to agro-environmental schemes and incentives for organic and environmentally sensitive farming, which help to maintain small and medium sized farmers. Restrictions on water abstraction and higher water charges reduce irrigated areas and irrigation depths. Irrigation efficiencies increase rapidly reflecting international investment in technological developments.

Delta (Local Stewardship)

This scenario describes a situation where priorities reflect social and environmental concerns, evident in policy interventions at a regional and local level. CAP is replaced by national/regional agricultural policies which attempt to reconcile the economic, social and environmental dimensions of sustainability. There is an emphasis on self-sufficiency using relatively low external-input agricultural systems. Total crop areas increase. Average yields reduce, average farm commodity prices rise, and input costs fall. Regional and local area markets place less emphasis on appearance related quality criteria, reducing incentives to irrigate. Market induced irrigation declines, areas contract and irrigation depths remain constant or decline depending on crop type. Water is used wisely because of its associated public good, rather than its commercial value, leading to high irrigation efficiencies.

Source: Reproduced from Weatherhead *et al.* (2000).

Table 5-17. Input factors for the IrriGrowth model for the reference trend and simplified scenarios.

Simplified Scenario data

1. Crop area changes (as % pa)

Constants used as linear growth factors on 2001 values, for all climates.

	Earlies	Maincrop	Sugar beet	Orchard	Small	Veg	Grass	Cereals
Reference trend	Values input directly as per 1994 "most likely" model data, updated to 2001 base year							
World Markets	-0.32	-0.8	-0.8	-1.24	0	-0.28	-0.4	-0.8
Global Sustainability	-0.32	-0.8	-0.8	-1.24	0	-0.28	-0.4	0.8
Provincial Enterprise	-0.2	-0.2	-0.2	-0.4	0	0	-0.4	0.8
Local Stewardship	0	0.4	0	0.2	0.4	0.48	-0.4	1

2. % irrigated changes (as %pa)

Constants used to calculate asymptotic rate of change towards 100% or 0% irrigated,

	Earlies	Maincrop	Sugar beet	Orchard	Small	Veg	Grass	Cereals
Reference trend	2	4	2	3	3	3	-4	-5
World Markets	1	3	0	3	3	2	-5	-8
Global Sustainability	0	1	-1	1	0	1	-8	-7
Provincial Enterprise	2	4	2	3	3	3	-4	-5
Local Stewardship	0	0	0	1	1	1	-8	-7

3. Depth applied changes (as % pa)

Constants used to calculate asymptotic rate of change towards economic optimum (+) or zero (-)
Note: if growth is positive and depth already exceeds economic optimum, depth is held

	Earlies	Maincrop	Sugar beet	Orchard	Small	Vegetables	Grass	Cereals
Reference trend	1	1	0	2	2	2	0	0
World Markets	1	1	0	2	2	2	0	0
Global Sustainability	0	0	-1	1	1	0	-2	-2
Provincial Enterprise	1	1	0	2	2	2	0	0
Local Stewardship	0	-1	-1	0	0	0	-3	-4

4. Optimum Demands

5. 2025 Weighted ratio economic/optimum demand factors (%)

A linear change between 2001 and the 2025 baseline value is assumed until another scenario starts, followed by a linear change from there to the selected scenario's 2025 value, then constant to 2055

	Earlies	Maincrop	Sugar beet	Orchard	Small	Vegetables	Grass	Cereals
Reference trend	95	100	90	65	100	100	50	50
World Markets	95	100	85	60	100	100	40	40
Global Sustainability	90	95	80	65	100	100	50	50
Provincial Enterprise	95	100	90	75	100	100	50	60
Local Stewardship	95	100	90	65	100	100	50	50

6. 2025 target efficiencies

A linear change between 2001 and the 2025 baseline value is assumed until another scenario starts, followed by a linear change to the selected scenario's 2025 value, then constant to 2055

	Earlies	Maincrop	Sugar beet	Orchard	Small	Vegetables	Grass	Cereals
Reference trend	75	85	85	85	85	85	85	85
World Markets	75	85	85	85	90	90	85	85
Global Sustainability	85	90	85	95	95	95	90	90
Provincial Enterprise	75	85	85	85	90	90	85	85
Local Stewardship	80	90	85	90	90	95	85	85

5.6.3 Climate change impacts on cropping patterns

Changes in cropping mixes, where crops are grown and which crops are irrigated are likely to occur in the mid - to long-term as a result of climate change. Such changes would be on top of changes that are already included in the socio-economic scenarios. However, following consideration of the potential impacts within England and Wales, as discussed below, these have not been introduced into this modelling.

Crop movement impacts: It is generally reported that climate change will lead to crop growing areas moving north and west. Higher temperatures, less frost and drier soils will make such areas more suitable. At the same time, land in the south and east may become less suitable for some crops due to increased droughtiness. It should be noted however that most of the published land-use studies e.g. REGIS, (Holman and Loveland, 2002) relate to non-irrigated crops. Where water is available, effective irrigation can negate the increased drought risk in the southeast. Most of the high value irrigated crops are successfully grown with irrigation in hotter drier climates such as Spain. Discussions with irrigators, however, suggested a high level of inertia in the location of irrigated cropping. Irrigated crop movement to date has mostly been to lighter soils for ease of harvesting, or to areas where water is more easily available, or to drier areas where harvest conditions are more reliable.

It is likely that climate change will decrease water availability, forcing changes in water allocation policy and shifts in crop distributions. Such shifts however would be in response to water policy rather than to climate change *per se*. Where such cropping shifts are included in studies of demand the exercise becomes self-fulfilling; irrigated crop movements would be modelled so that demand never exceeds allocated supply. Accordingly, they have been omitted from this study.

It is also inevitable that socio-economic and climatic changes elsewhere in Europe will impact on irrigated cropping in England. Salad crops grown in England compete with produce from southern Europe, particularly Spain, where investment in water resources is a political priority. Similarly, irrigated potato production will have to compete with imports from accession countries such as Poland. Literature on the manner in which other country's water policy influences production and competitiveness in surrounding countries is scarce. A European Union funded research project termed WADI (EVK1-CT-200-0057) is attempting to model the impact of European policy, including the Water Framework Directive and the Common Agricultural Policy on irrigated cropping across Europe, but has not reported yet. Any crop movement impacts due to climate change will be superimposed on these socio-economic, political and legislative impacts.

In the absence of usable data, and for calculating unconstrained demand, the figures presented assume there is no net impact of climate change on the location of irrigated crops (This mirrors the assumption behind the Environment Agency predictions without climate change, where similar crop change rates have been used for all regions, albeit from different reference figures).

New crop impacts: Climate change could potentially lead to new crops being introduced to England and Wales. Anticipated climate changes are relatively small by the 2020s, but by the 2050s the climate in south-east England resembles parts of France where maize is irrigated. The introduction of large areas of irrigated maize into England would substantially increase water demand, but is likely to be economically marginal and very unpredictable; no allowance for the introduction of new crops has been made in this project.

Other new crops are likely to fall into the vegetable or "other" categories, and would probably replace crops already included.

Irrigation cost - benefit impacts: Impacts on irrigation costs (excluding rises in water costs or abstraction charges as a result of shortage) are likely to be small; the marginal cost of applying extra water is a relatively small part of total irrigation costs.

Impacts on irrigation benefit are harder to predict, since they depend on impacts on crop prices internationally. The higher yields will reduce all input costs. The benefits relative to non-irrigated cropping will increase.

However, the survey confirmed that irrigation is already being concentrated in high value crops, and this trend continues in the future socio-economic modelling. It has been assumed therefore, that the modest climate change impacts shown for the 2020s is unlikely to change the economics of irrigating these crops. This assumption becomes less robust by the 2050s but again no net change is assumed.

5.6.4 Model results: climate impacts on volume of irrigation water demand

The scenario changes in total volumetric irrigation demands for England and Wales, for each socio-economic scenario and under the selected climate change scenarios, are summarised in Table 5-18. The climate change impacts here relate only to changes in rainfall and evapotranspiration. All data relate to economic optimum demand in a design dry year. All socio-economic scenarios were assumed to start in 2005, and the demand from "other crops" was held constant at the 2001 level of 6%.

The climate change impacts alone (i.e. comparing with and without values) are remarkably consistent in percentage terms between socio-economic scenarios (Table 5-19), whilst the absolute increases will be greater for the scenarios requiring most water.

The increases vary spatially across the country (Table 5-20). For example, in the Anglian region, demand in the 2020s increases by 29% with the Medium-High climate change scenario, which is close to the national average. In percentage terms, they are highest in the Thames, Midlands, Anglian and Southern regions. As these regions already contain most irrigation, the absolute increases are much higher in these regions.

It is notable that these weighted impacts are lower than the average impacts modelled for the individual weather station sites. For example, IrriGrowth suggests increases of 28% for maincrop potatoes from 2001 to 2020s and an increase of 48% from 2001 to the 2050s, both for the Medium-High climate scenario, whereas the weather station modelling showed average increases of 46% and 74%. Some difference is to be expected because the aggregated locations of the weather stations are not representative of potato growing areas. However, it is also possible that the correlation between PSMD and irrigation need does not remain constant with changing weather patterns. This finding indicates that the results are sensitive to the assumptions that have to be made in the modelling procedure, and should be interpreted accordingly.

Table 5-18. Changes in dry year water demand relative to 2001 (%) for England and Wales, by scenario, without and with climate change (rainfall and ET changes only)

Climate scenario	Reference	Alpha	Beta	Gamma	Delta
Baseline					
2001 (‘000m^3)	187286	187286	187286	187286	187286
Scenario differences from 2001 to 2020s					
Present climate	21%	34%	14%	-20%	-4%
Low	52%	69%	43%	1%	21%
Medium-High	55%	72%	45%	3%	23%
Scenario differences from 2001 to 2050s					
Present climate	29%	72%	24%	-31%	-6%
Medium-High	91%	155%	83%	2%	39%
High	101%	168%	93%	7%	46%

Note: U represents unchanged climate

Table 5-19. Impacts of climate change alone for England and Wales; changes in dry year water demand relative to demand in that year with unchanged climate, by scenario (rainfall and ET changes only), %

Climate scenario	Reference	Alpha	Beta	Gamma	Delta
Scenario differences for 2020s					
Low	26	26	26	26	26
Medium-High	28	28	28	28	28
Scenario differences for 2050s					
Medium-High	48	48	47	48	49
High	56	56	55	56	57

Table 5-20. Regional impacts of climate change alone, for Environment Agency Regions and Environment Agency Wales; % changes in dry year water demand relative to demand in that year with unchanged climate, for reference socio-economic scenario (rainfall and ET changes only).

	2020s Low	**2020s Med High**	**2050s Med High**	**2050s High**
EA Region:				
Anglian	27	29	48	55
Midlands	30	32	57	67
North East	14	16	35	43
North West	2	3	15	21
Southern	23	25	42	49
South West	11	13	28	34
Thames	32	34	57	65
EA Wales	7	8	19	25
Total England and Wales	**26**	**28**	**48**	**56**

Note: Percentage change is between the reference scenario with and without climate change, for the same time period (e.g., the 2020s). Summing errors due to rounding and statistical adjustments. Values for other socio-economic scenarios are typically within +/- 1%.

5.7 Future water demand under combined impacts

The results from Section 5.6 must now be combined with the impact of atmospheric CO_2 on yields and hence areas, to produce the combined impacts on total volumetric irrigation demands.

The results of combining the IrriGrowth outputs with the simple area reductions are shown in and Table 5-22, for each socio-economic scenario and the selected climate change scenarios. As before, all data relate to economic optimum demand in a design dry year. The socio-economic scenarios were assumed to start in 2005, and the demand from “other crops” was held constant at the 2001 level of 6%.

The increases due to rainfall and evapotranspiration changes are at least partly offset by the increased yield due to higher atmospheric CO_2. The percentage impacts by Environment Agency Region and for Environment Agency Wales are shown in Table 5-23 for the reference scenario; values for the other socio-economic scenarios are similar. The increases are again highest in the Thames, Midlands, Anglian and Southern regions. Notably in some regions the combined impact is very small or even negative.

Table 5-21. Changes in dry year water demand relative to 2001 (%), by socio-economic scenario without and with climate change for England and Wales, with CO_2 effects

Climate scenario	Reference	Alpha	Beta	Gamma	Delta
Baseline					
2001 (‘000m3)	187286	187286	187286	187286	187286
Scenario differences from 2001 to 2020s					
Baseline climate	21%	34%	14%	-20%	-4%
Low	43%	59%	35%	-5%	14%
Medium-High	45%	60%	36%	-4%	14%
Scenario differences from 2001 to 2050s					
Baseline climate	29%	72%	24%	-31%	-6%
Medium-High	63%	117%	56%	-13%	19%
High	67%	122%	60%	-11%	21%

Note: Baseline climate represent present agroclimatic conditions.

Table 5-22. Impacts of climate change with CO_2 effects for dry year water demand relative to demand in same period with unchanged climate, by scenario, with CO_2 effects

Climate scenario	Reference	Alpha	Beta	Gamma	Delta
2020s					
Low	18%	19%	18%	18%	19%
Medium-High	19%	19%	19%	19%	20%
2050s					
Medium-High	26%	27%	26%	26%	27%
High	29%	29%	28%	29%	30%

Table 5-23. Regional impacts of climate change with CO_2 effects for Environment Agency Regions and Environment Agency Wales for changes in dry year water demand relative to demand in same period with unchanged climate, for reference socio-economic scenario

	2020s Low	2020s Med High	2050s Med High	2050s High
England and Wales (average)	18	19	26	29
EA Region:				
Anglian	19	20	26	29
Midlands	22	23	34	38
North East	8	8	15	19
North West	-4	-4	-2	0
Southern	16	16	21	23
South West	5	5	9	11
Thames	24	25	34	37
EA Wales	1	0	2	4

Note: summing errors due to rounding and statistical adjustments. Values for other socio-economic scenarios are typically within +/- 1%

5.8 Limitations

The high degree of apparent precision, numerically and spatially, that this type of demand forecast modelling produces can be misleading. Some of the limitations and risks are discussed below:

- The UKCIP02 scenarios are not really designed for modelling the 2020s, because they are merely scaled results from the 2080s run. The levels of uncertainty implicit in the UKCIP02 methodology are discussed in the UKCIP Scientific Report (Hulme *et al.*, 2002).
- The absence of evapotranspiration data in the UKCIP02 5km database has necessitated some further modelling to derive the required data. A very poor correlation was observed between the mean annual maximum PSMDs calculated from this derived data and the equivalent PSMDs calculated from recorded climate at the 21 weather stations. The reasons for this correlation are not clear.
- Most GIS modelling gives an unwarranted pretence of spatial accuracy. The outputs can be very sensitive to the accuracy and spatial resolution of the input databases. Integrating databases of different resolutions, e.g. 1km, 2km and 5km as in this study, can introduce and propagate modelling errors.
- The irrigation need modelling procedure is believed to be reasonably accurate under current conditions, though there is a possibility that the correlation between PSMD and irrigation need could alter with climate change. Furthermore, the UKCIP02 data used gives changes in average monthly climate, and our modelling has to assume that the relationship between dry years and average years is unchanged.
- There is uncertainty over the net effect of the increased atmospheric CO_2 levels. This study assumed the direct impacts on evapotranspiration rates due to elevated atmospheric CO_2 levels cancel out. The study assumed a 30% increase in yields for a doubling of CO_2 for all crops, and calculated actual increases pro-rata at other CO_2 levels.
- Possible yield impacts due to temperature change were ignored.
- The IrriGrowth modelling assumed that there are no net climate change impacts on irrigated cropping mixes or irrigated crop distribution in the UK, other than changes already implicit in the socio-economic scenarios, and that there is no crop or farm practice adaptation to climate change. It is emphasised that the extrapolation of the socio-economic scenarios from 2025 to 2055 was only for the purpose of examining climate change impacts – these are in no way accurate forecasts of future demand without climate change.
- Finally, it is re-emphasised that all the figures are for unconstrained demand; actual water use will be limited by availability and price and the resulting responses will themselves alter demand elsewhere.

For all the above reasons, the figures should be used to give an indication of the trends in unconstrained demand that might happen nationally and regionally in response to climate change, and the sensitivity of these impacts to socio-economic scenarios. The absolute values depended mainly on the assumptions and extrapolations in the socio-economic scenarios and are less reliable. Unfortunately, it is extremely difficult to assess confidence limits associated with these results.

5.9 Conclusions

This objective of this section of the CCDeW project was to assess the sensitivity of unconstrained water demand in agriculture and horticulture to climate change, under the various Environmental Futures socio-economic scenarios, at regional level.

A survey of irrigation of outdoor crops in 2001 confirmed that water use for irrigation is still currently growing at 2-3% per annum, and provided a 2001 baseline for the demand modelling. The national dry year water demand modelled for a 2001 dry year was slightly higher than the previous 2001 predictions based on 1995 data, with a growth of 18% over the six years.

The study identified that climate change could impact irrigation water use via many different mechanisms, variously affecting plant physiology, yield, soil water balances, cropping patterns, the areas irrigated and the irrigation methods used.

The enhanced atmospheric CO_2 levels will increase plant growth rates, increasing plant height and leaf area index, increasing plant water use. Higher CO_2 levels will also increase stomatal resistance, decreasing plant water use. Computer modelling for the 2020s suggested that the effects for field crops would roughly cancel out over a season, but the literature is inconclusive and long-term field-scale experimental data is lacking.

The enhanced atmospheric CO_2 will also increase yields (on top of current trends) and hence reduce the crop areas needed for the same production level. This effect alone could reduce water demand by around 5-10% in the 2020s and 15-20% in the 2050s. However, increased temperature impacts may have the opposite effects. More data is required for the impacts on individual crops.

The review of impacts on cropping patterns provided very little information of impacts on irrigated crop location. Most previous land-use studies have concentrated on non-irrigated cropping. Climate change will extend the suitability for most crops northwards, and will make some land in the south unsuitable for non-irrigated cropping due to droughtiness. However, where irrigation is available, irrigated crops will have an increased competitive advantage in the south and may not move unless water constraints or higher prices become a significant driver. Most of the crops irrigated are currently grown abroad in much hotter and drier conditions than for England and Wales, even for the 2050s. The modelling assumed no net impact of climate change on crop distribution.

International climate change impacts on food trade have not been considered, but could have substantial effects on water demand in England. To date very little has been published on this subject.

The irrigation need modelling confirmed that agro-climatic zones based on soil-moisture-deficit will move northwards and westwards. In terms of irrigation need, central England will be similar to the present eastern England by the 2020s, and by the 2050s crops in much of eastern, southern and central England will have irrigation needs higher than are currently experienced anywhere in England (and roughly similar to the current climate in areas of France south west of Paris). Studies of land-use and cropping mixes in such areas might provide useful indicators of likely impacts.

The IrriGrowth water demand modelling suggested that changes in rainfall and evapotranspiration alone would increase dry year water demand nationally by around 30% by the 2020s and by around 55% by the 2050s. However, it was noted that the regional increases were lower than the average increases modelled at the weather station sites, suggesting that the methodology is sensitive to some of the assumptions and correlations used.

These impacts are highest in the midlands and the south-east, where most irrigation already occurs, reaching up to 35% by the 2020s and up to 65% by the 2050s. The percentage increases are similar for all the socio-economic scenarios.

When the assumed yield benefits of the higher atmospheric CO_2 and the IrriGrowth results are combined, the impacts nationally are around +20% by the 2020s and around +30% by the 2050s. In some regions and for Environment Agency Wales, the combined impacts are negligible.

These climate change impacts are additional to the socio-economic change impacts. They are all much smaller than the differences between the socio-economic scenarios. (Modelled growth without climate change varies from –19% to + 34% by 2025 and –29% to +65% by 2055, depending on the socio-economic scenario).

As a study of impacts on unconstrained demand, likely adaptations to water shortage, whether resulting from socio-economic change or climatic change, have not been included. Clearly some of the demand increases modelled would be untenable, even without the likely reductions in supply. Under water-scarce conditions, high water prices and/or non-availability of water will limit irrigation in many catchments. This could then prompt crop movement, raising demand elsewhere, changed cropping mixes and/or changes in irrigation practice to increase the efficiency of irrigation. Further studies are required to identify likely outcomes.

Aggregation of data to regional level, and the necessary use of generalised assumptions, creates a risk of over-simplifying the range of impacts on individual water users. It is inevitable that the water demands of some abstractors will increase much more sharply than the averages modelled here, and great care should be taken before applying these results at farm level. This implies that at least some irrigators already need to plan for substantial water resource increases within the planning horizon for major investments, particularly reservoirs.

It is noted that climate change impacts are not currently included in the CAMS methodology for assessing available water resources (RAM) or for determining water abstraction licenses; the results of this study suggest they could become significant in some regions and should be considered.

Although nationally only 3% of this water comes from mains supply at present, the proportion is as high as 20% in the south east and could grow substantially where climate change impacts cause direct abstraction to be restricted, with implications for water company resource planning.

5.10 Appendix

5.10.1 Appendix 5-A. The 2001 Irrigation Surveys

Surveys of the “Irrigation of Outdoor Crops” in England and Wales have been carried out roughly every three years by MAFF (now Defra). The questions were kept essentially unchanged between 1982 and 1995, giving six sets of directly comparable data, in 1982, 1984, 1987, 1990, 1992 and 1995 (1995 for England only). However, no surveys were commissioned after 1995, leading to worries that this project would be founded on old data. A new survey of irrigation in England was therefore commissioned as part of the CCDeW extension contract. A similar survey was undertaken separately for Wales.

Sending the questionnaire

A revised questionnaire was prepared following discussion with the national Agricultural Water Resources Liaison Group, comprising representatives of Defra, the Environment Agency, National Farmers Union (NFU), Country Land and Business Association (CLA) and UK Irrigation Association (UKIA). This survey aimed to continue the most important data series from the MAFF surveys, whilst revising some of the less useful questions.

The questions on areas irrigated and volumes applied, by crop, and the questions on dry-year irrigation, trickle irrigation and frost protection were not changed. An additional question was added asking about scheduling methods used by area. The water source categories were revised to match abstraction licensing definitions. The question asking whether certain types of equipment were used was replaced by one asking for the application methods used by area. The question on water storage was rephrased to refer to reservoirs, and subdivided between unlined/earth lined reservoirs and synthetically lined reservoirs.

A question in Defra’s June 2000 Agricultural Census, which was sent to all registered agricultural holdings in England, had asked: "What is the total area of all outdoor crops which you are able to irrigate if necessary this year? - exclude liquid manure spreading". Following completion of the requisite confidentiality statement and Defra survey approval form, Defra provided addresses and responses (for this question only) for the 5603 respondents in England who had indicated they could irrigate. Questionnaires were sent to all these, together with Freepost return envelopes.

A follow-up survey, covering letter and Freepost envelope were sent to 279 addresses, being those in the decile of largest irrigators (according to their cropping survey returns) who had not yet responded (the method of correcting for non-returns by size deciles ensures this did not bias the results). A few respondents were telephoned to clarify the responses to the question on trickle irrigation capacity.

Analysis of responses

Responses were received from 2301 holdings (41%). Only 83% confirmed that they ever irrigated (casting some doubt on the accuracy of the June 2000 Census database). Some 67% stated they had irrigated in 2001. Analysis subsequently showed the respondents represented around 55% of the total irrigated area reported in the June 2000 Census.

To allow for different response rates from different size farms, the holdings were divided into ten groups (deciles) ranked by the area they had reported in the June 2000 Census. Some respondents fully answered only some sections. Statistical corrections for non-respondents were therefore based on the proportion not responding to particular sections in each decile. An overall correction, based on Defra advice, was also made to allow for non-respondents to the June 2000 Census.

The adjusted national results are shown in the following tables. When comparing inter-annual variation, it is important to bear in mind the weather conditions in that year, which strongly impact on actual irrigation.

The aggregated responses to the questions on reservoir capacity and the total areas equipped for trickle irrigation and frost protection were clearly in error and have been withheld; the data given below on number of holdings using trickle and the area of trickle are therefore based on the answers to the question on methods used in 2001. It is unlikely that large areas of trickle were installed but not used, so this should give a similar result.

Table 5-24. Irrigated areas (ha), by crop category, 1982-2001

Crop category	1982	1984	1987	1990	1992	1995	2001
Early potatoes	8050	7720	5360	8510	8180	8730	7300
Maincrop potatoes	22810	34610	29520	43490	45290	53390	69820
Sugar beet	15770	25500	10100	27710	10520	26820	9760
Orchard fruit	3100	3250	1330	3320	2280	2910	1580
Small fruit	3610	3560	2230	3470	2750	3250	3770
Vegetables	14810	17460	11040	25250	20200	27300	39180
Grass	16440	18940	6970	15970	7240	10690	3970
Cereals	14800	24700	7510	28100	7160	13440	4620
Other crops	4100	4890	2440	8650	4320	9120	7280
Total	103490	140630	76500	164470	107940	155650	147270

Note: summing errors due to rounding.
Data up to 1992 for England and Wales, data for 1995 and 2001 for England only.

Table 5-25. Volumes of water applied (’000m^3), by crop category, 1982-2001

Crop category	1982	1984	1987	1990	1992	1995	2001
Early potatoes	4680	4920	2350	6770	5590	9345	5710
Maincrop potatoes	15280	32730	14700	51170	38520	74460	69940
Sugar beet	8260	17370	3430	20320	4860	21295	4630
Orchard fruit	2180	2430	550	2930	1220	2445	900
Small fruit	1890	2660	970	3180	2000	4320	3370
Vegetables	6830	11390	4640	18450	12180	25500	34120
Grass	10030	13550	3550	13100	4280	9920	2320
Cereals	5040	8300	2160	11830	2260	5625	1470
Other crops	1020	4030	1270	6040	4160	11160	8840
Total	55210	97380	33620	133790	75070	164070	131300

Note: summing errors due to rounding.
Data up to 1992 for England and Wales, data for 1995 and 2001 for England only.

Table 5-26. Dry year position assuming adequate water supply, 1982-2001

Crop category	1982	1984	1987	1990	1992	1995	2001
Area likely to be irrigated (ha)	na	189310	na	202620	218550	194000	282960
Volume likely to be applied (‘000m^3)	na	167000	na	179460	233610	244090	439470

Data up to 1992 for England and Wales, data for 1995 and 2001 for England only.

Table 5-27. Water source (% of water applied), 1982-2001

Source	1982	1984	1987	1990	1992	1995	2001
Surface water	34390	57210	19250	74070	41820	90860	75760
Ground water	16680	32420	11800	50540	28470	61620	47810
Public mains	2040	3840	1100	3860	2620	4390	4300
Rain collected			included in “other”				2050
Re-used water			included in “other”				670
Other	1830	3540	1470	5330	2160	4880	710
Total	54940	97730	33630	133790	75070	146960	131300

Surface water includes ponds, lakes, gravel or clay workings, rivers, streams or other water courses.
Ground water includes wells, bore holes and springs rising on the holding.
Data up to 1992 for England and Wales, data for 1995 and 2001 for England only.

Table 5-28. Scheduling method (% of area irrigated), 2001

Scheduling method	%
Water balance calculations (by hand or by computer)	23
In-field soil moisture measurement (e.g. neutron probes, tensiometers)	29
Other (including operator judgement, feeling soil, crop inspection)	48
Total	100

Note: question not asked before 2001.
Data for England only.

Table 5-29. Application method (% of area irrigated), 2001

Application method	%
Static or hand-moved sprinklers, spray lines	4
Hose reels with rain guns	72
Hose reels with booms	16
Centre pivots or linear moves	3
Trickle or drip	5
Other (please specify):	<<1
Total	100

Note: question not asked in this format before 2001.
Data for England only.

Table 5-30. Trickle irrigation (Number of holdings and area equipped/used*, ha), 1982-2001

	1982	1984	1987	1990	1992	1995	2001
Number	890	640	490	600	720	820	910
Area (ha)	2040	1550	1330	1420	1970	4120	7040

*Up to 1995 refers to holdings and area equipped for trickle; for 2001 refers to trickle systems used.
Data for England only.

Interpreting the survey results

When comparing year-to-year variations, it is important to bear in mind some differences between the various surveys and the weather in each survey year.

Differences between surveys

Previous surveys were sent to respondents who replied positively to the irrigation question "do you irrigate outdoor crops?" in the Defra June Agricultural Census, sent to all main holdings. Because of fears that this would miss irrigators who were not irrigating in the particular year, the 1995 survey was sent to positive respondents in any of the three preceding June Agricultural Censuses (1993-1995), plus respondents to the MAFF 1992 Irrigation Survey (MAFF, 1996).

From 1995, sampling was introduced into the annual June Agricultural Census, so only about 60% of main holdings are surveyed each year http://farmstats.defra.gov.uk/cs/aboutcensus.htm (accessed 26/7/02). Fortunately, a full census, including minor holdings, was carried in June 2000, with an estimated 80.3% response. The irrigation question was also changed to "What is the total area of all outdoor crops which you are able to irrigate if necessary this year (exclude liquid manure spreading)?" which should identify all potential irrigators. The 2001 Irrigation Survey was sent to all positive respondents to that question.

Because of these changes, the address list used for this survey included many minor holdings that would have been missing from previous surveys. This would have affected any results related to "number of holdings", but is unlikely to have significantly affected the total areas and volumes or percentages of these quoted.

Weather in survey years

In the UK, the irrigated areas and the volumes of irrigation water applied each year vary considerably depending on the summer weather. The data from the irrigation surveys partly reflect the weather in each census year, superimposed on any underlying trends in demand.

Table 5-2 shows, for example, the ranked theoretical irrigation needs (mm) for maincrop potatoes grown at Silsoe (Bedfordshire) for 1970 to 2001. Broadly, in irrigation terms at Silsoe, 1982 and 1984 were average years, 1987 was wet, 1990 was a dry year, 1992 was wet again, and 1995 was a very dry year. In 2001 there was dry period in the middle of the irrigation season, around June, but this was followed by a very wet July, leaving 2001 ranked overall as a wet year. Similar rankings are obtained for other irrigated crops.

Irrigation in Wales

Irrigation in Wales represents only about 1% of the irrigation in England and Wales combined, and was omitted from the MAFF 1995 irrigation survey. Following a request from the Environment Agency, the 2001 irrigation survey was extended to Wales (note: this falls outside the terms of this contract, but is reported here for completeness). The questionnaire and covering letter were translated into Welsh, and both versions were sent to 152 addresses in Wales, provided by the Welsh Assembly Government. Forty responses were received within the (shorter) time allowed, representing a 26% response rate. After separate statistical corrections, the data on crops irrigated and volumes of water applied have been incorporated into the datasets used in the study.

6 Leisure

6.1 Introduction

Leisure has been identified as a sector in which the demand for water might be particularly susceptible to climate change, through an increase in the use of leisure facilities and in the water use of those facilities. The following sections consider water use in leisure facilities in general terms and sets out how such use might be assessed.

6.2 Characteristics of demand

The breakdown of industrial commercial consumption into the sectors identified by the Environment Agency (Table 4-4) does not identify the leisure sector (SIC code O) on its own. Consumption in this sector is included in the “other” category. There are therefore no consumption data specifically related to leisure facilities from which to conduct analysis.

Intuitively however, the use of outside recreational facilities is likely to increase from a winter low through the spring, reaching a peak in summer and then falling back to a winter minimum.

The main uses of public water supplies for outdoor leisure activities are:
- Irrigation of golf courses (though this may be through direct abstraction rather than treated mains water);
- Irrigation of football pitches to create and maintain “playability”;
- Private swimming pools.

Other outdoor water based leisure and recreation requires natural or man-made water bodies such as lakes, reservoirs and gravel pits, so apart from showering and washing facilities there would be no additional demands on public water supply.

Demand for leisure facilities is influenced by a range of factors, particularly affluence and transport. As for the agricultural sector, changes in these factors (both locally and abroad) is likely to exert a significant influence on the demand for water emerging from the leisure sector.

Gardening in the Global Greenhouse (Bisgrove and Hadley, 2002), commissioned by UKCIP, reports on the possible impacts of climate change under UKCIP02 scenarios on domestic gardens, heritage and large public gardens and retail horticulture outlets. The summary report (Gates, 2002) includes a list of challenges and opportunities for these three divisions. The full report describes relevant climate changes, the physiological effects on plants, their diseases and weeds and includes some discussion on effects on water demand.

They report that climate change affect many components of the garden. In particular, the report addresses the potential impacts of climate change on: soils, water supplies and water bodies; trees, shrubs, sub-shrubs, herbaceous, perennials, bulbs and annuals; lawns; paths, buildings and other structures; garden staff. The discussion of demand for water in for horticulture, gardens and golf courses is based on Herrington’s (1996) findings. For example assuming some increase in the number of golf courses, Herrington (1996) estimates that water demand in the south east for irrigation of golf courses might increase from 3.3 Ml/d (1992) to

4.8 Ml/d (2021) in the absence of climate change. A 1.1°C increase in temperature by 2021, and a 2.1°C increase by 2051 (similar to temperature changes projected under the UKCIP02 medium high emissions scenario) is expected to add 4% (by 2021) or 8% (by 2051) to the requirements which would be expected in the absence of climate change. This 8% increase compares with estimates of 11.8% increase for agricultural irrigation, and 37.5% increase for air-conditioning. The total of 5 Ml/d estimated water use by golf courses in the south east in 2021 with moderate climate change, represents less than 0.1% of domestic water consumption and is therefore insignificant in terms of the total amount of water used.

Also of relevance are calculations of garden use of water in the Thames and Lee Valley catchments, which suggest that public water supplies will need to increase by 1.2% to meet increases in demand related to climate change by 2050 on an annual basis, but this represents a 3-4% increase in demand for the six months April - September, or 7-8% for June-July. In East Anglia, 3% of annual water use in an average household was used in the garden in the wet year of 2001 (Chivers, *pers. comm.*, cited in Bisgrove and Hadley, 2002). This figure was 6% in the dry year of 1996. Concentrated in the two driest months, the peak demand may rise to 25% above the average level of water use. The impacts of gardens on water demand as a result of climate change will, they report, be a modest increase in total demand for water, but a very marked increase in peak demand in hot, dry summers. They conclude that as climate change continues beyond 2050, and as expectations of gardens continue to rise, water use for gardens may cease to be a minor proportion of total domestic demand.

They also report that water shortage is likely to be the most serious single impact of climate change on gardens and suggest ways of counteracting this including modifying planting regimes, irrigation (though will become increasingly expensive) improving the water holding capacity of the soil and storage of water in private reservoirs and water butts.

6.3 Methodology

The potential for changes in demands in the recreation and leisure sectors attributable to climate change were discussed at the various practitioner workshops associated with this project, and resulted in further investigations being conducted to explore ways of quantifying the change.

Significant increased water demands are expected from climate change impacts on golf and other turf-grass based sports. Table 5.15 suggested that the irrigation need for agricultural (grazed) grass in the 2020s would increase by up to 32% (Low scenario) and 78% (Medium-high scenario) in some regions. Higher atmospheric CO_2 levels may temper these increases through reduced transpiration for turf-grasses, which are kept mown at constant height, but there are no compensating water savings from the higher grass yield. Indeed, the area irrigated could increase very substantially to maintain playability in hotter drier summers. Unfortunately there is very little data available on the areas presently irrigated, or the proportions supplied from mains water versus direct abstraction, for the different sports.

The main consumptive use of water from recreation and leisure facilities is therefore likely to be from indoor and outdoor swimming facilities. Research into outdoor leisure facilities suggests that the popularity of “Lidos” has waned since its 1930s heyday. Those Lidos in active use are listed on various websites, but the general impression is of declining, rather than increasing popularity.

One particular area of growth in recent years has been public and private sports and leisure centres. In order to gain more insight into trends in water consumption arising from increased use of these pools, the Institute of Public Finance's statistics on the annual expenditure on public facilities (including swimming pools) annual reports giving visitor numbers was examined. The data are generated by returns from the various Local and other Authorities, and there appear to be differences from year to year in the number of returns used to compile the statistics.

Similarly, the published annual data on number of pools, total surface area and visitor numbers were examined for any trends in use that might be related to climate. Although the data are adjusted to account for missing returns, there was considerable inter-annual variation in statistics such as, "Total number of facilities" suggesting that the data may be unreliable. No trends that might be climate related were apparent.

No information on the growth in private sports centres and how this might have been influenced by climate is available. In circumstances where such centres are supplied with water from the public water supply system rather than from private sources, it is possible that their consumption is included in the water company statistics.

Key leisure centres, such as Center Parcs, are already operating at high occupancy rates, so large increases in water demand are likely to come from the development of new sites rather than increased occupancy. New developments will be subject to the normal planning processes.

Information on private swimming pool ownership is very scarce, but increased swimming pool ownership and use could be an important impact arising from climate change. Broad assumptions about current and future swimming pool ownership, the size of outdoor pools, and the evaporative losses have been made to give an overall view of potential impacts.

As discussed in Chapter 4, greater ownership and use of swimming pools is intuitively a likely outcome of higher summer temperatures over an extended period. However, statistics from the Institute of Public Finance suggest that expenditure on public swimming pools has not significantly increased during the last six years. No robust data are therefore available from which to form an opinion of current water use, let alone changes in use under future climate scenarios. There is, however, a perception that demand for private pools is linked to increasing affluence. The calculations in Table 6.1 illustrate the possible magnitude of the climate change impacts on private swimming pools.

Ownership of private swimming pools is expressed as a percentage of total households. Each water company has been assigned a category of swimming pool ownership: "high", "medium", "low". "High" ownership in the south, "medium" in the main urban areas and the midlands and "low" in the north and in Wales. The percentage ownership under each category is assumed to be 5%, 2.5% and 1% respectively. The assumed numbers for the 2020s – no reliable figures on current ownership appear to be available – are shown for each region in Table 6-1.

Estimates of the possible increase in water consumption based on assumptions of changes in ownership, surface area and other variables have been made. The active swimming season is assumed to last from May through to September inclusive; estimates of the seasonal evaporative losses have been extracted from the CCDeW database. The average size of swimming pools is estimated as 100m^2. For the purpose of these illustrative calculations, ETo has been used as a surrogate for open water evaporation, and no allowance has been made for direct rainfall on the pool surfaces.

Table 6-1. Assumed ownership of private swimming pools in the 2020s

Region	Assumed Number of pools	Evaporative Losses 2020s (m^3/day)	
	('000s)	without climate change	with climate change
Anglian	104.55	4,276	11,241
Midlands	85.33	3,355	8,809
North East	28.50	243	2,428
North West	27.20	254	2,493
South West	72.97	3,134	8,225
Southern	84.70	3,312	8,499
Thames	146.00	5,631	14,617
Wales	12.46	110	1,103
Overall	**561.71**	**20,315**	**57,415**

6.4 Discussion

No specific methodology for estimating climate change impacts on water consumption in the leisure sector has been developed. The impacts are likely to be very location specific, and therefore would not show up in the regional results presented in this report:

- The analysis of potential impacts of climate change on the leisure sector has been limited by the lack of robust historic data from which to establish relationships between climate variables and consumption.
- With a warmer and drier summer climate, the popularity of outdoor leisure, and in particular water-based activities is expected to grow.
- Some of these water-based activities such as boating and canoeing on lakes, reservoirs, rivers, estuaries and the sea would not of themselves be expected to increase the demand for water from public water supplies.
- Other activities such as use of outdoor swimming pools would be expected to increase water consumption, but the current level of consumption through use of outside public pools is thought to be low. Given the low expenditure on public leisure facilities in the past 10 years, significant increases in public use are not considered to be likely.
- Increases in the ownership and use of private pools are likely under climate change, but affluence will remain a major driver. Given heroic assumptions on the future ownership and size of swimming pools, it is estimated that the open water evaporation losses from private pools in the 2020s could increase by 37 Ml/d from the non-climate change case. Whilst this figure is interesting, it suggests that the impact will be relatively small when compared to the expected change in industrial commercial demand for example.
- Larger climate change impacts are expected through increased irrigation on golf courses. The incremental demand on public water supplies will depend on the number of golf courses that will take irrigation water from public water supplies, but insufficient data is available to quantify this.

Part III: Understanding and interpreting climate change impacts on water demand

7 Role of human behaviour: explorations using agent based modelling of demand

In practice, the planning of investment in long-lived infrastructure requires the planners to form some view of likely magnitudes of future demands and relevant environmental conditions. To form such a view on the basis of forecasts informed by expert judgement is the best available approach (Armstrong and Collopy, 1998).

We claim that, while these forecasts are suitable and appropriate points of departure for the planning process, it is important to explore the possible substantial changes resulting from climate change over the next 30 years and more. One interesting, common conclusion from the companion studies reported here is that direct social effects are likely to dominate the direct climatic effects. It is in its ability to incorporate these important social effects that agent based modelling presents particular benefits.

Agent-based social simulation produces the same kind of frequency distributions of daily water consumption found in neighbourhood level data. Because these distributions have no defined variance and possibly no defined mean, it is not legitimate to apply conventional statistical modelling procedures to either the real or the simulation-generated data. As a result conventional statistical or econometric models based on the assumption of a normal or any other finite-variance distribution are not an adequate basis for the planning of any long-term investment programme in water supply infrastructure and management of domestic water demands.

Evidence that the use of conventional techniques are inapposite to forecasting domestic water demand is presented in the next section. We then turn to the importance of agent based modelling in water resource planning before describing the structure of the base domestic water demand model and summarising the results. We then offer our conclusions for the investment planning process. There are four appendices with the graphs of the outcomes in terms of aggregate demand; detailed model specification; data sources and references.

7.1 The statistical properties of fine-grain domestic water demand data

All statistical forecasting techniques rest on the presumption that observed data is drawn from some underlying population distribution of all possible events. If this population distribution has a fixed mean, standard deviation and possibly higher moments (the third moment is skewness and the fourth is kurtosis (= peakedness)), then increasing the size of the observed data set will, by virtue of the law of large numbers, tend to bring the mean and standard deviation of observed values closer to the underlying population mean and standard deviation. Consequently, good estimates of the population means and standard deviations in these circumstances provide a sound basis for forecasting since future observations effectively increase the sized of the observed data and, accordingly tend to converge to the correctly estimated means and standard deviations. If, moreover, these distributions are stable, then the law of large numbers will apply to functions that add together random variables with their own population means and standard deviations. This latter property is essential for any multiple regression analysis and, therefore, for any statistical forecasting model that depends on more than a single variable.

Nearly 40 years ago, Benoit Mandelbrot (Mandelbrot, 1963) demonstrated that the stable Paretian distribution (a) describes financial asset price changes in organised exchanges and (b) has no defined (or finite) standard deviation and (c) is as likely to have no defined population mean as it is to have one. Recently, Moss (Moss, 2002) demonstrated that the same features applied to a wide range of sales and consumption data including alcoholic beverages of all types in US and UK markets, shampoo, shaving preparations, tea and biscuits sold in UK supermarkets. In the course of our validation procedures with regard to models of domestic water demand, we found that the same statistical properties are found in daily metered water consumption data at neighbourhood level.

A hallmark of the stable Paretian distribution is the much greater height and thinness of the peak of the distribution than is found in finite-variance (*e.g.* normal) distributions and the consequent relative fatness of the tails of the distribution. This characteristic is called *leptokurtosis* (= thin-peaked). The standard representation of the relevant frequency distributions is given in Figure 7-1 for daily metered water consumption based on neighbourhood data provided by one of the participating water supply companies.

The histogram in Figure 7-1 gives the frequency distribution of daily and monthly values of water consumption and the continuous curve is the normal distribution for the same mean, standard deviation and sample size. The standard test for normality is the Kolmogorov-Smirnov statistic which gives, to three significant figures, a zero probability that the observed distribution is normal. The relative changes in daily and monthly domestic water consumption are given in the same format in Figure 7-2. Figure 7-3 shows the changes as time series. These data represent the change from one day (or month) to the next day (month). The same zero probability of normality is indicated by the Kolmogorov-Smirnov statistic.

Aggregating data, *e.g.* from daily to monthly data, tends to hide leptokurtosis since the central limit theorem still holds (Mandelbrot, 1997) and one month's data is effectively a sample of 30 or so daily observations. Even so, the Kalmogorov-Smirnov statistic indicates that the monthly distributions are normal at less than the 2 % confidence level.

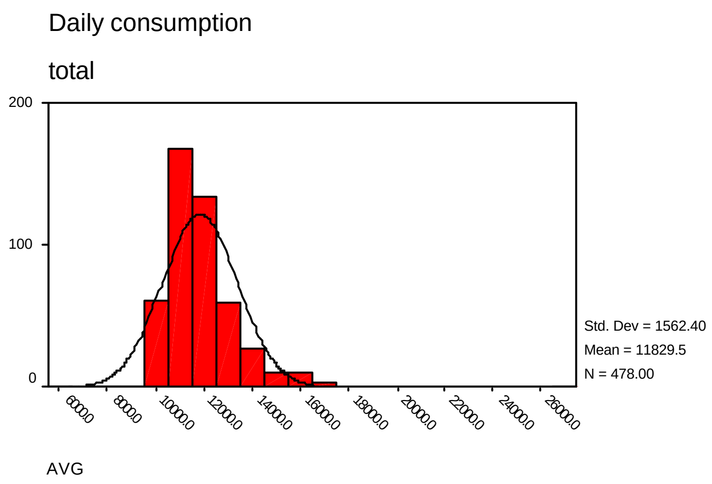


Figure 7-1. Daily metered domestic water consumption

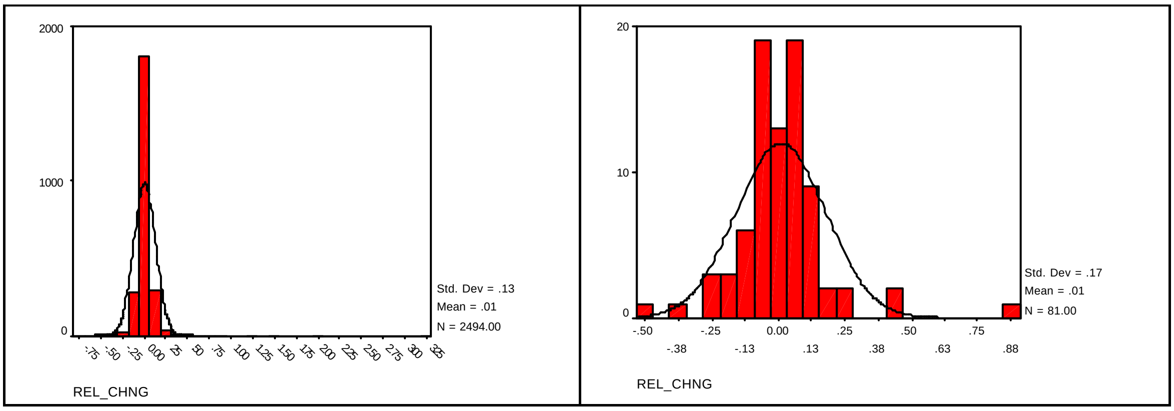


Figure 7-2. Relative changes in domestic water consumption

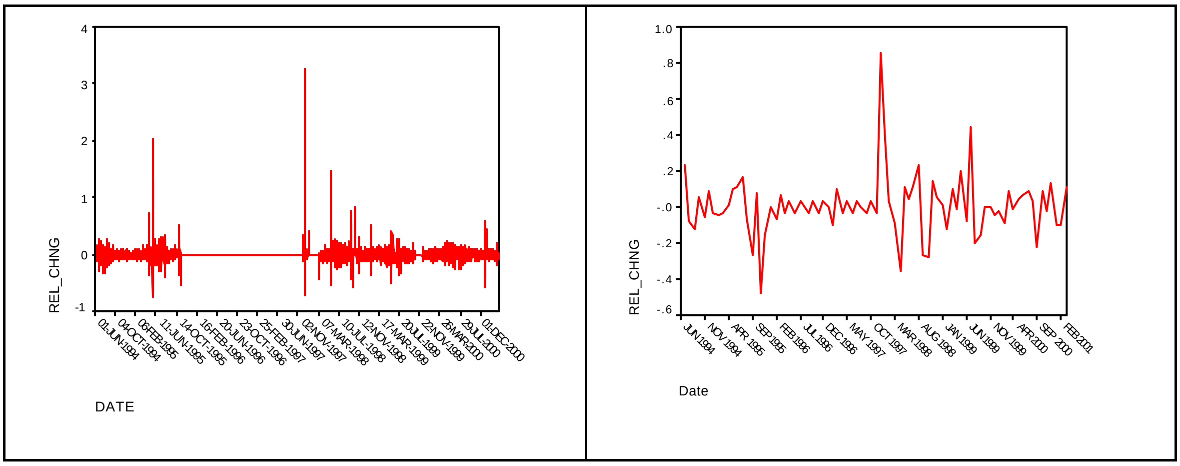


Figure 7-3. Relative change in daily and monthly water consumption. The flat segments of the time series on the left of Figure 7-3 correspond to periods where the data supplied is constant from late 1995 to late 1997. The variability in the middle of the "flat period" in the monthly data on the right is due to the variability of the number of days in the months.

7.2 The nature and use of agent-based modelling

Extensive experience in simulation modelling in both agent based social simulation and in statistical mechanics (Bak *et al*., 1987; Bak, 1997) indicates that leptokurtosis together with clustered episodes of volatility (as in December, 2000 to January, 2001) is, in all known cases, a consequence of interaction among independent, metastable entities. In a social context, this implies that individuals respond to stimuli only when the stimuli become substantial and that individual's influence but do not imitate one another. An example of these phenomena is found in the model of domestic water demand developed for this report.

The model incorporates a runoff model driven by monthly precipitation and temperature data for the Thames Valley from 1970 to 1998, inclusive. The time series of relative changes in one typical run of the model is given in Figure 7-4 and the frequency distribution of the relative changes is given in Figure 7-5. Like the real data, it displays leptokurtosis and demand reductions in conditions of drought. It also has symmetrical frequency distributions of relative changes and there is some evidence of clustered volatility in both the real and the simulation data.

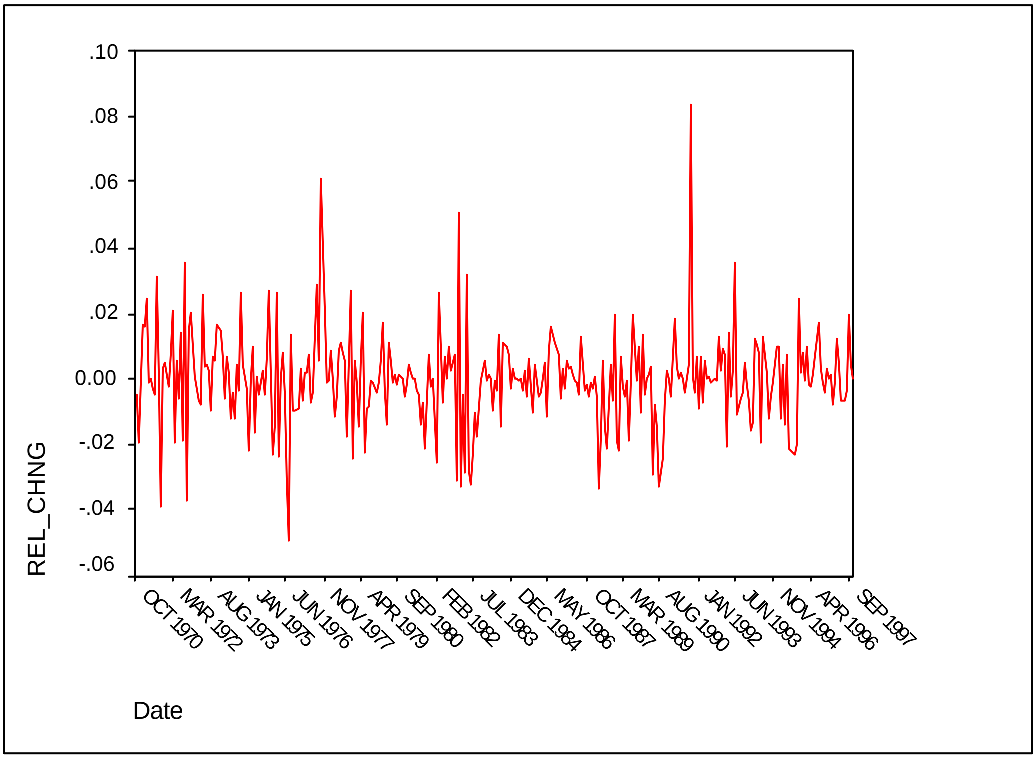


Figure 7-4. Simulated relative change in monthly consumption

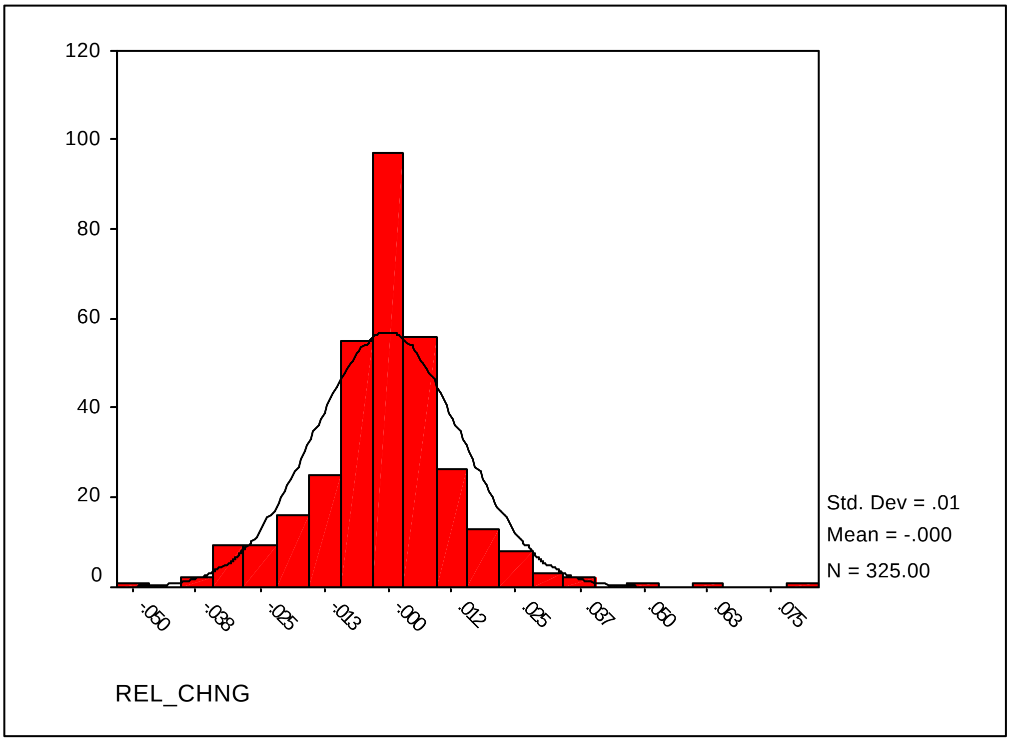


Figure 7-5. Relative changes in simulated monthly water consumption

7.3 The model set-up

This model, presented below, focuses upon the behaviour of households, in particular how the household-to-household imitation of behavioural patterns may affect the aggregate demand for water. Thus the heart of the model is a network of agents each of which represents a single household. These are distributed randomly on a 2-D grid. These 'households' can only interact with other households within a certain distance of them. The totality of households and their potential interactions can be considered to represent a community or cluster.

The external environment for each household consists of:

- The temperature and precipitation;
- The exhortations of a policy agent to use less water during a drought.
- The neighbouring households.

Each household has a number of different water-using devices such as showers, washing machines, hoses etc. The distribution and properties of these devices among households is done such that this matches a real distribution. The output is the amount of water the households use.

The time is divided into months. Each month, each household adjusts its water-using habits, in terms of the amount it uses each device, and whether it acquires new devices (such as power showers). It does this adjustment based on:

- The devices it has;
- Its existing habits;
- What its neighbours do (except for private devices such as toilets); and
- What the 'policy agent' (which is either the government or the water company) may be suggesting (in times of drought).

The weighting that each household uses for each of the means by which it makes adjustments is different and is set by the modeller. In many of the runs it was set such that about 55% of the households were biased towards imitating a neighbour; 15% were predisposed to listen to the water company and the rest were largely immune to outside suggestion. It is not known what proportions might be more realistic in terms of representing real communities, but anecdotal accounts suggest it varies greatly between communities.

The "policy agent" represents the body responsible for issuing water-use guidance to consumers in times of water shortage (currently this is the individual water companies in each area). In the model there is a calculation of the level of ground water, derived from the climate data, and the policy agent starts issuing suggestions during the second month in which the ground is dry. In subsequent dry months the agent's suggestions are to use increasingly less water.

The model structure is illustrated below in Figure 7-6.

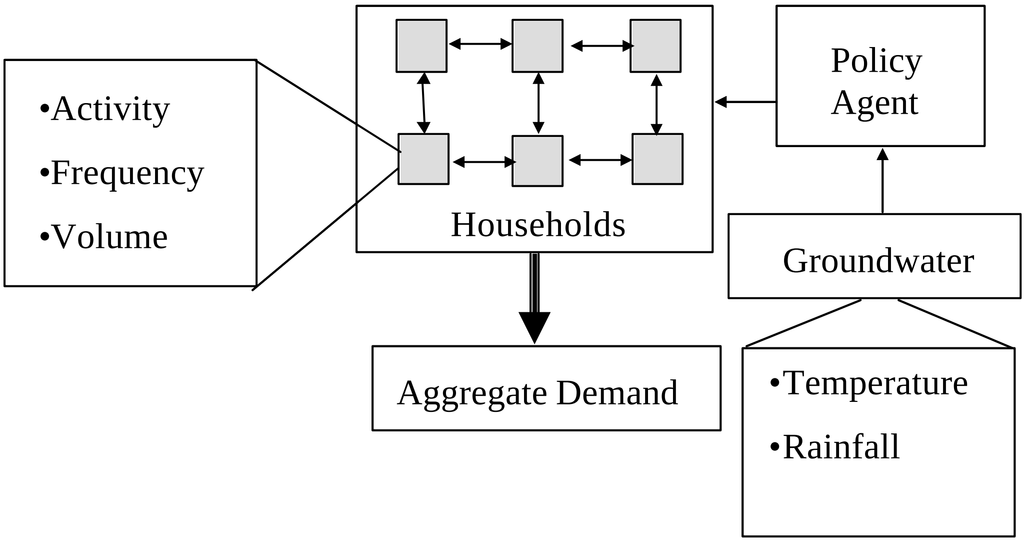


Figure 7-6. The general structure of the agent-based model

In this model there are two new devices that become available to the households:

- new washing machines (which use much less water than the older ones) and,
- power showers (which use much more water than traditional UK showers).

These devices may be acquired by a household at any time after their becoming available, and in particular, when their existing device needs replacing. The replacement rate of devices is estimated by using a Weibull distribution parameterised according to the type of device and an average life of 5 years.

7.4 What the model does not attempt to cover

The model does not attempt to capture all the influences upon water consumption. In particular it does not include any direct influence of the weather upon micro-component usage nor does it include any inherent bias towards increased usage due to background social norms such as increased cleanliness. The behaviour of the policy agent is not sophisticated since it is the reaction of the households that is important here.

We had hoped to use some fine-grained data from Anglian Water which would have allowed us to specify any direct influence of micro-component data by the weather and any overall discernable trends in water consumption, however access to this data was not finalised at the time of writing. It is hoped that this can be included in future developments.

7.5 Model runs

Several sets of runs were done, in order to make three basic comparisons, namely to compare the runs with the UKCIP02 Medium-High emissions climate scenario for the mid-Thames region for 2050; the runs with different dates for the introduction of the new technologies; and the runs with different percentages of neighbour biased households (i.e. those with a bias towards imitating their neighbours.

The base case is with unmodified climate data for 1970-1997, with realistic dates for the introduction of power showers (4/90) and water saving washing machines (10/92), and with 55% of the population being biased towards imitating neighbours.

The first comparison is with a set of runs with the climate data modified so that it is consistent with the UKCIP02 Medium-High emissions for the mid-Thames region for 2050 (see Appendix 7-C for details).

The second comparison is with a set of runs with different dates for the introduction of power showers (10/92) and water-saving washing machines (2/88).

The third and fourth sets of comparisons are with different proportions of neighbour-biased households, namely 30% and 80%. Each of these comparisons was done with the unmodified and modified climate data.

Table 7-1 summarises the settings and the sets of runs done, each run takes between 6 and 18 hours to run with 40 households over the dates 1970-1997.

Table 7-1. Agent based model experiments

% Neighbour biased	UKCIP02 Emissions Scenario	Introduction date of power showers	Introduction date of new washing machines	Number of runs
30	Current	4/90	10/92	16
	Medium High	4/90	10/92	14
55	Current	4/90	10/92	12
	Medium High	4/90	10/92	10
80	Current	4/90	10/92	13
	Medium High	4/90	10/92	9
55	Current	10/92	2/88	24

In each graph each line represents the scaled demand resulting from a different run of the simulation but with the same settings. The set of runs thus represents a sample of the possible demand patterns that can result from the model.

For each of these sets of runs we show two graphs of the resulting scaled aggregate demands. The first of these is where the demands are scaled so that January 1973 is 100 units – this makes plain the deviations of the demands in the separate runs over the subsequent years. In these graphs the broad line is the average of these. The second graph is where each line is scaled so that the average of each resulting demand time series is 100 – this has the effect of 'lining up' the lines in the central region to facilitate their comparison.

For ease of reference the dates that innovations (i.e. power showers and water saving washing machines) are marked on the graphs as solid vertical lines and the most severe droughts shown as broken vertical lines. In the historical climate scenarios these occur during the years of 1976 and 1990. Under the Medium-High emissions scenario they occur during 1976, 1989, 1990, 1995 and 1996.

When looking at the results, it should be recalled that the purpose of the model is to highlight *qualitative* different possibilities that may arise. The model is *not* designed to make statistical predictions as to the likely outcome, for the reasons discussed above. Similarly the fact that the distribution of outcomes is highly leptokurtotic and the likelihood that there is no defined moments, means that any measure of spread would be meaningless[1]. In many ways exhibiting any graphs of the results is misleading, but they are included (see below) so that modellers and other experts can see the results.

The simulations were done using data from 1970-1997, however many of the runs exhibited transient instability over the first year before they settled down into a definite pattern. This behaviour is typical of this type of model, it occurs because of the lack of a long social history at the start of the simulation, resulting in no social norms to constrain the model possibilities. Given that there is great uncertainty about what kinds of socially grounded behaviour resulted in the past aggregate demand and that (in reality) there is a long social history to constrain the possibilities, we have discarded the first two years worth of resultant aggregate demand and scaled the resultant outcomes. This is consistent with the fact that we are looking at qualitatively different outcomes rather than accurate levels. We did the scaling in two ways:

- By scaling all the model outcomes so that the level at 1973 was 100
- By scaling each line so that its average level from 1973-1997 was 100.

The former has the effect of lining up the outcomes at the start and the second has the effect of lining up the outcomes over the majority of its course.

Thus in each graph, each line represents the scaled demand pattern that resulted from a separate run of the model with the same environmental conditions and distribution of types of households, though with a different set of random household positions and initial endorsements (representing different previous social histories). The variety of lines on each graph, then, represents a possible sample of demand patterns given a particular climate and policy scenario. This variety indicates the difference that the internal social processes can generate – different set-ups of households can result in very different demand patterns due to the different social interactions that can arise in these set-ups.

7.6 Summary of the results

- Although some of the runs follow similar demand patterns in the graphs, many are substantially different - see the post 1992 period in Figure 7-7 (left hand diagram) for example. In all the sets of runs, there are demand patterns with substantially different tendencies resulting in very different demand levels.

- In general, the higher the proportion of households that were biased towards imitating their neighbours, the more stable were individual demand lines (compare 1970s and early 1980s in Figures 7-9, 7-10 and 7-11, left hand diagram) for example. That is to

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[1] Of course, for a finite number of runs, it is possible to measure *their* spread, but in a such a situation the extent of the spread will depend on the number of runs and arbitrary limiting factors due to the finite size of the model – it would not correspond in any meaningful way to any variety found in reality.

say the lines tended to be 'flatter' in these cases. Also the higher proportion of households so biased, the less effect that periods of drought seemed to have on the demand, that is the more 'independent' they were to suggestion (see Figure 7-9 for the 1970s and early 1980s (left hand diagram).

- Demand patterns also changed greatest after the introduction of new appliances (see Figure 7-9 for the 1990s).

- In general, periods of drought (and hence exhortation by the policy agent to use less water) had the effect of depressing the demand levels during the drought and a short time afterwards (Figure 7-9). In a few runs droughts resulted in a permanent drop in demand (Figure 7-7 right hand diagram). This permanent drop in demand seemed to occur more often in those runs simulating the Medium-High emissions scenario (Figure 7-8).

- In general the demands were less stable in the runs using the Medium-High emission time series (Figure 7-8), than those using the historical climate data, i.e. they showed greater variety. The more frequent and lower suggestions made by the policy agent seemed to have the affect of perturbing the demand patterns.

7.7 Inference from the model results

The model does not tell us what people or communities will do, or even what they are likely to do. Indeed in runs of the model we got a large variety of qualitatively different outcomes (in terms of the shape and size of aggregate domestic water demand), given a very simple range of simulated behaviours and exactly the same environmental conditions. In the simulations certain behaviours can become established and then be robust against subsequent outside influence. This is because behaviours are imitated from simulated household to simulated household and so can become entrenched through mutual reinforcement. Once this occurs, if the social reinforcement process is strong enough, the behavioural pattern can last for many years. High turn-over rates in water appliances reinforce the persistence of behaviour.

In the model, runs during periods of drought usually resulted in a slight drop in demand, but this quickly reverted to previous levels. In a very few runs the drought seemed to cause a significant and permanent drop in demand. This suggests that it is *possible* that droughts might only have a long-term effect on household behaviour if the social conditions are right.

In general, differences in climate (such as might result from climate change in the medium term) did not usually cause a significant change in demand in this model, but in a few more runs there was a permanent drop in demand. This does *not* suggest that climate won't affect household behaviour but it does suggests that it is *possible* that the social effects within clusters of households may be a significant factor in determining the level of household demand, and so should not be ignored when considering climate effects.

AGGREGATE DEMAND SERIES SCALED SO AS THAT EACH RUN AVERAGE = 100

AGGERGATE DEMAND SERIES SCALED SO 1973=100

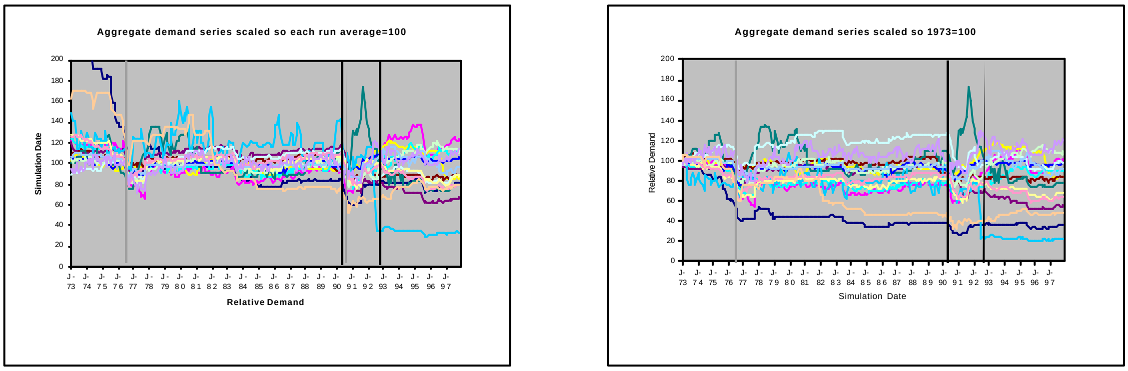


Figure 7-7. 30% Neighbour biased, Medium-High scenario, historical innovation dates

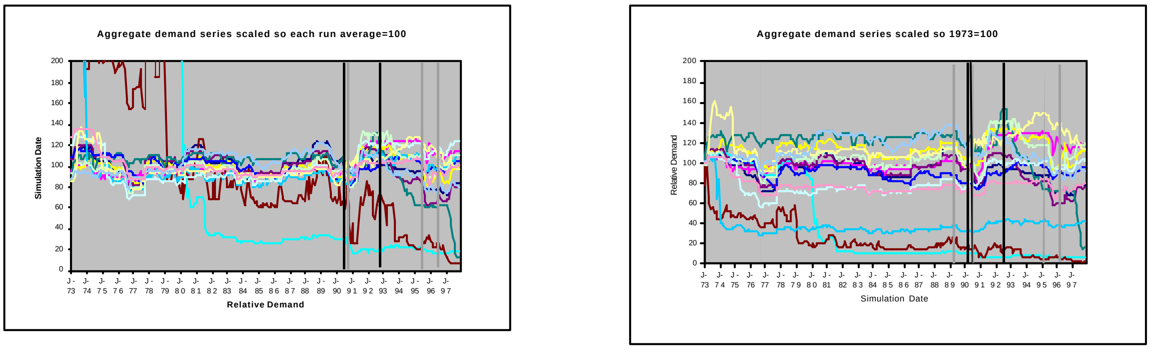


Figure 7-8. 30% Neighbour biased, Medium-High scenario, historical innovation dates

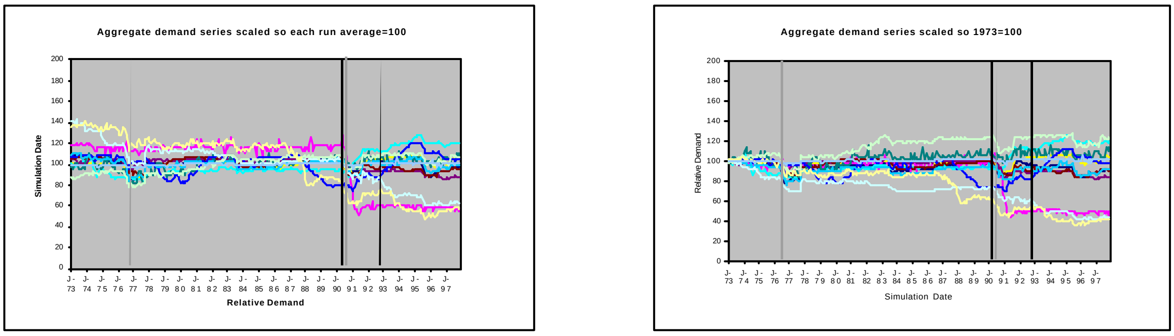


Figure 7-9. 55% Neighbour biased, historical scenario, historical innovation dates

AGGREGATE DEMAND SERIES SCALED SO AS THAT EACH RUN AVERAGE = 100

AGGERGATE DEMAND SERIES SCALED SO 1973=100

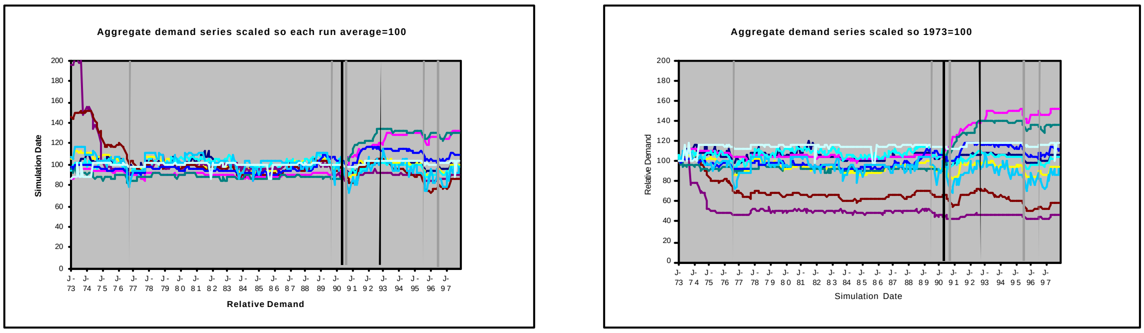


Figure 7-10. 55% Neighbour biased, Medium-High scenario, historical innovation dates

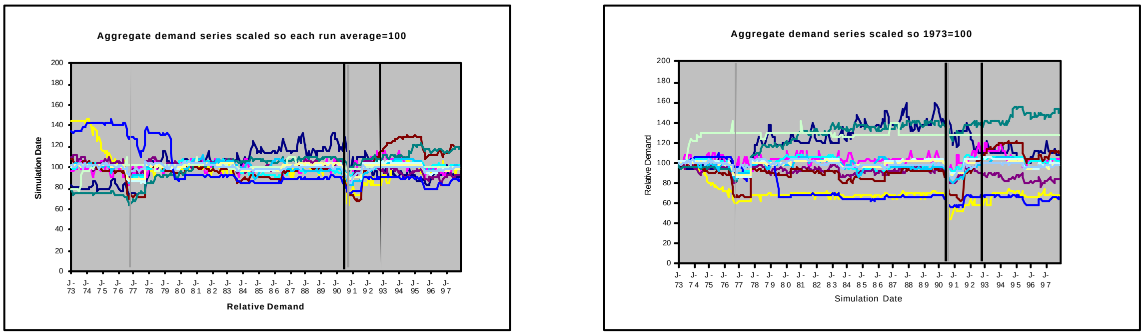


Figure 7-11. 80% Neighbour biased, historical scenario, historical innovation dates

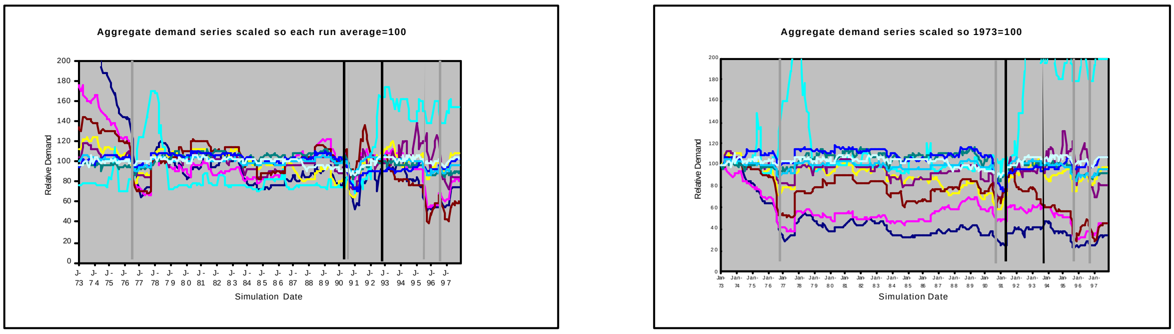
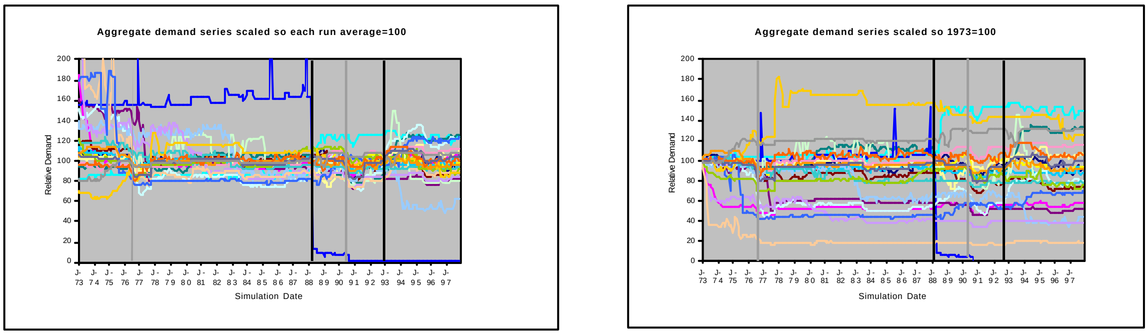


Figure 7-12. 80% Neighbour biased, Medium-High scenario, historical innovation dates



AGGREGATE DEMAND SERIES SCALED SO AS THAT EACH RUN AVERAGE = 100

AGGERGATE DEMAND SERIES SCALED SO 1973=100

Figure 7-13. 55% Neighbour biased, historical scenario, changed innovation dates

In the model runs the availability of new devices (such as new water-saving washing machines and power-showers) sometimes had a significant, but not completely predictable, impact on demand. This suggests that it is *possible* that the availability of new products that are developed in response to climate change may have as profound an impact upon household water consumption as exhortation or direct, climate effects on behaviour.

In the simulations the particulars of how the households were clustered and (socially) connected, and where the households looked to inform their behaviour substantially affected the outcomes in terms of demand. Unfortunately, there is not much information concerning how people do behave in this regard, so as to inform the modelling of these aspects. Thus the agent-based model points out the importance and potential of investigating such behaviour. What would be required is a longitudinal study of household behaviour in small (100) clusters of households indicating in particular where consumers seek to gain information on before purchasing water-consumptive appliances. This information might be extremely useful when trying to plan and direct public exhortation in situations of water shortage. Whilst there have been considerable advances in the development of techniques to measure changes in the environment and water demand, there has been relatively little effort towards detecting social changes that may effect water demand. The results from the agent-based model indicate that it is possible that social changes could be significant in their effect on domestic demand patterns.

7.8 Policy applications and validation

The aim of this kind of agent-based modelling is not to predict what outcomes will occur, and certainly not to capture all the real possibilities. What it might be able to do is: (1) pre-figure some of the possibilities so that if something similar does occur we can be prepared for them (if only mentally); (2) improve our understanding of the possible processes so that we are less often mislead and (3) facilitate the development of appropriate monitoring and response options (4) suggest important questions and further research.

The technique does not stand independently in a policy or planning process. Producing credible future outcomes composed of believable interactions requires a lot of good information (both qualitative and quantitative) about the kind of interactions that actually occur. Such models are inevitably complex and require a lot of checking in as many different ways as possible. These models have a great many adjustable parameters and possible outcomes, so that a comprehensive set of runs covering all the possibilities is not usually feasible. Consequently, considerable domain expertise is required in the design and validation of the models. An effective means of acquiring such domain expertise is to involve stakeholders in both model design and model validation. The models become a formal expression of the stakeholders' views of the behaviour of themselves and other stakeholders, how and why stakeholders interact and the likely results from that behaviour and interaction. The power of the models is that they generate scenarios and then support the interrogation of the models by the stakeholders. It is possible to determine why agents representing one stakeholder or group of stakeholders behaved as it did. The formality of the models requires and assists the stakeholders to develop consistent, sound and comprehensible accounts of the futures they deem likely.

At this stage the agent-based models need a lot more development based on much richer information about the behaviour of the individuals and institutions concerned before the possibilities it indicates can be used in planning. The lack of such data reveals the paucity of our knowledge of the decisions concerning water use that people make and how they make those decisions. The models reported here indicate that such differences in how decisions are made can result in very different outcomes given only very small changes in the environment. This result is entirely compatible with the results obtained in the statistical and econometric models of industrial, agricultural and domestic water demand.

Clearly there are several ways in which the model could be made more realistic. To do this requires more and better information about household behaviour. Anglian Water's SOPCON data gives a 15 minute reading of what devices were used for a sample of 100 "golden households". This sort of detailed longitudinal data is essential if good agent-based models of household behaviour are to be built. Another aspect of which little is known is the topology of imitation networks in real neighbourhoods – a few detailed field studies of this would give us a handle on what real imitation processes might be occurring.

7.9 Appendices

7.9.1 Appendix 7-A. Detailed Model Specification

Static Structure

The model container is iterated each month and each year for the designated time periods (in this case 1970-1997). In this container the following sequence occurs: the ground module; the policy agent and the household cluster. Preceding and following this sequence the model container does some administrative calculations such as reading the relevant climate data and calculating the resultant aggregate demand each month. The container and sequence structure is shown in Figure 7-14.

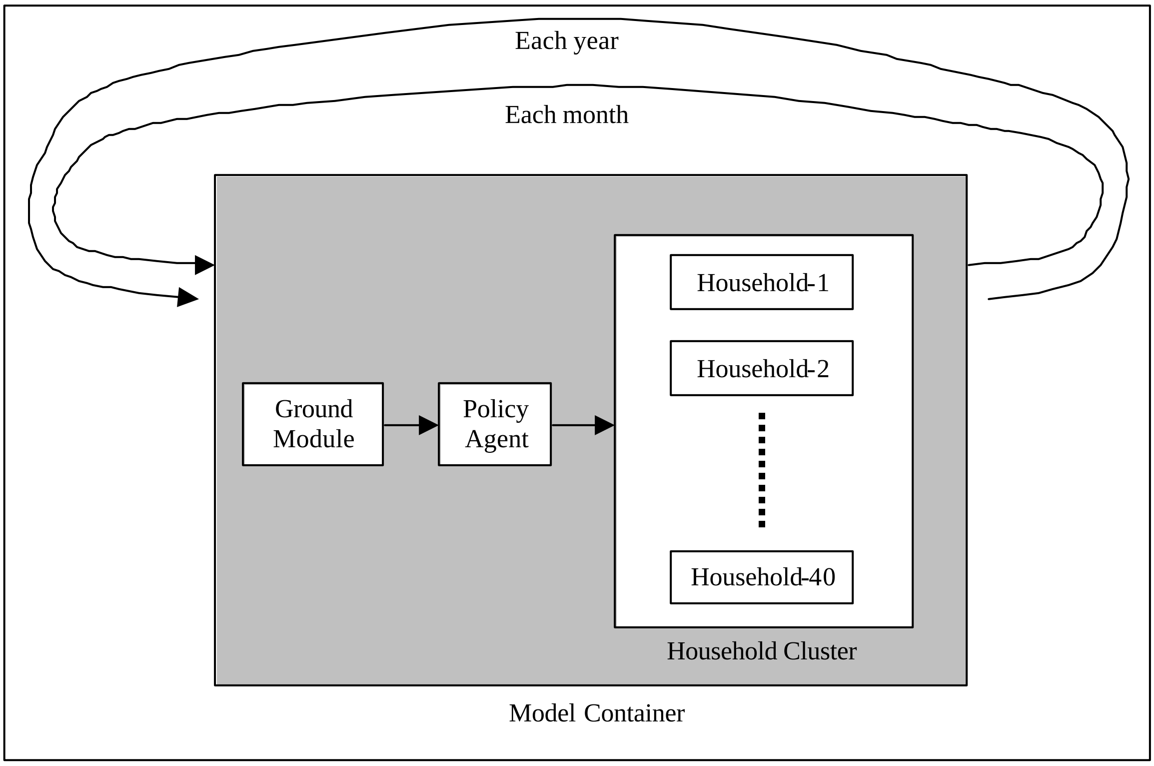


Figure 7-14. The agent and time structure of the model

The 40 households are executed in parallel, having access to others' actions in previous but not current actions. The households are randomly distributed about a 60×60 2D grid. Each household can 'observe' the public actions of households within 4 squares of themselves horizontally and vertically. An example of such a distribution is shown in Figure 7-15.

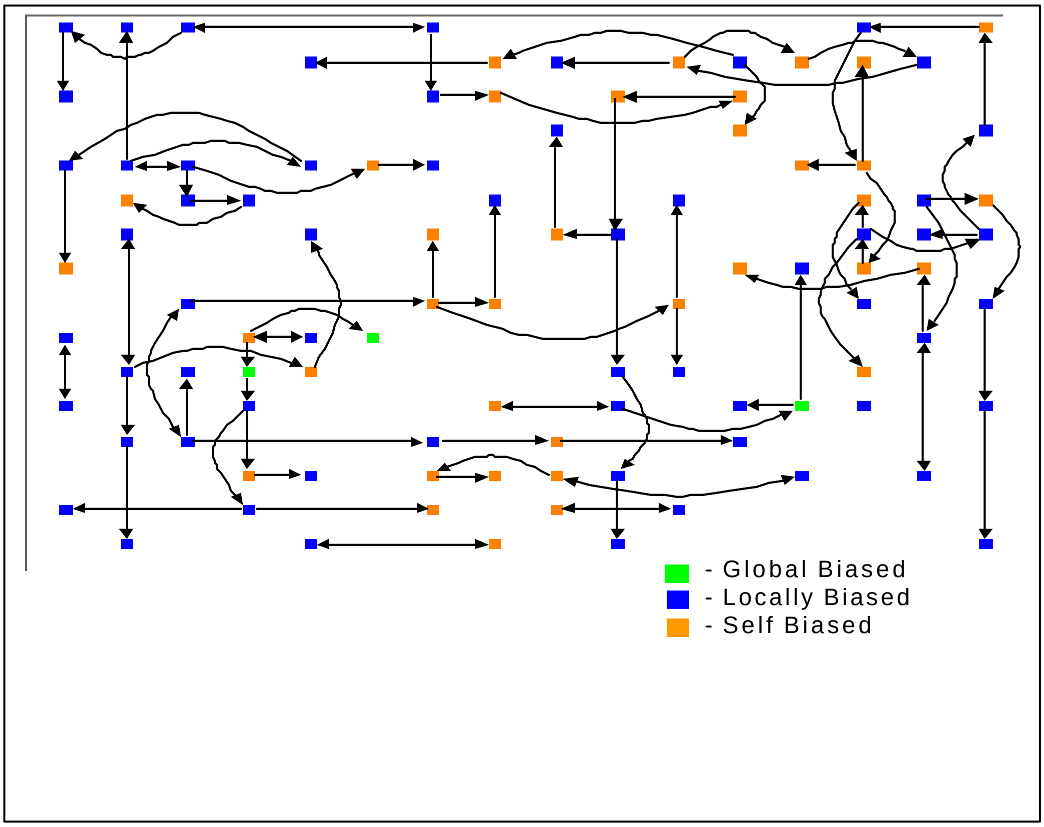


Figure 7-15. An example distribution of households (arrows show those households that aremost influential to another)

Each household has a memory of possible actions and their endorsements, these include: the observable actions of its neighbours, the observable actions of the neighbour most like itself, the recommendations of the policy agent, its own past actions, its own recent past actions, and those for new appliances (with a low endorsement to introduce it).

7.9.2 Appendix 7-B. Algorithms

This section outlines the model dynamics. The simulation time is composed of years and months. For the purposes of this report we have restricted ourselves to recent history, 1973-1997. Each month the following sequence is determined: Ground Water; Policy Agents; Household Decisions; and finally Aggregate Demand. These are described below.

Ground Water: Each month, the ground water module calculates the moisture content of the ground using the modified Thornthwaite algorithm, using mean temperature, precipitation and sunshine time series.

The modified Thornthwaite algorithm is used to compute the soil moisture through potential evapotranspiration (PET) from temperature and hours of daylight per day (as in Food and Agriculture Organisation 1986).

The value of the unadjusted PET at temperatures above freezing is calculated as:

PET	**Temperature (T) range**
$-415,8547 + 32.2441T - 0.4325T^2$	$26.5 = T$
$16.5 (9\ T / H)\ a$	$0 = T < 26.5$
0	$T < 0$

where H is heat defined as

$$H \equiv \left(\frac{T}{0.7} \right)^{1.514}$$

and the exponent *a* is

$$6.75\times10^{-7} H^3 - 7.71\times10^{-5} H^2 + 0.01792H + 0.49239$$

The day lengths are calculated from the day relative to the winter solstice and the latitude. The monthly PET values are adjusted to reflect the difference in water use between a grass surface and a mixed landscape of grass, trees and shrubs. The monthly correction factors are:

Nov – Dec - Jan – Feb – March	**April**	**May**	**June – July - Aug**	**Sept**	**Oct**
0.8	0.9	1	1.1	1.05	0.85

Policy Agent: The Policy agent monitors the groundwater content calculated by the Ground Water module. On a second consecutive month with less than 85% moisture content it starts to recommend the reduced use of water to the households. The longer the dry period continues (i.e. as long as there is no month with 85% or more moisture content), the lower are the usages it recommends to the households. The months of dryness characterised in this way is shown in Figure 7-16

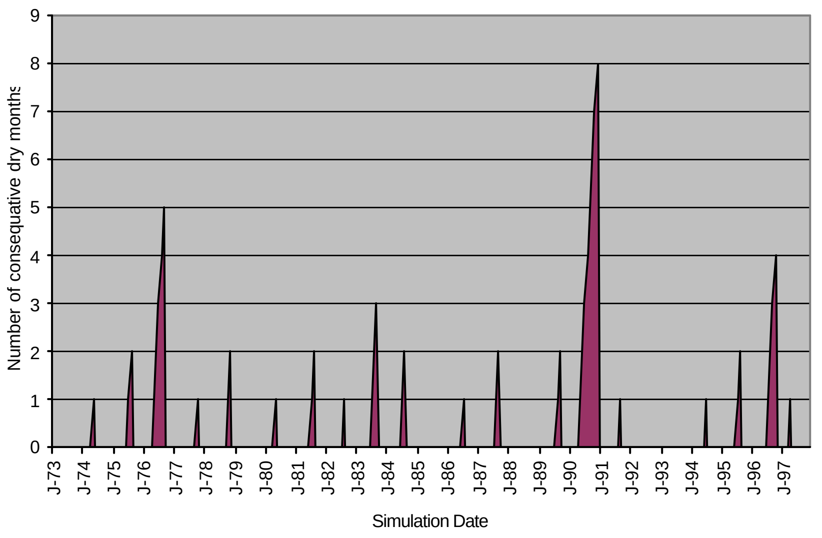


Figure 7-16. Number of consecutive dry months in historical scenario

Household decision making: Each month each household updates its consumption patterns concerning the use of each micro-component. It does this by considering its own actions, those of its neighbours, those of the neighbour that it considers is most similar to itself, the suggestions of the policy maker, and (in particular circumstances) possible new patterns with new appliances. In the current model the consumption is not directly affected by the weather.

To decide among these, the household uses an "endorsement" mechanism (Cohen, 1985), that is it remembers different suggestions as to the use of each micro-component along with its endorsement in the form of a label representing the source of the suggestion. When it comes to making a decision it weighs up these suggestions using its own system of endorsement weights. The set of base weights is randomly allocated to each household at the start of the simulation according to a distribution specified. This distribution is specified by the expected percentage of households that are more biased towards imitating from neighbours, those that are more biased towards adopting suggestions by the policy agent, and those who tended to ignore either. These biases do not determine behaviour rigidly, for example if it is not too biased towards listening to a policy agent if it has many neighbours which are suggesting a particular behaviour then this may "outweigh" the policy agent's suggestion.

The approached used here, is to define a number base b and evaluate each endorsed object according to the formula:

$$V = \sum_{e_i \geq 0} b^{e_i} - \sum_{e_i < 0} b^{|e_i|}$$

where e_i is a (usually integer) value associated with the i^{th} endorsement token. Negative values of endorsement tokens indicate naturally enough that they are undesirable. The higher the value associated with an endorsement token, the higher the class of tokens containing that particular token. The value of b is the importance of an endorsement token relative to the value of a token in the class below. If the base is 2, then an endorsement of class three contributes 8 to the endorsement value of an object while an endorsement of class two contributes only 4. For values of b larger than the number of tokens in any class used to endorse any object, the results from this evaluation scheme are the same as from Cohen's evaluation scheme. For smaller values of b it is possible for a large number of lesser endorsements to outweigh a small number of endorsements of greater value.

Aggregation: The model adds together all the water use for all the households to produce the aggregate demand for that month.

Key settings and parameters: The most important settings are (setting options used in brackets):

- The size of the 2D grid (10);
- The number of households (40);
- The years over which the simulation is run (1970-1997);
- The range over which households can see each other (4 squares);
- The monthly average temperature and total precipitation time series (actual from Thames region; modified to be consistent with UKCIP02 Medium-High emissions scenario for 2050);
- The latitude (51°);
- The critical triggers for water use advice from the policy agent (85% moisture, 2nd consecutive dry month);

- The available micro-components and their distribution among the households (from 3 Valleys data 1997/98);
- The dates for the introduction of new devices (4/90 power showers, 10/92 water saving washing machines or 10/92 power showers, 2/88 water saving washing machines);
- The proportion of households biased towards imitating from neighbours (30%, 55%, 80%);
- The proportion of households biased towards listing to suggestions from policy agent (15%);

Initialisation: The households are initially randomly distributed about the 2D grid. They are initialised with water-consuming devices according to the given OVF distribution. They are provided with a random set of weights (or biases) so that the population of households is divided up to match the parameters given. They are given a minimal random set of behaviours that are minimally endorsed to start with.

Emergent model dynamics: An example as to how the endorsements affect the selection of a particular action from the first month of its adoption until it was replaced 6 months later, is shown in Table 7-3. It shows how an action was reinforced by a combination of the endorsements: recent, neighbour sourced and self sourced (remembered, but not necessarily recent), until action-8472 eventually overtakes it by being neighbour sourced four times including being endorsed by the 'most alike neighbour'. How many neighbour sourced endorsements are necessary to 'overcome' endorsements such as 'self sourced' and 'recent' depends upon the weightings the agent is given during the model initialisation.

Table 7-2. An example of how endorsements may affect action choice

Month 1	used, endorsed as **self sourced**
Month 2	endorsed as **recent** (from personal use) and **neighbour sourced** (used by agent 27) and self sourced (remembered)
Month 3	endorsed as **recent** (from personal use) and **neighbour sourced** (agent 27 in month 2).
Month 4	endorsed as **neighbour sourced** twice, used by agents 26 and 27 in month 3, also **recent**
Month 5	endorsed as **neighbour sourced** (agent 26 in month 4), also **recent**
Month 6	endorsed as **neighbour sourced** (agent 26 in month 5
Month 7	replaced by action 8472 (appeared in month 5 as neighbour sourced, now endorsed 4 times, including by the **most alike neighbour** – agent 50)

As a result of the learning and decision making by households, a self-reinforcing household-to-household imitation pattern can occur. If the households are (on-the-whole) sufficiently biased towards imitating from neighbours then each household in a cluster may copy a substantial part of its behaviour from these neighbours who have copied the behaviour from their neighbours etc. If the households are sufficiently clustered then patterns of behaviour may be copied back and forth, thus reinforcing itself. Thus there is a sort of competition between different patterns of behaviour and the 'locking-in' of winning behaviour can result.

7.9.3 Appendix 7-C. Data Sources

Climate time series: Monthly average temperature and total precipitation time series for Central England for 1970-1997 were used as inputs to the ground module, also a value for the latitude of 51° from which the hours of daylight are calculated.

Modifications to the climate time series to reflect the UKCIP02 Medium-High emissions 2050 scenario: In order to include a comparison of the outcomes under the UKCIP02 Medium-High emissions 2050 scenario and current conditions the above time series were modified to reflect this UKCIP02 forecast for the upper Thames region. This involved modifying the temperature and precipitation data as follows:

Table 7-3. Monthly modification to precipitation time series

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
+12.5%	+10%	0%	-5%	-10%	-20%	-30%	-20%	-15%	-7.5%	+0%	+10%

Table 7-4. Monthly modification to temperature time series

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
+1.0%	+1.0%	+1.0%	+1.5%	+1.5%	+1.5%	+2.0%	+2.0%	+2.0%	+1.5%	+1.5%	+1.5%

Activity, Frequency, Use micro-component settings: The OVF data came from Environment Agency Strategies - Provincial Enterprise Scenario, Three Valley's Water - Resource Zone 2 for years 1997/98 and 2000/01.

Weibull parameterisations for micro-component replacement rates: The Beta parameter, which determines the shape of the distribution, was taken from typical values given in (Bloch and Geitner, 1994). The *eta* parameter is a scale parameter and was set so that the life expectancy of a device was 5 years.

8 Variability, confidence and uncertainty

This chapter looks across the sectors to address key issues relating to the question: How robust is our present understanding of climate change impacts on demand for water? It begins with a summary of the main sources of uncertainty in a scenario-driven climate change impacts study. It then explores potential uncertainties related specifically to demand for water, grouped according to those that would lead to higher or lower estimates of the impact of climate change.

8.1 Uncertainty in climate impact assessment

In drawing reference from climate impacts for formulating appropriate policy, the innate uncertainties in climate and climate impacts projections need to be acknowledged. Where the conclusions drawn from a specific study are extrapolated beyond the bounds of their applicability, or without an awareness of the limitations of the conclusions, they can easily constitute misinformation.

All climate forecasts are uncertain and there is emerging awareness that the variability within climate forecasts may itself be influenced by climate forcing (Wilby and Wigley, 1997, Allen *et al*, 2000). Where uncertainty and variability are innate to the system being studied, the onus is on research not to posit artificially definitive conclusions. Identifying the sources of uncertainty and variability in climate projections can be useful in the formulation of appropriate policy (Shackley and Wynne, 1997) and can challenge understanding of the physical processes governing climate change and crop growth (Weaver and Zweirs, 2000).

New and Hulme (2000) have identified sources of uncertainty innate to climate forcing, ranging from the extent of future emissions through to the manner in which these impact upon a specific component of society. Such a cascade of uncertainty (see Figure 8-1) underlies this study and amplifies the uncertainty introduced by the modelling process.

Additional uncertainty in this study stems from the paucity of data available. It is possible that better data or a more detailed parameterisation of the interaction between climate change and specific sectors would reveal additional or different sensitivities.

That the manner in which climate changes will impact upon the UK in the future cannot be fully understood is arguably cause for additional, not less, concern (Shackley and Wynne, 1997). Risk aversion is related to exposure to economic impacts (Ray, 1998) and the possibility that warmer climates will impose additional production costs and heightened risks on already vulnerable populations and economic is a concern throughout the UK.

8.2 Uncertainty in climate impacts on demand for water

The sources of uncertainty in an assessment like the CCDeW project are numerous, and few are easily addressed given the available data. Here we group the sources of uncertainty into those that are likely to lead to higher estimates of climate change impacts and those that tend to more conservative estimates. We provide examples of the uncertainties from the present method—but these should not be taken as a comprehensive risk assessment. Below we provide an overall conclusion regarding the robustness of the results.

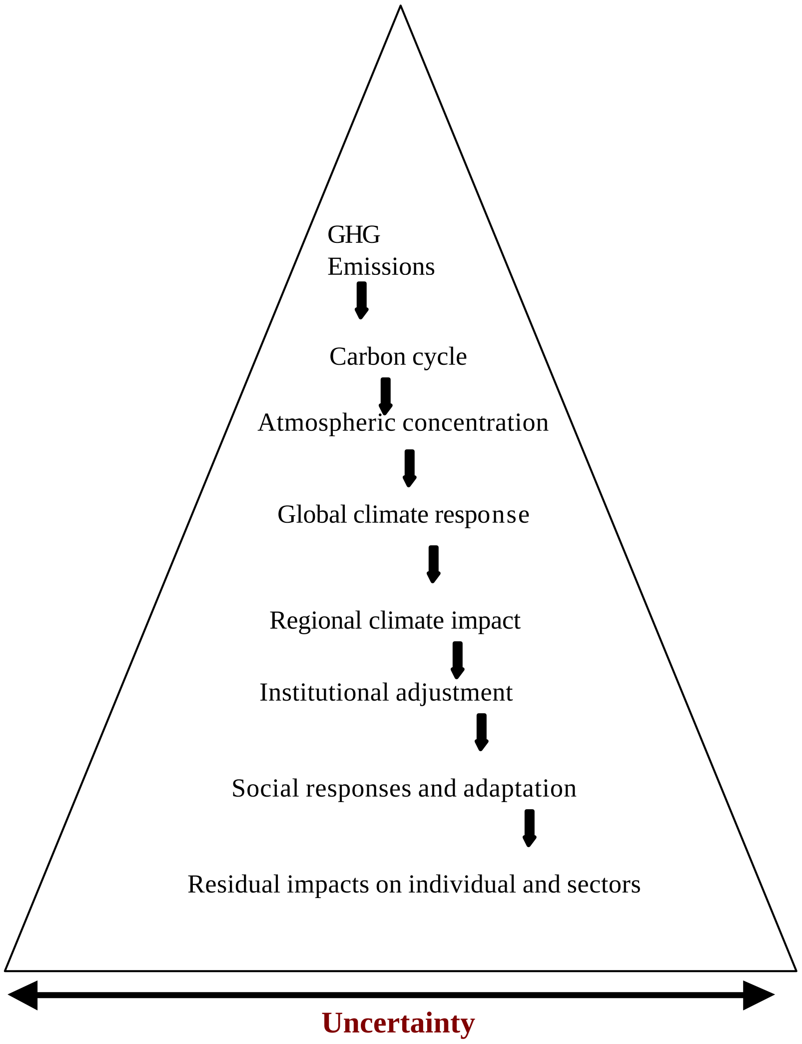


Figure 8-1. Cascade of uncertainty in climate impact assessment. Levels of uncertainties in this study are amplified at the local level. Source: after New and Hulme (2000).

8.2.1 Toward higher impacts of climate change

Extremes and risk avoidance: There is a growing awareness that models based on average climate change may under-report the risks associated with climate change – particularly the risk associated with the higher frequencies of unfavourable conditions and extreme events. For example, where mean climate (or mean temperature) is modelled, the number of unfavourable climate episodes may have to increase drastically before the model shows mean conditions to be unfavourable. Probably the single most important caveat of the findings of this report is the poor understanding of the risk of extreme events and their impacts on demand. This has two, intertwined, aspects.

First, the climate scenarios provided by the UKCIP did not adequately address extreme events. The project did not feel competent (or have the mandate) to extend the scenarios with explicit changes in the variability of future climates. Nor were estimates of changes in the frequency of extended droughts available. For example, water planners are concerned with the likelihood of extremes such as a two year drought, or a series of dry winters that reduce groundwater recharge followed by a hot summer.

Second, the importance of extreme events in water planning is clear, but the regulatory regime is changing and a threshold for demand is not easy to identify. While demand is calculated for the dry year, the statistical basis of this varies among regions and water companies. The design condition used in company water resource plans is the "dry" year demand set against the deployable output of the water resource system. Deployable output represents the output of the system under drought conditions. For surface water systems it is for a defined level of service, for ground water systems it is for the worst drought on record. In addition, the statistical definition of a drought year for supply (e.g., dry winters) is different from a drought year for demand (e.g., a hot summer).

Under the current water resources planning methodology, uncertainty in the individual components of demand and supply are built into headroom. Climate change uncertainties feed into both supply side and demand side estimates. To address this the water industry has conducted research to investigate more refined approaches to incorporate uncertainty into the current deterministic approaches to estimating supply/demand balances. However, an integrated analysis of changes in the probability of a supply/demand deficit is now required.

Notwithstanding the above limitations, some sense of the importance of climatic extremes and risk can be garnered from the CCDeW project results:

- For agriculture, irrigation engineers use the 80% dry year as the benchmark for planning irrigation water requirements. So the results presented above already include an estimate of a common risk threshold.
- In the domestic sectors, the results from the CCDomestic model can be used to estimate the impact of climate change on demand for water during a dry year. Here we (artificially) define the dry year as one occurring in 3 out of 10 years. This is somewhat less restrictive than for irrigation. In southern England the difference between simulations for the present dry year and a dry year with the High scenario of climate change is about 4% (for the period between the 2020s and 2050s). So, while the mean impact is on the order of 2-3%, the dry year impact might be an additional 1%.
- For industrial and commercial users, a risk threshold is not commonly applied, partly following from the assumption that metered supplies to industry will be a priority even during a water shortage. Existing data are not sufficient to make an estimate of the dry year impact, but it may well be on the same order of magnitude as for the domestic sector, i.e. an additional 1% above the mean impact of climate change.

Climate scenarios: Every few years new climate scenarios are produced, both globally and nationally. The UKCIP02 scenarios are slightly more adverse across the UK, for water demand, than the UKCIP98 scenarios, but somewhat less adverse than the first generation of scenarios (as used by Herrington (1996)). The key uncertainty is whether the present scenarios adequately represent the range of uncertainty in plausible climate futures. We cannot answer this question adequately. However, the IPCC Third Assessment Report shows a range of future risks that have higher temperature changes and significantly worse impacts for the UK than those derived from the UK Met Office model. There is a clear need to develop probabilistic scenarios that represent the full range of risk.

Feedbacks on water use: The CCDomestic model presents a constrained analysis of climate change impacts. The ownership of appliances and frequency of use are externally forced and do not change in response to mean climatic changes or extreme events. The impacts themselves are based on s-shaped curves that limit the impact to an upper threshold (e.g., a 60% increase in the frequency of taking showers). It seems plausible that at least some people would respond to warmer weather by investing in their gardens, developing water features and spending more time outdoors. This implies buying and using more hosepipes, and maybe even in-ground pools. Similarly, hotter weather may accelerate trends in buying power showers. The simulations reported in Section 7 illustrate the potential for significant behavioural feedbacks.

Variability among water resource zones: The regional results reflect average climate change and generalized relationships with demand. Some WRZs will have unique features of demand and may have additional supply/demand constraints that make them more sensitive to climate change impacts. Table 8-1 shows the range of results for each region. For instance, in the Anglian region for the Medium-High climate scenario and the Alpha and Beta reference scenarios for the 2020s, the average increase (in total pcc) was estimated to be 1.83%. The minimum and maximum among the water resource zones within the Anglian region were 1.25% and 2.43%, with a standard deviation of 0.63. For the 2050s the minimum, average and maximum, all increase. However, the effect in the 2050s compared to the 2020s on the standard deviation is not consistent across the regions. Such estimates perhaps provide some limits on the range of regional impacts.

8.2.2 Decreasing estimates

Water saving technology: The Environment Agency reference scenarios bracket a range of futures in which existing technologies affect domestic demand. While climatic changes might accelerate the adoption of more water appliances (such as power showers), it might also lead to greater awareness of water resource issues among consumers and adoption of water saving technology (see Chapter 7). The trend to use less water in toilets is already established, while more efficient garden watering could become common.

Demand management: Policy and consumer attitudes would also affect expectations of levels of service and willingness to voluntarily restrict demand during periods of water shortage. Metering and tariff structures could be important in reducing the impact of climate change, and particularly so for episodes of extreme events. Dynamic demand management is not incorporated in the CCDomestic model.

For both of these influences on demand, the agent-based results suggest that interactions with climatic episodes could influence future demand quite dramatically (see Chapter 7).

Table 8-1. Regional impacts of climate change on domestic per capita consumption (pcc), %, with range of results for water resource zones for Medium-High emissions scenario

	Alpha and Beta							
	2020s				2050s			
Region	Min	Average	Max	StdDev	Min	Average	Max	StdDev
Anglian	1.25	1.83	2.43	0.63	2.54	3.04	3.35	0.24
Midlands	1.25	1.83	2.43	0.42	2.42	3.68	4.95	0.92
North East	1.27	1.48	1.61	0.36	2.54	3.04	3.35	0.24
North West	1.15	1.43	1.67	0.47	2.39	2.97	3.40	0.34
Southern	0.94	1.45	2.19	0.39	1.74	2.92	5.03	0.75
South West	0.96	1.39	1.70	0.41	1.81	2.81	3.48	0.56
Thames	1.00	1.37	1.88	0.46	2.01	2.67	3.59	0.53
EA Wales	1.08	1.45	1.97	0.45	2.05	2.79	3.90	0.46
Total	**0.94**	**1.46**	**2.43**	**0.26**	**1.74**	**2.90**	**5.03**	**0.60**

	Gamma and Delta							
	2020s				2050s			
Region	Min	Average	Max	StdDev	Min	Average	Max	StdDev
Anglian	0.52	1.28	2.22	0.63	0.76	2.18	3.18	0.80
Midlands	0.43	1.10	1.62	0.42	1.23	2.30	3.36	0.73
North East	0.63	1.13	1.62	0.36	0.26	2.10	4.67	1.02
North West	0.26	1.08	2.12	0.47	0.20	2.11	3.28	0.85
Southern	0.25	1.07	1.64	0.39	0.53	1.81	3.05	0.85
South West	0.35	0.95	1.55	0.41	0.33	1.92	3.77	0.91
Thames	0.31	1.02	1.83	0.46	0.20	2.05	4.67	0.94
EA Wales	0.25	1.06	2.22	0.45	0.20	2.05	4.67	0.94
Total	**0.25**	**1.06**	**2.22**	**0.45**	**0.20**	**2.05**	**4.67**	**0.94**

Note: The values are the minimum, average, maximum, and standard deviation of estimates of climate change impacts in the water resource zones in each region.

8.3 Conclusion – variability, confidence, uncertainty

In summary, while CCDeW estimates of long-term impacts of climate change on average demand appear realistic, they are not projections of the future. Rather, we have employed a methodology that structures insight into the major sensitivities of changing water demand in the future. Clearly, the underlying trend in the structure of demand is more important than the marginal effect of climate change. Also apparent is that the interactions of behaviour (whether farmers adopting irrigation or consumers saving water during a drought) could lead to substantially greater or lower impacts of climatic variations in the future than experienced at present.

9 Conclusions and recommendations

This section summarises the assessment, first for the individual components of demand—domestic, industrial/commercial, agriculture and horticulture, and leisure. Then we 'scale up' the component results to show the aggregate impacts of climate change on total regional and national demand for water. Notes on further research for future water planning indicate the progression from a scenario-based, what-if analysis, to an integrated assessment of water supply/demand balance risks associated with climate change. Finally, we provide initial guidance on how these results may be used, particularly in the current regulatory review of water resources in England and Wales.

9.1 Synthesis of component results

9.1.1 General

On balance, what is our interpretation of the several lines of evidence presented on the impact of climate change on demand for water?

While the structure of future water demand is clearly important, the 'choice' of Environment Agency reference scenario appears to be even more important in determining overall water use in the future. The impact of climate change is relatively small, compared with the increases or decreases suggested in the Environment Agency water strategy.

Given the uncertainty of quite different but plausible future scenarios, the impact of mean climate change on demand from the public water supply is likely to be relatively modest over the next 20 years or so. Table 9-1 presents the range of results for each component of demand. The minimum change expected (the Gamma reference scenario and the Low climate scenario) for the 2020s suggests impacts of 1-3% for domestic and commercial/industrial demand, and about 18% for agriculture.

The high-impact scenario—the Beta reference and Medium-High climate scenarios for the 2050s—suggests that the impacts would be in the range of 2.5-6% (including the proportion of agriculture from the public water supply). The impacts in the 2020s across the four reference scenarios fall between these two marker scenarios.

The available data and models, particularly the model dependency on mean climate change, are likely to under-estimate the potential risks of extreme events. Another 1995-type drought should be expected in the next 20 years, and indeed if some scenarios are believable could become common by the end of the current planning horizon. Clearly, drought contingency planning and dynamic demand management are essential.

9.1.2 Domestic

The CCDeW analysis of the impact of climate change on domestic demand for water shows a fairly modest estimate of about a 1-1.5% increase for the 2020s. By the 2050s, the impacts might be in the range of 1.5-3%.

We have used the EA water resources strategy scenarios as the reference case. About 40% of domestic demand at present is accounted for in personal washing, garden watering and car washing—the main micro-components sensitive to climatic variations.

Table 9-1. Range of results, showing the selected marker scenarios for the EA reference scenarios and the UKCIP climate change scenarios, for the 2020s and 2050s

Domestic demand:

	2020s	2020s	2050s
	Low	**Med High**	**Med High**
Alpha		1.4-1.8%	
Beta			2.7-3.7%
Gamma	0.9-1.2%	1.0-1.3%	
Delta			

Industrial/commercial demand:

	2020s	2020s	2050s
	Low	**Med High**	**Med High**
Alpha		1.7-2.7%	
Beta		1.8-3.0%	3.6-6.1%
Gamma	1.8-2.9%	2.0-3.1%	
Delta		1.7-2.7%	

Agricultural demand:

	2020s	2020s	2050s
	Low	**Med High**	**Med High**
Alpha		19%	
Beta		19	26%
Gamma	18%	19%	
Delta		20%	

Notes: For domestic and commercial/industrial demand, the range of changes refers to the lowest and highest impacts at the regional level. For agriculture, a national estimate is calculated in the model—the regional results are quite variable. The domestic model does not differentiate between the Alpha/Beta and Gamma/Delta scenarios since the impacts were very similar.

The impact of climate change is much greater for the Alpha and Beta scenarios, where personal washing and garden watering increase. The differences between the four reference scenarios (i.e., from about 115 l/h/d to over 200 l/h/d in the 2020s) is much greater than the additional impact of climate change.

Most of the modelled impacts are attributed to the increased use of baths, showers and power showers and are based on the assumption that the frequency of bathing is likely to increase.

We have relied primarily on dynamic simulation models calibrated for selected water resource zones. We included several statistical explorations as well as social simulation results that indicate qualitative responses to climatic variations and water scarcity. The dynamic simulation model is more conservative than statistical correlations.

The agent based social simulation model (reported in Part III) indicates that an increased frequency of drought could trigger long-term reductions in demand through adoption of water saving technology. Alternatively, consumers might increase their demand beyond the high reference scenarios if the presumption of entitlement to a private good exceeds willingness to conserve water during periods of drought.

Major uncertainties remain. The most important is likely to be the treatment, in the modelled impacts and climate scenarios, of extreme events. Preliminary results indicate that 'dry year' demand increases somewhat more than mean demand, perhaps on the order of an additional 1%.

9.1.3 Industry and commerce

The analysis presented in Chapter 4 suggests that the climate change impacts on industrial/commercial demands are likely to be higher in percentage terms – up to 2.8% in the 2020s - than the impacts on domestic consumption. The detailed results from the modelling, of which Table 4-9 is a summary, suggest that the impacts do not seem to be notably different across the scenarios. In contrast to the domestic demands, there do appear to be differences between the regions; this is due to the different mix of industrial/commercial sectors in each region.

The results of the analysis are based on a number of heroic assumptions about the current allocation of total industrial/commercial demands to different sectors, and the relationships between consumption and climate variability. Climate change impacts are considered to be small in the context of the underlying uncertainty in industrial/commercial forecasts, and the sensitivity of consumption to local, national and global economy.

In its work on demand forecasts behind the regional and national water resource strategies, the Environment Agency identified 19 different sectors into which industrial/commercial consumption could be divided. The sectors selected, and those aggregated in the "other" category provide some useful insight. Of the sectors most likely to be impacted by climate change, only the Food & Drink (SIC Code DA) and Hotel (SIC code H) sectors have been identified as separate categories. Others such as agriculture (SIC code A) and social, recreation and leisure (SIC code O) were aggregated into the "other" category by the Environment Agency.

The impacts are small in comparison with the range of forecast demands for each of the four reference socio-economic scenarios, and with the percentage change in forecast baseline demands between 1997/98 and 2024/25.

Inspection of the temperature-water consumption relationships for WRZs in Southern Region suggests that in some sectors there are differences between coastal WRZs and those located in-land. Given that the analysis has been conducted on data at water company level, rather than WRZ level, it was not possible to accommodate this type of spatial difference in the analysis.

9.1.4 Agriculture and horticulture

The survey of irrigation of outdoor crops in 2001 confirmed that water use for irrigation is currently growing at 2-3% per annum, and provided a new baseline for the demand modelling.

Climate change could impact irrigation water use via many different mechanisms, variously affecting plant physiology, soil water balances, cropping patterns, the areas irrigated and the methods used.

The enhanced atmospheric CO_2 levels predicted will increase plant growth rates, increasing plant height and leaf area index and hence increasing plant water use, but they will also increase stomatal resistance, decreasing plant water use. Modelling suggested the effects would roughly cancel out, but the literature is inconclusive and long-term field-scale experimental data is lacking. The enhanced atmospheric CO_2 levels will also increase yields (on top of current trends) and hence reduce the crop areas needed for the same production level. This impact alone could reduce irrigated areas and hence water demand by around 5-10% in the 2020s and 15-20% in the 2050s.

Climate change will extend land suitability for most crops northwards, and will make some land in the south unsuitable for the present rainfed crops due to droughtiness. However, irrigated crops may not need to move unless water constraints become a significant driver. The modelling assumed no net impact. International climate change impacts on food trade have not been considered.

Soil-moisture-deficit based agroclimatic zones will move northwards and westwards. By the 2020s, central England will be similar to the present eastern England, and by the 2050s eastern, southern and central England will have irrigation needs higher than currently experienced anywhere in England.

The water demand modelling suggests that predicted changes in rainfall and evapotranspiration alone would increase dry year water demand by around 30% by the 2020s and by around 55% by the 2050s. The percentage increases are similar for all socio-economic scenarios. They are greatest in the midlands and the south-east. When offset by the assumed impact of higher yields, the increases are around 20% by the 2020s and around 30% by the 2050s. However, it is noted that the IrriGrowth modelled increases were significantly lower than results for specific weather station sites, suggesting the methodology is very sensitive to the assumptions and correlations used. The uncertainties in this modelling and in the underlying UKCIP data suggest these figures should be used with caution.

Overall, the modelled impacts of climate change are smaller than the differences between the four socio-economic scenarios. In studying impacts on unconstrained demand, adaptation to water shortage and climatic change has not been included. Clearly some of the demand increases simply cannot be met; water pricing and/or restrictions on water supplies will limit irrigation in many catchments. This could then prompt crop movement (raising demand elsewhere), a change in the crops irrigated, and/or changes in irrigation practice to increase the efficiency of irrigation. Further studies are needed to identify actual outcomes.

9.1.5 Leisure

The analysis of potential impacts of climate change on the leisure sector has been limited by the lack of robust historic data from which to establish relationships between climate variables and consumption.

With a warmer and drier summer climate, the popularity of outdoor leisure, and in particular water-based activities is expected to grow. Some of these water-based activities such as boating and canoeing on lakes, reservoirs, rivers, estuaries and the sea would not of themselves be expected to increase the demand for water from public water supplies.

Other activities such as use of outdoor swimming pools would be expected to increase water consumption, but the current level of consumption through use of outside public pools is thought to be low. Given the low expenditure on public leisure facilities in the past 10 years, significant increases in public use are not considered to be likely.

Increases in the ownership and use of private pools are likely under climate change, but affluence will also be an important contributor. Given heroic assumptions on the future ownership and size of swimming pools, it is estimated that the open water evaporation losses from private pools in the 2020s could increase by 37 Ml/d from the non-climate change case. This however represents a very small fraction of industrial/commercial demand.

Larger climate change impacts are expected through increased irrigation on golf courses. The study suggested that transpiration of agricultural grass could increase by up to 78% by the 2020s in the medium high scenario, and irrigated areas would increase (Section 6.3). The incremental demand on public water supplies will depend on the number of golf courses that will take irrigation water from public water supplies, but insufficient data is available to quantify the change.

9.2 National and regional impacts on demand

The impacts of climate change, as reported for each sector in the preceding chapters, can be aggregated to the regional and national level based on the EA scenarios of future water demand. The starting point is the EA regional scenarios of demand given in the water resources strategy (2001b, Appendix 17). This report shows water demand in 2024/25 for:

- Direct abstraction:
    - Industry and commerce
    - Spray irrigation (in agriculture)
- Public water supply
    - Household
    - Non-household
    - Leakage
    - Water used in delivery operations and unmeasured use (DSOU)

For each component, the regional-average climate impact is applied. This is only a first approximation—some water resource zones will be very different from the regional average. To relate to the EA components, we make several assumptions:

- We have not estimated the extent to which leakage might be affected by climate change. Although fewer cold peaks would reduce winter pipe breaks, increased variability and short term dry/wet episodes might increase soil movement and leakage.
- Spray irrigation is assumed to be equivalent to the average for agriculture and horticulture. It may be that irrigated agriculture will draw more upon the public water supply in future. Equally, production of high quality horticulture may be relatively indifferent to water pricing and become an increasing component of demand from public water supplies. Other agricultural uses, such as for livestock, are not included.
- Industrial and non-household demands are assumed to have similar impacts as our industrial/commercial average assessment.

- The estimates for household (domestic) demand are taken from our assessment in Chapter 3.

Table 9-2 shows the national impacts of climate change for the six marker scenarios. The Medium-High climate scenario suggests impacts of 1.4-2.0% across the four EA reference scenarios. The Low climate change scenario is only slightly less—a national impact of 1.8% for the Gamma reference scenario.

In this summary the estimate for the Medium-High climate scenario applies to the Beta reference scenario for 2024/25 (the EA report does not show projections beyond this time period). Clearly, the increased climate change leads to greater impacts—perhaps a further increase of 1-2% in the regional impact of climate change.

Table 9-2. Summary of results for England and Wales, for the selected marker scenarios, for 2024/25

	Climate change		
EA Reference	**Low**	**Med High**	**Med High(2050s)**
Alpha		1.4%	
Beta		2.0%	3.8%
Gamma	1.8%	2.0%	
Delta		1.8%	

Notes: The EA reference scenarios are for 2024/25, from Appendix 17 in EA (2001b). The climate change impacts are from the component chapters above, for the 2020s low and Medium-High marker scenarios. The Medium-High (20250s) climate scenario uses the component estimates for the 2050s (reflecting higher climate changes) applied to the EA beta reference scenario for the 2020s. This assumes that the 2024/25 scenarios in the EA report continue to the 2050s (at least in their relative proportion of total regional water use). This is allows us to present at least a sense of the potentially greater impacts of climate change over the longer term.

Table 9-3 breaks down the national results for each region (Appendix 9-A provides further tables of results). The aggregate impact of climate change in the 2020s, for the Beta reference scenario and Medium-High emissions climate change scenario, is a 2% increase in water demand for England and Wales. Of course the impacts vary considerably by region, and even more so for individual water resource zones, due to differences in the structure of domestic, commercial/industrial and agricultural demand. For example, the Anglian region, with the largest proportion of spray irrigation, shows an impact of nearly double the national total. The North west region has the lowest impact, some 1.3% for the given scenario.

Table 9-3. Regional total impacts of climate change for the 2020s, Beta reference scenario and Medium high scenario of climate change

		Anglian	**Midlands**	**North east**	**North west**	**South west**	**Southern**	**Thames**	**Wales**	**Eng & Wales**
Source	**Reference scenario, Beta 2020s, Ml/d**									
Direct	Industrial/commercial	196.1	656.6	747.8	624.5	62.4	116.3	113.0	573.8	3090.5
	Spray irrigation	309.3	121.0	27.4	11.5	13.1	42.8	22.6	13.6	561.3
PWS	Leakage	272.5	400.8	443.7	460.9	219.4	182.7	784.3	287.9	3052.1
	Non-household	675.9	803.0	795.4	666.7	502.9	304.7	1184.1	376.8	5309.4
	Household	1235.6	1454.7	1154.3	1149.8	792.6	789.8	2192.1	504.7	9273.6
	DSOU and unbilled	25.0	29.0	50.7	25.7	22.0	13.3	31.3	12.1	209.1
Total		2714.4	3465.1	3219.4	2939.1	1612.3	1449.5	4327.4	1768.9	21496.1
Climate impact factors, %										
Direct	Industrial/commercial	2.6	1.8	1.8	1.8	3.0	2.7	2.5	2.4	
	Spray irrigation	20.0	23.0	8.0	-4.0	5.0	16.0	25.0	0.0	
PWS	Leakage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Non-household	2.6	1.8	1.8	1.8	3.0	2.7	2.5	2.4	
	Household	1.8	1.8	1.5	1.4	1.4	1.5	1.4	1.5	
	DSOU and unbilled	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Scenario impacts, 2020s Medium-High, ML/d										
Direct	Industrial/commercial	201.2	668.5	761.2	635.8	64.3	119.4	115.8	587.6	3153.7
	Spray irrigation	371.2	148.8	29.6	11.0	13.7	49.7	28.3	13.6	665.9
PWS	Leakage	272.5	400.8	443.7	460.9	219.4	182.7	784.3	287.9	3052.1
	Non-household	693.4	817.4	809.8	678.7	518.0	312.9	1213.7	385.8	5429.7
	Household	1257.9	1480.9	1171.6	1165.8	803.7	801.6	2222.8	512.3	9416.6
	DSOU and unbilled	25.0	29.0	50.7	25.7	22.0	13.3	31.3	12.1	209.1
Total		2821.2	3545.4	3266.6	2978.0	1641.0	1479.5	4396.2	1799.3	21927.2
Change from reference scenario, %										
Direct	Industrial/commercial	2.6	1.8	1.8	1.8	3.0	2.7	2.5	2.4	2.0
	Spray irrigation	20.0	23.0	8.0	-4.0	5.0	16.0	25.0	0.0	18.6
PWS	Leakage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Non-household	2.6	1.8	1.8	1.8	3.0	2.7	2.5	2.4	2.3
	Household	1.8	1.8	1.5	1.4	1.4	1.5	1.4	1.5	1.5
	DSOU and unbilled	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		3.9	2.3	1.5	1.3	1.8	2.1	1.6	1.7	2.0

Source: EA (2001b, Appendix 17 for the reference scenario); chapters 3, 4 and 5 for the impact factors

9.3 Climate impacts methodology, revisited

The CCDeW project built upon Herrington's (1996) benchmark study. The estimates in this study for increases in demand for water as a result of climate change are less than those made in the Herrington report (particularly for agriculture and horticulture). The respective results, are not however directly comparable. Given the relative lack of data from which to undertake the analysis, the findings of both studies have had to be based on heroic assumptions. Herrington notes that his estimates are founded on what seem to be plausible assumptions, with the objective of assisting understanding of the possible order of magnitude of water demand increases that could result directly from climate change impacts.

In the intervening years, methods for assessing climate change impacts have improved and several distinctions between the two studies should be noted:

- **New climate scenarios were developed by the UKCIP**, which did not exist at the time of Herrington's work. The scenarios are somewhat less severe than those used by Herrington, and have a higher regional resolution. It is still an open question whether the present scenarios adequately represent the range of climatic risks for individual water resource zones, or indeed for the UK regions.
- **Explicit socio-economic reference scenarios**. The Environment Agency water resources strategy scenarios provide a range of potential futures against which to compare climate change impacts. In contrast to a trend projection (as in Herrington, and common in water planning), this study provides a more robust assessment of the range of future risks.
- **Improved data sets are now available**. At the water resource zone level, the CCDeW project has had access to several time series of observed demand. The Environment Agency reference scenarios provide complete coverage, not only of a range of plausible futures but also of a consistent baseline.
- **Micro-component analysis**. The improved data sets allowed the CCDeW project to employ a more quantitative and comprehensive approach than was possible at the time of Herrington's assessment. However, the data sets still require further development.
- **A range of analytical methods**. The CCDeW project explored several analytical methods, whereas Herrington relied principally on statistical relationships. The dynamic simulation approach facilitates the incorporation of alternative baselines and allows extrapolation of climate sensitivity beyond the present experience. Great attention was paid in CCDeW to expert judgment and consultation with water companies as to their ongoing assessments.
- **Behavioural modelling**. The agent based simulations provide a means to explore the inter-relationships between climatic episodes (e.g., droughts) and consumer behaviour. While these results are still exploratory, they provide some indication of the structure of future demand and the nature of uncertainty in projecting climate change impacts.
- **Guidance on risk assessment**. Based on our discussions with experts in the water industry and parallel projects on headroom and risk assessment, we provide an outline of how the results of the CCDeW project could be used in current planning.

9.4 Monitoring, data and future research

A future assessment should continue to build upon more sophisticated methodologies and take advantage of improved time series of demand. It should also aim to quantify the potential risk of future extreme events. The main features that should be anticipated to ensure a robust assessment in the future include:

- Probabilistic scenarios of climate change and climatic variability. These should include probabilistic or at least 'worst case' scenarios of specific extreme events of importance in water planning, such as a two-year droughts;
- Adequate water demand time series to calibrate the main features of impacts models. For example, most company billing databases identify industrial/commercial customers according to SIC code. Analysis of revenue data sector by sector, and for different geographical areas would provide more robust data from which to assess relationships between climate variables and consumption. The 19 industrial/ commercial categories used by the Environment Agency in its analysis of consumption from public water supplies should be revised to include agriculture and leisure as separate sectors. The periodic irrigation survey should be continued. Access to company monitoring of selected households should be improved.
- Demand should be understood in relation to supply. So, supply scenarios should be included in order to calculate the supply/demand balance and plausible interactions with household adoption of technology and water use;
- Further model development is warranted--multi-agent models are ideal to represent the diversity of water demand and its social determinants.

More detailed analysis of the relationship between consumption and climate variables such as temperature is recommended, but depends on the availability of appropriate data, and should be conducted at the WRZ scale. Once more robust temperature/consumption relationships have been determined, the analysis described in earlier sections could be repeated.

9.4.1 Domestic

Domestic demand data that has been made available to this project from water companies has mainly been based upon strategic supply areas or control areas such as individual streets. This data is useful if it is collected at regular intervals (daily, monthly) as opposed to occasional water readings taken by the householder. Data value is increased when it can be combined with information on the timing and spatial extent of voluntary and enforced restrictions on water use. In analysing climate change impacts, it is also important to locate households geographically using identity codes at least to the nearest town (this was not always possible with the data received). Spatial positioning allows consumption to be compared to recorded local meteorological data.

Household surveys are also essential. Information on new appliances, new occupants, age ranges and water use habits etc along with monitoring of each water appliance would significantly improved the understanding of personal water use and allow for further development of scenarios of the populations' future water use. Interviews regarding household perspectives on water consumption, appliance changes and the use of water saving technologies would also be useful.

The usefulness of information at the household, or small cluster, level in modelling future changes increases with the length of record. Data sets over a longer period of time, say at least five years, would be particularly helpful.

Another aspect of which little is known is the topology of imitation networks in real neighbourhoods – a few detailed field studies of this would give start in understanding what real imitation processes might be occurring which are vital for agent-based modelling of water use behaviour.

9.4.2 Industry/ Commerce

Most company billing databases identify industrial/commercial customers according to SIC code. Analysis of revenue data sector by sector, and for different geographical areas would provide more robust data from which to assess relationships between climate variables and consumption. The 19 industrial/commercial categories used by the Environment Agency in its analysis of consumption from public water supplies should be revised to include agriculture and leisure as separate sectors.

Much greater discrimination between water consumption data in various industrial/commercial sectors and for different regions is a prerequisite for a better understanding of the impact of climate on water demand. Although it is recognized that the reluctance on behalf of companies to have their core data displayed in the public domain, may restrict the exchange of data between water companies and external bodies, the following recommendations for data collection would improve the robustness of future analysis:

- Allocation of SIC codes to industrial/commercial customers to be consistent across water companies
- Monthly meter readings to be consolidated into monthly water consumption data on a water resources zone level
- Where patterns of consumption within a given sector vary across a water resource zone – for example a zone that includes inland urban areas, and coastal areas popular for tourism – additional sub-zones should be considered for industrial/commercial data.

9.4.3 Agriculture/Horticulture

The methodology for forecasting agricultural demand depends on the availability of base year data and underlying trends from the Irrigation Surveys. It is essential that these are repeated regularly to retain a coherent data series.

Complementary data is available from the Environment Agency on direct abstraction for irrigation. However, there is limited data from the water companies on mains water supplied for agricultural and horticultural irrigation. With an increasing proportion of irrigation water coming from the mains in southern England, this could become an important data set for the relevant water companies to monitor.

There is still uncertainty about the impacts of climate change (other than via water supply) on the extent and location of irrigated cropping, and the impact of enhanced atmospheric CO_2 on crop water use at field level; both topics require further research.

9.4.4 Leisure

There is much less known about the extent of leisure irrigation (sports-turf, landscaping etc) than about agricultural irrigation. Though it is still probably a relatively small user, industry surveys suggest it is growing more rapidly than agricultural irrigation, and a larger proportion is believed to be fed from mains supply. Future studies will need more data on the extent, growth rates and water sources of the various categories of leisure irrigation.

9.5 Guidance on estimating climate impacts on demands

Earlier chapters of the report describe the analysis conducted and present results of the potential impacts of climate change at given time horizons and for each Environment Agency Region expressed as percentage changes from a reference case.

One of the main objectives of the project was to provide water resource practitioners with results that they can use when preparing forecasts of the potential demands for potable water. This section of the report therefore provides guidance for the practitioner on how the results should be applied to without climate change demand forecasts. The guidelines show how the results can be downscaled from the regional level to water resource zone (WRZ).

Water companies prepare forecasts of future demands as part of their analysis of the supply/demand balance. A water resource plan is then developed taking account of any surpluses and/or deficits in the supply/demand balance. As part of the process, companies will consider uncertainties in the demand and supply forecasts and evaluate the risks posed by such uncertainties.

Climate change impacts are just one component of uncertainty that in the past have been included in the headroom allowance. For the water resource practitioner therefore, estimates of climate change impacts on demand need to be framed in the overall context of the supply/demand balance that is built up from each WRZ into a company total.

The supply/demand balance as set out in regulatory returns to OFWAT and the Environment Agency is based on specified design conditions. One of the important decisions for water resource planning is therefore the choice of design conditions from which planning and investment decisions will be made. A combination of unfavourable hydrological conditions that restrict the output available from sources – the condition for which deployable output (DO) has been defined – with periods of high demands associated with “dry” year conditions is typically used.

For the water company, the results from this study have to be applied to “dry” year demands and at the scale of the WRZ. For water resource planning, climate change impacts should be added to the forecast “dry” year demands

9.5.1 Domestic

Domestic demand is calculated from population and per capita consumption (pcc) (l/h/d), with the latter often calculated from an analysis of micro-components. A distinction between unmeasured and measured pcc is made, either explicitly through micro-component analysis, or simply as a percentage change from the unmeasured value.

Three options are proposed for applying this assessment in water planning at the regional to local level.

A: Regional mode: The regional results shown here are fairly modest for the 2020s and it may not be worth the effort to undertake more detailed assessments. Based on total pcc projected to 2020s in water plans, an analyst would simply use the average regional impact for all of the Environment Agency reference scenarios and climate change scenarios. The same increment would apply to both measured and unmeasured demand. A variation would be to match the total pcc projected by the company for 2020s, to one of the Environment

Agency scenarios for the region. For instance, it makes sense to use the Beta scenario if personal washing is projected to grow.

B: Water resource zone mode: If the analyst has total pcc calculated at the WRZ level and believes there are reasons for significant variation in climate impacts among the WRZs, then a more detailed analysis may be warranted. Total pcc without climate change, would be projected for each WRZ to 2020s. The regional impacts of climate change would be applied to the WRZs total pcc, either using the same regional value or adopting estimates for each WRZ. In the latter case, the estimates should be within the range shown above for each region and taking account of potential differences in the baseline demand for water (e.g., prevalence of garden water and different household types) and climate scenarios (e.g., the seasonal balance of precipitation and evapotranspiration). This is likely to be a semi-quantitative process—drawing upon the published UKCIP scenarios, water resource strategy documents and company data on household use.

C: Micro-component modelling: The site approach developed for the CCDeW project can be replicated for each WRZ in the region. The inputs include:

- OFV for the water resource zone. We used the Environment Agency database but water companies will have their own estimates for each micro-component.
- Scenarios of climate change. The CCDeW database includes the UKCIP02 scenarios interpreted to the WRZ level for temperature, precipitation and potential evapotranspiration (estimated)
- An impact model relating climate variations to demand. This might be a WRZ version of the CCDomestic model (as used in our site results), a statistical model developed from time series data, or an expert-guided interpretation of thresholds of impacts for each micro-component.[2]

Our judgment is that the simple approach is reasonably robust, given the relatively modest impacts associated with 2020s. The more detailed site modelling (C) might reveal important uncertainties, particularly regarding extreme events and risk management. However, the constraints noted above would not necessarily lead to more robust estimates. The intermediate analysis suggested in B would therefore be recommended in current water resource planning.

Note that we do not recommend using the statistical equations directly. While this may be possible, the results are sensitive to the input data and water planners may have somewhat different data (e.g., baseline demand in 2002) than the equations were based on.

9.5.2 Industry/Commerce

Current approaches do not distinguish between “normal” and “dry” year demands in the industrial/commercial sector. The approach is therefore to apply the regional results presented in Chapter 4 to forecasts of “normal” year demands.

The application of the results depends on the manner, and scale, whole company area or water resource zone, for which industrial/commercial forecasts have been made. For this analysis it

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[2] The CCDomestic model can be readily adapted to new water resource zone data and the authors are willing to assist water plannings in carrying forward a more detailed, local analysis.

is assumed that the results presented at regional scale can be applied at water resource zone level.

Three different approaches are discussed:

- industrial/commercial forecasts do not distinguish between the industrial and commercial sectors
- industrial/commercial forecasts distinguish between the industrial and commercial sectors but do not breakdown consumption any further
- industrial/commercial forecasts distinguish between the different sectors industrial and commercial sectors

Note that as discussed in Chapter 4, the forecasting of industrial/commercial demands is more uncertain than the domestic forecasts. Future consumption is strongly influenced by economic conditions, and interpretations of 20 year forecasts, let alone 50 forecasts, should take cognisance of the uncertainty which the influence of unpredictable economic conditions introduces.

A: Total industrial/commercial demand: The bottom row of Table 4.9 gives for each region the change attributable to climate change in the 2020s and 2050s expressed as a percentage of the baseline – no socio-economic change – forecasts. Thus for a WRZ in Southern Region, the percentage change in the 2020s attributable to climate change would be 2.5%. In the 2050s in the Midlands, then change would be 3.4%.

B: Industrial and service sector demands: Table 4.9 gives the percentage changes for the Industrial, the Service and the Other sectors. Inspection of the Table shows that for the 2020s in Southern Region the changes attributable to climate change would be:

Industrial sector	2.9%
Service sector	3.3%
Other Sector	0.8%

For the 2050s in the Midlands Region the corresponding percentages would be:

Industrial sector	3.3%
Service sector	6.9%
Other Sector	1.9%

C: Individual sectoral demand: As discussed in Chapter 4 the regional approach adopted for this project may have smoothed for the regional results differences that might have otherwise have appeared at WRZ level. Given that the contribution of any one of the 19 industrial/commercial sectors to the overall level of demand in a given WRZ will be relatively small, the application of the regional results for the separate sectors to WRZ analysis is considered to be reasonable.

Thus for a WRZ in Southern Region the 2020s would see a 6.4% increase attributable to climate change in the extraction industry demand. Fuel refining is not represented in the data, and the Textile, Wood, Paper and Rubber sectors would have zero climate change impact.

Given the assumptions used for the analysis using the 2050s, results for this level of analysis are not considered to be appropriate.

9.5.3 Agriculture and horticulture

Care is needed before applying the regional results to mains water resource zones. The results from the agriculture and horticulture modelling revealed a strong regional variation, reflecting both the different changes in climate and the different crop mixes in different regions. It is unlikely that the crops irrigated by direct abstraction are representative of those irrigated by relatively high-cost mains water. Furthermore, a switch by farmers from direct abstraction to mains water use, in response to local licence restrictions, could be much more important factor than the gross increase in total irrigation water use.

Where the use of mains water is relatively unimportant, and direct abstraction licences are still available, it is probably adequate to apply the relevant regional increase to existing demand. Elsewhere, it would be preferable to re-run the model using the crop mix presently being irrigated from mains supply in that WRZ, and to assess the extent of the switch locally of other crops to mains water.

9.5.4 Leisure

Similar problems arise with estimating increases in mains water use at WRZ level for leisure irrigation. Each WRZ will have a very different pattern of present leisure irrigation use. Again, increases in turf/plant water use may be minor compared to changes in the areas irrigated and the proportion of the water taken from mains supply.

The results from Chapter 5 on regional irrigation demand of grazed grass (volume per unit area) can be used as an initial estimate of the increased demand for turf-grass. A judgement would then have to be made on the change in irrigated area, and changes in the source of the irrigation water.

No specific methodology for estimating climate change impacts on water consumption in the other leisure sectors has been developed. The impacts are likely to be very location specific, and therefore would not show up in the regional results presented in this report.

9.6 Appendix

9.6.1 Appendix 9-A. Regional impacts of climate change

The following tables show the regional synthesis based on the EA technical report for the water resource strategy (EA, 2001b, Appendix 17). The tables show:

- The EA scenario for 2024/25
- The climate impacts factors (%) for each component of water use, taken from the analyses in chapters 3, 4 and 5
- The scenario for water use in 2024/25 including climate change
- The percentage difference between the reference case and with climate change, in %

The Medium-High climate scenario is shown for all four reference scenarios for 2024/25 (the 2020s climate) and the Low climate scenario for the Gamma reference scenario. The text above includes a first approximation for the Beta/Medium-High scenario for the 2050s. However, the EA strategy does not make an explicit projection for the 2050s. To avoid confusion (and over-interpretation of the regional results) the regional breakdown for that projection is not shown here.

Table 9-4. Regional impacts for Alpha scenario, Medium-High climate change, 2020s

	Anglian	Midlands	Northeast	Northwest	South West	Southern	Thames	Wales	Eng&Wales
Reference scenario, Ml/d*1000									
Direct abstraction									
Industry & commerce	191.9	584.5	652.0	610.6	66.8	136.2	118.8	622.2	2,983.1
Spray irrigation	359.5	141.9	31.4	13.2	14.9	46.9	25.1	15.6	648.5
Subtotal	*551.3*	*726.5*	*683.4*	*623.8*	*81.7*	*183.1*	*143.9*	*637.8*	*3,631.6*
Public water supply									
Household demand	1,302.7	1,657.2	1,310.2	1,316.2	878.1	858.5	2,421.3	572.0	10,316.1
Non-household demand	564.7	738.8	692.2	591.5	408.3	255.4	899.8	318.2	4,468.9
Supply leakage	1,468.1	1,839.0	1,624.5	1,566.7	1,044.1	974.3	2,783.4	755.1	12,055.1
DSOU	25.0	29.0	50.7	25.7	22.0	13.3	31.3	12.1	209.1
Subtotal	*3,360.4*	*4,263.9*	*3,677.7*	*3,500.1*	*2,352.5*	*2,101.4*	*6,135.8*	*1,657.5*	*27,049.2*
Total	*3,911.7*	*4,990.4*	*4,361.1*	*4,123.9*	*2,434.2*	*2,282.5*	*6,279.8*	*2,295.3*	30,678.8
Climate impact factors: Medium-High, %									
Industry & commerce	2.6	1.7	1.7	1.7	2.7	2.4	2.5	2.3	
Spray irrigation	20.0	23.0	8.0	-4.0	5.0	16.0	25.0	0.0	
Household demand	1.8	1.8	1.5	1.4	1.4	1.5	1.4	1.5	
Non-household demand	2.6	1.7	1.7	1.7	2.7	2.4	2.5	2.3	
Scenario impacts									
Industry & commerce	196.8	594.5	663.1	621.0	68.6	139.5	121.8	636.5	3,041.8
Spray irrigation	431.4	174.6	33.9	12.7	15.6	54.4	31.4	15.6	769.5
Subtota:l Direct abstraction	*628.2*	*769.1*	*697.0*	*633.6*	*84.3*	*193.9*	*153.2*	*652.1*	*3,811.4*
Household demand	1,326.5	1,687.5	1,329.6	1,335.1	890.3	870.9	2,454.4	580.3	10,474.6
Non-household demand	579.4	751.3	704.0	601.5	419.3	261.6	922.3	325.5	4,564.9
Supply leakage	1,468.1	1,839.0	1,624.5	1,566.7	1,044.1	974.3	2,783.4	755.1	12,055.1
DSOU	25.0	29.0	50.7	25.7	22.0	13.3	31.3	12.1	209.1
Subtotal: Public water supply	*3,398.9*	*4,306.8*	*3,708.8*	*3,529.0*	*2,375.7*	*2,120.0*	*6,191.5*	*1,673.1*	*27,303.7*
Total	*4,027.1*	*5,075.9*	*4,405.8*	*4,162.7*	*2,459.9*	*2,313.8*	*6,344.7*	*2,325.2*	*31,115.1*
Percentage change from reference scenario									
Direct abstraction	13.9%	5.9%	2.0%	1.6%	3.1%	5.9%	6.4%	2.2%	5.0%
Public water supply	1.1%	1.0%	0.8%	0.8%	1.0%	0.9%	0.9%	0.9%	0.9%
Total	3.0%	1.7%	1.0%	0.9%	1.1%	1.4%	1.0%	1.3%	1.4%

Table 9-5. Regional impacts for Beta scenario, Medium-High climate change, 2020s

	Anglian	Midlands	Northeast	Northwest	South West	Southern	Thames	Wales	Eng & Wales
Reference scenario, Ml/d*1000									
Direct abstraction									
Industry & commerce	196.1	656.6	747.8	624.5	62.4	116.3	113.0	573.8	3,090.5
Spray irrigation	309.3	121.0	27.4	11.5	13.1	42.8	22.6	13.6	561.3
Subtotal	*505.4*	*777.6*	*775.2*	*636.0*	*75.5*	*159.1*	*135.6*	*587.4*	*3,651.8*
Public water supply									
Household demand	1,235.6	1,454.7	1,154.3	1,149.8	792.6	789.8	2,192.1	504.7	9,273.6
Non-household demand	675.9	803.0	795.4	666.7	502.9	304.7	1,184.1	376.8	5,309.5
Supply leakage	272.5	400.8	443.7	460.9	219.4	182.7	784.3	287.9	3,052.2
DSOU	25.0	29.0	50.7	25.7	22.0	13.3	31.3	12.1	209.1
Subtotal	*2,209.0*	*2,687.5*	*2,444.1*	*2,303.1*	*1,536.9*	*1,290.5*	*4,191.8*	*1,181.5*	*17,844.4*
Total	*2,714.4*	*3,465.1*	*3,219.4*	*2,939.1*	*1,612.3*	*1,449.5*	*4,327.4*	*1,768.9*	*21,496.1*
Climate impact factors: Medium-High, %									
Industry & commerce	2.6	1.8	1.8	1.8	3.0	2.7	2.5	2.4	
Spray irrigation	20.0	23.0	8.0	-4.0	5.0	16.0	25.0	0.0	
Household demand	1.8	1.8	1.5	1.4	1.4	1.5	1.4	1.5	
Non-household demand	2.6	1.8	1.8	1.8	3.0	2.7	2.5	2.4	
Scenario impacts									
Industry & commerce	201.2	668.4	761.3	635.7	64.3	119.4	115.8	587.6	3,153.7
Spray irrigation	371.2	148.8	29.6	11.0	13.8	49.6	28.3	13.6	665.9
Subtotal: Direct abstraction	*572.4*	*817.2*	*790.9*	*646.8*	*78.0*	*169.1*	*144.1*	*601.2*	*3,819.6*
Household demand	1,258.2	1,481.3	1,171.4	1,166.2	803.6	801.3	2,222.1	512.0	9,416.2
Non-household demand	693.5	817.5	809.7	678.7	518.0	312.9	1,213.7	385.8	5,429.8
Supply leakage	272.5	400.8	443.7	460.9	219.4	182.7	784.3	287.9	3,052.2
DSOU	25.0	29.0	50.7	25.7	22.0	13.3	31.3	12.1	209.1
Subtotal: Public water supply	*2,249.2*	*2,728.6*	*2,475.5*	*2,331.5*	*1,563.0*	*1,310.2*	*4,251.4*	*1,197.9*	*18,107.3*
Total	*2,821.5*	*3,545.8*	*3,266.4*	*2,978.3*	*1,641.0*	*1,479.3*	*4,395.5*	*1,799.0*	*21,926.9*
Percentage change from reference scenario									
Direct abstraction	13.2%	5.1%	2.0%	1.7%	3.3%	6.3%	6.3%	2.3%	
Public water supply	1.8%	1.5%	1.3%	1.2%	1.7%	1.5%	1.4%	1.4%	
Total	3.9%	2.3%	1.5%	1.3%	1.8%	2.1%	1.6%	1.7%	2.0%

Table 9-6. Regional impacts for Gamma scenario, Medium-High and Low climate change, 2020s

	Anglian	Midlands	Northeast	Northwest	South West	Southern	Thames	Wales	Eng&Wales
Reference scenario Ml/d*1000									
Direct abstraction									
Industry & commerce	83.9	226.9	232.8	236.7	32.1	61.3	55.9	298.1	1,227.6
Spray irrigation	220.7	86.2	18.6	7.7	8.8	30.6	16.4	9.5	398.6
Subtotal	*304.6*	*313.0*	*251.5*	*244.4*	*40.9*	*92.0*	*72.4*	*307.6*	*1,626.2*
Public water supply									
Household demand	738.4	864.4	670.2	688.0	488.7	478.4	1,372.0	301.7	5,601.8
Non-household demand	391.5	427.8	369.7	313.5	331.2	183.7	578.2	210.5	2,806.2
Supply leakage	188.1	222.7	302.9	270.6	145.8	133.4	318.2	128.1	1,709.7
DSOU	25.0	29.0	50.7	25.7	22.0	13.3	31.3	12.1	209.1
Subtotal	*1,343.0*	*1,543.9*	*1,393.5*	*1,297.8*	*987.7*	*808.8*	*2,299.8*	*652.4*	*10,326.8*
Total	*1,647.5*	*1,856.9*	*1,645.0*	*1,542.2*	*1,028.5*	*900.8*	*2,372.1*	*960.0*	*11,953.0*
Climate impact factors: Medium-High, %									
Industry & commerce	2.7	2.0	2.1	2.1	3.1	2.8	2.9	2.6	
Spray irrigation	20.0	23.0	8.0	-4.0	5.0	16.0	25.0	0.0	
Household demand	1.3	1.1	1.1	1.1	1.0	1.1	1.0	1.1	
Non-household demand	2.7	2.0	2.1	2.1	3.1	2.8	2.9	2.6	
Scenario impacts									
Industry & commerce	86.2	231.4	237.7	241.7	33.0	63.0	57.6	305.8	1,256.4
Spray irrigation	264.8	106.0	20.1	7.4	9.3	35.5	20.5	9.5	473.2
Subtotal: Direct abstraction	*351.0*	*337.4*	*257.8*	*249.0*	*42.3*	*98.6*	*78.1*	*315.3*	*1,729.5*
Household demand	747.8	873.9	677.8	695.4	493.3	483.5	1,386.0	304.9	5,662.7
Non-household demand	402.1	436.4	377.5	320.1	341.5	188.9	595.0	215.9	2,877.3
Supply leakage	188.1	222.7	302.9	270.6	145.8	133.4	318.2	128.1	1,709.7
DSOU	25.0	29.0	50.7	25.7	22.0	13.3	31.3	12.1	209.1
Subtotal: Public water supply	*1,363.0*	*1,561.9*	*1,408.9*	*1,311.8*	*1,002.6*	*819.1*	*2,330.5*	*661.1*	*10,458.8*
Total	*1,713.9*	*1,899.3*	*1,666.7*	*1,560.9*	*1,044.9*	*917.6*	*2,408.6*	*976.4*	*12,188.4*
Percentage change from reference scenario									
Direct abstraction	15.2%	7.8%	2.5%	1.9%	3.5%	7.2%	7.9%	2.5%	6.4%
Public water supply	1.5%	1.2%	1.1%	1.1%	1.5%	1.3%	1.3%	1.3%	1.3%
Total	4.0%	2.3%	1.3%	1.2%	1.6%	1.9%	1.5%	1.7%	2.0%

Climate impact factors: Low, %									
Industry & commerce	2.4	1.8	1.9	1.9	2.9	2.5	2.6	2.3	
Spray irrigation	19.0	22.0	8.0	-4.0	5.0	16.0	24.0	1.0	
Household demand	1.0	1.2	1.0	1.0	1.0	1.0	0.9	0.9	
Non-household demand	2.4	1.8	1.9	1.9	2.9	2.5	2.6	2.3	
Scenario impacts									
Industry & commerce	85.9	230.9	237.2	241.2	33.0	62.8	57.4	304.9	*1,253.4*
Spray irrigation	262.6	105.2	20.1	7.4	9.3	35.5	20.3	9.6	*470.0*
Subtotal: Direct abstraction	*348.5*	*336.1*	*257.4*	*248.6*	*42.2*	*98.4*	*77.7*	*314.6*	*1,723.4*
Household demand	745.8	874.6	676.9	695.2	493.4	483.2	1,384.0	304.5	5,657.6
Non-household demand	400.9	435.5	376.7	319.5	340.8	188.3	593.2	215.3	2,870.3
Supply leakage	188.1	222.7	302.9	270.6	145.8	133.4	318.2	128.1	1,709.7
DSOU	25.0	29.0	50.7	25.7	22.0	13.3	31.3	12.1	209.1
Subtotal: Public water supply	*1,359.7*	*1,561.8*	*1,407.3*	*1,310.9*	*1,002.0*	*818.1*	*2,326.7*	*660.0*	*10,446.7*
Total	*1,708.2*	*1,897.9*	*1,664.6*	*1,559.5*	*1,044.3*	*916.5*	*2,404.5*	*974.6*	*12,170.1*
Percentage change from reference scenario									
Direct abstraction	14.4%	7.4%	2.4%	1.7%	3.4%	7.0%	7.5%	2.3%	6.0%
Public water supply	1.2%	1.2%	1.0%	1.0%	1.5%	1.2%	1.2%	1.2%	1.2%
Total	3.7%	2.2%	1.2%	1.1%	1.5%	1.8%	1.4%	1.5%	1.8%

Table 9-7. Regional impacts for Delta scenario, Medium-High climate change, 2020s

	Anglian	Midlands	Northeast	Northwest	South West	Southern	Thames	Wales	Eng&Wales
Reference scenario, Ml/d*1000									
Direct abstraction									
Industry & commerce	92.9	260.7	288.2	283.2	35.1	74.3	61.0	350.8	1,446.1
Spray irrigation	269.0	105.2	21.6	11.6	10.5	37.8	19.8	11.6	487.1
Subtotal	*361.9*	*365.9*	*309.8*	*294.8*	*45.6*	*112.0*	*80.8*	*362.3*	*1,933.2*
Public water supply									
Household demand	771.6	978.6	765.1	782.0	523.8	509.7	1,527.3	342.7	6,200.8
Non-household demand	349.9	410.6	356.5	304.7	276.0	159.0	485.6	186.1	2,528.2
Supply leakage	210.0	301.1	344.5	346.7	168.4	136.7	588.9	203.8	2,300.2
DSOU	25.0	29.0	50.7	25.7	22.0	13.3	31.3	12.1	209.1
Subtotal	*1,356.5*	*1,719.3*	*1,516.9*	*1,459.0*	*990.2*	*818.7*	*2,633.2*	*744.7*	*11,238.4*
Total	*1,718.4*	*2,085.2*	*1,826.7*	*1,753.8*	*1,035.8*	*930.7*	*2,714.0*	*1,107.0*	*13,171.6*
Climate impact factors, %									
Industry & commerce	2.5	1.7	1.8	1.8	2.7	2.4	2.6	2.3	
Spray irrigation	20.0	23.0	8.0	-4.0	5.0	16.0	25.0	0.0	
Household demand	1.3	1.1	1.1	1.1	1.0	1.1	1.0	1.1	
Non-household demand	2.5	1.7	1.8	1.8	2.7	2.4	2.6	2.3	
Scenario impacts									
Industry & commerce	95.2	265.1	293.4	288.3	36.0	76.0	62.6	358.8	1,475.6
Spray irrigation	322.8	129.4	23.4	11.1	11.0	43.8	24.8	11.6	577.8
Subtotal: Direct abstraction	*418.0*	*394.6*	*316.8*	*299.4*	*47.0*	*119.8*	*87.4*	*370.4*	*2,053.4*
Household demand	781.5	989.4	773.8	790.4	528.8	515.2	1,542.9	346.3	6,268.2
Non-household demand	358.6	417.5	362.9	310.1	283.4	162.8	498.2	190.3	2,584.0
Supply leakage	210.0	301.1	344.5	346.7	168.4	136.7	588.9	203.8	2,300.2
DSOU	25.0	29.0	50.7	25.7	22.0	13.3	31.3	12.1	209.1
Subtotal: Public water supply	*1,375.1*	*1,737.0*	*1,531.9*	*1,472.9*	*1,002.7*	*827.9*	*2,661.4*	*752.6*	*11,361.6*
Total	*1,793.1*	*2,131.6*	*1,848.7*	*1,772.3*	*1,049.7*	*947.8*	*2,748.8*	*1,123.0*	*13,415.0*
Percentage change from reference scenario									
Direct abstraction	15.5%	7.8%	2.2%	1.6%	3.2%	7.0%	8.1%	2.2%	6.2%
Public water supply	1.4%	1.0%	1.0%	1.0%	1.3%	1.1%	1.1%	1.1%	1.1%
Total	4.3%	2.2%	1.2%	1.1%	1.3%	1.8%	1.3%	1.4%	1.8%

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